The effects of 30 GW offshore wind energy in the Netherlands in 2030 - 2050

A qualitative comprehensive energy security analysis

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TU Delft

Ministerie van Economische Zaken

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By

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Preface & acknowledgements

Writing my master thesis is the final step to obtain my master's degree in Complex Systems Engineering and Management. This research project was quite challenging for me, because I never conducted a research of this kind and it was also very challenging to keep up with the fast developments in the offshore wind sector in the Netherlands. The past months have been a great learning experience for me. I want to take the opportunity to thank the people who helped my complete this research.

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There are also some people who I would like to thank, that were not a part of this thesis project. First of all, I want to thank my family, my parents and Paulien, for all the endless support you have given me, not only during my thesis project, but during the entire length of my studies. I want to thank my friends and Daan for providing distraction and for always listening to my graduation stories.

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Francien Seeverens

Delft, 2017

Executive summary

The Netherlands wants to be less dependent on fossil fuels and it wants to reduce the CO_2-emissions to meet climate targets. These are the most important reasons for the Dutch government to stimulate renewable energy. The goal is that the Netherlands will have a decarbonized electricity production in 2050. The Dutch government wants to stimulate electricity production from renewable energy sources, such as solar energy, wind energy, biomass and geothermal energy. Offshore wind energy will play a large role in the Dutch energy transition, because the North Sea has good conditions for offshore wind energy. It has relative shallow waters and good wind resource. The Dutch government wants to expand the generation capacity of offshore wind energy, which is planned to be 4,450 MW in 2023 by 1 GW per year in the period of 2023-2030. This will bring the total amount of generation capacity of offshore wind to around 11.5 GW by 2030. The Ministry of Economic Affairs is looking at the possibilities to extend the policy for the development of offshore wind energy until 2050. This means that there will be around 30 GW installed capacity for offshore wind energy in 2050.

The Ministry of Economic Affairs wants to know what the potential economic costs and benefits are, for example in terms of employment, export of electricity to surrounding countries, importance and growth of harbours, the Dutch offshore industry, network costs, transport costs, and nature for the Netherlands. On the more strategic implications the Ministry wants to know if countries in the region have similar plans.

There is currently no framework or method to investigate these strategic and economic implications of large-scale renewable energy projects. There are only frameworks to explore strategic and economic implications of oil and gas related energy projects, and not for renewable energy related projects. There is a difference in requirements between these systems, and the indicators are not sufficient to investigate the requirements for renewable energy sources. These differences are in: infrastructure, possibilities for storage, and import and export to other countries. None of these frameworks are comprehensive enough. To this end, a new framework is made, to make strategic decisions for the energy sector of the Netherlands.

Theories of energy security are a good way to explore the strategic and economic implications of energy projects. However, there are no indicators for renewable energy integration and they do not take the broader energy system into account, which shows the interdependencies between stakeholders and components in the system. A new framework is created, based on the indicators of current energy security frameworks. System analysis is used to extend the framework with indicators. System analysis is a good addition to the energy security framework, because it gives a good overview of the system and gives insights into the relations and interdependencies between components in the system. This new comprehensive energy security framework gives insights in the political, economic, environmental, and technological effects of large-scale wind energy. It consists of five dimensions: availability, affordability, technology development & efficiency, environmental & social sustainability, and regulation & governance. These are divided in 17 components and 53 indicators to explore the energy security effects of large-scale offshore wind energy. The new comprehensive energy security framework is used to answer the following main research question:

What are the comprehensive energy security effects of 30 GW offshore wind energy for the Netherlands in 2050?

An overview is given of the current state of the offshore wind energy sector and the expected developments. An important driver in the wind farm developments is the Levelised Cost of Energy (LCOE), which needs to be low. This can be decreased by low capital expenditures and low operational expenditures and by a high energy production. Factors can be optimized to increase the attractiveness of developing a wind farm. Increasing wind turbines in size and capacity, and cost reductions will bring the LCOE down.

Many stakeholders and interest groups are interested in the developments of offshore wind sector. Some of these will be positively affected by the developments, others negatively. The most important stakeholders and interest groups in this research are: wind farm developers, wind turbine manufacturers, wind farm constructers, grid operators, operators, decomissioners, energy companies, oil & gas companies, wind lobby groups, consultants, governmental organizations, environmental organizations, sea ports, shipping industry, fishing & aqua culture, R&D & education, and other users of the North Sea.

Offshore wind can be realized under different conditions. It can be realized by the Netherlands alone, or in a multilateral and international setting. To this end, two scenarios are developed: a national interest scenario and an international scenario to investigate the comprehensive energy security effects of 30 GW offshore wind energy. The national scenario is relevant, because the Dutch exclusive economic zone is large enough to construct 30 GW offshore wind without any other country involved and the developments in offshore wind energy are currently national, it is not certain that this will become international. The international scenario is relevant, because many countries are developing offshore wind energy in the North Sea. International cooperation would contribute to overcome hurdles and to create more efficiencies. The effects are both compared to a benchmark, and then the results of the national and international scenario are compared to each other.

The effects on the dimension *availability* are better in the international scenario. The security of supply is better in the international scenario. The increase in generation capacity contributes positively in both scenarios, but there is more demand in the international scenario as a result of exports. This is good, because the large inflexible supply can cause congestion. A larger demand is then needed. The component production is equal for both scenarios. Better wind resources create a more positive effect in the international scenario, the increase rate is the same for both scenarios and the total installed electricity generation capacity is better in the national scenario, because it is likely that energy storage, which can generate electricity, will play a role. The dependency is better in the national scenario, because it is less dependent on imports and exports of other countries. Diversification is better in the international scenario, because the diversification of ownership of energy companies is higher, because there are also international companies. The geographic dispersion of energy facilities is also higher, because it is likely that offshore wind is also constructed further offshore. The share of renewable energy in the total energy supply is likely to be the same.

The effects on the dimension *affordability* are better in the international scenario. The price stability is better in the international scenario, because the CO_2-price is higher. Also, the electricity price is less volatile, because there are more interconnections. Still, they will both be very volatile as a result of an inflexible energy supply. The fuel-prices are also higher, which makes wind energy more competitive. The electricity price is also higher, as a result of more electricity export. This makes the investment risk for developers lower. Access and equity is equal in both scenarios: the grid connection is better in the international scenario as a result of more interconnections. The rate of electrification is better in the national scenario, as a result of lower electricity prices and the site conditions are better in the national scenario as a result of less waves. The affordability is equal in both scenarios. Balancing costs are higher in the national scenario, because it is harder to deal with variability in supply and demand, because there is less interconnection capacity. Construction costs are better in the international scenario, because there is more competitiveness and technological innovation to reduce the costs. The total investment risk is higher, as a result of higher investments that are needed for grid extensions. The marginal cost of electricity power generation is the same in both scenarios, because the marginal costs will go down and have price spikes in both scenarios. The transmission costs are higher in the international scenarios due to grid extensions.

The effects on *technology development & efficiency* are better in the international scenario. The effects on the construction technique are very positive in both scenarios, due to innovations as a result of a clear roll- out of wind energy. There are more research budgets in the international scenario, because international funds will be available next to the national funds. The technological innovation is very positive in both scenarios, due to the clear roll-out of wind energy. The efficiency is better in the international scenario, because there is more economic growth and more cost reductions, which results in a higher decrease in energy intensity of the economy. Safety and reliability is better in the international scenario, because the frequency of interruption of supply is lower, because there is less variability as a result of interconnections. O&M strategies are better as a result of international cooperation and the predictability of power supply is better due to international coupling of prediction systems. Resilience is also better in the international scenario, because the system adequacy is better as a result of the higher interconnection capacity. The generation adequacy is for both negative, because of the increase in variability in supply. Investment & employment is better in the international scenario. Average return on investment is higher in the international scenario, due to average higher electricity prices. Direct employment, indirect and induced employment in the industry are higher as the result of more economic activities. Investment in transmission capacity is higher as the result of more grid extensions. O&M costs are better in the international scenario as a result of more international cooperation, and international clustering of O&M.

The dimension *environmental & social sustainability* is better in the international scenario. The land / water use component is the same in both scenarios, because there are more areas in which wind energy can be installed, but there is less space required in the national scenario, because then there is only construction close to shore. The size of the installations is in both scenarios the same. Climate change effects are better in the international scenario, because there are less CO_2-emissions from the electricity sector outside of the Netherlands as well, because the Netherlands can export green electricity. The CO_2-reduction targets are the same in both scenarios and the presence of climate change goals and targets is better in the international scenario, due to the possibility of additional agreements.

The dimension *regulation & governance* is better in the international scenario. The component governance is better in the international scenario, because the regulation is more on a European level. There will be more programme responsible parties in both scenarios, but there will a higher increase in the international scenarios, because international parties are allowed in the market also. Therefore, the international scenario is better on this point. Permit procedures will be the same in both scenarios, because there will both be more given out up till 30 GW. The provision of priority grid access to renewable energy will not be the case for both scenarios. Trade and regional interconnectivity will be better in the international scenario as the result of more interconnection capacity. Competition and markets are better in the international scenarios, because there is a more interconnected electricity market in Europe and there are more renewable energy subsidies, making wind energy more competitive. The market share of the largest three electricity suppliers will go down in both scenarios as result of more participants in the market.

These comprehensive energy security effects have implications for policies, stakeholders, and surrounding countries. The focus of the Ministry of Economic Affairs should be shifting from a project level to a more integrated system level to increase flexibility in the system, reduce congestion, reduce variability in supply and demand, and prevent overinvestments or underinvestments in the system. The view should include decisions on the technical elements of the system to make it more flexible, on the responsibilities within the system, and should nudge actors in a certain direction. Technical elements that are important are: grid reinforcements, energy storage, electrification, power-to-X, and demand-response technologies.

A timely signal from the government for a clear roll-out of offshore wind in this period is needed to increase the security in the production market and to decrease the investment risks for stakeholders, resulting in more investments in the offshore wind sector and cost reductions for offshore wind energy. It increases the employment opportunities and gives an economic boost in the regions where it is developed.

Ministry of Economic Affairs should stimulate more international cooperation between the North Sea countries to make a European roll-out of offshore wind farms possible. Policy measures should facilitate this: Energy systems of the North Sea countries that are connected to an offshore grid need to be harmonized, distribution of the costs and benefits of constructing such a system needs to be organized, subsidy schemes, regulatory schemes, legislation, and rules should be harmonized between the participating countries.

The limits for the impact on ecology are reached soon and the Ministry of Economic Affairs should take measures to prevent this. Timely announcing the reduction in noise limits for construction will increase innovations in construction technologies, because companies have enough time to invest in this and develop this. Other measures that could be taken are closing the wind farms for other sectors, and improve ecology after construction, by actively stimulating under water nature. To prevent reaching limits from the birds and bats, the government could protect more breeding grounds of birds and bats, and when there is large migration stop the turbines. Another measure to protect the birds and bats is placing the turbines further apart, but the effects of this are not yet certain.

The implications for stakeholders are that they can be winners or losers, or both, depending on their abilities to change. Winners are: wind farm developers, offshore wind industry, Dutch industry, sea ports and electricity users. Losers in the scenarios are: grid operators and fishing & aqua culture, and other North Sea users. Stakeholders that can be both winners & losers, depending on their ability to change their business plans are the oil & gas sector and energy companies. Interest groups that can be positively or negatively indirect affected are: governmental organizations, the environment, and R&D & education.

Implications for other countries in the North Sea region are that they can profit from the electricity that is brought to the market if they cannot generate enough electricity themselves. Enough interconnection capacity is needed for this. Cooperation is needed to optimize the North-Western electricity grid if the Netherlands and other countries all develop a lot of offshore wind energy in the North Sea. The development of wind farms far offshore increases the demand for an offshore grid, or for the possibilities to connect the wind farm of one country to another country's shore to create more efficiency, or to develop international wind farms. Subsidy systems, regulations, and legislations should be adapted and harmonized between countries to facilitate this. This will require intensive negotiations between the North Sea countries. The distribution of costs and benefits of multinational windfarms and an offshore grid needs to be negotiated. These can be about: investments, contribution to emission reduction targets, amount of subsidy per country.

Recommendations are made for future research for the Ministry of Economic Affairs are to investigate the comprehensive energy security effects of large-scale offshore wind on a North-Western European scale, to do a more quantitative comprehensive energy security assessment, to do research into shared use of wind farms, and to do research on the economic impact of large-scale offshore wind on other North Sea users.

Recommendations for future research in the academic field are to create a framework with weighted indicators and to create a framework with indicators more related to training and education, impact on other renewable energy sources, the cost of financing projects, and nature and ecology.

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ACER	Agency for the Cooperation of Energy Regulators
ACM	Authority for Consumers & Markets
AEP	Annual electricity production
CAPEX	Capital expenditures
CCS	Carbon capture and storage
CRF	Capital recovery factor
DSO	Distribution system operator
EC	European Commission
EEZ	Exclusive Economic Zone
ETS	Emission trading scheme
EU	European Union
GW	Gigawatt
IEA	International Energy Agency
LCOE	Levelised Cost of Energy
MOG	Meshed Offshore Grid
MoU	Memorandum of Understanding
MW	Megawatt
MWh	Megawatt hour
NIMBY	Not in my backyard
OEM	Original equipment manufacturers
OPEX	Operating expenditures
O&M	Operation and maintenance
TSO	Transmission system operator

1. Introduction

1.1 Ambitions Dutch electricity sector

The Netherlands wants to be less dependent on fossil fuels and it wants to reduce CO_2 emissions to meet climate targets. These are the most important reasons for the Dutch government to stimulate renewable energy. Key principles of Dutch electricity policies are that the energy supply should be clean, affordable, and reliable for users (Ministry of Economic Affairs, 2016b).

Goals are set in the Energy Agreement for Sustainable Growth, the Energy Report, and the Energy Agenda (Government of the Netherlands, 2013b; Ministry of Economic Affairs, 2016a; Ministry of Economic Affairs, 2016b). These agreements should result in a clean and affordable energy supply, and should create economic and employment opportunities for the Netherlands. Main principles here are CO_2 reduction, to seize economic opportunities that the energy transition offers, and to integrate energy in spatial planning policy (Ministry of Economic Affairs, 2016b). The goal is a decarbonized electricity production in 2050 for the Netherlands. To realize this goal, the government wants to continue and expand its coordinating role in the energy transition to more renewable energy supply. The Dutch government wants to stimulate electricity production from renewable energy sources, such as solar energy, wind energy, biomass and geothermal energy (Ministry of Economic Affairs, 2016a).

The Dutch electricity market is a complex system of producers, consumers, suppliers and system operators. The challenge is to reduce the CO_2 emissions by 80-95% by 2050, but at the same time guarantee security of supply and affordability of electricity to consumers (Ministry of Economic Affairs, 2016b).

1.2 Offshore wind energy

Offshore wind energy will play a large role in the Dutch energy transition, because “conditions for offshore wind energy are ‘excellent’, it believes, with relatively shallow waters, good wind resource, good harbour facilities, an experienced industry and a new, robust support system” (De Bruijne et al., 2016). Therefore, the Dutch government wants to expand the generation capacity of offshore wind energy, which is planned to be 4,450 MW in 2023 (Government of the Netherlands, 2013a), by 1 GW per year in the period of 2023-2030. This will bring the total amount of generation capacity of offshore wind to around 11.5 GW by 2030.

In the past years, the Dutch government has played a coordinating role in the development of offshore wind energy. This has led to reductions in costs of the development of offshore wind energy. It is desirable that the current approach continues in the years 2023-2030. There is a road map being developed for the development of offshore wind energy in the Netherlands between 2023 and 2030 by the Ministry of Economic Affairs of the Netherlands. The main principles in this road map are:

- Expansion of offshore wind generation capacity by 1 GW per year;
- To stimulate cost reduction, innovation and competition in offshore wind energy development;
- To seize economic opportunities and expand employment opportunities;
- To achieve synergy effects by combining different activities on the North Sea;
- And to prepare for large-scale and multinational wind parks and international connections at the North Sea to connect these wind parks (Ministry of Economic Affairs, 2016a).

1.2.1 Development offshore wind energy 2030-2050

The Ministry of Economic Affairs is looking at the possibilities to extend the policy for the development of offshore wind energy until the year 2050. This means that there will be around 30 GW installed capacity for offshore wind energy in 2050, and that there might be a surplus in generation capacity for electricity, dependent on the development of the electricity demand in this period. This large expansion of offshore wind energy in the

Netherlands will have an impact on the electricity market in the Netherlands, electricity markets of countries in the region, and the cross-border trade of electricity. It could have political and economic effects (Ministry of Economic Affairs, 2016b). However, the effects of 30 GW offshore wind energy capacity are still unknown. Possible effects are: the impact on affordability of the electricity supply, impact on the electricity grid, changes in the import and export of electricity, changes in the electricity price for consumers, impact on the employment opportunities in the Netherlands, changes in cross-border electricity trade with neighbour countries, and impact on the security of supply of electricity (Ivanov, 2015).

1.3 Problem statement

The Ministry of Economic Affairs wants to know what potential additional economic benefits are, for example in terms of employment, export of electricity to surrounding countries, importance and growth of harbours and the Dutch offshore industry. It also wants to know what potential costs are in terms of network costs, transport costs and nature. On the more strategic level the Ministry wants to know if countries in the region have similar plans.

There is currently no framework or method to investigate these strategic and economic implications of large-scale renewable energy projects, there are only frameworks to explore the strategic and economic implications of oil and gas related energy projects. A new framework necessary to make strategic decisions for the energy sector of the Netherlands. There are different frameworks that asses either energy security, strategic implications of projects or economic implications of energy projects. However, none of these frameworks combine all elements.

1.3.1 The need for a new comprehensive energy security assessment framework

Systems with a lot of oil and gas are different from systems with a lot of renewable energy generation capacity. The infrastructure is different, the abilities for storage are different, and the dependencies between countries are different. Frameworks for systems with a lot of oil and gas are not useful for systems with a lot of renewable energy. Therefore, a new framework is needed. This new framework should give insights in the effects of large-scale offshore wind energy. This research provides a comprehensive assessment framework that cannot only be used for the 30 GW wind energy case, but also for other large-scale energy projects. The comprehensive assessment framework will combine an energy security framework and a system analysis.

This new framework should give insights in what the case of 30 GW wind energy will mean for the Netherlands in terms of political, economic, environmental, and technical effects. Energy security literature is the core of the research and a system analysis will be used to enhance the framework with indicators from system analysis. This new framework will be used to explore the energy security effects in terms of political, economic and technical effects of large-scale renewable energy projects. In chapter 2, a more detailed approach of the construction of the framework is given.

1.4 Research objective

The aim of the project is to know the effects of 30 GW offshore wind energy on the comprehensive energy security of the Netherlands. To this end, a new comprehensive energy security assessment framework is developed that can give insights in political, economic, environmental and technical effects of large-scale energy projects. It gives insight in what effects will be of the implementation of large-scale offshore wind energy in the Netherlands, especially for the Dutch energy sector. The main focus is on the energy security implications and what this means for stakeholders.

At the end of the research, recommendations will be made to the Ministry of Economic Affairs, about the choices that the Netherlands has to make, concerning large-scale offshore wind energy policies. A comprehensive energy security assessment framework will be made, that can be used for other large-scale renewable energy projects.

1.5 Research questions

Before the Ministry of Economic Affairs can decide to extend the policy in 2030-2050, more insights in possible effects of the extended offshore wind policy are necessary. From the previous paragraphs, the following research question arises for the Ministry of Economic Affairs of the Netherlands:

What are the comprehensive energy security effects of 30 GW offshore wind energy for the Netherlands in 2050?

To answer the main research question, several sub questions are made:
SQ. 1: How should the comprehensive energy security effects of large-scale renewable energy projects be assessed?
SQ. 2: What are the political and economic implications of 30 GW offshore wind energy in 2050?
- 2.1: What are the potential economic and operational benefits and costs of 30 GW offshore wind energy in 2050?
- 2.2: Which stakeholders are the expected winners and which are challenged by 30 GW offshore wind energy in the North Sea?
- 2.3: What are the strategic implications for other countries in the North Sea region?
- 2.4: What are the policy implications for the Ministry of Economic Affairs?

SQ. 3: What are the comprehensive energy security effects of 30 GW offshore wind energy for the Netherlands 2050?

1.6 Scoping

The geographical scope in this project is the Netherlands and the North Sea region. The Netherlands is the country with the main focus of this research, but the North Sea countries are also taken into consideration in this research.

The used time scale in this research is the period from the year 2030 until 2050. What will be decided for the years before that, from 2023-2030, will be taken into account. The starting point for reference data will be 2016.

The renewable energy solution that will be looked at in this project is offshore wind energy. In this research, the framework will be used on the case of 30 GW offshore wind energy for the Netherlands.

1.7 Relevance

Scientific relevance
As described in 1.3, there is no comprehensive energy security assessment framework that combines elements of energy security and system analysis. This research proposes a framework that combines these elements. It will be applied to the 30 GW offshore wind case for the Netherlands. It cannot only be used for this case; the framework can be used for other large-scale energy projects also. Currently, the literature on energy security is very limited when it comes to renewable energy options, see chapter 2, and this study will provide a tool to research the effects for energy security. This is necessary, because countries are shifting to more renewable energy in the coming years (IEA, 2015).

Not much research is done in the field of energy security of renewable energy sources. This study provides more insight in what concepts of energy security for conventional energy sources can be used for energy security of renewable energy sources and which concepts will be less relevant, or not relevant anymore. This study gives insights in the relation between the indicators, components and dimensions of energy security and how they relate to a broader system. This study takes the interactions between stakeholders and components into account, something that is not done in current energy security studies.

This new framework is better than previous energy security frameworks, because previous frameworks focus on oil and gas systems. Oil and gas systems are very different from systems were a lot of renewable energy is present: other infrastructure e.g. pipeline versus transmission grid, the possibilities for storage are different e.g. easy storage versus expensive storage, and the dependencies between countries changes. So, there is a new framework necessary to show the energy security in systems with a lot of renewable energy, and this study provides that.

Relevance for the Ministry of Economic Affairs
The results of the case of 30 GW offshore wind energy in the Netherlands will be presented to the Ministry of Economic Affairs. Based on the research, recommendations will be made concerning implications of 30 GW offshore wind energy in relation to winners and losers, comprehensive energy security, and the strategic implications for surrounding countries. The Ministry will know what potential additional economic benefits are for

example in terms of employment, export of electricity, importance and growth of harbours and the Dutch offshore industry. It will also know what potential costs are in terms of network costs, transport costs and nature. On a more strategic level the Ministry will know the export potential of electricity to countries in the region and if there is a chance of exporting large amounts of electricity to countries in the region.

1.8 Research approach

The research strategy mainly entails a qualitative research approach. The research will be a combination of an energy security study and a system analysis. This will be done by adding indicators of a system analysis to the energy security framework. These will be combined in a framework to answer the sub questions and the research question. Figure 1 shows a visualisation of the research approach, based on the main research question (RQ) and the sub questions (SQ).

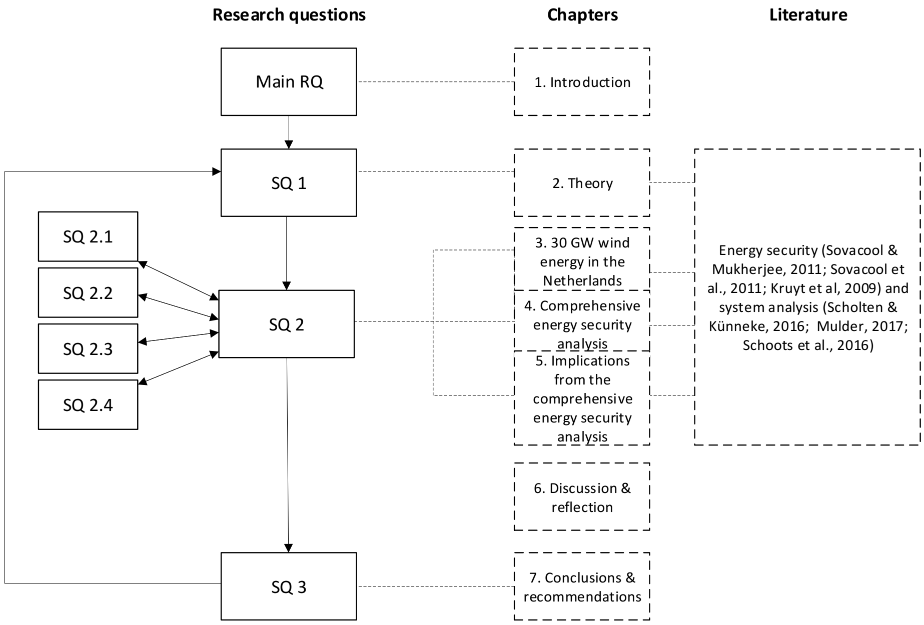

FIGURE 1: VISUALISATION OF THE RESEARCH APPROACH

1.9 Methods

The research starts with a theoretical phase. This is the preliminary research. A literature study on different concepts surrounding this topic is conducted. Two scenarios are developed for analysis. In the first scenario, the 30 GW offshore wind energy capacity will be a project from the Netherlands in the Dutch Exclusive Economic Zone (EEZ), without other countries involved. In the second scenario, the 30 GW wind energy capacity will be a joint project of the North Sea countries, but it will be constructed in the Dutch EEZ. Also, a stakeholder analysis will be conducted in this phase. This is used to decide which experts will be interviewed.

Sub question 1: How should the comprehensive energy security effects of large-scale renewable energy projects be assessed?

This question is part of the conceptual phase of the project. Research methods that are used, are: a literature research and expert interviews. These are used to develop the framework for energy security, based on the existing framework of energy security of Sovacool & Mukherjee (2011). Indicators of system analysis will be added to this framework. These are based on a system analysis of the energy sector of the Netherlands and stakeholder analysis. Data that will be required are the indicators for energy security and the indicators for the system analysis. Literature on: energy security framework, offshore wind energy, electricity markets, energy infrastructure as a socio-technical system. The research papers of Sovacool & Mukherjee (2011) and Kruyt et al. (2009) are the starting point of the literature research for this sub question. The book of Mulder (2017) and the research of Schoots et al. (2016) are the starting point of the literature research on the system analysis for this sub question.

Sub question 2: What are the political and economic implications of 30 GW offshore wind energy in 2050? This question is divided in several sub questions:

2.1: What are the potential economic and operational benefits and costs of 30 GW offshore wind energy in 2050?
2.2: Which stakeholders are the expected winners and which are challenged by 30 GW offshore wind energy in the North Sea?
2.3: What are the strategic implications for other countries in the North Sea region?
2.4: What are the policy implications for the Ministry of Economic Affairs?

These questions are part of the empirical and the analytical phases. Data is gathered for the new comprehensive energy security framework. Data is obtained by interviewing experts and by a literature study and is analysed by using the framework to investigate the effects of 30 GW offshore wind energy for the Netherlands. Literature on: energy security frameworks, electricity markets, Dutch energy sector, energy infrastructures, value chain of electricity, energy markets, energy sector, stakeholders, (economic) activities in the North Sea region, Dutch energy intensive industries, supply chain of the offshore wind energy sector, European Union's (EU) climate policies, EU electricity policies, national energy policies, electricity market, (economic) activities North Sea region, cooperation between North Sea region countries. Findings from the comprehensive energy security assessment are used to give recommendations to the Ministry of Economic Affairs, concerning policy implications of 30 GW offshore wind energy

Sub question in 3: What are the comprehensive energy security effects of 30 GW offshore wind energy for the Netherlands 2050?

This is part of the synthesis phase; it combines results of the analytical and empirical phases. Findings from the 30 GW offshore wind case study are used answer this question. There will be no additional literature research for sub question 3. This question uses information from previous sub questions.

The main research question will be answered, based on the answers of the sub questions. Suggestions for the improvement of the framework are made. Recommendations are made to the Ministry of Economic Affairs, and recommendations are made for future research.

1.9.1 Constructing the new comprehensive energy security assessment framework

The framework of Sovacool et al. (2011) will be used to create a new framework. They present 20 indicators with corresponding components, divided over 5 dimensions. These are all related to energy security. The following steps are taken to construct the framework:

- Every indicator will be reviewed to see if it is relevant for this research, by looking if it is relevant in an energy system with a lot of renewable energy, if it is relevant for the situation in the Netherlands.
- The next step is to search for additional energy security indicators in the study of Sovacool & Mukherjee (2011) and Kruyt et al. (2009). These are already divided over the same components and dimensions as described in Sovacool et al. (2011).
- A system analysis is conducted, to retrieve additional relevant indicators.
- All indicators are compared to each other, to see I there is overlap. If so, they are combined to 1 indicator. The name of the most comprehensive indicator is chosen for the combined indicator.
- The indicators are divided over the components and dimensions. Sometimes the indicators can be placed in several components. It is then placed in only one component, to count each indicator once. The component that fits the indicator best is chosen to place the indicator in.
- The framework is shown to the Ministry to discuss the usefulness and relevance of the framework, and to see if indicators are missing or irrelevant.

This results in the new comprehensive energy security assessment framework.

1.9.2 Expert interviews

Several experts are interviewed for this research, to add data to the research. In this paragraph, actor groups that are useful in this research are identified. The interviewees will be based on the stakeholder analysis in chapter 3. 13 interviews will be conducted. The Ministry of Economic Affairs will be used to get in contact with these experts. The experts that will be interviewed for this should have substantial knowledge of the energy sector and are from different backgrounds. They can be categorized in the following groups:

- Industry;
- North Sea actors;
- Research institutes;
- Public/governmental organisations.

In preparation of the interviews a short list of topics to discuss will be send to the interviewee. Appendix VII shows the list of questions that is used during the interview. The set-up of the interviews will be semi-structured. This allows for new ideas to be brought up to discuss during the interviews, as a result of what the interviewees say. The questions will be case related. The effects of the 30 GW offshore wind case in the Netherlands will be discussed for the two scenarios that are developed in the theoretical phase. The questions will be related to the sub question 2. The interviews will be about the implications of the scenarios. They will be about the surplus of electricity, winners and losers, and technical development. The topics can be categorized as in the theoretical framework of figure 2, in paragraph 2.1. These topics are:

- Availability effects;
- Affordability effects;
- Technology development and efficiency effects;
- Environmental and social sustainability effects;
- Regulation and governance effects.

1.9.3 Interview data analysis

Each interview will take approximately 1 hour and will be recorded, with permission of the interviewee. The recorded interviews will be summarized, and the summarized interview will be send to the interviewee for approval. After this, the interviews will be analysed by the qualitative data analysis tool ATLAS.ti. ATLAS.ti is a data analysis tool that is suited to analyse large bodies of textual data. It can be used to code the interviews and to link the coded data.

The summarized interviews can be found in appendix VII. After summarizing the interviews, the interviews are coded. The codes are then used to easily find data for the indicators in the new comprehensive energy security framework in the two scenarios. The interviews are used as an additional source for input data for the framework, next to literature sources.

1.9.4 Constructing the scenarios

The scenarios are based on the North Sea scenario studies that are presented by PBL in workshops about the future of the North Sea (Planbureau voor de Leefomgeving, 2017). The first axis in the scenarios of PBL is: slow dynamics versus high dynamics. On the other axis of PBL's scenario studies are: current ambitions versus sustainable ambitions. PBL shows in this scenario study four scenarios. For this research, it chosen to only use the low dynamics and high dynamics axis, because the implementation of 30 GW offshore wind shows a sustainable ambition. There are more international tensions and conflicts in the world in the low dynamics scenario. This results in a more national focus of countries. The high dynamics scenario is on the other end of the axis. This means that there is an international focus and there is international trust and more global trade. These scenarios from PBL are made for policy testing, to investigate developments in different policy fields, and for inspirational purposes, and are therefore very useful in this study. The scenarios of PBL are used to create scenarios for this study. However, they are a bit shortened, things that are not relevant for offshore wind development in this study are left out. This results in a national scenario and an international scenario. Investing the effects of 30 GW offshore wind in a national scenario and in an international scenario is very relevant, because the development is now mainly nationally organized. There is an increased demand from the industry to arrange the development of offshore wind internationally. However, it is not certain that the offshore wind sector will become more international. Also, the Dutch EEZ is large enough to construct 30 GW offshore wind without the consent of any other country. Therefore, it is useful to explore the development in large-scale offshore wind in both scenarios. These scenarios will be used to explore energy security implications of 30 GW offshore wind energy under both types.

2. Theory

The first building block of the theoretical framework is the main research question. To answer this question, theories on energy security and system analysis are used. The base of the research will be energy security literature. Theories about energy security are not comprehensive enough to answer this question. System analysis will be used to retrieve indicators to analyse renewable energy projects. These indicators will be combined into a new comprehensive energy security assessment framework. This new framework will explore the comprehensive energy security effects of 30 GW wind energy in the Netherlands.

2.1 Energy security

2.1.1 Definition

Energy security is a “concept with a strategic intent” (Chester, 2010), it is about “the absence of, protection from or adaptability to threats that are caused by or have an impact on the energy supply chain” (Winzer, 2012). Different studies show different dimensions. Sovacool & Mukherjee (2011) describe 5 dimensions: availability, affordability, technology development and efficiency, environmental and social sustainability, and regulation and governance. These correspond to 320 simple and 52 complex indicators, metrics that can be used to measure energy security.

2.1.2 Indicators

In a second paper, Sovacool et al. (2011) describe 20 components and indicators for energy security measurements. These are the starting point for finding indicators for a new comprehensive assessment framework, with additional indicators from their first paper. This energy security framework will be enhanced with elements from system analysis. Not all indicators will be used from the energy security frameworks. The focus is on energy security indicators that can measure availability, affordability, technology development & efficiency, environmental & social sustainability, and regulation & governance effects as presented in figure 2.

2.1.2.1 Availability

Availability is related to security of supply, having sufficient supply of energy and being energy independent of other countries (Sovacool & Mukherjee, 2011). It is the availability of energy to an economy. The elements are related to the absolute availability of energy and the geological existence of energy (Kruyt et al., 2009).

Security of supply can be defined in many different ways. In this research, security of supply is about the relation between the supply of energy in a country and the demand of energy in a country. Security of supply is about having sufficient supplies of energy for consumers, so that the consumer will not encounter disruptions in energy supply. This is strongly related to the security of demand in a country. Security of supply risks are related to mismatches in supply and demand (ECN & CIEP, 2007).

Production is related to ability of a country to produce its own electricity, instead of only importing electricity. It is relevant to know what the electricity generation capacity is in a country and the rate at which this grows in a year.

Dependency has as an underlying value independence of other countries. It shows the extent to which a country relies upon energy imports to meet its energy needs. The more a country depends on other countries for their energy supply, the more it is under influence of price shocks and disruptions in supply. Having more interconnections with different countries and increasing the domestic production, decreases vulnerability and countries will be less dependent, because it reduces the dependence on one country (European Commission, 2013).

Diversification is a component that relates to a diverse energy mix, geographical dispersion of import sources and energy facilities, and diversification of ownership of energy companies. The more diversified this is, the less vulnerable a country is to shocks affecting an energy source, country, or supplier (European Commission, 2013).

2.1.2.2 Affordability

The affordability dimension is related to the costs of energy supply. It is about producing energy services at the lowest cost, having price stability for energy, and the equity and access to energy (Sovacool & Mukherjee, 2011). Affordability is about the economical elements of energy security (Kruyt et al., 2009).

Price stability is a component that is important for the predictability of electricity prices and services. It shows the changes in the electricity prices for the consumers (Sovacool et al., 2011).

Access and equity is about the connection of consumers to the grid and enabling equitable access to energy services. A factor in this is the rate of electrification for industry and households (Sovacool et al., 2011).

Affordability is about actual prices that end-users pay for electricity. This can differ per sector. These prices depend on the marginal costs of electricity power generation, and transmission cost for electricity (Sovacool et al., 2011).

2.1.2.3 Technology development and efficiency

Technology development and efficiency is about adapting to interruptions of supply and recovering from interruptions of supply. It covers investments in research and development of techniques, infrastructure, sustaining a reliable energy supply, safety of energy supply, and energy efficiency. (Sovacool & Mukherjee, 2011).

Innovation and research relates to the work that is systematically undertaken to increase knowledge and to use this for new applications in renewable sources of energy. It covers basic research, applied research, and experimental development. An important indicator for this is the research intensity, which can be defined as the research budgets for renewable energy sources (Sovacool et al, 2011).

Energy efficiency is measured in the country for the efficiency of national economic activities; this is also called energy intensity of an economy. Energy intensity gives an indication of the effectiveness with which energy is being used in a country to produce added value. It gives a comprehensive picture regarding the link between energy use and economic development (European Commission, 2013).

Safety and reliability is about the ability of the electricity system to supply electricity to the consumer under normal conditions, without having interruptions in supply (McCarthy et al., 2007). The ability to prevent interruptions can be seen in the frequency of interruptions of supply to the consumers.

Resilience of an electricity system relates to the system adequacy. It covers the ability of the system to respond to interruptions of supply. These are important components to prevent outages (McCarthy et al., 2007).

Investment and employment relate to making the right investments in infrastructure, operation, and maintenance of an energy system. This will increase the reliability of the energy system (Sovacool & Mukherjee, 2011).

2.1.2.4 Environmental and social sustainability

This dimension focuses on minimization of environmental impact, preserving natural habitat, pollution, and adapting to climate change (Sovacool & Mukherjee, 2011). It covers environmental and social elements (Kruyt et al., 2009).

Energy generation facilities require a certain space that sometimes cannot be used for anything else. The increase in required areas for these facilities can cause a decrease in nature areas, offshore and onshore. This might affect the habitat and ecology in the area.

Climate change and decarbonizing the energy sector are important factors in the European energy policies. These can be found in national and international targets and roadmaps to reduce greenhouse gases (European Commission, 2017a).

2.1.2.5 Regulation and governance

This dimension focuses on political elements of the energy supply. It is about transparent policy making, integrity, and stability. It also has international elements: trade, interconnectivity, competitiveness, and export are all included in this dimension (Sovacool & Mukherjee, 2011).

Governance refers to the ability of a group of people, most of the time policy makers and law enforcement, to set and enforce rules that are needed to achieve a certain desired outcome (Florini & Sovacool, 2009).

Trade and regional interconnectivity refer to the energy market in an international perspective. National or regional electricity markets are connected to other electricity markets, by connecting the high-voltage grids. This allows for international transport and trade of electricity (TenneT, 2017a).

Competition and markets are about the fairness of the system and the ability to deliver energy to consumers. Competition keeps prices low and it allows consumers to choose their energy suppliers. Markets should provide the right incentives for consumers and producers to act according to the rules (European Commission, 2017c).

2.1.3 Energy security literature

Energy security literature is chosen as the core of this research. Not all aspects of current energy security studies are relevant for this research. The study of Sovacool & Mukherjee (2011) and Kruyt et al. (2009) will be the start of this study. After selecting indicators from energy security studies, indicators of system analysis will enhance the framework. These indicators from the system analysis will focus more on the renewable energy source and its characteristics, the broader political-economic context of the energy system in which the offshore wind energy will develop, and on economic and technical implications.

Sovacool & Mukherjee (2011), Sovacool et al. (2011) and Kruyt et al. (2009) provide a framework for analysing national energy security policies and performance. They provide “clarity and focus to the often-ambiguous concept of energy security” (Sovacool & Mukherjee, 2011). Their studies argue that energy security is a complex goal, and that energy security questions are about how to equitably provide available, affordable, reliable, efficient, environmentally benign, properly governed and socially acceptable energy services.

The International Energy Agency (IEA) has multiple studies on energy security and energy security indicators. The IEA (2011) describes different dimensions of energy security and gives indicators to measure energy security. A downside of this study is that it focuses on the short-term energy security and not on the long-term. In this research, a long-term perspective is desirable, because of the scope of the project, see paragraph 1.6. In a later study, IEA (2014a) focuses on electricity system security. Important factors here are fuel security, adequacy, and system security, electricity prices for businesses, individuals, and system operation. They focus on system thinking in the energy sector, but do not present a framework to measure the electricity system security.

Chester (2010) and Winzer (2012) both present studies to define the concept of energy security and relate it to the management of risks in the energy supply. Chester (2010) describes that it has a strong relation to strategic intent of energy sources, such as oil supply. Winzer (2012) focuses on the risk in energy supply continuity. The framework consists of sources of risk, severity of risks and the impact of risk. Winzer (2012) uses environmental and economic indicators, but does not use indicators that describe the system or strategic elements.

2.1.4 Shortcomings energy security literature

To measure comprehensive energy security effects of large-scale offshore wind in the Netherlands, it is important to take a broader look at the system in which it is developed. Political and economic forces that are present in a country influence the effects of large-scale renewable energy in a system. Interactions between stakeholders, institutions, and the environment influence the energy security in a country. Existing energy security literature focuses a little on government and economics, but it does not focus on interactions within a system. It does not take a look at the broader system in which it is developed. Existing energy security studies mainly focus on systems where a lot of conventional, fossil fuels are present. They do not provide indicators for the implementation and characteristics of renewable energy sources.

Kruyt et al. (2009) and Sovacool & Mukherjee (2011) focus mainly on fossil fuels, the oil and gas sector, and strategic implications are not part of the framework. The oil and gas sector is a totally different sector than the renewable energy sector in terms of infrastructure, abilities for storage, and dependencies on other countries. There are no indicators related to renewable energy that cover these aspects for renewable energy. They only to cover the amount of CO_2-emissions. Kruyt et al. (2009) hardly focuses on sustainability and economic elements, only on the share of zero-carbon fuels in the energy mix. Kruyt et al. (2009) also does not take into account the factor electricity, because the focus in this framework is on fossil fuels. Sovacool & Mukherjee (2011) and Sovacool et al. (2011) include the environmental & social sustainability dimension in their framework. However, they take the characteristics of renewable energy into account; they only provide an indicator for the amount of CO_2-emissions. There are no strategic elements in the framework and the economic elements are not comprehensive enough. It does have the indicators of direct and indirect employment, which are useful for the research. Nevertheless, these studies can be used as a start to get indicators for constructing the new framework.

The IEA (2011) study on energy security does not take many different renewable energy sources into account either. The only renewable energy sources they take into account are biomass and waste energy. The other energy sources are only conventional energy sources. There is no system aspect in this study and there are no economic indicators. In the IEA (2014) study, there is a focus on system thinking, but there are no indicators provided.

Another shortcoming of the energy security literature is the focus on the difference in energy security between different nations and not the effects of certain actions in one country and how this will change the interactions in a country. To investigate this, a broader perspective on the national setting in which the actions take place are needed, and how this relates to the different components in the system.

2.2 System analysis

Multiple studies focus on economics of offshore wind energy or on strategic implications of offshore wind energy. Studies that focus on economics are for example cost-benefit analysis (Snyder & Kaiser, 2009; Blanco, 2009), but they do not focus on energy security or strategic implications. Studies that focus more on strategic implications often use the SWOT analysis, but these studies do not include energy security or economics (Li et al., 2013).

System analysis is a method to create a complete overview of the system. It focuses on the interactions between the different components of the system. It gives an overview of the different actors and their roles in the system and the how they relate to the different components of the system. This can be done by conducting a PEST-analysis. A PEST-analysis is used as a market analysis tool to identify developments in the external business environment of businesses and it supports their strategic decisions. PEST stands for Political, Economic, Social, and Technological analysis (Ho, 2014). In this research, the PEST analysis is used to identify different indicators from the system analysis and group them into political, economic, social, and technological indicators. A literature research is used to do the system analysis.

2.2.1 The added value of system analysis to energy security

As described in 2.1.3 current energy security studies have shortcomings concerning the broader political-economic context in which offshore wind energy will develop, the interactions of different components in the system, and the small amount of renewable energy indicators. System analysis can provide insights on all these aspects and therefore it is very useful to enhance the current energy security indicators. System analysis is a method to create a complete overview of the system. It focuses on the interactions between the different components of the system. It gives an overview of the different actors and their roles in the system and the how they relate to the different components of the system. System analysis can show the interactions between stakeholders, institutions, and environment. It can provide indicators for the implementation and characteristics of renewable energy sources into an already existing energy system. By using the PEST analysis tool, system analysis can be used to conduct additional indicators that are needed: to identify interactions and to add more renewable energy indicators. The added value of the PEST-analysis tool is that it gives structure in conducted indicators, by dividing them in 4 categories: political, economic, social, and technological elements. These elements relate to the dimensions of energy security. The political indicators relate the most to regulation & governance, the economic indicators relate the most to affordability, the social indicators relate the most to environmental & social sustainability, and the technological indicators relate the most to technology development & efficiency. Therefore, system analysis has an added value to the energy security analysis.

2.2.2 Indicators

Two techniques have been used to identify indicators for offshore wind development in the Netherlands. These techniques are: energy security analysis and system analysis. For the system analysis, the PEST analysis tool is used.

2.2.2.1 Political indicators

Political indicators cover government interventions such as legislation, regulation, financial incentives, and policies (Ho, 2014). In this research, the government interventions related to offshore wind energy in the Netherlands are described. From this, the main political indicators will be derived.

2.2.2.2 Economic indicators

Economic indicators cover macro-economic conditions, taxation, international trade trends, industry trends, distribution trends, interest rates and exchange rates, and customer drivers (Ho, 2014). In this research, the economic indicators related to offshore wind energy in the Netherlands will be derived.

2.2.2.3 Social indicators

In general, the social indicators in a PEST analysis cover a broad range of indicators such as social, cultural, and demographic indicators of the external environment (Ho, 2014). However, a large part of this is outside of the scope of this research. Therefore, in this research we focus on the attitude of other North Sea users towards wind energy on the North Sea. From this the social indicators will be derived.

2.2.2.4 Technological indicators

Technological indicators cover the activities and characteristics related to the technology, infrastructures, technological incentives, and technological changes (Ho, 2014).

2.3 Integration into a new framework

Figure 2 shows how the integration of the energy security framework and system analysis will result in a new framework.

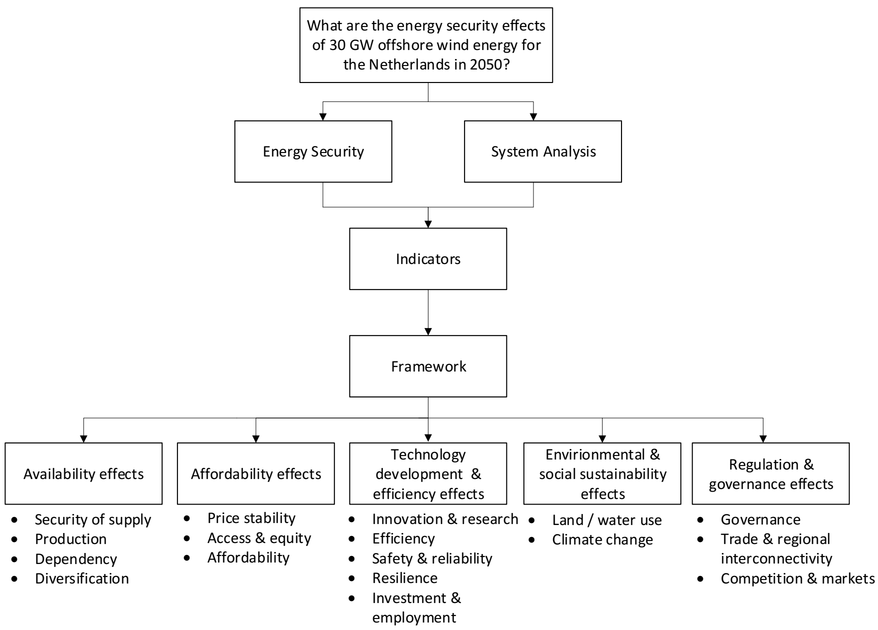

FIGURE 2: VISUALISATION OF THE DEVELOPMENT OF THE NEW ENERGY SECURITY FRAMEWORK

2.3.1 Selection of energy security indicators

As described in paragraph 2.1.2, Sovacool et al. (2011) describe 20 components and indicators that can be used for energy security measurements. These are the starting point for finding indicators for the new comprehensive assessment framework, with additional indicators from their paper with 320 indicators that are related to electricity. In this paper, the components and indicators are distributed over 5 dimensions: availability, affordability, technology development and efficiency, environmental sustainability, and regulation and governance, see appendix I. From these indicators, a selection is made. The following indicators from Sovacool et al. (2011) are considered relevant:

- *Total energy supply* is relevant to determine the security of supply in a country. A high total energy supply increases the availability of energy in a country.
- *Self-sufficiency* is relevant to determine to what extent a country is energy independent of other countries. Energy independence increases security of supply and availability of energy in a country.
- *Share of renewable energy in total primary energy supply* is relevant, because a higher share of renewable energy in the total energy supply increases independence of other (oil and gas supplying) countries. It also contributes to a sustainable energy supply.
- *Stability of electricity prices* is used to assess affordability of energy in a country. More stable electricity prices make it easier to predict future electricity prices. Predictable energy prices give investors a smaller investment risk, resulting in better affordability of energy facilities.
- *Retail price of gasoline/petrol* refers to the affordability of energy in a country.
- *Research intensity* indicates the amount of money that is invested in research to technology development.
- *Energy intensity* indicates energy efficiency in a country. Higher energy intensity means a lower energy efficiency of a country. More efficiency leads to less energy needed, which is important for energy independency of other countries and it results in lower energy prices.
- *Grid efficiency* indicates investments in the grid in a country and it is related to performance of the grid.
- *Water availability* indicates the amount of water that can be used in the energy system. Higher water availability is good for the energy system.
- *Per capita energy related carbon dioxide emissions* shows how sustainable the energy system of a country is, how polluting it is, and if the country is meeting the reduction targets for greenhouse gasses.
- *Energy exports* shows how much trade and connectivity there is in energy in a country. When this high, the supply is more than the demand in a country. Energy exports are good for the economy.
- *Per capita energy subsidies* indicates the amount of subsidy that is given to energy; this indicates how competitive the energy market is. This is important to the affordability of energy in a country.

The following indicators are considered as not relevant for renewable energy projects in the Netherlands:

- *Average reserve-to-production ratio for the three primary energy fuels (coal, natural gas, and oil):* because renewable energy sources are not considered in this indicator.
- *% population with high quality connections to the electricity grid:* this is already the case for the Netherlands.
- *Per capita sulphur dioxide emissions*: the government of the Netherlands has a CO_2 reduction focus.
- *Households dependent on traditional fuels:* because this is almost none in the Netherlands already.
- *Energy resources and stockpiles*: because renewable energy sources in general do not have stockpiles and are intermittent sources.
- *Forest cover*: in the Netherlands the renewable energy sources such as wind and solar energy are in general not placed in forest areas
- *Worldwide governance rating:* this is not relevant for renewable energy projects, because it is only for the Netherlands and not in comparison with another country.
- *Quality of energy information:* transparency is the task of the energy companies and the regulator and this is not relevant for this research.

However, some indicators from the 320 indicators from Sovacool & Mukherjee (2011) are considered very relevant for the research, but are not used in in Sovacool et al. (2011). These are added to the indicators that are used from the energy security framework. These indicators are:

- *Total electricity demand* is relevant to know if the electricity supply in a country is enough to for the demand. This is important for security of supply and it measures the availability of energy to a country.
- *Total installed electricity generation capacity* relates to the ability of supplying enough electricity to meet the demand. This is important for security of supply and it the availability of energy to a country.
- *Geographic dispersion of energy facilities* indicates if the supply is diversified, which contributes to security of supply and that it does not depend on the situation in a few locations. This contributes to availability of energy to a country.
- *Diversification of ownership of energy companies* indicates if the supply of energy is diversified. This contributes to security of supply and that it is not dependent on a few suppliers. This contributes to availability of energy to a country.
- *End-use energy prices by fuel* is relevant for the affordability of energy in a country.
- *Electricity price volatility* indicates the affordability of energy in a country. A higher stability of electricity prices, makes it easier to predict electricity prices. Predictable energy prices give investors a smaller risk, resulting in better affordability of energy.
- *Rate of electrification* shows demand for electricity in a country and access to affordable electricity.
- *Marginal cost of electricity power generation* indicates the electricity price in a country. This is important for the affordability of electricity in a country.
- *Transmission costs for electricity* indicates the affordability of electricity in a country.
- *Research budgets for renewable sources of energy* indicates investments in research in renewable energy. This stimulates technology development related to renewable energy sources, making them more competitive with other energy sources.
- *Frequency of interruption of supply*: this indicates the reliability of the energy system of a country.
- *Generation adequacy* indicates the ability of generation in the electricity system to match consumption in the electricity system.
- *System adequacy* indicates the ability of an electricity system to supply load in standard conditions.
- *Direct employment* indicates the amount of people working in the energy sector. This is relevant for the economic activity that is created by the sector.
- *Indirect & induced employment* indicates the amount of people working in the energy sector. This is relevant for the economic activity that is created by the energy sector.
- *Average rate of return on energy investments* indicates investments in the sector and the investment risk for investors in the system.
- *Required space* indicates the amount of space that is needed to for energy production. This is important to indicate impact on environmental and social sustainability.
- *Water use* reflects the needed for water for energy production, to indicate environmental and social sustainability.
- *Presence of climate change goals and targets* indicates support for a sustainable energy system in a country and the desire to reduce climate change.
- *CO_2 emissions from electricity sector* indicates sustainability of the electricity sector in a country.
- *Number of electricity system regulators* reflects legitimate policy making and competitiveness of markets.
- *Provision of priority grid access to renewable energy* indicates governance of grid access and renewable energy implementation. It relates to the competitiveness of renewable energy.
- *Amount of transnational electricity trading* reflects international trade of energy and globalization.
- *Total interconnection capacity* reflects international trade of energy and globalization.
- *Market share of largest three electricity suppliers* reflects competition in the market. A lower market share of the largest three electricity suppliers means that there is a more competitive market.

2.3.2 Selection of system analysis indicators

2.3.2.1 Political indicators

Offshore wind energy policy

The government of the Netherlands concluded the Energy Agreement for Sustainable Growth with businesses, trade unions, environmental organizations and others in 2013. This contains agreements on energy conservation, increase in electricity supply from renewable energy sources, and job creation (Government of the Netherlands, 2013b). It stated that the development of offshore wind power in the Netherlands should speed up and scale up. The following agreements were made in this topic: 4,450 MW offshore wind capacity in 2023, a cost reduction of 40% per MWh until 2024, innovation throughout the supply chain of wind energy, a robust legal framework should be created for locations, concessions, and subsidies, and TenneT will be responsible for the offshore grid (Government of the Netherlands, 2013b).

The Energy Agenda describes steps towards a low-carbon energy supply in 2050. Key elements for the electricity sector are: decarbonize electricity production, improve the North-Western European electricity market, make the electricity system more flexible, and adapt the electricity system to decentralized supply. There is a road map being developed for offshore wind energy in 2023-2030, and a look ahead at the period 2030-2050. Key principles here are to increase offshore wind energy by 1 GW per year until 2030, to stimulate cost reduction, innovation, and competition in the development, to seize economic opportunities and expand employment opportunities, to achieve synergy effects on the North Sea, and to prepare for large-scale and multinational wind parks and international connections at the North Sea to connect these wind farms (Ministry of Economic Affairs, 2016).

Offshore wind energy law

The offshore wind energy law (Wet Windenergie op zee) provides a legal framework for the realization of offshore wind energy in the Netherlands. This law applies to the Dutch territorial sea and the Dutch EEZ. This law should result in cost reductions for the development and construction of offshore wind farms and shorter lead times. Developers get the assurance that the location is suitable for wind turbines and the conditions of the area. It also allows developers to choose between different types of technologies, within the stated environmental and ecological frameworks. The law assumes that there is cohesion between the optimal spatial planning at the North Sea and on shore, the development of the electricity grid and the development of wind farms. It creates a framework for the decision of the wind farm zones, the locations of the wind farms, with a connection to the grid on shore. This decision is made by the Ministry of Economic Affairs and the Ministry of Infrastructure and the Environment. When making this decision, the following aspects were taken into account: multiple functions of the North Sea, effects on third parties of appointing wind farm zones, ecological interests, costs of realizing a wind farm in a certain area, and the importance of connecting the wind farm to the grid. Permits are an important part of the offshore wind energy law. It is not allowed to construct or exploit a wind farm without a licence from the Ministry of Economic Affairs in the Dutch territorial sea or EEZ. This law sets rules for the supervision and law enforcement (Noordzeeloket, 2017d).

National Water Plan

The National Water Plan is the North Sea policy plan of the Dutch government for the period until 2021. It includes the general frameworks for harmonization between the various users of the North Sea. It also specifies the relation with the marine ecosystem (Noordzeeloket, 2017a). The National Water Plan is used to designate the wind farm zones in the Dutch EEZ. Only within these zones wind farms are allowed (Netherlands Enterprise Agency, 2015).

Tender process

The Dutch government takes a pro-active role in the development of offshore wind parks. It designates wind farm zones, carries out site investigations, determines requirements for building and operating a wind farm and issues tenders for subsidy and permit (RVO, 2016). There are several steps in the tender process. First, the government decides on sites where wind farms can be constructed within the wind farm zones. These site decisions are taken by the Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs. In this decision, the requirements and conditions for the construction presented. The Netherlands Enterprise Agency (RVO) provides characteristics of the site: the soil, water and wind conditions and an environmental impact assessment will be conducted. This data will be made public, this gives parties interested in the development and exploitation of a wind farm an opportunity for choosing the best technical options for these conditions and realize a design at the lowest possible costs. Parties can start the bidding. Producers with the winning bid will receive financial compensation for the electricity they generate for 15 years. The lowest bidder will be the winner and the bid will be in €/kWh for the wind farm. The lowest bidder will be awarded with the grant and the permits to build and operate the wind farm, according to the previous set conditions (RVO, 2016).

Stimulation of Sustainable Energy Production (SDE+) grant
The SDE+ is an operating grant to encourage sustainable energy production. This grant is commissioned by the Ministry of Economic Affairs. It compensates producers of renewable energy for the unprofitable component for a fixed number of years, for offshore wind energy this is 15 years. The unprofitable component is the difference between the cost price of renewable energy and the market price, when the cost price is higher than the market price. Companies, institutions, and non-profit organizations can apply for this grant. It is also for other techniques for the production of renewable electricity, gas, or heat (Netherlands Enterprise Agency, 2017).

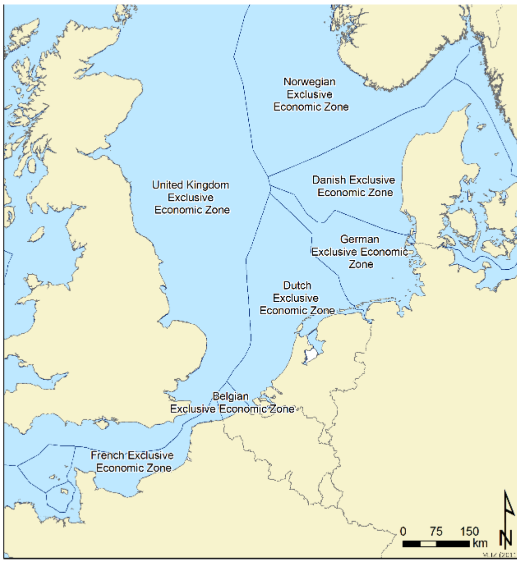

FIGURE 3: EEZS IN THE NORTH SEA (MARINE REGIONS, 2017)

North Sea countries
The Netherlands is not the only country that is developing offshore wind energy at the North Sea. Other North Sea countries are developing offshore wind energy. These countries are developing offshore wind energy in their EEZs, see figure 3. These developments also affect the Dutch electricity grid and generation capacity. These North Sea countries cooperate with each other, to develop a more efficient energy infrastructure. One of these efforts to cooperate is the Memorandum of Understanding (MoU), to enhance cooperation on renewable energy, and in particular the cooperation on offshore wind energy. Following countries signed the agreement: Germany, the Netherlands, Luxembourg, Norway, Sweden, France, Denmark, Ireland, United Kingdom, and Belgium. The agreement aims to reduce costs and accelerate the deployment of offshore wind energy (WindEurope, 2016).

The derived political indicators are:
- Renewable energy targets
- CO_2 reduction targets
- Renewable energy generation capacity
- Responsibilities
- Increase rate of renewable energy generation capacity
- Regulatory uncertainty
- Permit procedures

- Renewable energy subsidy
- International cooperation
- Spatial planning

2.3.2.2 Economic indicators

Electricity markets

The current Dutch electricity market consists of multiple related markets. The largest volume, about 85%, of electricity is sold in the bilateral market. In this market, there are bilateral contracts between customers and generating companies. These consumers are large consumers, energy supply companies, or traders. Energy supply companies sell the electricity to the smaller consumers, such as households. The Dutch power exchange is done in the European Power Exchange, the EPEX SPOT, which is part of the EEX Group. This is a short-term market for electricity. On the EPEX SPOT market electricity is traded on an hourly basis for the next day, where there is only one price for each hour. It covers Germany, France, United Kingdom, the Netherlands, Belgium, Austria, Switzerland and Luxembourg (EPEX SPOT, 2017). The balancing market is the balancing mechanism of the wholesale market. Producers can offer reserve power in this market. TenneT contracts this reserve power, to maintain the balance on short notice in the Dutch electricity system. Import / export capacity allocation takes place in the import capacity auctions, where the capacity of interconnectors is allocated in auctions. TenneT operates these auctions with the TSO of the other side of the interconnector.

The Dutch electricity market gets more integrated in the North-Western European market. Developments in the Dutch electricity market are under influence of events in the surrounding countries. Generation capacity, development of renewable energy sources, and supply and demand are influenced (Schoots et al., 2016).

EU ETS

The EU Emissions Trading Scheme (EU ETS) is since 2005 the EU's main policy instrument for reducing CO_2 emissions. Currently the ETS' CO_2 price is very low and it is expected to remain low in the coming years, and that it will take a long time before it is cost effective for industries to emit less CO_2 (Ministry of Economic Affairs, 2016a).

Supply & Demand

Energy production from renewable sources will increase in the coming years. The production mix will change from conventional sources, such as oil, natural gas, and coal, to renewable energy sources: sun, wind, and biomass. The energy supply will also become more decentralized, local generation will increase (Schoots et al., 2016).

Electricity demand will increase in the coming years, because of the electrification in transport, low-temperature heating, electrification of the industrial sector, and because of the increase in households. On the other hand, the demand will decrease a bit through investments in energy conservation. It is important that the supply of electricity can meet the demand of electricity (Ministry of Economic Affairs, 2016a).

Electricity trade

An important aspect in integrating the Dutch electricity grid in the European electricity grid is the interconnection capacity. Currently it has connections with Germany, Belgium, Great-Britain, and Norway. Between the Netherlands and Denmark, a connection is under construction. With an increase in interconnection capacity, the price differences between these countries will decrease. The price in Belgium and France will be a bit higher than the price in the Netherlands. This is mainly caused by the difference in electricity generation techniques per country. In the coming years, the Netherlands will become a net exporter of electricity (Schoots et al., 2016).

Costs of offshore wind energy

The life cycle of offshore wind energy is: planning, design, construction, operation, and decommissioning. Most costs are made in the construction phase. These costs are in the construction of turbines, foundation, cables within the farm, and the installation. These costs are for the developer of the wind farm. Next to this, the developer has costs in the operation and maintenance (O&M) phase and in the design & planning phase. The costs for the connection to the onshore grid of the wind farms on the grid are for the TSO, TenneT. Offshore wind energy is an intermittent energy source, and therefore there are balancing costs for the grid. Cost reductions are expected to continue in the construction of wind farms. Main reasons for this are: technological development, better design of wind farms, more efficiency in the system, cooperation between wind farms offshore, learning effects, and optimization of management and organization of wind farms. When wind farms will be constructed further offshore, the price will increase. This is mainly due to the fact that the water is deeper and the distance to shore is longer, and longer cables are needed. On the other hand, there are more wind hours and there is stronger wind (Natuur & Milieu, 2016).

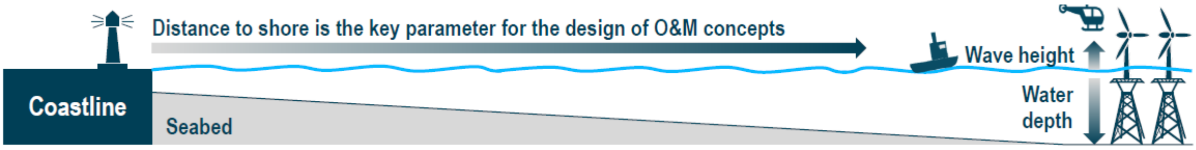

FIGURE 4: DISTANCE TO SHORE AND O&M COSTS (ROLAND BERGER, 2013)

Financing offshore wind energy
At this moment, financing offshore wind energy in the Netherlands is done by several parties. The main party is the developer of the wind farm. This can also be a consortium, with more parties. There is an increase in financing from banks and in time other institutional investors will become interested in investing in offshore wind energy.

Financibility of offshore wind farms mainly consists of three variables: level of subsidy, capital costs, and construction costs of wind farm. As discussed above, most costs are in the construction phase of the wind farm. Large upfront costs and long lead times create a financial risk for investors. Further reduction in the costs for construction will reduce the investment risk. Most risks are reduced by closer cooperation between the government and market parties: in management, monitoring, and execution of projects (Nederlandse Investeringsinstelling, 2014).

Offshore wind industry
The Dutch offshore wind industry consists of more than 200 companies with activities related to offshore wind. Dutch companies do not only construct wind farms in the Dutch EEZ, but they also perform well internationally. The sector consists of companies that specialize in materials, foundation, offshore technology, electrical infrastructures, and wind turbine technology. Engineering companies design turbines, rotor blades, foundations, installations and maintenance ships. In Europe and in other parts of the world, there is an increase in investments in offshore wind energy (WindEurope, 2017a). This creates opportunities for the Dutch wind energy sector to export products and services. There is also a boost for the industries that supply materials for the construction.

Employment
Developing offshore wind farms requires jobs in the offshore wind sector in the Netherlands. These jobs are needed in all the phases of the development of the wind farms: in development, production, construction, and exploitation phase, and eventually also in the decommissioning phase. Employment opportunities are related to production of parts, construction and maintenance of wind farms, research in the development of technology and policy for offshore wind, and exploitation of wind parks. When wind farms are build close to the shore, wind farms have an indirect effect on the economic activities onshore, such as tourism (Natuur & Milieu, 2016).

The derived economic indicators are:

- Electricity market design
- Total energy supply
- Total energy demand
- Total electricity supply
- Total electricity demand
- CO_2 price
- Balancing costs
- Cross-border electricity trade
- Development costs
- Operation and maintenance costs
- Investment risk

- Employment in industry
- Energy price
- Electricity price
- Investment in electricity transmission capacity

2.3.2.3 Social indicators

Other users of the North Sea

There is a lot of activity in the North Sea. For many actors, the North Sea is of importance. Building more wind farms in the North Sea requires an effort in spatial planning. The main activities and structures in the Dutch EEZ are shipping, sand and shell extraction, fishing, military defence, cables and pipes, gas platforms, wind farms. Next to this, there are also areas reserved for natural preservation and habitat. All these activities require that there is enough space at the North Sea, to do the activities save and efficient. For this there are already many reserved areas. However, if the offshore wind energy sector increases, this activity requires more space.

The derived social indicators are:

- Available areas
- Required space for renewable energy option

2.3.2.4 Technological indicators

Offshore conditions

Performance and the costs of the wind farm are strongly related to the conditions of the site. One of the most reasons is the wind speed, which affects the amount of wind energy that is generated. This influences the revenues from wind farms. The seabed, wave action, and water depth affect the construction and mechanics of wind turbines, which influences the foundations and structures of wind turbines and the costs of constructing and maintaining the wind farms. Further off the coast means the water is deeper. This brings more costs to constructing a wind farm.

Innovation

Innovation in the offshore wind sector can play an important role in bringing the costs down. There is a lot of research in the Netherlands and in other countries to support innovation. There are innovations possible in: grid systems, operation & maintenance, industrialisation, and the offshore balance of plant. (WindEurope, 2017c)

Wind turbine design

The turbine that is used the most in offshore wind farms are horizontal-axis turbines. At the top of the turbine, there is the main rotor and an electrical generator. These are pointed into the wind. There is a gearbox, which makes the rotation quicker and suitable for an electrical generator. Usually, offshore wind turbines have three rotor blades. Larger rotor blades generate more electricity. If the rotor blades are twice the size, generated energy will be 4 times as much. This makes it attractive to the producer to make larger wind turbines (Siemens, 2017).

Wind farm design

For the design of the wind farm, the location of the wind farm is important. This influences construction costs, grid connection costs, and the revenues from wind. Other wind farm design indicators are the number of wind turbines that can be constructed, distance between de wind turbines and relative positioning of turbines to each other. These are positioned in a way that they are not in the zone with less wind behind other turbines.

Construction

For the construction of turbines the shape of the seabed, current, water depth, and waves are taken into account. These influence foundations of turbines and the difficulty of the construction. Parts are brought by a large vessel to the site. The vessels are also used for the installation. To work from a vessel at sea, means that the vessel is very susceptible to the waves. To reduce the difficulties that this gives, the vessel puts legs to the sea bed, which make the vessel more stable. These conditions make it more attractive for constructors to construct as much as possible onshore. Construction onshore is cheaper than constructing offshore (The Crown Estate, 2017).

Operation and maintenance

A wind turbine is available when it can generate electricity. When it is connected to the grid and supplying electricity to the electricity grid it is in operation. Maintenance on turbines offshore is more difficult than onshore, because there are more wind and waves, and it is less accessible. To get to the turbine a vessel or a helicopter is required. Maintenance can take place on all parts of the turbines and the offshore grid. Because the circumstances are more difficult offshore, the costs of maintenance are also higher than the costs onshore. This means reliability is more important with offshore wind turbines than for the onshore wind turbines (The Crown Estate, 2014).

Grid connection
TenneT is appointed to develop the Dutch offshore grid and to be the operator of the offshore grid. (TenneT, 2017b). These tasks are included in the law for the realization of the Energy Agreement. The operator of the offshore wind farm is responsible for the cables for the connections from the wind turbines to the offshore substation, this is represented in figure 5 by the orange line. TenneT is responsible for the construction and operation of the offshore substation, the sea cable from the offshore substation to the shore, the land cable onshore, the substation onshore and the high voltage grid onshore (TenneT, 2017d).

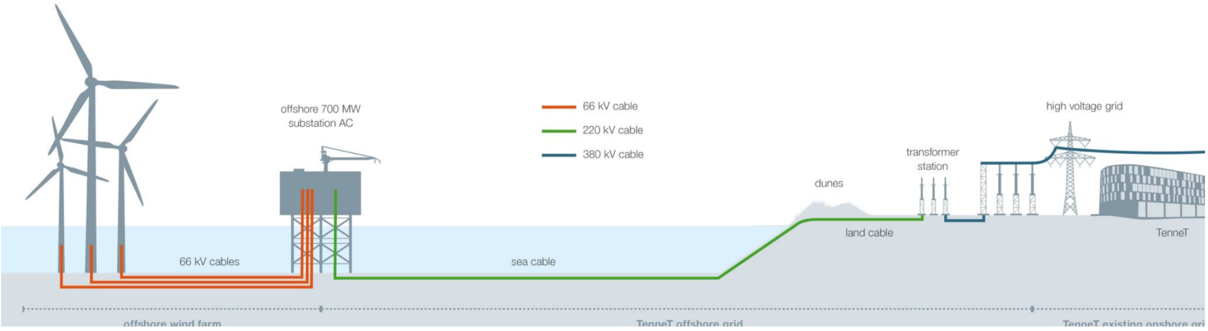

FIGURE 5: ONSHORE AND OFFSHORE GRID CONNECTIONS (TENNET, 2016).

Network stability
The electricity network needs to be adapted to be more flexible. This is necessary for the implementation of more renewable energy sources, such as offshore wind power. It is very difficult to predict the amount of generation electricity that is produced offshore, due to the changes in wind speed. Wind energy is a variable energy source, which causes intermittency. The difficulties in the predictability of generated electricity offshore can cause problems for the grid, such as congestion. Therefore, it will save costs when the predictability increases.

The derived technical indicators are:

- Availability of renewable energy resource
- Site conditions
- Technological innovation
- Generation capacity
- Size of installation
- Construction technique
- Operation and maintenance strategies
- Grid connection
- Network stability
- Predictability of power supply

2.4 Relation between new indicators and dimensions and components

The additional indicators, see appendix IV, are divided over the components and dimensions of energy security. The indicators that were used in these studies already, remain with the same components as before. Some indicators fit in multiple components and dimensions, but they are only place once, in the one which suits best. The reasoning for the distribution of the new indicators over the components and dimensions are described below:

- *Total energy demand* relates to security of supply, because that is about the relation between supply and demand. To investigate if there is enough energy available, it is important what the energy demand is.
- *Total electricity supply* relates to the component security of supply, because it is about the relation between supply and demand of electricity. To investigate this relation, it is important to know what the supply of electricity is in a country.
- *Availability of renewable energy resource* relates to the component production, because the availability of renewable energy resources influences the generated power in a country.
- *Increase rate of renewable energy generation capacity* relates to the component production, because this influence the amount of generation capacity in a country, and also the amount of produced energy.
- *Total installed electricity generation capacity* relates to production component, because it influences the amount of electricity that can be produced and the ability of a country to meet the electricity demand.
- *CO_2 price* relates to the price stability component, because it is an important factor in the predictability of the electricity prices. A higher CO_2 price can cause higher electricity prices, when fossil fuels are used as the energy resource.
- *Electricity price* relates to the price stability component, because it is an important factor when showing the changes in price for consumers. A change in the electricity generation portfolio of a region can cause changes in the electricity price, this can influence the price stability and predictability in a country.
- *Grid connection* relates to the access & equity component. It is about the connection of the electricity generation plants to the grid and the ability to transport the generated electricity.
- *Site conditions* relates to the access & equity component. It is about the ability to access the electricity generation plant. Rougher site conditions can increase the costs to reach the site.
- *Balancing costs* relates to the affordability component, because it influences the prices of the electricity for the consumers and the affordability of electricity for consumers.
- *Construction costs* relates to the affordability component, because it influences the affordability of a plant to the developer, this can influence the price that end-users pay for their energy.
- *Investment risk* relates to the affordability component, because it influences the affordability of a plant to the developer. A higher investment risk, could lead to higher interest rates and less attractive financiability options. This can increase the energy prices for the consumer.
- *Construction technique* relates to the innovation & research component, because as long as there are disturbances while constructing plants and cost reductions in construction can be expected, this will influence the innovation and research agendas.
- *Technological innovation* relates to the innovation & research component, because as long as it expected that there can be cost reductions or more sustainable and efficient techniques, technological innovation will take place. This will influence the innovation and research agendas.
- *Operation and maintenance strategies* relates to the safety & reliability component, because these strategies influence the ability of a reliable energy supply to the consumer, without interruption. It can prevent a break-down of the plants and when planned right, not all plants have maintenance at the same time and operate when there is enough demand.
- *Predictability of power supply* relates to the safety and reliability component, because a higher predictability of power supply can contribute to a more stable system, with less interruptions in supply.
- *Indirect and induced employment in the industry* relates to investment & employment component, because it relates to employment that is created in the value chain of electricity and in development of the plants.
- *Investment in electricity transmission capacity* relates to the investment & employment component, because it relates to the investments that are made to transport the generated electricity.
- *Operation and maintenance costs* relates to the investment & employment component, because it relates to the investments that are made into the right O&M of the system. This increases the reliability of a system.

- *Available areas* relates to the land / water use component, because it indicates the amount of potential space that can be used for energy plants. When there are not enough available areas to construct power plants, it can cause problems in the power generation in a region.
- *Required space for renewable energy option* relates to the land / water use component, because it indicates the space the needed areas for sufficient power generation in a region.
- *Size of installation* relates to the land / water use component, because it indicates the space that is needed for a certain capacity of generation capacity.
- *CO_2 reduction targets* relates to the climate change component, because it relates to the policies to create a more sustainable energy supply.
- *Permit procedures* relates to the government component, because it refers to the way that rules are set and permission is given when developing an energy plant.
- *Responsibilities* relates to the governance component, because it refers to the tasks and responsibilities of a group of actors to get the desired outcome.
- *International cooperation* relates to the trade & regional interconnectivity, because it refers to the international agreements that facilitate trade.
- *Electricity market design* relates to the competition & markets component, because it refers to the ability of the system to bring the generated electricity from the producer to the consumer.
- *Renewable energy subsidy* relates to the competition & markets component, because subsidy can make renewable energy more attractive than conventional energy. This influences competition in the energy market.

2.5 New comprehensive energy security assessment framework

All indicators from the system analysis and the energy security analysis studies are compared to each other. Many indicators have some overlap. When there is overlap, the most comprehensive indicator is chosen. Appendix IV shows the indicators that have overlap, and which name for the indicator is chosen.

The next step was to divide the indicators over the components and dimensions of energy security. The indicators can be placed in several components sometimes. It is then placed in only one component, to count each indicator once. The component that fits the indicator best is chosen to place the indicator in.

This resulted in the new framework, see table 1. This new energy security framework will be used to investigate the political, economic and technical effects of 30 GW wind energy for the Netherlands.

The new comprehensive energy security assessment framework is presented to the Ministry of Economic Affairs, to discuss the usefulness and relevance of the framework, and to see if indicators are missing or irrelevant.

The effects will be measured in a qualitative way. The effects can be *very negative* (--), *negative* (-), *no effect* (0), *positive* (+), or *very positive* (++). The business as usual is based on the predictions in the NEV 2016. An overview is given of the indicators and the ranges for the effects on each indicator in the operationalization table in appendix X.

-- = It has a very negative effect compared to the business as usual.
\- = It has a negative effect compared to the business as usual
0 = No effect, the same as in business as usual
\+ = it has a positive effect compared to the business as usual
++ = it has a very positive effect compared to the business as usual

Dimension	Component	Indicator
Availability	*Security of supply*	Total energy demand Total energy supply Total electricity demand Total electricity supply
	Production	Availability of renewable energy resource Increase rate of renewable energy generation capacity Total installed electricity generation capacity
	Dependency	Self-sufficiency
	Diversification	Diversification of ownership of energy companies Geographic dispersion of energy facilities Share of renewable energy in total primary energy supply
Affordability	*Price stability*	CO_2 price Electricity price volatility End-use energy prices by fuel Electricity price
	Access & equity	Grid connection Rate of electrification Site conditions
	Affordability	Balancing costs Construction costs Investment risk Marginal cost of electricity power generation Transmission costs for electricity
Technology development & efficiency	*Innovation & research*	Construction technique Research budgets for renewable sources of energy Technological innovation
	Efficiency	Energy intensity
	Safety & reliability	Frequency of interruption of supply Operation and maintenance strategies Predictability of power supply
	Resilience	Generation adequacy System adequacy
	Investment & employment	Average rate of return on energy investments Direct employment Indirect and induced employment in the industry Investment in electricity transmission capacity Operation and maintenance costs
Environmental & social sustainability	*Land / water use*	Available areas Required space for renewable energy option Size of installation
	Climate change	CO_2 emissions from electricity sector CO_2 reduction targets Presence of climate change goals and targets
Regulation & governance	*Governance*	Number of electricity system regulators Permit procedures Provision of priority grid access to renewable energy Responsibilities
	Trade & regional interconnectivity	Amount of transnational electricity trading International cooperation Total interconnection capacity
	Competition & markets	Electricity market design Market share of largest three electricity suppliers Renewable energy subsidy

TABLE 1: COMPREHENSIVE ENERGY SECURITY ASSESSMENT FRAMEWORK

2.6 Conclusion

Energy security indicators and system analysis indicators are combined into a new comprehensive energy security assessment framework. The new comprehensive energy security assessment framework can research the effects of large-scale renewable energy development, while taking into account the broader system in which it develops. This broader system for developing 30 GW offshore wind energy in the Netherlands is described in chapter 3. It gives an overview of the current state of offshore wind energy in the Netherlands and the expected developments. It is about the value chain of offshore wind energy, the value chain of electricity, stakeholders, and the producers and consumers of electricity.

3.
30 GW wind energy in the Netherlands

This chapter gives an overview of the current state of offshore wind energy in the Netherlands and the expected developments. It is about the value chain of offshore wind energy, the value chain of electricity, stakeholders, and the producers and consumers of electricity. At the end of the chapter, two scenarios are introduced that can influence the effects of offshore wind energy for the Netherlands.

3.1 Policy plans

When it comes to the Netherlands, the "conditions for offshore wind energy are 'excellent' […] with relatively shallow waters, good wind resource, good harbour facilities, an experienced industry and a new, robust support system" (De Bruijne et al., 2016). Therefore, the Dutch government wants to expand the generation capacity of offshore wind energy, which is planned to be 4,450 MW in 2023 (Government of the Netherlands, 2013b), by 1 GW per year in the period of 2023-2030. This will bring the total amount of generation capacity of offshore wind to around 11,450 GW by 2030. The question in this research what the effects are if this policy is extended until 2050, resulting in 30 GW offshore wind energy.

Implementing 30 GW offshore wind energy in the Dutch EEZ requires a large effort in spatial planning. Figure 6 shows spatial agenda of the Dutch EEZ. This contains the following designated wind energy areas:

- A: Ijmuiden Ver: maximum of 7,020 MW;
- B: Borssele: maximum of 2,064 MW;
- C: Coast of Holland: maximum of 7,350 MW;
- D: To the north of the Frisian Islands: maximum of 1,200 MW.

This results in the capacity that can be installed in the designated areas is a total of 17,634 MW (Government of the Netherlands, 2013a). For the construction of 30 GW wind energy, more areas are necessary. However, when looking at the spatial planning in figure 6, choosing suitable areas are difficult. Building in shallow waters, close to shore is economically more attractive than building far offshore. Far from the shore, the water is deeper, cables need to be longer, and there are longer shipping and flying times to the wind farms. These make developing the wind farms further offshore less attractive, due to higher costs. However, when looking at figure 6, it can be seen that there is more space available further offshore. Also, the wind speeds are higher further offshore and there are more wind hours in a year. This results in more electricity that can be generated.

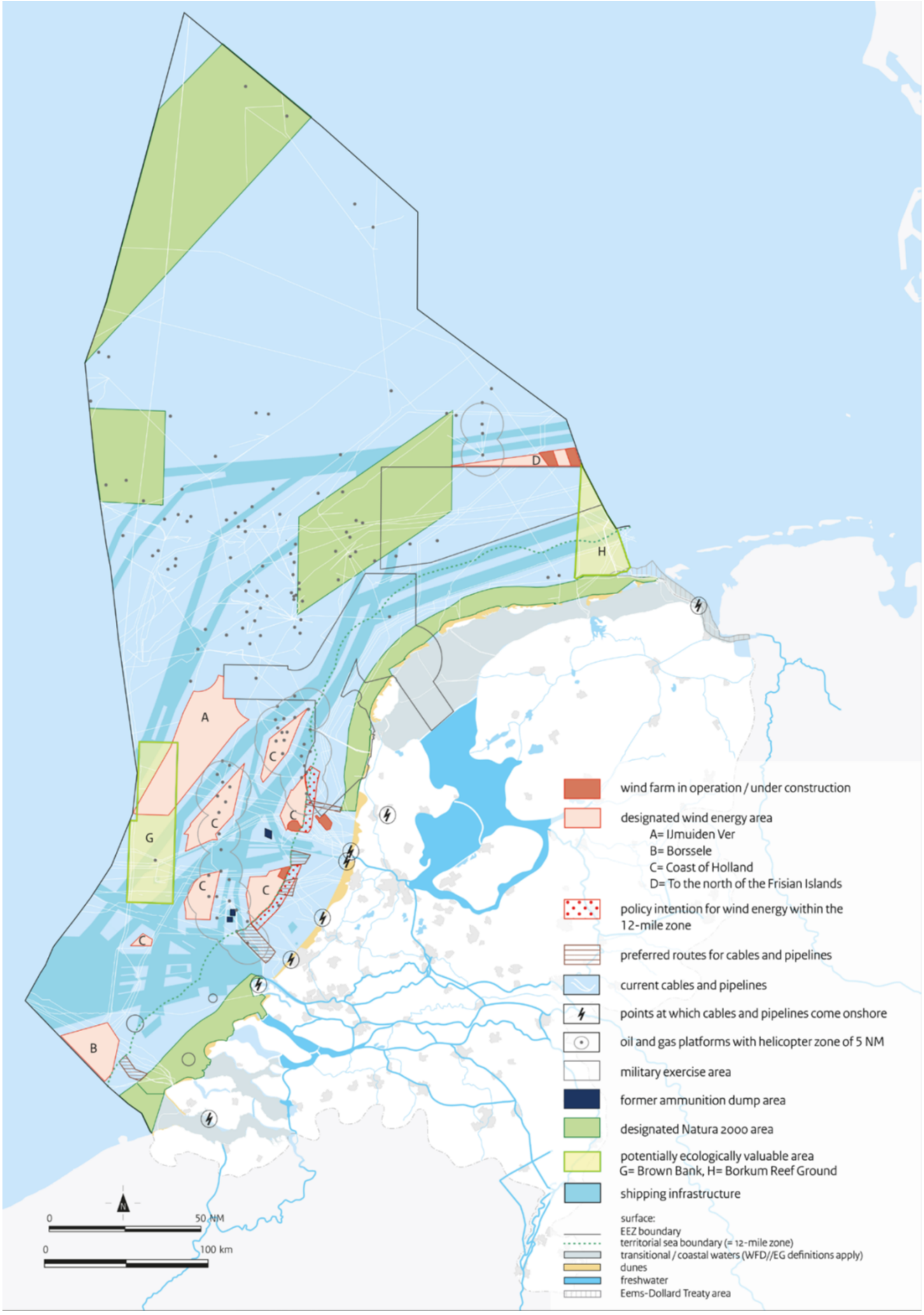

FIGURE 6: SPATIAL AGENDA DUTCH EEZ NORTH SEA (SOURCE: NOORDZEELOKET, 2015)

3.2 Technology and economics of offshore wind farms

3.2.1 Wind turbine development

The largest wind turbine manufacturers in terms of installed capacity are Siemens and Vestas. There is a trend in the increasing size of wind turbines and increasing capacity per turbine (Kaldellis & Kapsali, 2013), see figure 7. At the moment, the largest wind turbine that is generating electricity is 8 MW and it is developed by Vestas, together with Mitsubishi Heavy Industries.

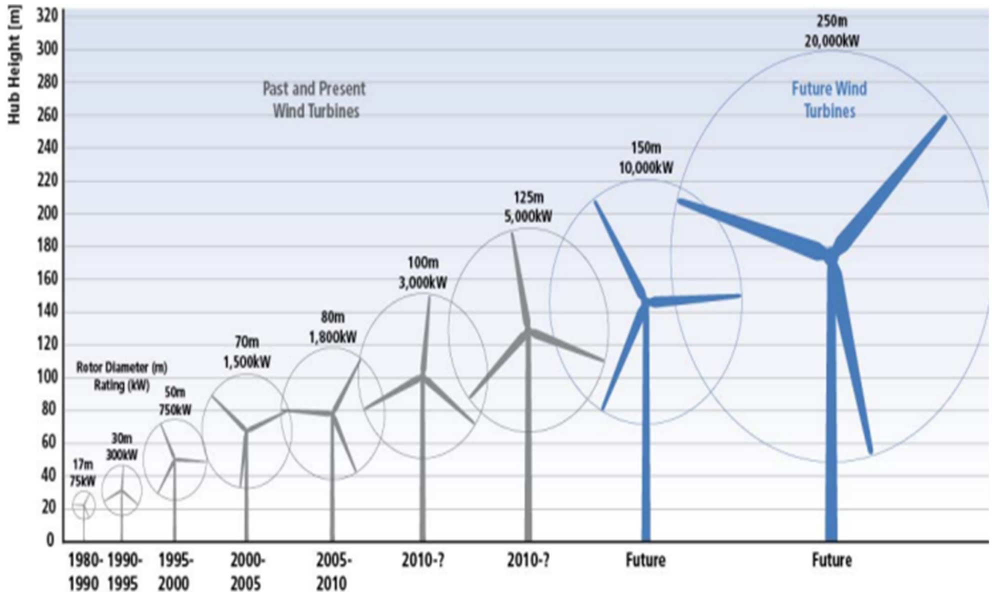

FIGURE 7: GROWTH IN SIZE AND CAPACITY OF WIND TURBINES (IPCC, 2012).

The majority of commercial offshore projects still use shallow-water technology, which is in less than 40 metres water depth. The monopile technique is used in these projects, see figure 8, this is a bottom-fixed structure. When building wind farms further from shore, the water becomes deeper, so other techniques are necessary (Kaldellis & Kapsali, 2013). In water deeper than 40 meters, jacket and tripod foundations are necessary, these are still bottom-fixed structures, see figure 8. In water deeper than 50 metres, floating structures are necessary, because when the water depth increases, the load also increases and this requires larger structural dimensions, which are economically not viable (Kaldellis & Kapsali, 2013). This technique is still not economically viable, but it is expected to be economically viable before 2030. Due to more stable wind conditions further offshore, it is expected to offer a more continuous and stable supply of electricity (WindEurope, 2017b).

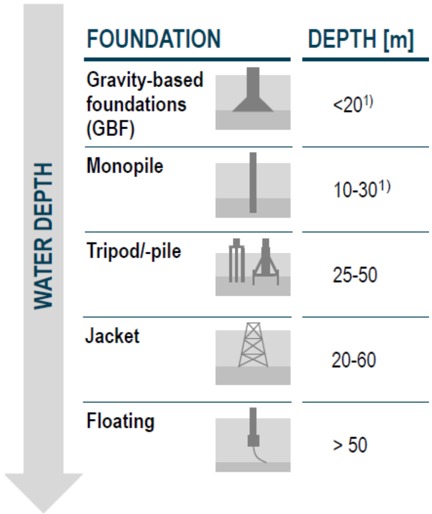

FIGURE 8: TYPES OF OFFSHORE WIND TURBINE FOUNDATIONS (ROLAND BERGER, 2013).

3.2.2 Wind farm development

The main driver for the wind farm design is the Levelised Cost of Energy (LCOE). This is calculated by the following formula, where CAPEX are the capital expenditures, CRF is the capital recovery factor, OPEX are the operating expenditures and AEP is the annual energy production:

$$LCOE = \frac{CAPEX * CRF + OPEX}{AEP}$$

It is desired to keep the LCOE as low as possible. CAPEX mainly concerns the construction of the offshore wind farm. OPEX mainly concerns the maintenance costs of the offshore wind farm.

The AEP is determined by the wind speed. The wind speed in a wind farm is however under influence of the layout of the wind farm. When there are no wind turbines, the wind speed on a site will be even. However, wind turbines cause wake effects. Wind turbines extract energy out of wind, which results in that the wind is less strong behind a wind turbine. If another turbine is place directly behind the first wind turbine, the wind will be less strong, and the turbine will produce less. Therefore, the turbines are usually not placed in a straight grid pattern (Ostachowicz et al., 2016). Another measure to prevent this is to increase the distance between the wind turbines. The rule is that the distance between the wind turbines should be at least 6 times the rotor diameter of the turbines.

To drive the LCOE down, the factors can be optimized. As described in 3.2.1, the wind turbines increase in size and generating capacity. This means that for the same amount of installed capacity, there are less turbines necessary than when smaller turbines are used. This results in less CAPEX, due to fewer turbines that are necessary, less cables, and a shorter construction time. It also results in less OPEX, due to less maintenance costs. The maintenance costs go down, because there are fewer turbines to maintain.

3.3 The Dutch offshore wind sector

3.3.1 Life-cycle phases positioned within the broader energy sector context

Figure 9 shows the life cycle phases of the offshore wind projects and how the stakeholders are related to these phases. The first layer represents the stakeholders in the lightest part, the offshore wind sector stakeholders. These are companies with the strongest connection to the development of offshore wind farms. Their business activities are most influenced by the implementation of 30 GW offshore wind energy. The second layer represents the energy sector stakeholders. They experience effects by the changes in the energy system. The third layer is for the other sectors. They experience an indirect effect of changes in the energy system and by increasing offshore wind energy.

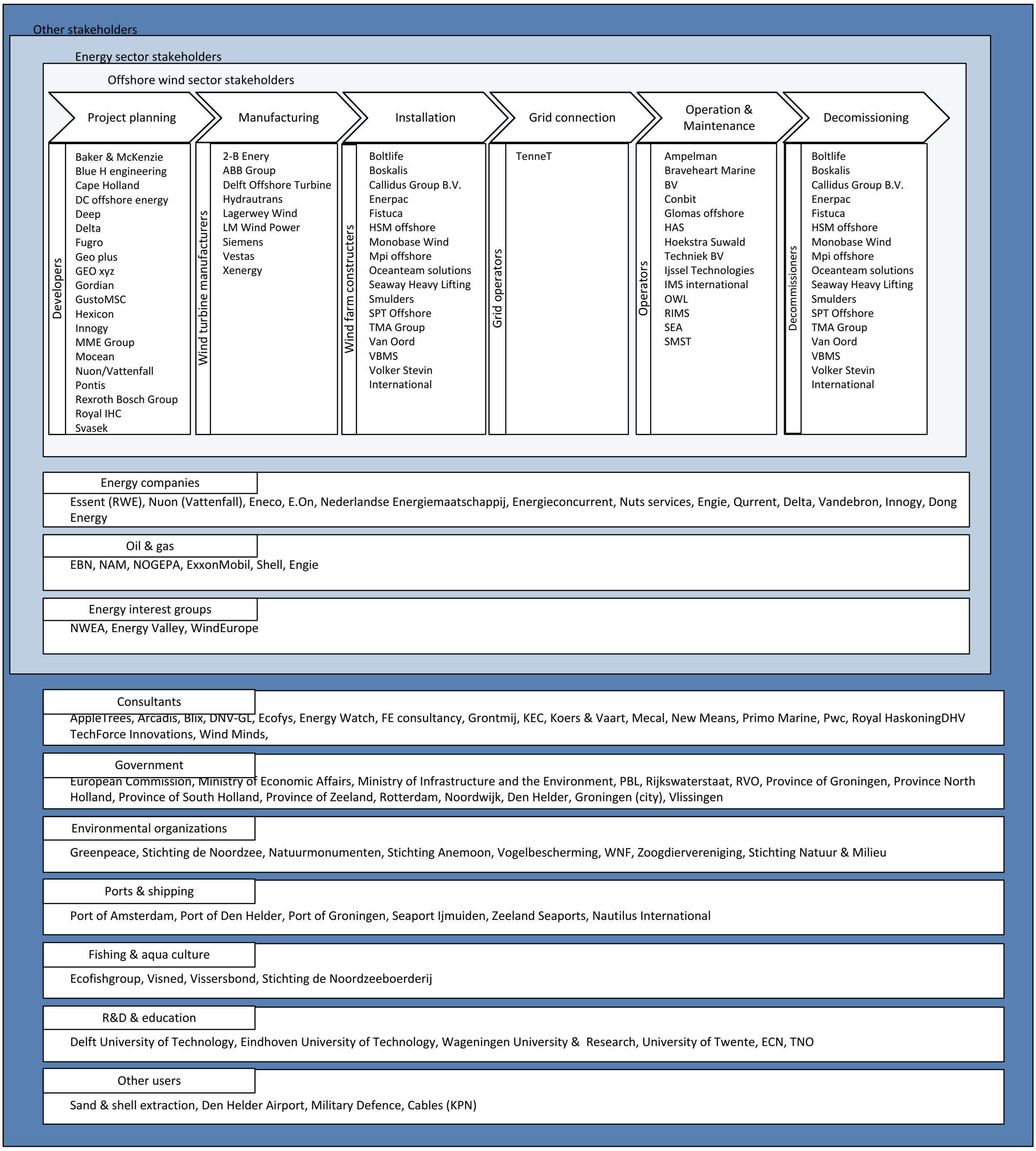

FIGURE 9: STAKEHOLDERS IN THE BROADER ENERGY SECTOR CONTEXT

3.3.2 Offshore wind energy stakeholders & interest groups

Developing large-scale offshore wind in the Netherlands is a complex task. It involves many stakeholders. Stakeholders can have different attitudes, interests, power and opinions towards the development of offshore wind in the Dutch EEZ. These stakeholders are described below.

Governmental organizations

Governmental organizations operate on a local, regional, national or international level. These levels influence responsibilities, tasks and perceptions towards the energy infrastructures. An important stakeholder on international level is the EC. On national level the Ministry of Economic Affairs, Ministry of Infrastructure and Environment, PBL, Rijkswaterstaat, and RVO are important stakeholders. On a regional level the provinces on the coast of the North Sea with sea ports are important, these are: Groningen, North Holland, South Holland, and Zeeland. On a local level municipalities with sea ports or where cables will land on shore are important stakeholders. These are: Rotterdam, Noordwijk, Den Helder, Groningen, Vlissingen (Noordzeeloket, 2017c; RVO, 2017c). On an international and national level attitudes towards offshore wind energy are positive, due to the contribution to climate targets and economic growth. On regional and local level the opinions are mixed, due to visual pollution caused by wind turbines, construction work for cables, and economic growth (Waldo, 2012).

Energy companies

Energy companies are utility companies that supply gas or electricity to consumers. In this research, the focus is on energy companies that supply electricity. Several energy suppliers in the Netherlands offer the possibility to the consumer to choose for renewable energy. There are over 40 energy suppliers in the Netherlands. The large energy suppliers are: Essent (RWE), Nuon (Vattenfall), Eneco, E.ON, Nederlandse Energiemaatschappij, Energieconcurrent, Nuts services, Innogy, Dong Energy, and Engie. Some of the smaller companies are: Qurrent, Delta, and Vandebron (Energie Portal, 2017).

Oil & gas sector

The Dutch oil & gas sector is decreasing its activity in the Dutch EEZ. The Netherlands is the largest European producer of natural gas. The Dutch EEZ contains around 160 production locations, which are connected by a network of pipelines. Most fields are near the end of their lifetime, and abandonment of current wells is expected around 2035, resulting in a large amount of decommissioning or re-fit activities (Energy Academy Europe, TNO & ECN, 2016). Stakeholders that are important in the Dutch oil and gas sector are EBN, NAM, NOGEPA, ExxonMobil, and Shell (Noordzeeloket, 2017c). The sector is positive towards offshore wind, because gas and wind power can be combined. System integration helps the sector to reduce carbon emissions, to create a stable electricity grid, and to achieve a good balance in energy storage (EU2016nl, 2016).

Environmental organizations

The Dutch EEZ contains some valuable habitat and natural reserve areas. In these areas, fishing is permitted selectively, and most construction and exploration activities are forbidden (Energy Academy Europe, TNO & ECN, 2016). Many organizations represent interests of animals or nature. The ones that are most interested in offshore wind projects are: Greenpeace, Natuurmonumenten, Stichting Anemoon, Vogelbescherming, WNF, Zoogdiervereniging, and Stichting Natuur & Milieu. Opinions differ from positive to negative, depending on what they represent. Greenpeace is positive, due to the contribution against climate change, but Vogelbescherming is negative, due to the impact on bird popultions. Sea mammals get harmed by noise during the construction, but on the other hand there might be less fishing activities due to the wind farms (Noordzeeloket, 2017c).

Grid operators

The grid operator is responsible for integrating wind energy in the grid. The task is to install the cable from the wind farm to the grid (IRENA, 2014). The grid operator is also responsible for the capacity in the network to transport the electricity. The transmission system operator (TSO) is TenneT. It controls the high voltage grid in the Netherlands and in a part of Germany. Regional grid operators are the distribution system operators (DSOs); they control the lower voltage grids (TenneT, 2017c). TenneT is positive towards offshore wind energy, due to opportunities to connect the offshore grid with surrounding countries. However, there are concerns about the connection with the grid on shore and the grid costs (Noordzeeloket, 2017c).

Dutch Industry

The Dutch industry that is relevant in this research is energy intensive industry. The Netherlands has a strong energy-intensive industrial sector. Important activities in this sector include agriculture, refining, chemicals, base metals, building materials, paper and nutrition. It accounts for almost 25% of the CO_2 emissions of the Netherlands, and therefore it has a major task to reduce its emissions (Ministry of Economic Affairs, 2016). These industries are dependent on energy for economic growth.

Sea ports

These are: Port of Amsterdam, Port of Den Helder, Port of Rotterdam, Sea Port Ijmuiden, and Zeeland Seaports. An increase in offshore wind power can result in an increase in activities in sea ports, when constructing wind farms, and in the operational and maintenance phase. From these sea ports, the vessels will go to offshore wind farms. The companies that do these activities will be located in these port areas. This results in a positive attitude.

Fishing & aqua culture
The Dutch fishing industry is facing a decrease in available to fish. Fishing is forbidden in certain areas in the North Sea. Currently, they cannot fish in wind farms, near oil and gas infrastructure, protected nature areas, and in the shipping routes (Energy Academy Europe, TNO & ECN, 2016). Increasing the amount of wind turbines means that the fishing industry will probably lose more areas where they are allowed to fish. However, it increases the opportunities for aqua culture around the wind turbines. Stakeholders in this group are: Ecofishgroep, Visned, Vissersbond, and Stichting de Noordzeeboerderij. Stichting de Noordzeeboerderij is positive, due to the opportunities for nature and aqua culture, if shared use of the wind farms is allowed. Fishing sector is negative about the increase of wind energy on the North Sea, because they might lose fishing grounds when shared use is not allowed (Noordzeeloket, 2017c).

Interest groups
Interest groups connect companies, citizens, and organizations with each other. They focus on collaboration between these actors. In this research, the focus is on the groups that represent wind energy and the North Sea. These are: Netherlands Wind Energy Association (NWEA), Stichting the Noordzee, Energy Valley, and Wind Europe. They are positive towards offshore wind in the North Sea (Noordzeeloket, 2017c).

Shipping
The North Sea contains busy shipping lanes, because large European ports are situated at the North Sea cost. These are: Amsterdam, Antwerp, Hamburg and Rotterdam. Shipping is important to the Dutch economy (Energy Academy Europe, TNO & ECN, 2016). This sector is strongly related to the Dutch industry. An important stakeholder representing the shipping sector is Nautilus International, a trade union representing shippers (Nautilus International, 2017). The shipping industry is concerned that wind farms hinder the passage of ships, when transit through the wind farms is not allowed (Noordzeeloket, 2017c).

Wind farm developers
Specialised companies are planning wind farms by conducting feasibility studies and resource assessments, and making project designs. Stakeholders in this group are wind farm developers and specialized consultants (IRENA, 2014). In the Netherlands, there is a large group of stakeholders active in the designing and engineering part of this sector: ARC sustainable energy solutions, Baker & McKenzie, Blue H engineering, Cape Holland, DC offshore energy, Deep, Delta, Fugro, Geo plus, GEO xyz, Gordian, GustoMSC, Hexicon, Innogy, MME Group, Mocean, Nuon/Vattenfall, Pontis, Rexroth Bosch group, Royal IHC, Svasek. Specialized consultants are: AppleTrees, Arcadis, Berenschot, Blix, DNV-GL, Ecofys, Energy Watch, FE consultancy, Grontmij, KEC, Koers & Vaart, Mecal, New Means, Primo Marine, Pwc, Royal HaskoningDHV, TechForce Innovations, and Wind Minds (TKI Wind op Zee, 2017). This sector is positive towards the increase in wind energy, due to more employment (Blanco & Rodrigues, 2009).

Wind turbine manufacturing
These stakeholders manufacture parts of the wind turbines, such as rotor blades, towers and turbines (IRENA, 2014). Companies specialized in this are: 2-B Energy Holding, ABB Group, Delft Offshore Turbine, Hydrautrans, Lagerwey Wind, LM wind Power, Siemens, Vestas, and Xenergy (TKI Wind op Zee, 2017). This group is responsible for the majority of jobs in the wind energy industry. There is a relation between MW installed and the number of jobs. An increase in offshore wind energy means an increase in jobs in this sector (Blanco & Rodrigues, 2009). Therefore, they are positive towards the increase in wind energy in the North Sea.

Wind farm installation
Stakeholders in this group are companies that assemble the wind turbines on the site. These companies are mostly engineering, procurement, and construction companies (IRENA, 2014). Companies that are specialized in this are: Boltlife, Boskalis, Callidus Group B.V., Enerpac, Fistuca, HSM offshore, Monobase Wind, Mpi offshore, Oceanteam solutions, Seaway Heavy Lifting, Smulders, SPT Offshore, TMA Group, Van Oord, VBMS, and Volker Stevin

International (TKI Wind op Zee, 2017). The increase in installed MW offshore wind energy, means an increase in jobs (Blanco & Rodrigues, 2009). Therefore, they are positive towards more wind energy on the North Sea.

Wind farm operation & maintenance
These stakeholders perform operational and maintenance activities such as plant monitoring, equipment inspections and repair services. These are performed as long as the wind farm is operating. Companies that are specialized in this are: Ampelman, Braveheart Marine BV, Conbit, Glomas offshore, HAS, Hoekstra Suwald Techniek BV, Ijssel Technologies, IMS international, OWL, RIMS, SEA, and SMST (TKI Wind op Zee, 2017). They will be positive about increasing offshore wind capacity, because it means an increase in jobs (Blanco & Rodrigues, 2009). These are long-term activities, so the number of jobs is also in the long-term.

R&D and education
Several knowledge institutes are doing research in the field of offshore wind energy. Knowledge institutes can also educate and train people to work in the offshore wind energy sector. Important stakeholders are the three technical universities in of the Netherlands: Delft University of Technology, Eindhoven University of Technology, and the University of Twente. Wageningen University & Research also does studies related to wind energy. ECN is a research institute that specializes in energy. It has a unit wind energy, this unit positions itself between universities and the industry. TNO is an independent research institute positioned between businesses, science, and the government. It is in several ways involved in wind energy research (RVO, 2017a). This shows that there is a positive attitude towards offshore wind energy.

Other North Sea users
Sand and shell extraction in the North Sea will increase in the coming years. This is mainly used for construction projects and coastal maintenance (Energy Academy Europe, TNO & ECN, 2016). An area in the Dutch EEZ is reserved for sand and shell extraction. This extraction is given priority, but other use of the North Sea is also allowed in these areas. Increase in offshore wind farms may result in less space for sand and shell extraction in the North Sea, because this is not possible where there are cables and pipelines (Noordzeeloket, 2017b). This results in a negative attitude towards offshore wind energy in the North Sea.

Various areas along the Dutch North Sea coast are used for military defence purposes. These have various functions: artillery, mine disposal, former ammunition dumps and flight exercise. Most of these areas are restricted during all times (Energy Academy Europe, TNO & ECN, 2016). This means that for the flight exercises there is a low flight zone above the Southern part of the North Sea. With an increase in spatial pressure, the military areas may be combined with other functions of the North Sea, such as shell and sand extraction, and shipping. This may result in a negative attitude towards the wind farms.

Den Helder Airport is an offshore heliport. Helicopters are transporting offshore personnel to and from oil and gas platforms in the North Sea, and can be used for flights to wind farms as well. This means that there is a low flight zone near Den Helder and above the most southern part of the North Sea (Den Helder Airport, 2017). An increase in offshore wind farms results in increased activities at the North Sea. This means that there will be more flight activities at the North Sea from Den Helder Airport. With a decrease in use of oil and gas platforms, an increase in flights to wind farms is desirable for the airport. Therefore, it has a positive attitude towards wind energy at the North Sea.

3.3.3 Brief assessment of the current competitiveness of Dutch companies
Within the wind turbine generator original equipment manufacturers (OEM) there are two main market leaders. Siemens is the clear market leader, with MHI Vestas in the second place. After this, there are much smaller OEMs in the top 5: Senvion, Adwen, and GE ALSTOM. None of these companies have manufacturing facilities in the Netherlands, but in Europe in the UK, Germany, France, and Denmark (TKI Wind op Zee, 2015).

The Dutch offshore wind energy sector is strong in the research and development of wind turbines, developing foundations and installation tools, supply electrical infrastructure, and in some turbine parts. Companies are specialized in the installation of the turbines, the foundations, and the electrical infrastructure. The Dutch offshore wind sector is also strong in doing maintenance of wind farms (TKI Wind op Zee, 2013).

A growth from 11GW to 30 GW offshore wind energy, will have an impact on the offshore sector of the Netherlands. For companies and research institutes it is important to have a strong offshore sector, to stimulate technological innovation. Without a strong offshore sector close to where they are located, it might be difficult for the research institutes to test new technologies. For relative new or small companies it is important, because they don't have a track record yet. This may result in that it will be very difficult for them to participate in foreign innovation programs, which are mostly national oriented (TKI Wind op Zee, 2013).

A growth in offshore wind energy generation capacity will also be important to reduce the costs, because it increases the demand for products and services. Companies can supply their products more continuous, and this results in better production methods, less risk, and more efficiency. These aspects will reduce the production costs. A larger market will increase the business climate for companies, which will result in more companies that have production facilities in the Netherlands (TKI Wind op Zee, 2013).

Most Dutch offshore companies are also internationally active. Creating a stronger offshore market in the Netherlands, will result in more opportunities for Dutch companies to improve their track record. It is easier for companies to do that in a national setting, than in an international setting. If companies have a good track record it increases their chances of exporting their products of services (TKI Wind op Zee, 2013).

3.4 Grid development

Increasing renewable energy sources, mainly solar and wind power, results in a more variable energy supply, because these sources are dependent on the weather. This makes it more difficult to balance supply and demand, which is needed for the grid stability. To this end, a more flexible electricity system is desired, to deal with sudden increases or decreases in the electricity supply. This will result in a balanced system. Flexibility for small-scale users, can be increased by the implementation of smart meters, to increase the demand-response. Consumers can get real-time updates on the power price and can use more electricity when the price is low, or use less appliances when the price is high. This will reduce the peaks in electricity use (Ministry of Economic Affairs, 2016a). Demand-response technologies will better match supply and demand.

Energy storage can increase the flexibility in the energy system. It can be used balance the system, by storing energy when there is an oversupply and supplying energy when there is a shortage. Electricity can be stored in for example batteries. It can also be stored by using power-to-X: power-to-heat, power-to-gas, power-to-chemicals, and power-to-liquids. For example: the power can be used to electrolyze water and create hydrogen. The hydrogen can be used as a fuel. The hydrogen can also be stored. More innovation is necessary to develop these technologies and reduce the costs (Ministry of Economic Affairs, 2016a).

Trends of increasing renewable energy development and electrification also increase the amount of electricity that is brought to the electricity grid and that is transported. Therefore, the electricity grid needs to be extended, to increase the transport capacity of the grid (Ministry of Economic Affairs, 2016a). The transport capacity needs to be increased, because the places where the electricity is produced are different from the places where a lot of electricity is consumed. When no additional measures are taken, capacity problems of the transport grid will already arise around 2025, when there is around 6.5 GW offshore wind energy installed. The step towards 11.5 GW in 2030 and 30 GW in 2050 will bring a huge increase in these congestion problems in the onshore grid. These problems are a bottleneck in the development of large-scale offshore wind, when there is no grid reinforcement (NWEA, 2017c). Reinforcing the onshore grid is difficult, because many stakeholders are involved. NIMBY effects of stakeholders make the planning process lengthy and difficult, often resulting in expensive solutions (Energy Academy Europe, TNO & ECN, 2017).

Grid investments increase, due to the investments in the offshore grid. Investments are needed to connect the offshore wind farms to the onshore grid (Energy Academy Europe, TNO & ECN, 2017). These transport distances are at least 12 miles, just less than 20 km, to shore. Offshore transport cables are around 110,000.00 euros per km to connect 1 MW (Jepma & Schot, 2017), but they can get more expensive, depending on the site conditions and how deep the cable is in the ground (Schild, 2017). Onshore and offshore developments in grid infrastructure will cost billions of euros. In 2011 the estimated costs for the grid infrastructure towards 2050 was between 20–71 billion euros (Ministry of Economic Affairs, 2016a).

3.5 Two scenarios

Offshore wind can be realized under different conditions. It can be realized by the Netherlands alone, or in a multilateral and international setting. To this end, two scenarios are developed: a national interest scenario and an international scenario. The scenarios are based on the scenarios of Planbureau voor de Leefomgeving. The construction of the scenarios is described in paragraph 1.9.3. The scenario logic is described below.

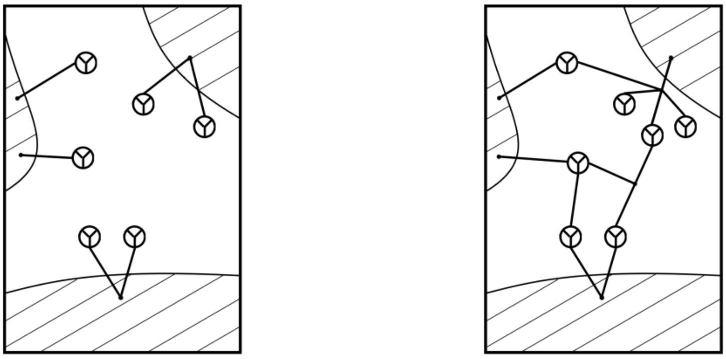

FIGURE 10: RADIAL GRID CONNECTION (LEFT) AND MESHED OFFSHORE GRID SOLUTION (RIGHT) (PIEPER, 2016)

3.5.1 National interest scenario

In this scenario, the focus of the Netherlands will be on national interests. The Netherlands will not be the only country that is focussing on national interests; this will be a global trend. There is little economic growth in the world, due to a decrease in globalization and a slow technological progress. This will result in less competition between companies. As a result of the little competition, innovation will be slow. Cost reductions and efficiency will be the main reasons to innovate. Little economic growth causes a small increase in the energy demand, but high levels of energy savings and increasing energy efficiency cause a decrease in energy demand. Overall, the energy demand decreases. National policies are respected. Most of the time, the international agreements are not respected. The international agreements are only respected in EU countries when this is in their national interest. Every country implements the climate agreements on its own terms, therefore there are different strategies between countries to reach the climate targets and there is less cooperation between countries. Energy prices of fossil fuels will increase, due to international conflicts. CO_2-prices will remain low, due to the fact that the international agreements are not respected by many countries and a decrease in energy demand. Carbon capture and storage (CCS) will not be used before 2050. It will not be feasible to operate it before then, because the CO_2-price is too low and due to little technological innovations CCS will remain expensive. Due to the green ambitions of the Netherlands, offshore wind farms will be developed in the Dutch EEZ. These wind farms will be national wind farms. A lot of space is required for the construction of these wind farms. They will be directly connected to the Dutch shore. It is also possible that the Dutch wind farms that are close to each other are connected in a sort of hub. From this hub, the power will go to shore via one cable, via a radial connection. Even though there is little international cooperation between the North Sea countries, there will still be interconnections between the countries to transport electricity. These interconnections will be point-to-point interconnections. This means that there will be a cable that directly from country A to country B. For example, this is already the case for the NorNed cable that connects the Dutch electricity grid to the Norwegian electricity grid.

3.5.2 International oriented scenario

In this scenario, the Netherlands will be focused on international cooperation. For the development of offshore wind energy, especially with the other North Sea countries.

There will be economic growth due to the globalization, because this increases the international trade. This is a global phenomenon. This causes competition between companies worldwide. Due to the increase of competition between companies, there will be many technological innovations, also in the green and sustainable technologies and in energy efficiency technologies. The growth of the population and the economic growth will cause an increase in the energy demand. Due to electrification of transport, heating, and the industry, the demand will be increasing for electricity and will decrease for oil and natural gas. The EU and Dutch policies are focused on stimulating the economy through a transition to a more sustainable and green society. There is a lot of international cooperation in energy projects and in the implementation of the international agreements regarding climate change. Energy prices will be influenced by international climate agreements. CO_2 prices will be high due to the climate agreements. Consumers will pay a higher price, due to the high CO_2 price that is included in the energy price. The price of fossil fuels will be quite low. Therefore, it is not profitable for the oil and gas industry to keep extracting oil and gas from the North Sea. This means that the current infrastructure such as platforms and cables will be decommissioned. A part of this infrastructure will be used for CCS. Also, due to increase in technological innovation the technique of CCS will be cheaper and this means that the business case for the implementation of CCS is feasible. Due to the green ambitions the 30 GW offshore wind energy will be realized by 2050. These wind farms will be international wind farms and national wind farms, and they will all be constructed in the Dutch EEZ. This means that a lot of space is required for the construction of these wind farms. These wind farms can be connected to the Dutch shore, an offshore power hub with a radial connection, or an offshore interconnector. International cooperation in the tendering of offshore wind farms, the development of the grid, and the development of the wind farms will bring the costs down. Interconnection will play an important role to integrate the offshore wind energy in the Dutch energy system and into the energy systems of other North Sea countries. There will still be point-to-point interconnectors, such as the NorNed cable, and interconnectors onshore. There are also be offshore interconnectors. There are several options for an offshore interconnection. These can facilitate an offshore grid, or a so-called meshed offshore grid (MOG). A MOG enables market integration through the interconnection of several markets. This interconnection will be offshore, by connecting several wind parks offshore. Another way to make a connection offshore is to create a power hub. This can connect wind parks to several countries. A third option to make the interconnection offshore is to create an international wind farm, in the Dutch EEZ, instead of connecting this wind farm to the Dutch shore, it can be directly connected to a different country.

Factor	*National scenario*	*International scenario*
Economic growth	Low	High
Technological innovation	Low	High
Fossil fuel prices – CO_2 price	High – Low	Low-High
Energy demand	Decrease	Increase
Policy	National interest	International agreements and targets
CCS	Yes	Yes
Offshore wind farms	National development	International cooperation
Interconnection	Little growth in interconnections, only radial connections and point-to point	Integrated grid, onshore and offshore connections

TABLE 2 SCENARIO LOGIC

3.6 Conclusion

The wind energy sector is undergoing rapid technological and economic developments. Wind turbines increase in size and capacity and can be built in deeper waters, further offshore. The LCOE decreases, due to decreases in costs and an increase in energy production. This makes it more attractive to construct wind farms. Therefore, most of the stakeholders are interested in increasing the offshore wind energy capacity. However, some stakeholders have concerns about the effects it has on available areas in the North Sea, the integration of 30 GW wind energy to the onshore grid, and the effects on nature and ecology.

The conditions in which the 30 GW offshore wind can be realized are not certain yet. To this end, two scenarios are developed. A national scenario and an international scenario. In chapter 4, the comprehensive energy security effects of 30 GW offshore wind energy in these two scenarios are investigated.

4.
Comprehensive energy security analysis

In this chapter, the comprehensive energy security analysis is carried out twice. Paragraph 4.1 describes the analysis for the Netherlands, when there is a national focus and when 30 GW offshore wind energy generation capacity is installed. Paragraph 4.2 describes the analysis for the Netherlands in an international focus. Paragraph 4.3 concludes this chapter.

The scenarios are used to investigate the effects of 30 GW offshore wind in a scenario, compared to the benchmark. The benchmark is the data on the indicators as presented in the NEV2016 by Schoots et al. (2016) and this is the 0-effect. The benchmark is the predictions on different elements in the system, when there is not 30 GW of offshore wind in the Netherlands. If the effect on the indicator is better compared to the situation without the additional 30 GW it gets a positive mark. If the effect on the indicator is worse in the situation with a lot of wind energy than in the benchmark situation, it gets a negative mark. The indicators are compared to the benchmark in both scenarios; in the end, the effects in both scenarios are compared. The ranges to score very positive, positive, neutral, negative or very negative compared to the benchmark are shown in operationalization of the indicators table in appendix X.

4.1 National scenario

4.1.1 Availability

4.1.1.1 Security of supply

Total energy demand

The energy use will decrease. The total energy use in 2030 will be 1838 PJ and in 2050 will be 1.640 PJ in this scenario. This is a direct result of low economic growth, a decrease in population and in energy intensity (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015). As a result, the total energy demand is negative.

Total energy supply

The energy supply is derived from the total primary energy use. It is the energetic energy use. This results in 2220 PJ per year in 2050 (Rooijer & Warringa, 2015). 30 GW offshore wind energy will increase the total energy supply.

Total electricity demand

Low economic growth causes a small increase in electricity demand, but high energy savings and an increase in energy efficiency cause a decrease in the demand. Electrification will increase the electricity demand. Electricity demand can increase to around 150 TWh per year (Planbureau voor de Leefomgeving, 2011), or around 540 PJ.

Total electricity supply

Total electricity production in the Netherlands will be around 525 PJ per year in 2035, or around 140 TWh (Schoots et al., 2016). It will increase until 2050. 30 GW wind energy will have a strong positive effect on the electricity supply in the Netherlands.

Indicator	Effect
Total energy demand	--
Total energy supply	+
Total electricity demand	++
Total electricity supply	++

TABLE 3: EFFECTS ON THE SECURITY OF SUPPLY IN THE NATIONAL SCENARIO

4.1.1.2 Production

Availability of renewable energy resource

The renewable energy resource in this case is offshore wind energy. Wind conditions in the North Sea are good. In general, it is the case that the further the parks are from the shore, the more wind there is available. Due to the national focus, most parks are not far-offshore, because the parks in the Dutch EEZ are all connected with radial connections to the Dutch shore. There are still good wind conditions, but further offshore they will be better, see appendix VIII. A lot of space required for 30 GW wind energy, so the locations will also be further offshore than they are now. This will have a positive effect on the availability of renewable energy resource. The average wind speed in the wind farms is 5 Bft, when they are built relatively close to shore.

Increase rate of renewable energy generation capacity

In both scenarios, offshore wind generation capacity will increase with 1 GW per year between 2030 and 2050. This has a positive influence on the increase rate of renewable energy production per year. Also, onshore wind energy, solar energy, and biomass will be important renewable energy sources. The increase rate of renewable energy production in the total energy production will be just under 1% (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015), without extra wind energy, so it is just over 1% with extra generation capacity, which is positive

Total installed electricity generation capacity

Electricity generation capacity increases after 2030. Generation capacity from fossil fuelled plants will decrease. Solar power will have a strong increase in capacity. Onshore wind will not increase after 2030, but remain about the same. In 2035, projected capacity without extra wind is around 55 GW (Schoots et al., 2016). Offshore wind energy will increase about 1 GW per year and this will have a very positive effect on the total capacity. The total capacity increases to around 80 GW if no additional measures are taken to increase or decrease this amount. Solar and wind energy can both increase, because it is almost complementary to each other: most of the time when there is a lot of wind, there is less sun and the other way around (TenneT, 2017f).

Indicator	Effect
Availability of renewable energy resource	0
Increase rate of renewable energy generation capacity	+
Total installed electricity generation capacity	++

TABLE 4: EFFECTS ON THE PRODUCTION IN THE NATIONAL SCENARIO

4.1.1.3 Dependency

Self-sufficiency

Self-sufficiency will increase, due to an increase in renewable energy production and a decrease in the use of fossil fuels. The increase in renewable energy production is the result of the implementation of 30 GW offshore wind energy. Fossil fuels, such as oil and gas, are mainly supplied by a few countries. Reducing the use of fossil fuels, decreases dependency on those countries (Planbureau voor de Leefomgeving, 2011). Due to a limited number of interconnections, energy storage will play a role. This increases self-sufficiency in moments when there is not enough wind or solar energy. Overall, self-sufficiency is high in this scenario.

Indicator	Effect
Self-sufficiency	++

TABLE 5: EFFECTS ON THE DEPENDENCY IN THE NATIONAL SCENARIO

4.1.1.4 Diversification

Diversification of ownership of energy companies

Diversification of ownership will increase, but compared to the benchmark the effect is 0. Mainly Dutch parties will operate in the Netherlands, or European parties that have a history in trade and operation in the Netherlands. Energy cooperations, local initiatives, individual citizens and companies will invest in renewable energy sources (Schoots et al., 2016). Large companies that are active in other sectors will invest more in offshore wind energy, e.g. Shell, Engie, and EDF. The market will consist of large players (Müller, 2017). Combinations of energy companies in development consortia will also take place. Consortia and utility companies are more likely to exploit large wind parks. Individual citizens and smaller companies are more likely to exploit smaller wind parks (Van Hövell, 2017).

Geographic dispersion of energy facilities

This will increase. Solar energy and onshore wind will result in a more dispersed and decentralized energy production in the Netherlands onshore (Ministry of Economic Affairs, 2016a). Offshore wind will not be spread over the Dutch EEZ in the North Sea, but it will be close to the shore, to reduce transport costs. However, due to the increase in amount of wind energy it will be more geographically diversified.

Share of renewable energy in total primary energy supply

The share of renewable energy in the total primary energy supply will increase. This is the result of the reduction of fossil fuelled generators and the increase of 1 GW offshore wind energy per year. This effect is very positive.

Indicator	Effect
Diversification of ownership of energy companies	0
Geographic dispersion of energy facilities	+
Share of renewable energy in total primary energy supply	++

TABLE 6: EFFECTS ON THE DIVERSIFICATION IN THE NATIONAL SCENARIO

4.1.2 Affordability

4.1.2.1 Price stability

CO_2 price

In 2030, the CO_2 price will be 15 euro per ton CO_2. This will increase to 40 euro per ton CO_2 in 2050, as a result of national climate and CO_2 reduction policies, but this is still low (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015). Offshore wind energy affects the CO_2 price, it contributes to a low CO_2 price. A high carbon price would make the market position of electricity from offshore wind better in relation to electricity from coal or gas and this would create more public support (Müller, 2017).

Electricity price volatility

The electricity price is very volatile, because it is sensitive to changes in supply and demand of electricity. The volatility of the electricity price makes it hard to predict the electricity price. This makes it difficult to predict what the revenues will be from wind parks (Van Bergen, 2017). The volatility will increase, due to the variability in supply that is the result of the intermittency of wind energy. Limited amount of electricity trading with the surrounding countries, results in that it cannot be smoothed, resulting in a high volatility and even the possibility of sometimes extremely high prices, sometimes negative prices. These negative prices are the result of inflexible power generation, such as offshore wind energy, and low demand (Epexspot, 2017).

Energy prices by fuel

Table 7 and 8 show the energy prices by fuel. Prices are high in this scenario, due to geopolitical tensions and the national focus of countries. High fuel prices cause the offshore wind energy to have a better market position (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015). High fuel prices are not good for an economy. If there is enough electricity generated from wind energy, that the more expensive fossil fuelled generators are priced out of the market, due to a lower marginal price of wind energy, resulting in a lower demand of fossil fuels. Large-scale wind energy will have a negative impact on the fuel prices. This is a desired effect.

Fuel prices	2030	2050
Oil ($/barrel)	135	160
Gas ($/ Mbtu)	12	15
Coal ($/tonne)	115	130

TABLE 7: FUEL PRICES IN CONVENTIONAL UNITS IN A NATIONAL SCENARIO (PLANBUREAU VOOR DE LEEFOMGEVING & CENTRAAL PLANBUREAU, 2015).

Fuel prices	2030	2050
Oil (€/GJ)	16.6	19.7
Gas (€/GJ)	8.6	10.4
Coal (€/GJ)	3.5	3.9

TABLE 8: FUEL PRICES IN SAME UNITS IN A NATIONAL SCENARIO (PLANBUREAU VOOR DE LEEFOMGEVING & CENTRAAL PLANBUREAU, 2015)

Electricity price
The average wholesale price for electricity will be 67 euros per MWh in 2030 and 90 euros per MWh in 2050 (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015). If there is a large amount of electricity from wind power on the market, the electricity price will decrease, because only a limited amount of power can be exported. Therefore, large-scale wind energy will have a negative impact on the electricity price. However, there is a lot of discussion concerning the predictions of the electricity price. There are different opinions about what it will be. Developers predict that the electricity price will increase (Van Bergen, 2017). Other parties think that the electricity price will decrease, due to the oversupply of wind power in the system (Hommel, 2017; Aksan, 2017; van Zuijlen, 2017). Therefore, for this scenario the assumption is that the electricity price will increase, but it will be lower than in the international scenario. A low electricity price is a risk for developers, because the margins on the cost of generating electricity and the benefits of the electricity are small. If costs are higher than expected, generating electricity will not be profitable for the developer, but low electricity prices will be an opportunity for the users (Hövell, 2017). If the electricity price will be very cheap, some industries will adapt their production processes and will produce when the price drops. If the average electricity price decreases, the welfare level of the Netherlands will increase (Van Zuijlen, 2017). Therefore, the effect on the price is positive.

Indicator	***Effect***
CO_2-price	-
Electricity price volatility	--
End-use energy prices by fuel	-
Electricity price	+

TABLE 9: EFFECTS ON THE PRICE STABILITY IN THE NATIONAL SCENARIO

4.1.2.2 Access & equity
Grid connection
Offshore wind parks will have a radial connection to the onshore grid, where the offshore wind park is connected to the Dutch shore, see figure 10. The amount of wind energy will not change the type of grid connections in this scenario, but it will change the amount of grid connections. Therefore, the effect is the same as the benchmark.

Rate of electrification
Electrification will play an important role in the transition (Hövell, 2017). This can take place in the industry, transport, and heating sectors. If 30 GW wind energy will be constructed and the price of electricity will decrease, all sorts of industries will adapt their production processes. They will produce when there is a lot of wind and the electricity price decreases (Van Zuijlen, 2017). In a national setting the electricity price will be lower than in an international setting, see paragraph 4.1.2.1 on the electricity price, and therefore it is likely that the electrification is an attractive option in a national setting to deal with an oversupply of electricity. Sea ports with an energy intensive industry, such as the Port of Rotterdam, can be a good location to start with electrification. It is convenient to use a location near the shore, to reduce transport costs of electricity and where energy consumption is high (Romeijn, 2017). 30 GW wind energy will have a very positive effect on the rate of electrification in this scenario.

Site conditions
In a national context, where all offshore wind parks will be connected to the Dutch shore, wind farms will be constructed as close to the Dutch shore as possible, because this reduces the length of the transport cable to shore. Increasing the distance will result in higher costs. Close to the shore the water is relative shallow and the wind is less strong than further offshore, see appendix VIII and appendix IX. The waves are smaller than further offshore. The water depth has a maximum of 35 metres in the areas close to shore. Smaller waves are better for boats to reach the location and for the foundation of the wind turbines. This leads lower construction, operation, and maintenances costs. However, also less electricity will be generated when the wind is not strong. Soil conditions are about equal across the North Sea; this will not have a large influence on the decisions on the locations of the wind parks (Van Bergen, 2017). Therefore, 30 GW wind energy will not have an effect on the site conditions in this scenario.

Indicator	***Effect***
Grid connection	0
Rate of electrification	++
Site conditions	0

TABLE 10: EFFECTS ON ACCESS & EQUITY IN THE NATIONAL SCENARIO

4.1.2.3 Affordability
Balancing costs
Balancing costs to match supply and demand will be high. It is more cost effective when supply and demand can be optimized across the borders. Doing this national or with a limited amount of international cooperation will create inefficiencies (Aksan, 2017). No exact data is available on the increase in costs, but 30 GW wind energy will bring more variability in the electricity supply, so it will be more difficult to match supply and demand. So, 30 GW wind energy has a very negative effect on the balancing costs.

Construction costs
Construction costs are higher in a national context than in an international context. Construction cost will decrease when there is a stable roll-out of 1 GW per year, because there is a clear signal to the market. This gives security to the market and investments can be spread over multiple projects, which will lead to cost reductions per project (Elsevier van Griethuysen, 2017; Romeijn, 2017; Molenaar, 2017; Van Bergen, 2017; Van Hövell, 2017). Construction costs will increase a bit due to stricter rules to protect nature. There is no data available for the expected construction costs in 2030-2050. Therefore, the assumption is that a clear roll-out in a national context will provide 0-20% decrease in construction costs.

Investment risk
Investment risks are related to the energy price, high upfront costs, and low operational costs. The energy price is very volatile and is extremely sensitive to supply and demand. This makes it difficult to predict the electricity price in the long-term. The volatility increases as a result of large-scale offshore wind energy, see paragraph 4.1.2.1. As a consequence, it is difficult to predict when the return on investment will be (Van Bergen, 2017). This is a risk for the developers, because financing projects can become more difficult.

Marginal cost of electricity power generation
Marginal costs of offshore wind energy are low, almost zero. This will be added to the total energy supply of the Netherlands, so the average marginal cost will go down. Next to this, the supply from fossil fuelled electricity generators will decrease (Schoots et al., 2016), which have higher marginal costs. As a result, the marginal costs will decrease. Due to the variable character of renewable energy, price spikes will appear in terms of scarcity.

Transmission costs for electricity
Transmission costs will increase. Offshore wind parks need to be connected to the onshore grid, which increases the costs. The grid onshore needs an extension to facilitate the transport of the large amount of electricity that is put on the grid (De Brouwer, 2017). There is no exact price for this yet, because the locations of the wind farms are not certain. However, a lot of wind farms are necessary, also the ones that are a bit further from shore. Therefore, it is expected that it will be on the high end of the range. It will have a negative effect compared to the benchmark.

Indicator	Effect
Balancing costs	--
Construction costs	+
Investment risk	-
Marginal cost of electricity power generation	-
Transmission costs for electricity	-

TABLE 11: EFFECTS ON AFFORDABILITY IN THE NATIONAL SCENARIO

4.1.3 Technology Development & efficiency

4.1.3.1 Innovation & research

Construction technique

The Dutch offshore sector is strong in the design, installation, and operation of offshore constructions (Van der Putten, 2017). The current construction technique is that parts of the wind turbine are constructed onshore, then transported to a location offshore, and then the assembly takes place offshore at the location of the wind park. This requires a lot of shipping and is costly (Romeijn, 2017; Van Zuijlen, 2017). Construction of wind parks creates noise and this is damaging to the sea mammals. Constructing 30 GW wind energy increases the noise. Innovation is needed to develop construction techniques that create less noise. Blue piling and gravity based foundations are examples of construction techniques with less noise (Hommel, 2017; Van Zuijlen, 2017). A decrease in the accepted level of noise will stimulate quieter construction techniques, because noise restrictive measures are very costly (Schild, 2017). It is expected that 30 GW wind energy will increase the innovations on all these elements in the construction techniques and therefore it has a very positive effect on the construction technique.

Research budgets for renewable sources of energy

Dutch offshore wind research mainly focuses on the offshore technology and the balance of plant, not on the turbine itself. National subsidies result in national developments in the North Sea. Dutch research subsidies provide research budgets for Dutch research parties. Research budgets are financed by the government and the offshore sector, because research is done to support the government policies and to support the Dutch offshore sector. This is mainly national. Research will be less efficient when it only has a national focus, because conditions are similar across the North Sea and countries have shared interests. This means that they could provide from knowledge sharing and working together in international relations (Van der Putten, 2017). However, due to a clear roll-out of 30 GW wind energy, the national research budgets will increase, but the international budgets will decrease. Therefore, the budgets will stay around the same level

Technological innovation

One of the most important technical developments will be the increase in size and capacity of turbines (Schild, 2017; Van Bergen; Van der Putten, 2017; Van Hövell, 2017) and this will be leading for the other technical developments (Van der Putten, 2017). For the same amount of GW there are less turbines and cables necessary and there will be other types of foundations (De Brouwer, 2017). The maximum size will increase and then stabilize at about maximum 20 MW (Molenaar, 2017).

An expected innovation in the construction technique is that the assembly of the wind turbines will be onshore and that the turbines can be placed at once offshore. This will increase efficiency. The production volume of 30 GW will facilitate this innovation, because then there will be enough to production to create facilities onshore for this (Romeijn, 2017; van Zuijlen, 2017). Another innovation in the construction technique will be the building with less noise, to reduce the effects on the ecology (Hommel, 2017; Schild, 2017; Van Zuijlen, 2017).

Technical innovations will take place in building with lighter materials and building with smaller diameters for the same capacity. This reduces costs. Innovation will take place in other techniques, blades that can adapt to the wind conditions, and big data to better predict the power generation of the turbines (Molenaar, 2017).

Energy storage will develop. As a result, interconnectors are less needed to balance the supply and demand (Müller, 2017; De Brouwer, 2017). This means that energy storage can play a big role in a national setting, when there is less interconnector capacity.

Sensors will play a big role in retrieving information from a distance. From a distance, operators can get information about the status of the wind park, optimize the generated electricity, measure the degradation of the turbines and the support system, and optimize maintenance and inspections (Van der Putten, 2017).

On the demand side of the energy system innovation will take place in demand-response, to better match supply and demand. This will increase the flexibility of the system (De Brouwer, 2017).

Indicator	Effect
Construction technique	++
Research budgets for renewable sources of energy	0
Technological innovation	++

TABLE 12: EFFECTS ON INNOVATION & RESEARCH IN THE NATIONAL SCENARIO

4.1.3.2 Efficiency

Energy intensity

Energy intensity of the Dutch economy will decrease. The rate of decrease will be -1.8%/year between 2030 and 2050. This decrease is the result of increased energy efficiency and energy savings and economic growth. Energy needs are not increasing as fast as the economic growth (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015). An increase in offshore wind energy will have a positive effect on the energy intensity of the Netherlands.

Indicator	Effect
Energy intensity	+

TABLE 13: EFFECT ON EFFICIENCY IN THE NATIONAL SCENARIO

4.1.3.3 Safety & reliability

Frequency of interruption of supply

Offshore wind is an intermittent energy source. This makes it more difficult to match supply and demand, because there is not only variability in energy demand, but also on the supply. If there is a large increase in offshore wind generation capacity, this effect will be stronger (Epexspot, 2017), due to the portfolio effect. If there is little wind on the North Sea, there will be less energy from offshore wind, because the wind parks are all generating less electricity at the same time. There is no exact number predictable of the interruptions of supply, but it is expected that there will be a large increase. An increase in offshore wind energy will have a very negative effect on the frequency of interruption of supply, when no additional measures are taken.

Operation and maintenance strategies

O&M services will be necessary for wind farms. This will be done from sea ports that are closest to the wind farms. Inspections and maintenance can be done from ships that leave those ports. When there are many offshore wind farms in the North Sea, this could be done from the most central sea port and the maintenance services will be optimized between the wind farms, so they are not all at the same time out of the running (Romeijn, 2017). Sensors can track the status of the wind farms and the turbines: this helps tracking the degradation of the wind farm or the turbines and can predict when repairs are necessary, or when replacements are needed. This will optimize maintenance and reduce the costs. Sensors can also be used in the operation, to optimize the electricity generation of wind parks (Van der Putten, 2017). 30 GW offshore wind energy will stimulate these O&M developments. It will have a positive effect on the O&M strategies.

Predictability of power supply

Wind energy is an intermittent energy source. It will be more difficult to predict the power supply. Large-scale offshore wind energy will decrease the predictability of power supply. However, it is expected that sensors will play a big part in the optimization and prediction of the power supply from offshore wind energy. These sensors are expected to make a better relation between the conditions in the environment and the amount of power that will be generated. This can be on the level of a single wind turbine of a whole wind park (Van der Putten, 2017).

Indicator	Effect
Frequency of interruption of supply	--
Operation and maintenance strategies	+
Predictability of power supply	-

TABLE 14: EFFECTS ON SAFETY & RELIABILITY IN THE NATIONAL SCENARIO

4.1.3.4 Resilience

Generation adequacy

Generation adequacy will decrease, because electricity supply will become inflexible. It will be more difficult to match supply and demand (Epexspot, 2017). However, there will be enough capacity when 30 GW offshore wind energy is installed to supply the demand when there is enough wind. There will be a problem in generation capacity when there is no wind, resulting in a shortage (Ministry of Economic Affairs, 2016a). In a national context, with limited amount of interconnector capacity, energy storage could be a solution to prevent shortages. The generation adequacy will decrease a bit. The assumption is that generation adequacy will decrease to under 50%, which is negative.

System adequacy

System adequacy will decrease, when offshore wind energy generation capacity increases, because the system will have lower ability to cope with the amount of electricity that will be brought to the system. It cannot transport the oversupply in electricity to surrounding countries, due to a limited amount of interconnection capacity and when transport capacity onshore is insufficient to transport the electricity from the generator to the consumer. The system will need more flexibility. Nationally, flexibility can come from demand-response technologies to make the consumer more flexible and from energy storage (De Brouwer, 2017). System adequacy is a percentage of interconnection capacity to installed production capacity (IEA, 2014c). Assumptions are: 80 GW production capacities and 9800 MW interconnection capacity. This results in a system adequacy of 12%. This is negative compared to the assumption of 17 percent of the benchmark.

Indicator	Effect
Generation adequacy	-
System adequacy	-

TABLE 15: EFFECTS ON RESILIENCE IN THE NATIONAL SCENARIO

4.1.3.5 Investment & employment

Average rate of return on energy investments

Rate of return on energy investments is strongly dependent on the energy price and construction costs. This is very volatile, because it is sensitive to supply and demand. It is also very difficult to predict future energy prices (Van Bergen, 2017). This makes it difficult to predict the average rate of return on investments. As discussed in 4.1.2.1 it is likely that in a national setting the price is lower than in an international setting. This results in low margins between the costs and revenues wind farms (Van Hövell, 2017) and lower rates of return on energy investments. However, there is a clear signal to the market when 30 GW needs to be constructed. This gives security to the market and investments can be spread over multiple projects, which will lead to cost reductions per project (Elsevier van Griethuysen, 2017; Romeijn, 2017; Molenaar, 2017; Van Bergen, 2017; Van Hövell, 2017). This will increase the rate of return on projects. This will be better in an international market, because then Dutch companies will have more business in other projects outside of the Netherlands to share the costs of projects. The assumption is that the average rate of return will be 15 years, as the SDE+ subsidy time for offshore wind is now.

Direct employment

A stable roll-out of 1 GW per year, 30 GW in total, will have a positive effect on the employment in the Dutch offshore wind sector, because it attracts investments to the Netherlands, which will create employment opportunities. For example: a wind turbine manufacturer or a cable manufacturer will open a production location in the Netherlands, something that is currently not in the Netherlands. (Hommel, 2017; Molenaar, 2017; Van Bergen, 2017; Van Hövell, 2017). An important factor is that there are enough people with the right qualifications for the job. This can be a bottle neck. It is important to create employment opportunities by creating the right education programs and training programs, with a curriculum that is known in the offshore wind sector (Molenaar, 2017; Romeijn, 2017; Van Bergen, 2017; Van Zuijlen). When there are enough people in a region with the right certifications to work in the offshore wind sector, it becomes attractive for companies to invest in a production location, because companies know they have access to a number of employees with the right qualifications. This is also the reason why when there is a large offshore sector, new companies will locate themselves in the same region (Romeijn, 2017). These factors will create a good base for employment (Molenaar, 2017).

Maintenance of wind parks creates more employment than the construction of wind parks. About three quarters of the employment opportunities in the offshore wind industry is related to maintenance work, which is mainly local and close to the offshore wind parks. (Molenaar, 2017).

Large-scale offshore wind energy development will have a positive effect on the employment opportunities in the offshore sector, which will increase. There will mainly be job opportunities in the Netherlands, so the growth will not be large. Therefore, it has a positive effect compared to the benchmark.

Indirect and induced employment in industry

The offshore sector will increase and more large players in the offshore sector and smaller companies in the components industries will focus on offshore wind, when there will be a stable roll-out for offshore wind (Müller, 2017). Oil and gas companies that have offshore activities, will also make a shift to the offshore wind industry, by modification of ships, retraining employees, and taking a developer role in the wind parks (Romeijn, 2017). Employment will increase as a result of: economic activities in the component and service industries and training and testing facilities (Bais et al., 2017). The benchmark is 40.000 fte per year, as is expected by NWEA (2017b) for 2020. It is expected that a large-scale roll-out will increase this number. They will only have job opportunities in the Netherlands, so the growth will not be large. Therefore, it has a positive effect compared to the benchmark.

Investment in electricity transmission capacity

This will increase, even though there is not a focus on expanding interconnection capacities. The grid onshore needs to be expanded to transport the electricity from the shore to the places where it is consumed and where congestion is expected (Aksan, 2017; De Brouwer, 2017; Van Zuijlen, 2017). This needs good planning, otherwise there is a risk that grid is not ready when there will be an increase in offshore wind energy that comes to the grid and this might be a bottleneck in the development of offshore wind energy (Elsevier van Griethuysen, 2017; Hommel,2017). The grid offshore needs expansion from the wind parks to the shore, and maybe between the wind parks in the Dutch EEZ. Therefore, large-scale offshore wind energy has a neutral compared to the benchmark, because there will be the same sort of grid.

Operation and maintenance costs

Distance to shore and water depth influence the O&M costs (Van der Putten, 2017). When the wind parks are as close to the Dutch shore as possible, the distance will be relative short and the water will be shallow, which results in lower O&M costs. Maintenance is locally arranged (Van der Putten, 2017), from sea ports that are closest to the wind parks (Romeijn, 2017). Data analysis and sensors will be used to predict and plan when maintenance is needed and when components need to be replaced. By using data analysis and sensors this can be optimized, which leads to cost reductions (Molenaar, 2017). It is expected that turbines will break down less and be more reliable, which results in cost reductions. In the first years, maintenance and repair is part of the warranties of the suppliers, after this specialized maintenance companies and mechanics will take this over (Van Bergen, 2017). Therefore, large-scale offshore wind energy will stimulate the innovations and efficiency that will bring the cost down of O&M. This means that it has a positive effect.

Indicator	***Effect***
Average rate of return on energy investments	-
Direct employment	+
Indirect and induced employment in industry	+
Investment in electricity transmission capacity	0
Operation and maintenance costs	+

TABLE 16: EFFECTS ON INVESTMENT & EMPLOYMENT IN THE NATIONAL SCENARIO

4.1.4 Environmental & social sustainability

4.1.4.1 Land / water use

Available areas

At sea, there is more space available for wind energy than onshore in the Netherlands, because the Dutch EEZ is large. As can be seen in chapter 3 in figure 6, there are a lot of activities in the North Sea from different sectors. Especially close to the shore, there are many activities. More zones will be appointed to wind energy, when the roll-out will be 30 GW (De Brouwer, 2017). Not all space of the Dutch EEZ can be used. The assumption is that it has the same space as the benchmark, close to shore.

Required space for renewable energy option

A lot of space is required for 30 GW wind energy, which results in a negative effect on required space. Depending on the capacity per wind turbine, the number of wind turbines differs for 30 GW and therefore also the required space for a wind park. Currently, the largest wind turbine is 8 MW. It is assumed that the size and capacity of the wind turbines will grow (IPCC, 2012). Table 17 shows how much wind turbines are necessary of a certain capacity for 30 GW. When the size of the rotor diameter increases, the distance between the wind turbines will also increase, because of it needs to be at least 6 times the rotor diameter. The turbines will be more efficient and more MWs can be constructed per km^2.

Capacity per wind turbine (MW)	*Number of turbines for 30 GW*	*Height of tower (m)*	*Rotor diameter (m)*	*Distance between turbines (m)*
8	3750	200	130	780
10	3000	220	150	900
15	2000	260	200	1200
20	1500	300	250	1500

TABLE 17: CAPACITY AND SIZES OF WIND TURBINES

Size of installation

The size of the installation is the size of the wind turbine. Wind turbines will increase in size. The rotor diameter and the height of the tower will increase (De Brouwer, 2017; Molenaar, 2017; Schild, 2017; Van Bergen, 2017; Van Hövell, 2017; Van der Putten, 2017). Table 17 shows the expected heights of the tower and the length of the rotor diameter for the capacity. It is expected that the capacity will stay below 20 MW, because otherwise the impact will be too big when one turbine cannot produce electricity because of a break-down or maintenance. Also, wind turbines will get too unique, because there are less turbines needed. This means there will be less economies of scale in the production and this makes the production less efficient. Another problem is that the supply chain industry needs to change their ships to transport the turbines. It is expected that a large-scale roll-out of offshore wind will increase the innovation, and therefore also the size of the turbine. Therefore, this has a positive effect.

Indicator	*Effect*
Available areas	-
Required space for renewable energy option	+
Size of installation	+

TABLE 18: EFFECTS ON LAND / WATER USE IN THE NATIONAL SCENARIO

4.1.4.2 Climate change

CO_2 emissions from electricity sector

The marginal costs of wind energy are almost 0 and the CO_2 emissions are also 0. This will decrease the price when there is a lot of electricity produced from wind energy in the market and push more expensive fossil fuelled electricity generators out the market. The Netherlands has more sustainable energy system (De Brouwer, 2017; Hommel, 2017), compared to the benchmark.

CO_2 reduction targets

Offshore wind energy will contribute to reach the CO_2 reduction targets and to the reduction of other greenhouse gasses. Developing wind energy is a good method to reduce climate change (Hommel, 2017) and to create a CO_2

neutral energy system. Not only in the electricity generation sector, but also 'green gas' can be produced, with power-to-gas methods, and this can replace 'grey gas' (Jepma & van Schot, 2017). This will contribute to the 80-95% reduction targets of the Energy Agenda. 30 GW wind will have a positive effect on CO_2 reduction targets.

Presence of climate change goals and targets
International goals are not always respected, but national goals and targets are respected. Goals are set in the Energy Agreement for Sustainable Growth, the Energy Report, and the Energy Agenda (Government of the Netherlands, 2013b; Ministry of Economic Affairs, 2016a; Ministry of Economic Affairs, 2016b). The goal is that the Netherlands will have a decarbonized electricity production in 2050. To realize this, the national government wants to stimulate electricity production from renewable energy sources, such as solar energy, wind energy, biomass and geothermal energy (Ministry of Economic Affairs, 2016a). The challenge is to reduce the CO_2 emissions by 80-95% by 2050, but at the same time guarantee security of supply and affordability of electricity to consumers (Ministry of Economic Affairs, 2016b). The development of offshore wind effect will not have an effect on the presence of climate change goals and targets, only on sorts of energy sources that are used.

Indicator	Effect
CO_2 emissions from electricity sector	+
CO_2 reduction targets	+
Presence of climate change goals and targets	0

TABLE 19: EFFECTS ON CLIMATE CHANGE IN THE NATIONAL SCENARIO

4.1.5 Regulation & governance

4.1.5.1 Governance
Number of electricity system regulators
Each country will have its own electricity system regulator. In the Netherlands, the Dutch Office of Energy Regulation and this is part of the Netherlands Authority for Consumers & Markets (ACM). This scenario will be negative compared to the benchmark.

Permit procedures
Permits will be given out by the government of the Netherlands for the wind parks in the Dutch EEZ. Permits are a part of the offshore wind energy law (Wet Windenergie op zee). It is not allowed to construct or exploit a wind farm without a license from the Ministry of Economic Affairs in the Dutch EEZ. The offshore wind energy law provides a legal framework for the realization of large-scale offshore wind energy in the Dutch EEZ. It creates a framework for the decision on the wind farm zones, the locations where the wind parks will be developed, with a connection to the grid on shore. This decision is made by the Ministry of Economic Affairs and the Ministry of Infrastructure and the Environment. The following aspects are taken into account: multiple functions of the North Sea, effects on third parties of appointing wind farm zones, ecological interests, costs of realizing a wind farm in a certain area, and the importance of connecting the wind farm to the grid. This law also sets rules for the supervision and law enforcement (Noordzeeloket, 2017d). The tender process will be a part of the permit procedure. A large-scale roll-out of offshore wind energy will increase the number of permits, small- and large-scale, for offshore wind energy and therefore it has a positive effect.

Provision of priority grid access to renewable energy
There will be no priority grid access to renewable energy. Grid access will be based on the marginal price. The marginal price of renewable energy is lower than the marginal price of fossil fuelled energy, so it will get priority on the grid, but only based on the price. 30 GW offshore wind energy has no effects on the provision of priority grid access to renewable energy.

Responsibilities
TenneT is the TSO in the Netherlands. Every day, programme responsible parties specify what they expect to feed in and take out of the grid for the next day. At the end of the day, the programme responsible parties measure what they actually supplied to the grid or extracted from the grid. TenneT settles the imbalance between what they expected and what they actually did (TenneT, 2017e). This will be the same procedure as the current

procedure. There will be more programme responsible parties, due to an increase in energy companies. So, this indicator will increase. Therefore, 30 GW offshore wind energy has a negative effect on the responsibilities.

Indicator	Effect
Number of electricity system regulators	-
Permit procedures	+
Provision of priority grid access to renewable energy	0
Responsibilities	-

TABLE 20: EFFECTS ON GOVERNANCE IN THE NATIONAL SCENARIO

4.1.5.2 Trade & regional interconnectivity

Amount of transnational electricity trading

Existing interconnection capacity will be used. Due to the implementation of 30 GW wind energy, the electricity price will be relatively low. Therefore, the Netherlands will become a net exporting country for electricity. Therefore, 30 GW offshore wind energy has a positive effect on the amount of transnational electricity trading.

International cooperation

International cooperation will be low. This will continue on the policies that are already implemented, such as already existing international trade of electricity. International cooperation on intensifying climate and CO_2 reduction policies will not happen. International agreements will only be respected, when this is in the national interests (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015).

Total interconnection capacity

Existing interconnection capacity will still be used, but there will be no additional interconnectors build after 2030. Due to an increase in offshore renewable energy there will be an extension of the capacity until 2030. This will result in 9.800 MW interconnection capacity towards 2050 (Schoots et al., 2016). See table 21 for the capacities to each country. 30 GW offshore wind energy has no effect on the interconnection capacity in this scenario.

Countries	MW
Netherlands – Germany	5000
Netherlands – Belgium	2400
Netherlands – Denmark	700
Netherlands – United Kingdom	1000
Netherlands – Norway	700

TABLE 21: INTER CONNECTION CAPACITY BASED ON THE NEV2016 (SCHOOTS ET AL., 2016)

Indicator	Effect
Amount of transnational electricity trading	+
International cooperation	-
Total interconnection capacity	0

TABLE 22: EFFECTS ON TRADE & REGIONAL INTERCONNECTIVITY IN THE NATIONAL SCENARIO

4.1.5.3 Competition & markets

Electricity market design

The Dutch electricity market will not get a little more integrated in the North-Western European electricity market after 2030. Each country in North-Western Europe will have its own national electricity market, and these markets will be coupled via few interconnectors (Schoots et al., 2016).

The Dutch wholesale market consists of sub-markets:

- The commodity market for trade in bilateral contracts;
- The day-ahead physical and financial trading;
- The balancing market for control and reserve power, operated by the TSO: TenneT (IEA, 2014c).

Market coupling will be the same with other countries, on volume and price. Therefore, 30 GW offshore wind energy has no effects on the electricity market design.

Market share of largest three electricity suppliers
The market share of the largest electricity suppliers will decrease. Energy cooperations, local initiatives, individual citizens, and companies will invest in renewable energy sources (Schoots et al., 2016). Also, large companies that are active in different sectors will invest more in offshore wind energy, when 30 GW offshore wind energy will be developed. Examples are: Shell, Engie, and EDF. The market will consist of many large players (Müller, 2017). Therefore, large-scale wind energy has a positive effect on the market share of largest three electricity suppliers for the Netherlands. 30 GW offshore wind energy gives the opportunity for more parties to enter the market, due to tenders. This results in a smaller share for the largest players, than in the benchmark scenario, which is positive.

Renewable energy subsidy
Renewable energy subsidies will decrease, due to cost reductions. Cost reductions reduce the initial investments for offshore wind energy. Large-scale development of offshore wind energy will stimulate the cost reductions. This has a positive impact on the renewable energy subsidies. Developers speculate on the electricity price and then do the bid. The risk is that if the electricity price is too low, they still need subsidy (Van Bergen, 2017). When the Netherlands has a national focus, but an oversupply in generated electricity, the price will be low. This means that renewable energy subsidies will be needed longer, then when the price would be higher, because the margins are too thin (Hommel, 2017). National renewable energy subsidies will increase, but due to the decrease in European subsidies, the effect will be 0. Tax incentives will still be used. Therefore, it has the same score as the benchmark.

Indicator	Effect
Electricity market design	0
Market share of largest three electricity suppliers	+
Renewable energy subsidy	0
Total amount of annual public energy subsidies	+

TABLE 23: EFFECTS ON COMPETITION & MARKETS IN THE NATIONAL SCENARIO

4.2 International scenario

4.2.1 Availability

4.2.1.1 Security of supply
Total energy demand
Total national energy use will decrease from 2017 PJ in 2030 to 1832 PJ in 2050 in this scenario. This decrease is a direct result of international energy savings targets and the decrease of energy intensity. (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015). Low energy prices will result in a small decrease in demand, this is negative compared to the benchmark.

Total energy supply
Total energy supply is derived from the total primary energy use. It is the energetic energy use and the non-energetic energy use combined. This results in 1500 PJ per year in 2050 (Rooijer & Warringa, 2015). 30 GW offshore wind energy will cause an increase in the total energy supply by 946 PJ. The total supply will be around 2446 PJ. This is positive compared to the benchmark, this is the result of energy.

Total electricity demand
Economic growth causes a small increase in the electricity demand, but the high level of energy savings and an increase in energy efficiency cause a decrease in electricity demand. Electrification will cause an increase in electricity demand. Electrification will be more attractive when electricity prices are low. 30 GW wind energy can contribute to the decrease of electricity prices. Electricity will be used in the transport sector, for the mobility, and it will be used for low-temperature heating. The increase resulted from this depends on the rate of electrification. The electricity demand can increase to around 150 TWh (540 PJ) per year (Planbureau voor de Leefomgeving, 2011). Therefore, 30 GW wind energy has a very positive effect on the electricity demand compared to the benchmark.

Total electricity supply

The total electricity production in the Netherlands will increase from around 500 PJ/year in 2030 to around 660 PJ/year in 2050. (Rooijers & Warringa, 2015). 30 GW wind energy will have a strong positive effect on the electricity supply in the Netherlands, compared to the benchmark.

Indicator	Effect
Total energy demand	--
Total energy supply	+
Total electricity demand	++
Total electricity supply	++

TABLE 24: EFFECTS ON SECURITY OF SUPPLY IN THE INTERNATIONAL SCENARIO

4.2.1.2 Production

Availability of renewable energy resource

The renewable energy resource that is relevant for this case is wind energy. Wind conditions in the North Sea are good. In general, it is the case that the further the parks are from the shore, the more wind there is available. There are not only wind farms developed close to shore, but also far-offshore. These wind farms have excellent wind resources. Wind farms can be put in places where there is an average wind force of 6 Bft or higher, see appendix VIII, this is positive compared to the benchmark.

Increase rate of renewable energy generation capacity

In both scenarios, the offshore wind generation capacity will increase with 1 GW per year between 2030 and 2050. This has a positive influence on the increase rate of renewable energy production per year. Onshore wind energy, solar energy, and biomass will be important renewable energy sources. The increase rate of renewable energy production in the total energy production will be just over 1%, positive compared to the benchmark (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015).

Total installed electricity generation capacity

There is a strong increase in electricity generation capacity after 2030. Generation capacity from conventional fossil fuelled installations will decrease. Solar power will have a strong increase in installed capacity. Onshore wind will not increase after 2030, but remain about the same (Schoots et al., 2016). Offshore wind energy will increase about 1 GW per year. Solar and wind energy can both increase, because it is almost complementary to each other: most of the time when there is a lot of wind, there is less sun and the other way around. In summer, there is more sun and in winter, there is more wind (TenneT, 2017f).

Indicator	Effect
Availability of renewable energy resource	+
Increase rate of renewable energy generation capacity	+
Total installed electricity generation capacity	+

TABLE 25: EFFECTS ON PRODUCTION IN THE INTERNATIONAL SCENARIO

4.2.1.3 Dependency

Self-sufficiency

Self-sufficiency will increase, due to an increase in renewable energy production and a decrease in the use of fossil fuels. Fossil fuels, such as oil and gas, are mainly supplied by a few countries. Reducing the use of fossil fuels, decreases dependency on those countries (Planbureau voor de Leefomgeving, 2011). Offshore wind stimulates the decrease in fossil fuel imports. Imports are still needed when there is not enough production from renewable energy and interconnection facilitates this import. Most of the time, there will be export, due to oversupply and large generation capacity in offshore wind energy. Therefore, the effect is positive compared to the benchmark.

Indicator	Effect
Self-sufficiency	+

TABLE 26: EFFECTS ON DEPENDENCY IN THE INTERNATIONAL SCENARIO

4.2.1.4 Diversification

Diversification of ownership of energy companies

Diversification of ownership will be large. International parties and national parties can operate in the Netherlands. Energy cooperations, local initiatives, individual citizens and companies will invest in offshore wind (Schoots et al., 2016). A lot of large companies that are active in different sectors will invest more in offshore wind energy, when 30 GW offshore wind energy will be developed. Examples are: Shell, Engie, and EDF. The market will consist of many large players (Müller, 2017). Combinations of energy companies in development consortia will also take place. It is likely that consortia and utility companies will exploit large wind parks, while the individual citizens, wind cooperations, and smaller companies exploit smaller wind parks (Van Hövell, 2017). The effect of large-scale offshore wind energy on the diversification of energy companies will be very positive, because the market is more open to international players.

Geographic dispersion of energy facilities
Solar energy and onshore wind will result in a more dispersed and decentralized energy production in the Netherlands onshore (Ministry of Economic Affairs, 2016a). Offshore wind will be spread over the Dutch EEZ, located in situations that are good to connect it to an offshore grid. Large-scale offshore wind will have a very positive effect on the geographic dispersion, because locations further offshore can also be used.

Share of renewable energy in total primary energy supply
The share of renewable energy in the total primary energy supply will increase. This is the result of the reduction of fossil fuelled generators and the increase of 1 GW offshore wind energy per year. The effect will be more positive than the result of the benchmark.

Indicator	Effect
Diversification of ownership of energy companies	++
Geographic dispersion of energy facilities	++
Share of renewable energy in total primary energy supply	++

TABLE 27: EFFECTS ON DIVERSIFICATION IN THE INTERNATIONAL SCENARIO

4.2.2 Affordability

4.2.2.1 Price stability
CO_2 price
The CO_2 price will increase from 40 euro per tonne in 2030, to 160 euro per tonne in 2050, as the result of international ambitious climate and CO_2 reduction policies (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015). A high carbon price makes the market position of electricity from offshore wind better in relation to electricity from coal or gas and this would increase the offshore wind developments. This would create more public support (Müller, 2017). Fossil fuels will be expensive when the CO_2 price is high and only used in times of scarcity (Van Zuijlen, 2017). Offshore wind energy contributes to a decrease of the CO_2 price.

Electricity price volatility
The electricity price is volatile, because it is sensitive to changes in supply and demand of electricity. Volatility will increase, due to an inflexible supply of offshore wind energy. This effect is stronger, when wind energy increases and renewable energy in surrounding countries increases. The volatility of the electricity price makes it hard to predict the electricity price. This makes it difficult to predict the revenues from wind farms (Van Bergen, 2017). Interconnections will reduce volatility, due to reduction in the variability in supply and demand and this has an impact on the price volatility (De Brouwer, 2017). 30 GW offshore wind has a negative impact on the volatility compared to the benchmark, although it is a bit smoothed by the interconnections.

Energy prices by fuel
Table 28 and 29 show the energy prices by fuel. Prices are relative low in this scenario, due to a global decrease in demand for fossil fuels, as a result of international climate agreements with a focus on energy savings, increasing renewable energy supply, and increasing energy efficiency. This will have an impact on the price (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015). A possible effect is that if there is enough electricity generated from wind energy, that more expensive fossil fuelled generators are priced out of the market, due to a lower marginal price of wind energy. When there is enough export, this effect will also be in other European countries,

resulting in even lower fuel prices. Large-scale wind energy will have a strong negative impact on the fuel prices. This is a desired effect.

Fuel prices	2030	2050
Oil ($/barrel)	65	80
Gas ($/ Mbtu)	6	7
Coal ($/tonne)	85	85
Biomass ($/GJ)	8	28

TABLE 28: FUEL PRICES IN CONVENTIONAL UNITS IN AN INTERNATIONAL SCENARIO (PLANBUREAU VOOR DE LEEFOMGEVING & CENTRAAL PLANBUREAU, 2015).

Fuel prices	2030	2050
Oil (€/GJ)	8.0	9.8
Gas (€/GJ)	4.6	5.2
Coal (€/GJ)	2.6	2.6
Biomass (€/GJ)	6.0	21.0

TABLE 29: FUEL PRICES IN SAME UNITS IN AN INTERNATIONAL SCENARIO (PLANBUREAU VOOR DE LEEFOMGEVING & CENTRAAL PLANBUREAU, 2015)

Electricity price

The WLO report predicts that the wholesale price for electricity is 90 euros per MWh in 2030 and 100 euros per MWh in 2050 (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015). There is a lot of interconnection capacity, so it can export to surrounding countries. When the price is high in the Netherlands, it will import from other countries. The result will be that the price for electricity is almost equal across North-Western Europe and it will be less volatile. There is a lot of discussion concerning the predictions of the electricity price. There are many different opinions about the price. Developers predict that the electricity price will increase (Elsevier van Griethuysen, 2017; Van Bergen, 2017). Other parties think that the electricity price will decrease, due to the oversupply of wind power in the system (Hommel, 2017; Aksan, 2017; van Zuijlen, 2017). Therefore, this scenario assumes that the electricity price will increase and that it will be higher than in the national scenario. Offshore wind energy will impact the electricity price, it will decrease, but not as much as in the national scenario, due to the export of electricity.

Indicator	Effect
CO_2 price	++
Electricity price volatility	-
End-use energy prices by fuel	++
Electricity price	++

TABLE 30: EFFECTS ON PRICE STABILITY IN THE INTERNATIONAL SCENARIO

4.2.2.2 Access & equity

Grid connection

Offshore wind farms will have a connection to a meshed offshore grid. This also connects the countries of the North Sea. Figure 10 shows a schematic example of a meshed offshore grid. Large-scale offshore wind development in the Netherlands and in other parts of Europe will have a positive effect on the grid design compared to the benchmark. It can be a driver for the meshed solution, to create more efficiency. This can result in a fully integrated offshore grid (Müller, 2017)

Rate of electrification

Electrification will play an important role in the transition (Hövell, 2017). All sorts of industries will adapt their production processes, if the price decreases. Companies will produce when there is a lot of wind and the electricity price decreases (Van Zuijlen, 2017). The rate of electrification will be slower than in a national scenario, because the average electricity prices are higher. Electrification is less attractive in this scenario. Sea ports with a high energy usage, such as the Port of Rotterdam, are a good location to start with electrification, because it is convenient to use a location near the shore, to reduce transport costs of electricity (Romeijn, 2017). The rate of electrification will have more positive than the benchmark situation.

Site conditions
In an international context, where Dutch wind parks can be connected to the Dutch shore, to an interconnector cable, directly to another country, or to an offshore hub, wind farms can be built far offshore, depending on the costs. Constructing further offshore will become more attractive. Further offshore the waves are higher, and there is more wind. It is more difficult to reach the wind parks by boat, but there will be more electricity generated due to higher wind speeds. Soil conditions are equal across the whole North Sea, this will not have a large influence on the decisions on the locations of the wind parks (Van Bergen, 2017). Wind farms can be constructed in areas that are 60m deep. This results in a negative effect compared to the benchmark.

Indicator	Effect
Grid connection	++
Rate of electrification	+
Site conditions	-

TABLE 31: EFFECTS ON ACCESS & EQUITY IN THE INTERNATIONAL SCENARIO

4.2.2.3 Affordability
Balancing costs
Balancing costs to match supply and demand will be lower in an international context than in a national context. It is more cost effective when supply and demand can be optimized across the borders. International cooperation is necessary to create more efficiency (Aksan, 2017). 30 GW wind energy will bring more variability in the electricity supply, so it will be more difficult to match supply and demand. Interconnection will help match supply and demand. However, the balancing costs are negative compared to the benchmark.

Construction costs
When there is a stable roll-out of 1 GW per year, the construction costs will decrease. There is a clear signal to the market when 30 GW needs to be constructed. This gives security to the market and investments can be spread over multiple projects, which will lead to cost reductions per project (Romeijn, 2017; Molenaar, 2017; Van Bergen, 2017; Van Hövell, 2017). International cooperation can create a minimal European roll-out and then the construction costs will reduce more, because there are more projects to divide the costs over. Almost all companies in the Netherlands are internationally active, so they will benefit from a European roll-out (De Brouwer, 2017). Construction costs can increase due to stricter rules to protect ecology. The effect of 30 GW wind energy on the construction cost will be very high in an international setting, due to more competition in the market.

Investment risk
The biggest investment risk is related to the energy price. The energy price is very volatile and is extremely sensitive to supply and demand. This makes it difficult to predict the electricity price in the long-term. As a consequence, it is difficult to predict when return on investments will be (Van Bergen, 2017). This is a risk for developers. The average electricity price is expected to be higher in this scenario than in the national scenario (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015) and the construction cost are expected to be lower, so the investment risk will be low in this scenario for the windfarms itself. However, investments in the grid have very high upfront costs and low operational costs and wind farms have high upfront costs and low operational costs. So, the investment risk will be high. The effect of the development of 30 GW offshore wind on the electricity price and construction costs result in a very positive effect on the investment risk.

Marginal cost of electricity power generation
Average marginal cost of electricity generation will decrease. Marginal costs of offshore wind energy are low, almost zero. This will be added to the total energy supply of the Netherlands, so the average marginal cost will go down. Also, the supplies from fossil fuelled electricity generators will decrease (Schoots et al., 2016), which have higher marginal costs. As a result, the marginal costs will decrease.

Transmission costs for electricity
Transmission costs will increase. Offshore wind parks need to be connected to the offshore grid and to shore. This increases the costs. The grid onshore needs an extension to facilitate the transport of the large amount of electricity that is put on the grid. In this scenario, there will be more interconnections and this will result in more

investments in the transmission grid. 30 GW offshore wind energy will have a very negative impact on the transmission costs for electricity compared to the benchmark, due to higher investments.

Indicator	*Effect*
Balancing costs	-
Construction costs	++
Investment risk	-
Marginal cost of electricity power generation	-
Transmission costs for electricity	--

TABLE 32: EFFECTS ON AFFORDABILITY IN THE INTERNATIONAL SCENARIO

4.2.3 Technology Development & efficiency

4.2.3.1 Innovation & research

Construction technique

The Dutch offshore sector is strong in design, installation and operation of offshore constructions (Van der Putten, 2017). The current construction technique is that parts of the turbine are constructed onshore, then transported to the location offshore, and then the assembly takes place offshore at the location of the wind park. This requires a lot of shipping and is costly (Romeijn, 2017; Van Zuijlen, 2017).

Construction of wind parks creates noise and this is creating damage to sea mammals. When 30 GW wind energy is constructed, the amount of noise that is created increases. Innovation is necessary to reduce noise. Blue piling and gravity based foundations are examples of construction techniques with less noise (Hommel, 2017; Van Zuijlen, 2017). When the accepted level of noise decreases, it is expected that this will bring more construction techniques that make less noise, because noise restrictive measures are very costly (Schild, 2017) and these techniques can be exported. It is expected that 30 GW wind energy will increase the innovations in the construction techniques and therefore it has a very positive effect on the construction technique.

Research budgets for renewable sources of energy

Dutch offshore wind research mainly focuses on offshore technology and the balance of plant, not on the turbine itself. European subsidies will play a bigger part in the research market in North-Western Europe, so in the Netherlands as well. This will be used to create European standards. European research cooperations will get a larger role in the research market, and research will be done for shared interests (Van der Putten, 2017). This creates more efficiency in the research market. A clear roll-out of 30 GW wind energy in the Netherlands and other European projects will increase the research budgets. The current Dutch budget is around 130 million euros from the Topsector Energie (RVO, 2017d). So, it will be more than 130 million euros. However, due to cost reductions in renewable energy technologies, it will not increase very much. Therefore, large-scale offshore wind energy has a positive effect on the research budgets compared to the benchmark.

Technological innovation

One of the most important technical developments will be the increase in size of turbines (Schild, 2017; Van Bergen; Van der Putten, 2017; Van Hövell, 2017). Developments in size of turbines will be leading for other technical developments (Van der Putten, 2017). This means that for the same number of GW, less turbines and cables are needed, and other types of foundations are needed (De Brouwer, 2017). The maximum size will increase and then stabilize at about maximum 20 MW (Molenaar, 2017).

Creating an international meshed offshore grid will be an innovation. The infrastructure will be used for electricity that is generated by the wind farms, and it will be used as interconnection between countries (Müller, 2017).

An expected innovation in the construction technique is creating more efficiency, by assembling the turbines onshore and placing them at once offshore. This reduces shipping parts. The production volume of 30 GW will facilitate this innovation, because there will be enough produced to create facilities onshore for this (Romeijn, 2017; van Zuijlen, 2017). Another innovation in the construction technique will be building with less noise, to reduce the effects on the ecology (Hommel, 2017; Schild, 2017; Van Zuijlen, 2017).

Building with lighter materials and smaller diameters for the same capacity, will reduce costs. Innovation will take place in other production techniques, blades that can adapt to the wind conditions, and big data to better predict the power generation of the turbines (Molenaar, 2017).

Energy storage will develop. Energy storage can play a big role in balancing supply and demand. This affects the need for interconnections to balance the supply and demand (Müller, 2017; De Brouwer, 2017).

Sensors will play a role in retrieving information from a distance. From a distance operators can get information about the status of a wind park, optimize generated electricity, measure degradation of turbines and the support system, and optimize maintenance and inspections (Van der Putten, 2017).

On the demand side of the energy system innovation will take place in demand-response, to better match supply and demand. This will increase the flexibility of the system (De Brouwer, 2017). Technological innovation will have a very positive effect compared to the benchmark.

Indicator	*Effect*
Construction technique	++
Research budgets for renewable sources of energy	+
Technological innovation	++

TABLE 33: EFFECTS ON INNOVATION & RESEARCH IN THE INTERNATIONAL SCENARIO

4.2.3.2 Efficiency

Energy intensity

Energy intensity of the Dutch economy will decrease. The rate of decrease will be -2.5%/year, between 2030 and 2050. This decrease is the result of increased energy efficiency and energy savings and economic growth. The energy needs are not increasing as fast as the economic growth (Planbureau voor de Leefomgeving & Centraal Planbureau, 2015). The energy intensity will be higher than in the benchmark setting.

Indicator	*Effect*
Energy intensity	++

TABLE 34: EFFECTS ON ENERGY INTENSITY IN THE INTERNATIONAL SCENARIO

4.2.3.3 Safety & reliability

Frequency of interruption of supply

Offshore wind is an intermittent energy source. Due to inflexible supply, it becomes more difficult to match supply and demand. If there is a large increase in offshore wind generation capacity this effect will be stronger. If there is little wind on the North Sea, there will be less energy from offshore wind. (Hommel, 2017; Van Zuijlen, 2017). Therefore, an increase in offshore wind energy will have a negative effect on the frequency of interruption of supply compared to the benchmark scenario, even though there are more interconnections, because it is possible that the same situation happens in neighbouring countries.

Operation and maintenance strategies

Distance to shore and water depth influence the O&M costs. When wind farms are far from shore, different concepts of O&M are needed. An energy island can be the solution for this, with joint maintenance facilities, from different countries (TenneT, 2017f). 30 GW offshore wind energy will stimulate these O&M developments. It is very likely that O&M will happen in international clusters of windfarms, to create more efficiency. O&M strategies are very positive compared to the benchmark.

Predictability of power supply

Wind energy is an intermittent energy source. It will be more difficult to predict the power supply. Large-scale offshore wind energy will decrease the predictability of power supply. However, it is expected that sensors will play a big part in the optimization and prediction of the power supply from offshore wind energy. Sensors are expected to make a better relation between the conditions in the environment and the amount of power that will be generated. This can be on the level of a single wind turbine of a whole wind park (Van der Putten, 2017). Predictability of power supply from offshore wind farms will be better in an international setting, because international prediction systems can be coupled. Coupling of these systems will contribute to the prediction of wind speed, so the prediction of the power supply per wind farm will be more accurate (Hommel, 2017). Predictability of power supply will decrease compared to the benchmark.

Indicator	*Effect*
Frequency of interruption of supply	-
Operation and maintenance strategies	++
Predictability of power supply	-

TABLE 35: EFFECTS ON SAFETY & RELIABILITY IN THE INTERNATIONAL SCENARIO

4.2.3.4 Resilience

Generation adequacy

Generation adequacy will decrease, because of the variability on the generation side increases. It will be more difficult to match supply and demand and this has a negative impact on the generation adequacy. When there is an oversupply of wind energy this can be exported to other countries. When there is not enough wind, electricity can be imported from other countries. The maximum generation reserve capacity is likely to decrease, because these are mainly conventional power stations (IEA, 2014c). Therefore, the generation adequacy will decrease.

System adequacy

System adequacy will increase, because the system will have a higher ability to cope with the amount of electricity that will be brought to the system, when the grid is optimized across the borders. System adequacy is the interconnection capacity as a percentage of the generation capacity (IEA, 2014c). International cooperation is necessary to align grid expansion plans with surrounding countries, to optimize grid reinforcements and to have sufficient capacity to transport the electricity from the supplier to the consumer (Aksan, 2017). In an international scenario with a lot of import and export capacity over the interconnectors it is less difficult to meet the flexibility that is necessary. Interconnectors, integrated energy markets and a good planning of the TSOs that is aligned with the TSOs from surrounding countries are necessary to facilitate the integration of large-scale renewable energy into the energy system (De Brouwer, 2017). It will have a positive effect compared to the benchmark situation.

Indicator	*Effect*
Generation adequacy	-
System adequacy	+

TABLE 36: EFFECTS ON RESILIENCY IN THE INTERNATIONAL SCENARIO

4.2.3.5 Investment & employment

Average rate of return on energy investments

It is difficult to predict the rate of return on energy investments, because it is difficult to predict the energy prices. However, in an international scenario the price for electricity will be higher than in a national scenario, because there will be a lot of export via interconnectors. Higher electricity prices will result in a higher rate of return, which is good for the investors and developers. There is a clear signal to the market when 30 GW needs to be constructed, and there is a stable policy for the roll-out of this large amount of offshore wind energy. This gives security to the market and investments can be spread over multiple projects, which will lead to cost reductions per project (Elsevier van Griethuysen, 2017; Romeijn, 2017; Molenaar, 2017; Van Bergen, 2017; Van Hövell, 2017). Therefore, large-scale offshore wind will have a positive impact on the average rate of return on energy investments compared to the benchmark.

Direct employment

Maximum direct employment could be about 30.000-40.000 fte per year in the Netherlands and 300.000-400.000 for Europe (Van Zuijlen, 2017). A stable roll-out of 1 GW per year in the Netherlands and a stable roll-out of European offshore wind projects in the North Sea will have a positive effect on employment in the Dutch offshore wind sector, because this attracts investments to the Netherlands and this will create employment opportunities (Hommel, 2017; Molenaar, 2017; Van Bergen, 2017; Van Hövell, 2017). An important factor is that there are enough people with the right qualifications for the job. This can be a bottle neck. It is important to create employment opportunities by creating the right education programs and training programs, with a curriculum that is known in the offshore wind sector. These employees can also work internationally (Molenaar, 2017; Romeijn, 2017; Van Bergen, 2017; Van Zuijlen).

When there are enough people in a region with qualifications to work in the offshore wind sector, it becomes attractive for companies to invest in a production location, because they know they have access to a certain number of employees with the right qualifications. When there is a large offshore sector, new companies will settle in the same region (Romeijn, 2017). These factors will create a base for employment (Molenaar, 2017).

Maintenance of wind parks creates more employment than the construction of wind parks. About three quarters of the employment in the offshore wind industry is related to maintenance, this is mainly local and close to the offshore wind parks (Molenaar, 2017)

Dutch companies with a good track record can work in international projects and also their employees can work abroad. This will increase employment opportunities for the Dutch offshore sector. The effect will be very positive compared to the benchmark.

Indirect and induced employment in industry
Employment opportunities in the offshore sector will increase, due to a stable roll-out on a national and European level. Most companies already work internationally and have a good reputation. A lot of people from the offshore oil and gas sector will become available and can be trained to work in the offshore wind sector (Van Zuijlen, 2017). Employment will increase as a result of: economic activities in the component and service industries and training and testing facilities (Bais et al., 2017). Large-scale offshore wind energy development will create a spin-off in economic activities. It creates a positive effect on the employment in a whole region. Regions with a strong offshore cluster and a sea port attract other offshore companies, which creates even more employment in the region. In Rotterdam, the employment that is created could be around 10.000 fte (Romeijn, 2017). When there are more projects, also internationally, there will be more economic activities, resulting in more spin-offs for the region. Large-scale offshore wind energy development will have a very positive effect on the employment opportunities compared to the benchmark.

Investment in electricity transmission capacity
Developing a large-scale offshore grid is costly and also the grid onshore needs to be expanded. However, a coordinated long-term design will bring substantial cost reductions in the long run (Haesen & van der Leun, 2017). This needs good planning, otherwise there is the risk that the grid is not ready when there will be an increase in offshore wind energy. This might be a bottleneck in the development of offshore wind energy (Elsevier van Griethuysen, 2017; Hommel, 2017). Therefore, large-scale offshore wind energy has a very positive impact on the investments in electricity transmission capacity compared to the benchmark.

Operation and maintenance costs
Distance to shore and water depth influence O&M costs (Van der Putten, 2017). When wind farms are far-offshore, new concepts are needed to keep offshore wind profitable. Sharing of infrastructure and materials with different countries and companies will decrease the costs. When there are many wind farms offshore, an energy island could be the solution to decrease O&M costs (TenneT, 2017f). 30 GW offshore wind energy will stimulate innovations and efficiency that will bring the cost down of O&M. This means that it has a very positive effect.

Indicator	Effect
Average rate of return on energy investments	+
Direct employment	++
Indirect and induced employment in industry	++
Investment in electricity transmission capacity	++
Operation and maintenance costs	++

TABLE 37: EFFECTS ON INVESTMENT& EMPLOYMENT IN THE INTERNATIONAL SCENARIO

4.2.4 Environmental & social sustainability

4.2.4.1 Land / water use

Available areas

Areas further offshore will be interesting for wind energy development in an international setting, the red lines in figure 11 show these areas. There at not many activities, there is more wind far from the shore, and these are areas close to other countries' EEZs. This gives the opportunity to share infrastructure or develop multi-national wind farms. Shared use of space for wind energy can increase available areas. Wind farms can be combined with ecology, fishing sector, or oil- and gas sector (Noordzeeloket, 2017c). These factors have a positive impact on available areas.

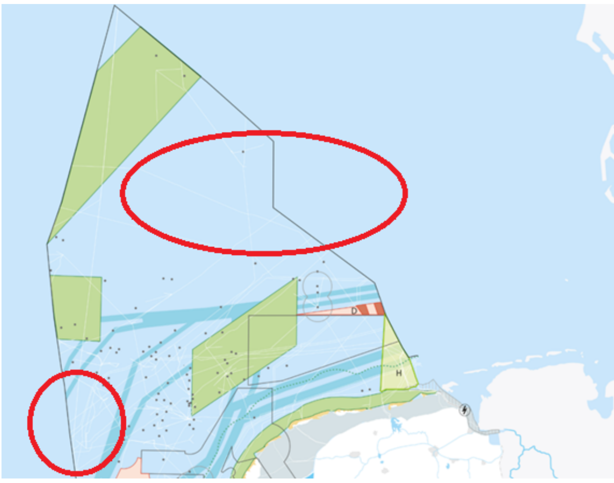

FIGURE 11: PART OF THE SPATIAL AGENDA OF THE DUTCH EEZ (ADAPTED FROM: NOORDZEELOKET, 2015)

Required space for renewable energy option

A lot of space is required for 30 GW wind energy, which results in a negative effect on required space. The assumption is of 6 MW/km^2, results in 5.000 km^2 space required. Depending on the capacity per wind turbine, the amount of wind turbines differs if 30 GW capacity is installed and therefore also the required space for a wind park. Currently, the largest turbine is 8 MW, and size and capacity of wind turbines will grow (IPCC, 2012). Table 17 shows how much wind turbines are needed of a certain capacity, when 30 GW capacity is necessary. More areas are available compared to the benchmark situation, but there are also more turbines needed, so more space is needed.

Size of installation

Size of installation is the size of wind turbines. Wind turbines will increase in size. The rotor diameter and height of tower will increase (De Brouwer, 2017; Molenaar, 2017; Schild, 2017; Van Bergen, 2017; Van Hövell, 2017; Van der Putten, 2017). Table 17 shows the expected heights of the tower and the rotor diameter for each capacity. It is expected that capacity will stay below 20 MW, because otherwise the impact will be too big when one turbine temporarily cannot produce electricity (Molenaar, 2017). 30 GW offshore wind energy will increase innovation and efficiency: the same size of a turbine has higher capacity. This is positive compared to the benchmark.

Indicator	Effect
Available areas	+
Required space for renewable energy option	-
Size of installation	+

TABLE 38: EFFECTS ON LAND / WATER USE IN THE INTERNATIONAL SCENARIO

4.2.4.2 Climate change

CO_2 emissions from electricity sector

This will decrease, because fossil fuelled generators can be pushed out of the market. This gives the Netherlands the chance to have a more sustainable energy system (De Brouwer, 2017; Hommel, 2017). On days where there is not enough wind energy or solar energy available to meet the Dutch demand, it can import electricity from surrounding countries. When it has an oversupply, it can export green electricity. This will not only reduce the CO_2 emissions from the Dutch electricity sector, but also from surrounding countries. Therefore, 30 GW wind energy will have a very positive effect on CO_2 emissions from electricity sector.

CO_2 reduction targets
Offshore wind energy will contribute to CO_2 reduction targets, the reduction of other greenhouse gasses, and to create a carbon neutral energy system (Hommel, 2017). It also contributes to reduction targets of other countries, by exporting green electricity. Also, creating ‘green gas’ by applying power-to-gas methods, which can replace “grey gas”, contributes to these targets (Jepma & van Schot, 2017). 30 GW wind energy will have a very positive effect on CO_2 reduction targets, it will be on the upper limit of reduction targets between 95-100%.

Presence of climate change goals and targets
Goals set in the Paris Agreements, the Energy Agreement for Sustainable Growth, the Energy Report, and the Energy Agenda are respected. The goal is that the Netherlands will have a decarbonized electricity production in 2050. Surrounding countries will have similar goals. The challenge is to reduce the CO_2 emissions by 80-95% by 2050, and guarantee security of supply and affordability of electricity to consumers (Ministry of Economic Affairs, 2016b). Ambitious national and international climate agreements will be respected and there is a possibility that even more ambitious goals and targets will be set. Therefore, this is very positive compared to the benchmark.

Indicator	*Effect*
CO_2 emissions from electricity sector	++
CO_2 reduction targets	+
Presence of climate change goals and targets	++

TABLE 39: EFFECTS ON CLIMATE IN THE INTERNATIONAL SCENARIO

4.2.5 Regulation & governance

4.2.5.1 Governance
Number of electricity system regulators
There will be an overall European electricity system regulator. Harmonization of regulatory systems between countries is needed, when there is a European wind roll-out, because currently the approach varies by country. Countries have different perceptions about the concepts of the stimulation to have cost reductions, efficiency, and quality (EY, 2013). It will bring more efficiency in the system, when the system is harmonized across Europe. Therefore, 30 GW offshore wind energy will have a positive effect on this indicator compared to the benchmark.

Permit procedures
Development of offshore wind energy projects in the North Sea will go from national projects to European projects. Agreements between national governments are necessary to harmonize projects and to create a stable European roll-out (Müller, 2017). On a European level it will be decided when and where wind farms are developed. Based on these agreements, the Dutch government can give out permits for wind farms in the Dutch EEZ. Multi-national projects will have multiple countries working together, with a fair distribution in sharing the costs and benefits. 30 GW offshore wind energy will increase the number of permits in large-scale, medium-scale and small-scale projects. Therefore, it has a very positive effect compared to the benchmark.

Provision of priority grid access to renewable energy
There will be no priority grid access for offshore wind energy or other renewable energy options. Grid access will be based on marginal prices. Marginal prices of renewable energy are lower than marginal prices of fossil fuelled energy (VEMW, 2017), so it will get priority on the grid, but based on the price. Therefore, 30 GW offshore wind energy has no effects on the provision of priority grid access to renewable energy.

Responsibilities
European countries will realize that developing large-scale offshore wind energy in the North Sea is a European task and responsibility. An international vision on the roll-out and planning strategy of the development of

offshore wind projects, with agreements and plans on ecology, infrastructure, policy and costs, needs to be made by the North Sea countries (Müller, 2017). Also, responsibilities change on production and consumption side. Programme responsible parties need to specify what they expect to feed in and take out of the grid for the next day. The programme responsible parties measure what they actually supplied to the grid or extracted from the grid. The imbalance between what they expected and what they actually did is settled (TenneT, 2017e). This will change to a more European level. There will be more programme responsible parties, due to an increase in energy companies. More parties and a European responsibility result in a very positive effect compared to the benchmark.

Indicator	*Effect*
Number of electricity system regulators	++
Permit procedures	++
Provision of priority grid access to renewable energy	0
Responsibilities	++

TABLE 40: EFFECTS ON GOVERNANCE IN THE INTERNATIONAL SCENARIO

4.2.5.2 Trade & regional interconnectivity

Amount of transnational electricity trading

The markets and infrastructure will be better coupled to create more flexibility, to deal with the variability in supply and demand on a European level. European agreements will be made about interconnection capacity (De Brouwer, 2017; Molenaar 2017). 30 GW offshore wind energy has a very positive effect on the amount of transnational electricity trading compared to the benchmark.

International cooperation

European cooperation in offshore wind projects is very important to keep up with global developments in the sector. It will help the Netherlands to stay competitive in the global offshore market and to bring cost reductions to the industry (De Brouwer, 2017; Van der Putten, 2017). European policies and national policies need to converge. The Netherlands will be able to play an active role, because it has a large part of the North Sea and a good offshore sector (Müller, 2017). International cooperation is also needed to create more efficiency, because it is less expensive to optimize supply and demand across the borders. In the short-term, this cooperation can be done with: Belgium, the UK, and Germany. In the long-term cooperation with France, Austria, and Denmark is necessary. (Aksan, 2017). International cooperation is necessary to harmonize different rules and regulations between countries and cooperation in policy making will increase (Schild, 2017). Therefore, 30 GW offshore wind energy has a very positive effect on the international cooperation.

Total interconnection capacity

Total interconnection capacity will increase to more than the 9,800 MW that is presented in the NEV2016. Most countries have the same problems with the variability in supply and demand of electricity. International cooperation over the interconnection capacity will increase the security of supply (Hommel, 2017). International planning and coordination is crucial in developing the grid, especially when the Netherlands has an oversupply in electricity. In the long-term, interconnection between the Netherlands and France might play a role (Aksan, 2017). 30 GW offshore wind energy has a very positive effect on the interconnection capacity in this scenario.

Indicator	*Effect*
Amount of transnational electricity trading	++
International cooperation	++
Total interconnection capacity	++

TABLE 41: EFFECTS ON TRADE & REGIONAL INTERCONNECTIVITY IN THE INTERNATIONAL SCENARIO

4.2.5.3 Competition & markets

Electricity market design

The electricity markets in North-West Europe will be integrated into an open North-Western European electricity market, making the system more efficient. This is necessary when integrating a lot of offshore wind energy into the system (Elsevier van Griethuysen, 2017). Polies need to be made to change the electricity system. It is important that electricity can be exported immediately to another country, without be transported to the Dutch grid first. It should also be possible to convert electricity into heat or gas for the industry or mobility. This will increase economic opportunities (Van Hövell, 2017). Therefore, 30 GW offshore wind energy has a positive effect on the electricity market design compared to the benchmark.

Market share of largest three electricity suppliers
The market share of the largest electricity suppliers will decrease to less than 50%. More international companies will be interested in the Dutch energy sector. Also, energy cooperations, local initiatives, individual citizens and companies will invest in renewable energy sources (Schoots et al., 2016). Also, a lot of large companies that are active in different sectors will invest more in offshore wind energy, when 30 GW offshore wind energy will be developed. Examples are: Shell, Engie, and EDF. The market will consist of many large players (Müller, 2017). Therefore, 30 GW wind energy has a positive effect on the market share of largest three electricity suppliers compared to the benchmark.

Renewable energy subsidy
There is a need to change the renewable energy subsidies, to make them more international, when there will be multinational wind farms. This is necessary to increase efficiency and cooperation. This will facilitate the development of wind parks in one countries' EEZ, but connects it directly to another countries shore and grid (Elsevier van Griethuysen, 2017). Large-scale development of offshore wind energy will stimulate cost reductions. Therefore, it has a very positive impact on the renewable energy subsidies compared to the benchmark.

Indicator	Effect
Electricity market design	+
Market share of largest three electricity suppliers	+
Renewable energy subsidy	++

TABLE 42: EFFECTS ON COMPETITION & MARKETS IN THE INTERNATIONAL SCENARIO

4.3 Comparison of the two scenarios in the comprehensive energy security analysis

The comprehensive energy security effects are better in the international scenario than in the national scenario. When looking at the dimensions, the international scenario scores better on all the dimensions, except for the dimension affordability. The effects per dimension are discussed below.

4.3.1 Comparison of the effects on availability

In table 43, the results of the analysis are shown for the dimension availability. Overall, for availability the effects on energy security are better in the international scenario.

The effects on security of supply are better in the international scenario. Security of supply can have many definitions, but in this study, it is the relation between supply and demand. Security of supply is better in the international scenario. The increase in generation capacity contributes positively in both scenarios, but there is more demand in the international scenario as a result of exports. This is a desired development, because large inflexible supply can cause congestion. A larger demand is then needed. In a national scenario, supply is more domestic: less dependence on other countries, but also less abilities to import energy when necessary. Therefore, both scenarios contribute in other ways to the security of supply and the neither has a significant higher effect.

Effects on production are positive in both scenarios, but it is better in the international scenario, because the availability of renewable energy resources is better. This results in 3 positive effects in the international scenario, compared to 2 positive effects in the national scenario. In an international scenario, wind farms will be build further offshore. Far offshore, there are better wind conditions than close to shore, the wind speed is higher and there are more wind hours in a year.

The effect on dependency is better in a national scenario, because in the national scenario the Netherlands is less dependent on energy imports and energy exports from other countries.

Effects on diversification are better in the international scenario. Geographic dispersion is better in an international scenario, because wind farms are spread over the Dutch EEZ. Diversification of ownership of energy companies is better, because the market is more open and international, with international of energy companies.

Dimension	Component	Indicator	National scenario	International scenario
Availability	*Security of supply*	Total energy demand	--	-
		Total energy supply	+	+
		Total electricity demand	++	++
		Total electricity supply	++	++
	Production	Availability of renewable energy resource	0	+
		Increase rate of renewable energy generation capacity	+	+
		Total installed electricity generation capacity	++	+
	Dependency	Self-sufficiency	++	+
	Diversification	Diversification of ownership of energy companies	0	++
		Geographic dispersion of energy facilities	+	++
		Share of renewable energy in total primary energy supply	++	++

TABLE 43: ENERGY SECURITY EFFECTS FOR AVAILABILITY

4.3.2 Comparison of the effects on affordability

Table 44 shows results of the analysis for the dimension affordability. Overall, the effects on energy security are equal in both scenarios on a component level, but on the indicator level, the international scenario is better.

Price stability is better in an international scenario, because there is a less volatile electricity price, because there is more interconnection capacity. It is also better, because end-use energy prices by fuel are lower, making energy more affordable. The electricity price will be higher in the international scenario, due to more export in electricity.

Effects on access & equity are positive, and equal for both scenarios. The grid connection is better in the international scenario, due to a more integrated grid. Rate of electrification is better in the national scenario, due to lower prices and the effects on the site conditions are better in the national scenario, due to fewer waves.

The affordability component is equal in both scenarios. Balancing costs are lower in the international scenario, because the European electricity market is more integrated and more balanced. Construction costs are better in the international scenario, because innovations lead to cost reductions, and efficiency will increase when there is international cooperation in research and development. The investment risk for wind farms is high in both scenarios, due to high upfront costs and low operational costs, but higher in the international scenario due to higher grid investments. Effects on marginal costs of electricity power generation are the same in both scenarios, because it is for wind energy almost zero and the amount of wind energy that is brought to the grid is the same. Transmission costs for electricity are better in the national scenario, because more grid expansion is necessary in the international scenario, these costs are very high.

Dimension	Component	Indicator	National scenario	International scenario
Affordability	*Price stability*	CO_2 price	-	++
		Electricity price volatility	--	-
		End-use energy prices by fuel	-	++
		Electricity price	+	++
	Access & equity	Grid connection	0	++
		Rate of electrification	++	+
		Site conditions	0	-
	Affordability	Balancing costs	--	-
		Construction costs	+	++
		Investment risk	-	--
		Marginal cost of electricity power generation	-	-
		Transmission costs for electricity	-	--

TABLE 44: ENERGY SECURITY EFFECTS FOR AFFORDABILITY

4.3.3 Comparison of the effects on technology development & efficiency

Table 45 shows the results of the analysis for the technology development & efficiency dimension. Overall, for technology development & efficiency the effects on energy security are better in the international scenario.

The effect on the construction technique and technological innovation are the same in both scenarios, due to innovations in the industry. The effect on the research budgets is better in the international scenario, as a result of the presence of European budgets.

The effect on efficiency is higher in the international scenario, because there are more cost reductions in technologies in the international scenario. Effects on safety & reliability are better in the international scenario, because the frequency of interruption of supply is better than in the national scenario. Both are negatively affected, because of the intermittent supply of wind energy. However, in an international scenario this can be better balanced, because there is more interconnection capacity. O&M strategies are also better in an international scenario, because there is more efficiency and international cooperation, leading to innovative concepts and costs reductions. Effects on the predictability of the power supply are equal, because wind energy is an intermittent source.

Effects on resilience are also better for the international scenario, because system adequacy is better in the international scenario. The system will have higher ability to cope with the amount of electricity that will be brought to the system, when the grid is optimized across the borders. Effects on generation adequacy will be negative for both scenarios, because the supply of electricity will become more variable in both scenarios.

The effects on investment and employment are better in the international scenario. Average rate of return is higher in the international scenario, because construction costs are lower and the electricity price is more stable. The effects on direct employment and on indirect and induced employment in the industry are better in the international scenario, because companies have more economic activities if they can also participate in international projects, this will result in growth in the industry. This will boost the Dutch industry; create more employment opportunities and economic spin-off in the regions where they are located. The effect on the investment in transmission capacity is better in the international scenario, because there will be more investments in the transmission grid and in interconnections. O&M costs are lower in an international scenario, due to more innovative O&M strategies and cooperation in the international scenario.

Dimension	*Component*	*Indicator*	*National scenario*	*International scenario*
Technology development & efficiency	*Innovation & research*	Construction technique	++	++
		Research budgets for renewable sources of energy	0	+
		Technological innovation	++	++
	Efficiency	Energy intensity	+	++
	Safety & reliability	Frequency of interruption of supply	--	-
		Operation and maintenance strategies	+	++
		Predictability of power supply	-	+
	Resilience	Generation adequacy	-	-
		System adequacy	-	+
	Investment & employment	Average rate of return on energy investments	-	+
		Direct employment	+	++
		Indirect and induced employment in the industry	+	++
		Investment in electricity transmission capacity	0	++
		Operation and maintenance costs	+	++

TABLE 45: ENERGY SECURITY EFFECTS FOR TECHNOLOGY DEVELOPMENT & EFFICIENCY

4.3.4 Comparison of the effect on environmental & social sustainability

Table 46 shows the results of the analysis for the dimension environmental & social sustainability. Overall, the effects on energy security are better in the international scenario.

Effects on the component land/water use are equal in both scenarios, because the effect on available areas is better in an international scenario: more areas can be used, because it is possible to develop offshore wind far-offshore. Effects on required space for the renewable energy option are better in a national scenario, because only the areas close to shore are needed and effects for other sectors will be smaller. Size of the installation is equal for both scenarios.

Effects on climate change are better in the international scenario. The effect on CO_2-emissions will be higher in the international scenario, because the Netherlands can export green electricity to other countries. Therefore, not only the Dutch electricity sector will be more sustainable, but those of other countries as well. The effects on reduction targets are equal. Presence of climate change goals and targets are higher in an international scenario, because the international agreements will be respected and maybe more agreements will be made.

Dimension	*Component*	*Indicator*	*National scenario*	*International scenario*
Environmental & social sustainability	*Land / water use*	Available areas	-	+
		Required space for renewable energy option	+	-
		Size of installation	+	+
	Climate change	CO_2 emissions from electricity sector	+	++
		CO_2 reduction targets	+	+
		Presence of climate change goals and targets	+	++

TABLE 46: ENERGY SECURITY EFFECTS FOR ENVIRONMENTAL & SOCIAL SUSTAINABILITY

4.3.5 Comparison of the effects on regulation & governance

Table 47 shows the results of the analysis for the dimension regulation & governance. The number of electricity system regulators is better in an international scenario, because this will be internationally coordinated in Europe, which results in a better functioning market in Europe. Effects on permit procedures are positive in both scenarios, because more permits will be given out in both scenarios. There will be no provision of priority grid access to renewable energy in both scenarios, so this will remain the same in both scenarios. There will be more programme responsible parties in both scenarios, but there will be a higher increase in the international scenario, because international parties are allowed in the market. Therefore, the international scenario is better.

Effects on trade and regional interconnectivity are better in the international scenario. The amount of transnational electricity trading will be better in the international scenario, because there is more interconnection capacity. The international cooperation will be better in the international scenario, because there will be more international projects, interconnections and harmonization of plans. The effect on the total interconnection capacity will be very positive in the international scenario, because a lot of export of electricity is possible.

Effects on the competition and markets are better in the international scenario. The electricity market design will be more efficient in the international scenario, because markets in European countries are coupled. The effect on the market share of largest three electricity suppliers will be positive in both scenarios, because there will be more competition in the market, this results in a lower market share for the largest three electricity suppliers. The effects on renewable energy subsidy will be more positive in the international scenario, because the large-scale development of offshore wind energy will bring cost reductions and therefore fewer subsidies are needed. There will be more efficiency and less costs in the international scenario and therefore the effect is stronger. The total amount of public energy subsidies will go down in both scenarios, therefore the effect is positive.

Dimension	Component	Indicator	National scenario	International scenario
Regulation & governance	Governance	Number of electricity system regulators	-	++
		Permit procedures	+	+
		Provision of priority grid access to renewable energy	0	0
		Responsibilities	-	++
	Trade & regional interconnectivity	Amount of transnational electricity trading	+	++
		International cooperation	-	++
		Total interconnection capacity	0	++
	Competition & markets	Electricity market design	0	+
		Market share of largest three electricity suppliers	+	+
		Renewable energy subsidy	0	++

TABLE 47: ENERGY SECURITY EFFECTS FOR REGULATION & GOVERNANCE

4.4 Conclusion

In this chapter, the comprehensive energy security analysis is carried out twice: once for the national scenario and once for the international scenario. These scenarios describe the situation in which 30 GW wind energy can develop. Both scenarios are compared to a benchmark, which is based on the situation as described in the NEV2016. Both the national scenario and the international scenario show that 30 GW offshore wind energy will have a positive impact on the comprehensive energy security effects, compared to the benchmark situation. The international scenario has more positive effects than the national scenario, and is therefore better than the national scenario.

In the next chapter, it is discussed what the implications of these results are for policies, stakeholders and other countries in the North Sea region.

5. Implications from the comprehensive energy security analysis

The hypothetical step from around 11.5 GW offshore wind energy to 30 GW is a very large increase in offshore wind energy for the Netherlands. It creates an oversupply electricity. At times, there will be a large oversupply in electricity. The supply of electricity will become more variable and this will result in a more variable price. Congestion problems will start to play a big role after 2025, even without the extra developments after 2030. This large increase in offshore wind energy will make that even more. Chapter 4 shows that large-scale offshore wind development can have positive and negative effects in the energy system. This will have implications for stakeholders and interest groups. These implications are discussed in this chapter and based on chapter 4. 5.1 discusses the policy implications. 5.2 discusses the implications for stakeholders. 5.3 discusses the implications for other North Sea countries and surrounding countries. The implications are highlighted and an elaboration on the implication follows.

5.1 Policy implications

The Ministry of Economic Affairs should shift from a project level view to a more integrated system level view

The focus should shift from a short-term, where only a few projects are being done, to a view of the desired system towards 2050. The view of the desired system should define the different elements of the system and their functions and it should include goals and targets. The view should include the decisions on the technical elements of the system: if it includes storage, electrification, power-to-gas, power-to-heat, an offshore grid etc. Technical elements can be combined, but they influence each other's importance: when there is energy storage, there is less need for interconnections and vice versa, but they can both be implemented. The integrated system perspective can create more efficient investments, and reduce overinvestments (Haesen & Leun, 2017). For example: high interconnection capacity and a lot of storage at the same time makes it harder to make a return on all investments. It should also include the role of different actors: the government, energy companies, grid operators and consumers. It should be clear what the responsibilities will be for each actor in 2050, so they can take this into account. This does not mean that the government should lay out every detail of the future energy system. It means that the government should nudge in one or a couple of directions not leave everything to the market, but also not working everything out into detail. Not everything should be worked out into detail, because not everything is certain for this. For example, innovations could take a different role than expected and become more, or less important.

A timely signal from the government for a clear roll-out of offshore wind in this period is needed

The clear roll-out of the projects so far and the clear vision of the government in the Energy Agreement for Sustainable Growth, Energy Report, and Energy Agenda, should continue for the years 2030-2050. This will increase the security in the market and less investment risks for the stakeholders. It will reduce the cost price of offshore wind, because it will increase the demand for the products and services. This means that the companies can supply their products more continuous, and this results in better production methods and more efficiency. This increases the investments in the Dutch offshore sector and industry. This increases the attractiveness of the business climate for companies, which results in more companies that have production facilities in the Netherlands (TKI Wind op Zee, 2013). This increases the employment opportunities and gives an economic boost in the regions where this develops.

A more flexible energy system should be created

Grid congestion and inflexible power generation will be a big problem. It will already be a problem after 2025. These problems will increase rapidly when the step from 11 GW to 30 GW will be made. At times that there is a lot of wind energy, a lot of electricity comes to the grid onshore. The capacity of the grid onshore needs to be strengthened, to facilitate transportation to the consumers of that electricity. Reinforcement of the onshore grid will bring resistance from the population. The Netherlands is densely populated. Reinforcement of the grid in densely populated areas increases "not in my backyard" (NIMBY) feelings among citizens. This can hinder the grid extensions. Another problem arises when the demand is low and the supply is high: the electricity price drops. When the demand is high and the supply is low, the price peaks. This results in variability in electricity prices. This increases when the offshore wind energy generation capacity increases, because of the intermittent source: wind, an inflexible power generation source. The focus needs to increase on technologies that create a more flexible energy system and that creates a more stable power supply. These technologies are: energy storage, electrification, power-to-X, and demand –response technologies. This will increase the flexibility of the system, because it can store energy in times that there is an oversupply of electricity, or it increases the use of electricity when there is a lot of supply. In times that there is not enough energy production, it can produce from the energy storage or from the power-to-X, or the demand can decrease. This will result in a more balanced system, which results in more stable electricity prices. This will result in that the electricity prices will not be too low or too high. This will make the system more affordable for the consumers and the investors can still get a return on their investments. When power-to-X, electrification, and energy storage is developed close to where the wind power comes to shore, is will reduce the needed grid investments, because there less electricity is put on the inland grid.

The Ministry of Economic Affairs should increase international cooperation

This is necessary to create a European roll-out of wind farms. To create efficiencies and cost price reductions, a roll-out should be on a European level. Planning when to tender and construct wind farms should be planned on a European level, to create more efficiencies and be more competitive to other regions in the world. Most companies operate international, so then they can spread out the costs, resulting in lower cost per project.

International cooperation is also important when developing an offshore grid. Developing an integrated and extensive offshore grid could bring cost reductions, security of supply, a more stable supply and demand, and less grid congestions onshore. The energy systems in the different countries that are connected to the offshore grid need to be harmonized. The distribution of the costs and benefits of constructing such a system needs to be organized. The organization of such a grid, who controls it, should be clear. There could be a special offshore grid TSO, or a cooperation between the TSOs of the participating countries.

Subsidy schemes, regulatory schemes, legislation, and rules and regulations should be harmonized between countries

Developing offshore wind energy on a European scale and developing international wind farms is not possible without harmonizing the system. It is important to decide on the distribution of the costs and the benefits of multinational offshore wind parks. Rules and regulations, subsidy schemes, and legislation need to be harmonized between the participating countries, to create a fair distribution. It should also become clear, for which country the emission reduction counts, if it is generated in a multinational windfarm. There are currently no policies for this, and it is important for countries to know, before developing windfarms together.

Measures to prevent negative impacts on nature and ecology should be taken

Constructing large-scale offshore wind will also have a large impact on the ecology in the North Sea. Noise is a big problem in the construction phase. Especially sea mammals suffer from too much noise. It is expected that innovation will reduce the noise during the construction. In the operational phase birds and bats can collide with wind turbines. Mitigating measures can be taken, but the effects are very uncertain. More research is necessary for this. Mitigating measures can also increase the construction and operational costs. The limits of the effects on ecology are already almost reached, and these limits are put in international directives. A very large increase in offshore wind cumulates these effects for ecology and these limits will be crossed. The government should focus on policies to limit these effects are needed and to take measures. Possible measures are: reduce noise limits in construction, close wind farms to other users and stimulate nature recovery under water, increase the distance between wind turbines for less collisions with birds, stop wind power production temporarily when birds are migrating through the windfarm, compensate by developing and protecting breeding grounds (Schild, 2017). These measures will increase the costs of offshore wind energy.

5.2 Implications for stakeholders

5.2.1 The potential economic implications of 30 GW offshore wind energy in 2050

To determine potential economic and operational benefits and costs of 30 GW offshore wind energy in the Netherlands towards 2050, an overview is given of the current state of the sector in the Netherlands and the expected developments in de offshore wind energy sector. The potential economic implications that are a result of these developments are described below.

Other North Sea users will be affected by the space that large-scale development of offshore wind needs

To construct 30 GW wind energy, more areas are necessary than the currently designated wind energy areas. Choosing suitable areas is difficult. Building in shallow waters, close to shore is economically more attractive than building far offshore. Far from the shore, the water is deeper, cables need to be longer, and there are longer shipping and flying times to the wind farms. These make developing the wind farms further offshore less attractive, due to higher costs. However, there is more space available and more wind further offshore. Large-scale offshore wind development might affect the other users of the North Sea. If wind farm areas are closed to other users like fishery, shippers, and sand extractors, and are located in fishing, sand extraction, or shipping areas (Van der Putten, 2017; Van Zuijlen, 2017), these sectors need to migrate to other areas. These areas can be less suitable for their activities, and this can have a negative economic impact in these sectors.

The LCOE of offshore wind energy needs to decrease

It is expected that wind turbines will increase in size to a rotor diameter of 250 m and increase in capacity to about 20 MW. The foundations are also developing, to make it able to construct wind farms in deeper waters. Currently, most of the time the foundation type is the monopile. Further offshore jacket foundations or floating structures can be used. 30 GW wind energy and the need for the development in deeper waters can increase the speed of these developments. These elements influence the LCOE. Factors that determine this need to be optimized. This can be done by bringing the costs down, CAPEX and OPEX, or by increasing the energy production (Ostachowicz et al., 2016). Turbine capacity, structures, and site conditions determine some of these costs. A large-scale roll-out of offshore wind energy reduces the cost price of offshore wind, because it will increase the demand for the products and services. Companies can supply their products more continuous, and this results in better production methods and more efficiency (De Brouwer, 2017; Elsevier van Griethuysen, 2017; Harder, 2017; Van Bergen, 2017; Van Hövell, 2017).

30 GW offshore wind energy will increase economic activities in the offshore sector in the Netherlands

A larger market will increase the business climate for companies, which will result in more companies that have production facilities in the Netherlands. It will bring more economic activities and employment opportunities. Within the wind turbine generator OEMs there are two main market leaders: Siemens and MHI Vestas in the second place. After this, there are much smaller original equipment manufacturers in the top 5: Senvion, Adwen, and GE ALSTOM. None of these companies have manufacturing facilities in the Netherlands. An increase in wind energy development could bring manufacturing facilities to the Netherlands, and create more economic activity in the Netherlands, resulting in more employment opportunities (TKI Wind op Zee, 2015).

30 GW offshore wind energy will increase investments in the sector and stimulate technological innovation

Large-scale development of offshore wind increases the technological innovation, because there is more willingness to invest in research by the offshore sector and there is a stronger offshore sector. Without a strong offshore sector close to where they are located, it might be difficult for the research institutes to test new technologies (TKI Wind op Zee, 2013).

Most Dutch offshore companies are also internationally active. An international scenario is better for their economic activities than a national scenario. Creating a stronger offshore market in the Netherlands, will result in more opportunities for Dutch companies to improve their track record. It is easier for companies to do that in a national setting, than in an international setting. If companies have a good track record it increases their chances of exporting their products of services. This is also important for the development and growth of small companies, because they don't have a track record yet. Usually, small companies start in national projects, to create a track record of projects and gain experience, before they can go to foreign projects, because it is easier to participate in national innovation programs than foreign programs. Innovation programs are in most countries nationally oriented. This may result in that it will be very difficult for them to participate in foreign innovation programs (TKI Wind op Zee, 2013).

5.2.2 The winners & losers of 30 GW offshore wind energy

When 30 GW offshore wind energy is installed, there will be some clear winners and parties that will face challenges. Some stakeholders experience both positive and negative effects. The step from around 11.5 GW offshore wind energy to 30 GW creates an enormous oversupply in generation capacity. At times, there will be a large oversupply in electricity. The affected stakeholders and interest groups are described below.

The winners in the scenarios are:

- Wind farm developers: A clear target of wind energy capacity will increase the cost reductions of offshore wind development. This is an advantage for developers, because their investments per MW will go down.
- Offshore wind industry: A clear target of wind energy capacity will increase the production and the technological innovation in the offshore wind industry. This means that there will be more economic activities, which results in more revenues and employment opportunities in the industry. In an international scenario, this will be more than in the national scenario, because then they can get business from international projects, resulting in more economic activities.
- Dutch industry: The Dutch industry will profit from the development of large-scale offshore wind energy when the price for electricity will go down, because the marginal price for wind energy is low. This will contribute to the electrification of production processes. In the national scenario, the electricity prices will be lower, so they will profit more in the international scenario from wind energy. Their export opportunities that decrease are out of the scope of this research.
- Sea ports: Economic activities will be increased in sea ports. It is very likely that components of the wind farms will be developed in the ports. This will attract more companies and investments to the sea ports, maybe even a wind turbine manufacturer, such as Siemens or Vestas. During the O&M phase the sea ports will also profit from offshore wind, because these companies will also be located in the ports. Overall, the ship movements will increase. In an international scenario, this will be more than in the national scenario, because then the companies in the ports can get business from international projects, resulting in more economic activities in the port area.
- Electricity users: They will profit from the decrease in the electricity price. In a national scenario, the price will be lower than in the international scenario. However, frequency of interruption of supply will increase more in the national scenario than in the international scenario.

The parties that face challenges are:

- Grid operators: the development of 30 GW offshore wind energy leads to a more variable electricity supply. This will decrease the predictability of the power supply and therefore the balancing costs will be higher. A more flexible electricity grid is necessary and therefore grid investments are necessary. The investments in the grid are very high, more than billions of euros are necessary. At certain points the grid needs to be expanded and the connection from the wind farms to the grid is also the responsibility of the grid operator. This can be a difficult task, with NIMBY effects. In an international setting the interconnection capacity will also increase, and the length of the cables to shore will be longer. These elements will result in high investment costs for the electricity grid in the Netherlands. However, they have also a positive effect: they do profit from a more extended grid.

- Fishing & aqua culture: The development of 30 GW offshore wind energy requires a lot of space in the Dutch EEZ. If the wind farms are closed to the fishing & aqua culture industry, there is less space for them on the North Sea. If the wind farms are open to them, the risk of causing a collision and damage is high. This will result in high costs for the fishing and aqua culture industry.
- Other North Sea users: sand and shell extraction, military defence. More areas are necessary for the development of wind farms. It is possible that these sectors need to adapt their reserved locations, but this is still uncertain.

There are also some stakeholders that can be both winners and losers, depending on how they can make changes and adapt to the situation. Within the same sector: some stakeholders can be winners and some losers. These are:

- Oil & gas sector: Lower energy prices and low electricity prices will result in less demand for oil and gas. The result is less revenues for the oil and gas sector. However, electrification of gas platforms in the North Sea by wind farms is an opportunity to make the production process of gas cleaner. The development of power-to-gas can also give a boost to the oil and gas sector, but overall, the oil and gas sector will be disadvantaged.
- Energy companies can also be a winner and a loser. The low electricity prices will create lower margins on the electricity generation for the energy companies. This can create investment risks for the energy companies. However, due to electrification and interconnection the demand for electricity will increase and this is an advantage for the energy companies

There are some sectors that are nor winners nor losers, or only indirect affected, but they are still interested in, and/or affected by the development of large-scale offshore wind in the Dutch EEZ. These are the following stakeholders and sectors:

- Governmental organizations: The governmental organizations are considered as a winner, because the number of subsidies for energy goes down. Another advantage for the government is that offshore wind also contributes to a sustainable energy system, which contributes to the CO_2-reduction targets. However, investments in the electricity grid will increase.
- Environment: can be positively and negatively affected. It can benefit from wind parks that are closed for any other activities, such as fishing, and stimulation of the recovery of nature. It also benefits, because there will be a reduction in CO_2-emissions. Increasing offshore wind energy will contribute to a cleaner energy supply in the Netherlands. This will lead to less CO_2-emissions from the energy system. This will contribute to the reduction of climate change. Ecology can suffer from the construction of wind farms. In the construction phase, there is a lot of noise, which affects sea mammals. In the operational phase, it is dangerous for birds and bats.
- R&D and education: A clear roll-out of large-scale wind energy creates a signal in the market to develop innovative solutions to problems and to create more efficient techniques. Therefore, the R&D budgets and efforts will increase. Education in wind energy development will increase, because the amount of people that design, construct, operate and maintain wind farms need to increase, when the sector increases. In an international scenario, this will be more than in the national scenario, because research institutes will better cooperate and international subsidies will become available.

5.3 Implications for other countries in the North Sea region

The EC wants to cut the EU's greenhouse gas emissions to 80% in 2050 compared to the levels in 1990 and all sectors should contribute to this target. The power generation and distribution sector should reduce to almost 100%. This will result in a decarbonized energy system. The EC created a roadmap for the energy transition. This roadmap explores different routes to get to the greenhouse gas reductions target while increasing the competitiveness of the EU and increasing the security of supply in the energy system. Investments in renewable energy technologies, energy efficiency, and the electricity grid need to be made to achieve these targets (European Commission, 2017a). 30 GW offshore wind energy in the Dutch EEZ contributes these goals. If there is enough interconnection capacity, this can contribute to sustainability targets of multiple countries.

30 GW wind increases electricity export

Other countries can profit from an oversupply of energy in the Netherlands. A sufficient part of the North Sea belongs to the Dutch EEZ. The Dutch EEZ in the North Sea is relative large compared to some other countries. France and Belgium have a relative small part of the North Sea. Therefore, they can produce less offshore wind energy. When the Netherlands has a lot of wind energy, this could be exported to France and Belgium (Aksan, 2017).

30 GW wind will impact the grid and policies of surrounding countries

The Dutch electricity grid is integrated in the European electricity grid via interconnectors. This means that if the Netherlands connects 30 GW wind energy capacity to the grid, it will impact the electricity grid of surrounding countries as well. Other North Sea countries are developing wind farms also. These developments are also of influence on the Dutch electricity grid. These North Sea countries also cooperate with each other, to develop a more efficient energy system. One of these efforts to cooperate is the signing of the MoU by 10 countries, to enhance their cooperation on renewable energy, and in particular the cooperation on offshore wind energy (WindEurope, 2016). Due to the large increase in wind energy generation capacity cooperation between countries should increase, to overcome the hurdles that large-scale offshore wind energy cause. The negative effects that are indicated in the comprehensive energy security analysis are more negative if all North Sea countries rapidly increase their offshore wind energy capacity and most of these countries face the same problems. For example: when there is a lot of wind on the North Sea, all countries produce a lot of electricity from wind energy. The price could become very low, and there could be an oversupply of electricity. The development of wind farms far offshore will increase the demand for an offshore grid or for the possibilities to connect the wind farm of one country to another country's shore to create more efficiency. Subsidy systems, regulations, and legislations should be adapted and harmonized between countries to facilitate this.

As described in 5.1, new policies and changes in policies are necessary when offshore wind energy is developed in an international setting and when multinational windfarms and an international offshore grid are constructed. This affects the policies of surrounding countries as well, because they also need to participate in the harmonization of the energy system in terms of subsidy schemes, policies, regulations, and legislation. This will require intensive discussions between the North Sea countries. The distribution of costs and benefits of multinational windfarms and an offshore grid needs to be negotiated. These can be about: investments, contribution to emission reduction targets, amount of subsidy per country.

5.4 Conclusion chapter 5

The hypothetical step from around 11.5 GW offshore wind energy to 30 GW is a very large increase in offshore wind energy for the Netherlands and it will create an oversupply in electricity. This chapter gave an overview of the implications for policies, stakeholders, and other North Sea countries. In this paragraph, the comprehensive energy security effects are described and their implications are given.

The following energy security effects are the results of 30 GW offshore wind energy for the Netherlands:

A clear roll-out of wind energy for leads to: innovations, cost reductions, less subsidies, and creates employment opportunities. A high increase in offshore wind energy generation capacity increases energy independence and creates a sustainable energy system. Increasing offshore wind energy has a negative impact on the available space for other North Sea users and has a negative impact on nature and ecology. Increasing offshore wind energy makes the energy supply in the Netherlands less flexible and reliable, resulting in: more congestion, high price volatility, high balancing costs, and a higher need for interconnections and energy storage. The investment risks increase as a result of high price volatility and high upfront costs of wind farms, but they decrease as a result of cost reductions. The oversupply in electricity increases congestion, electricity exports, energy storage, electrification, and grid investments. Large-scale offshore wind energy development increases the programme responsible parties and creates more competition in the electricity market.

The most important policy implications are:

- The focus of the Ministry should shift from a project level to an integrated system level, to make decisions on the technical elements of the system, create more efficient investments and reduce overinvestments. It should also include the role and responsibilities of different actors in the system.
- A timely signal from the government for a clear roll-out of offshore wind in this period is needed, to increase production security in the market and increase investments in the Dutch offshore sector. This will result in a better business climate and more employment opportunities.
- The Ministry of Economic Affairs should focus on creating a flexible energy system, to reduce the problems with grid congestion, inflexible power generation, and the high variability in electricity prices.
- The Ministry of Economic Affairs should increase international cooperation, to create a more efficient system and reduce costs.
- Subsidy schemes, regulatory schemes, legislation, and rules and regulations should be harmonized between countries, to facilitate the development of multinational wind farms and an offshore grid.
- The Ministry of Economic Affairs should take measures to prevent negative impacts on nature and ecology

The most important implications for stakeholders are:

- Other North Sea users will be affected by the space that large-scale development of offshore wind needs, they might have to migrate to other, less suitable, areas for their activities.
- 30 GW offshore wind energy will increase economic activities in the offshore sector in the Netherlands, resulting in more employment opportunities.
- 30 GW offshore wind energy will increase investments in the sector and stimulate technological innovation, as the result of a clear roll-out and security in the market.

The most important implications for countries in the North Sea region are:

- 30 GW wind increases electricity export from the Netherlands.
- 30 GW wind will impact the grid and policies of surrounding countries and international cooperation is needed to create a more efficient system.

Stakeholders can be winners or losers, or both, depending on their abilities to change. Winners are: wind farm developers, offshore wind industry, Dutch industry, sea ports and electricity users. Losers in the scenarios are: grid operators and fishing & aqua culture, and other North Sea users. Stakeholders that can be both winners & losers, depending on their ability to change their business plans are the oil & gas sector and energy companies. Interest groups that can be positively or negatively indirect affected are: governmental organizations, the environment, and R&D & education.

6.
Discussion & reflection

This chapter reflects and discusses the research. Many choices have been made in all phases of the research process. In this chapter, the reflections on the most important decisions are presented and the limitations of the research are presented. Paragraph 6.1 reflects on the theory, paragraph 6.2 reflects on the used methods, and paragraph 6.3 discusses on the results.

6.1 Reflection on theory

Energy security is a term that can be defined in many different ways. Many studies show different definitions of energy security. The way in which the term energy security is interpreted in this study, has had a big influence on the research approach of this study. This study uses the term of energy security in a multi-dimensional way, based on the studies of Sovacool & Mukherjee (2011) and Sovacool et al. (2011). Their dimensions were the starting point for this study. Their dimensions are: availability, affordability, technology development & efficiency, environmental & social sustainability, and regulation and governance. These dimensions were leading for the construction of the framework. Taking on another definition of the term energy security, could have led to different dimensions, and also different indicators for energy security.

In the field of renewable energy security of renewable energy limited research is conducted. Most energy security studies focus on energy systems where fossil fuels have the largest share in the energy sources. In these studies, indicators have a focus on fossil fuels, in terms of import, export, prices, reserve-to-production ratios, and so on (Kruyt et al., 2009; Sovacool et al., 2011; Sovacool & Mukherjee, 2011). The literature on energy security was not sufficient to answer the research questions, because it mainly focuses on energy systems where oil and gas play a big role, not on systems where renewable energy sources play a big role. There is a difference in requirements between these systems, and the indicators are not sufficient to investigate the requirements for renewable energy sources. These differences are in: infrastructure, possibilities for storage, and import and export to other countries. Indicators for the broader system in which the energy transition takes place are necessary, and not only the energy sector. To this end, the system analysis theories are used. This study provides a new comprehensive energy security framework to measure the effects for the energy security. This is necessary, because countries are shifting more to renewable energy sources over the coming years. This study is a good addition to provide more insights in the field of renewable energy security, by providing more energy security indicators that are relevant in energy systems where more renewable energy sources are present.

The literature for the start of the system analysis is from Ho (2014), which presented the use of the PEST-tool. The system analysis provides the possibilities to have a broader look at the energy system, and the developments in a system. It provides the possibility to take into account the national context in which the changes in the energy system take place. It provides indicators that can be divided in the following sections: political, economic, social, and technological indicators.

The energy security framework of Sovacool & Mukherjee (2011) was a good start to create the comprehensive energy security framework that can be used in the field of renewable energy security. This provided a good start, with many dimensions, components, and indicators. The system analysis theory was a good addition to the energy security theory, and the framework of Sovacool & Mukherjee (2011) and the PEST analysis tool were a good combination. Most political indicators from the PEST analysis would go to the dimension of regulation & governance. Most economic indicators went to the affordability indicator. Most social indicators went to environmental & social sustainability. Most technological indicators went to technology development & efficiency.

6.2 Reflection on methods

This study is mainly a qualitative research, because it can be difficult to get exact numbers for the indicators for the period between 2030-2050. A qualitative approach allowed for these indicators to still be used. On the other hand, this makes it more difficult to give exact energy security effects and exact implications for the stakeholders and sectors involved.

A system analysis is done to create more indicators for renewable energy security. This was a good way to reflect the broader system that renewable energy generators are placed in. This broader system is divided in political, social, technological, and environmental sections in the PEST-analysis. The system analysis was more country specific and sector specific for the offshore sector and the Netherlands.

The scenarios are a good way to investigate the comprehensive energy security effects. However, along the way it became clear that the national scenario would be less relevant, due to the stakeholders that were mostly positive about the international scenario. Therefore, other scenarios might have been more relevant. However, this scenario is still used and important for the Netherlands, due to the fact that at this moment and for the foreseeable future most policies, subsidies, and development plans for offshore wind are nationally coordinated. There are initiatives, such as the MoU, to develop offshore wind in a more international setting, but it is not certain that there will be a turning point to international development. Therefore, the national provides insights in the possibilities and hurdles of large-scale offshore wind when this turning point will not appear. By having these insights, the policy implications become clearer and the government can better prepare for the consequences.

Another argument for the national scenario is that the EEZ is a sufficient part of the North Sea. Without any interference of other countries, the Netherlands can develop 30 GW offshore wind energy. It is good to know what this will mean, if the Netherlands develops large-scale offshore wind energy without other countries involved.

During the analysis of the interviews it became clear that there should be some additional indicators in the framework. They should be related to the education and training of people that can work in the offshore wind industry. The framework already shows the effect on employment, but the amount of studies and training that is related to offshore wind energy or other renewable energy sources will also be changed when there is a lot of offshore wind energy developed in the Netherlands. There should also be more indicators related to the effects on nature and ecology. Constructing windfarms creates a lot of noise and operating windfarms are dangerous for birds and bats. These elements are not in the current framework, but do have a huge influence on the development of offshore windfarms, due to limiting directives. Another indicator that would be relevant is the cost of financing projects. In a more mature market, this would go down, because banks and other financial institutions have more thrust in the market. The last indicator that would be interesting to add is the share of renewables per source; this could show the impact of large-scale offshore wind on solar energy and vice versa. This could be interesting to see the impact on other renewable energy sectors.

The method for data gathering to measure the comprehensive energy security effects was a literature research and conducting interviews. The wind industry and the energy industry are undergoing rapid developments. This resulted in difficulties in finding reliable data. Retrieving reliable data for the indicators for the period 2030-2050 from literature could sometimes be difficult. There was not always up-to-date data available. Conducting the interviews was a good way to complete the necessary data. However, interviewing stakeholders is not always completely reliable. A lot of experts were from companies, and they can have a more biased view than others. The stakeholders might not be objective and biased, or try to lobby for certain policies from the Ministry of Economic Affairs. Asking multiple stakeholders the same questions and combine the answers from the interviews with the answers from the literature was the strategy to create reliable and more objective answers.

6.3 Discussion of results

This paragraph discusses the choices that influenced the results. The implications of the results are discussed in chapter 5.

The results of the comprehensive energy security analysis are influenced by the chosen scenarios and by the chosen benchmark. The benchmark is used to compare the effects of wind energy on an indicator to the situation without all that extra wind energy generation capacity, and this is done twice: once in a national setting once in an international setting. The benchmark data would stay the same. The effects are divided in ranges, from very negative to very positive, see appendix X. The neutral, or no, effect would be the benchmark.

The benchmark is mostly based on the numbers in the NEV2016. The numbers from the NEV2016 are a good prediction of what might happen in the Dutch energy sector in the future, based on current and expected policies. It is constructed by ECN, PBL, CBS, and RVO. However, the NEV2016 did not have many predictions until 2050, but until 2035. Therefore, the numbers of the situation of the year 2035 were used as a benchmark. The NEV2016 did not have data for all indicators. When necessary, additional literature sources were consulted. The data for the benchmark has a strong influence on the ranges and the results. These might be different when choosing a different benchmark. However, the NEV2016 is a good source as a benchmark, it provides a lot of data and it is constructed by research institutions that are experienced in predicting trends in sectors in the Netherlands.

In this research, the narrow definition of security of supply is used: the relation between supply and demand. Then, the indicators are related to demand and supply of energy and electricity. This had an impact on the result of the effects on security of supply. When the imports and exports were taken into account, or the dependency on other countries, this might have been different. These indicators are represented in the component of dependency and the component of trade & regional interconnectivity. Therefore, they were not in the security of supply component.

Most effects are positive, especially in the international scenario. However, there are a lot of negative effects in the dimension affordability and especially in the components price stability and affordability. This is the result of the high investment risks, variability in the price, and high costs. There are high upfront costs and low operational costs, this results in a high investment risk. Next to this, a lot of changes need to be made into the energy system, to facilitate the transportation and use of this oversupply in electricity. The costs for grid expansion are very high, so this is also a risk. The variability in the price will also increase, due to the inflexible supply of offshore wind power. It is very hard to predict the price/MWh that a developer will get, which increases the investment risk. Also, the balancing costs will increase. Renewable energy sources have low operational costs and they are low in the merit order. When there is a large increase, the price might go down, so the margins for the developers are smaller. This will result in a higher investment risk.

A limitation of this framework is that the indicators all have the same level of importance, and this limits the results, because not all indicators are equally important. Therefore, the results of the energy security effects are equally important for all indicators. This can have a distorting effect on the result. However, all of these indicators are important in the comprehensive energy security assessment, and therefore the framework is still very useful.

7.
Conclusions & recommendations

In this chapter, the conclusions from the research are drawn and the recommendations will be made. This is done by looking at the results of the sub questions that are found along the way and finally answering the main research question. The structure in this chapter will follow the structure of this report. It will start with a short recap of the research problem. In the end recommendations are made to the Ministry of Economic Affairs and for future research.

7.1 Recap of the research problem

The Ministry of Economic Affairs is looking at the possibilities to extend the policy for the development of offshore wind energy until the year 2050. This means that there will be around 30 GW installed capacity for offshore wind energy in 2050. However, the effects of 30 GW offshore wind energy capacity in the Netherlands are still unknown.

The Ministry of Economic Affairs wants to know what the potential additional economic benefits are and what the potential costs are. On the more strategic implications the Ministry wants to know the export potential of electricity to countries in the region and whether countries in the region have similar plans.

7.2 Comprehensive energy security assessment framework

A new framework is created to assess the strategic and economic implications of large-scale renewable energy projects. Studies of Sovacool & Mukherjee (2011), Sovacool et al. (2011), and Kruyt et al. (2009) are used as a starting point to develop the new framework. These theories about energy security are not comprehensive enough to answer this question, because they mainly focus on energy systems with mainly fossil fuels as energy sources.

This new framework is better than the previous frameworks, because the previous frameworks focused on oil and gas systems. However, oil and gas systems are very different from systems were a lot of renewable energy is present: other infrastructure e.g. pipeline versus transmission grid, the possibilities for storage are different e.g. easy storage versus expensive storage, and the dependencies between countries changes. So, there is a new framework necessary to show the energy security in systems with a lot of renewable energy, and this study provides that.

Relevant indicators from the previous studies are used to create a new comprehensive energy security assessment framework. A system analysis is done to retrieve additional indicators that are relevant for the framework and to give a broader look at the system in which it is constructed. It also shows the relations between the different components in the system. The indicators from energy security and system analysis are combined into a new comprehensive energy security assessment framework, see appendix V. This new framework can investigate the energy security effects in terms of political, economic, environmental, and technical effects of 30 GW wind energy in the Netherlands. The comprehensive energy security assessment framework consists of five dimensions: availability, affordability, technology development and efficiency, environmental & social sustainability, and regulation & governance. These have 17 components and 53 indicators.

7.3 Conclusion

In this paragraph, the research question is answered. First, the conclusions are given. After this, the effects on the indicators, components, and dimensions are discussed. The main research question for this study was:

What are the comprehensive energy security effects of 30 GW offshore wind energy for the Netherlands in 2050?

Conclusions:

- A clear roll-out of wind energy for leads to: innovations, cost reductions, less subsidies, and creates employment opportunities;
- A high increase in offshore wind energy generation capacity increases energy independence and creates a sustainable energy system;
- Increasing offshore wind energy has a negative impact on the available space for other North Sea users and has a negative impact on nature and ecology;
- Increasing offshore wind energy makes the energy supply in the Netherlands less flexible and reliable, resulting in: more congestion, high price volatility, high balancing costs, and a higher need for interconnections and energy storage;
- The investment risks increase as a result of high price volatility and high upfront costs of wind farms, but they decrease as a result of cost reductions;
- The oversupply in electricity increases congestion, electricity exports, energy storage, electrification, and grid investments;
- Large-scale offshore wind energy development increases the programme responsible parties and creates more competition in the electricity market.

Offshore wind can be realized under different conditions. It can be realized by the Netherlands alone, or in a multilateral and international setting. To this end, two scenarios are developed: a national interest scenario and an international scenario. These scenarios are used to explore comprehensive energy security implications of 30 GW offshore wind energy in different contexts.

Overall, the comprehensive energy security effects are more positively affected in the international scenario than in the national scenario. The effects in the international scenario are also better on the level of dimensions than in the national scenario. On the level of components and indicators, the national scenario sometimes scores better than the international scenario.

The effects in the dimension availability: Security of supply is better in the international scenario. The increase in generation capacity contributes positively in both scenarios, but there is more demand in the international scenario as a result of exports. This is good, because the large inflexible supply can cause congestion. A larger demand is then needed. In an in international scenario there is more dependence on other countries. In a national scenario, the supply is more domestic: less dependence on other countries, but also fewer abilities to import energy when necessary. This can stimulate the developments in energy storage. Therefore, both scenarios contribute in other ways to the security of supply. High demand is better to reduce the congestion on the grid, which can happen when there is a lot of wind energy brought to the grid. The effects on production are positive, because the availability of renewable energy resources will increase. The wind conditions are better fare offshore than close to shore: the wind speed is higher and more wind hours in a year. A decrease in fossil fuels and an increase in renewable energy production have a positive effect on dependency. It is more positive in a national setting, where there is less import from other countries. The effects on diversification are positive. The effect on geographic dispersion is positive, because the wind farms are better spread out over the Dutch EEZ. The diversification of ownership of energy companies is better in an international scenario, because there is a more open and international market, so there are also international owners of energy companies. Overall, for availability the effects on energy security are better in the international scenario.

The effects in the dimension affordability: the effects on price stability are negative in the national scenario: the CO_2 prices are low, the volatility of the electricity price increases, and the fuel prices increase. Low CO_2 prices are not creating the desired effect of a more sustainable energy system and efficiency. The price stability component is better in the international scenario, because there is less volatility in the electricity price, because there is more interconnection that creates a more stable price. It is also better, because the end-use energy prices by fuel are lower, making energy more affordable. More electricity export results in higher electricity prices in the international scenario. High volatility in the prices increases the investment risk. Variable electricity prices result in less investments in renewable energies, because the margins are uncertain, resulting in a higher investment risk. However, the end-use prices by fuel are positively affected; they decrease, resulting in cheaper energy price, and making them too expensive for the market. Effects on access & equity are positive and equal for both scenarios. A more integrated grid results in a better grid connection in the international scenario. Due to lower prices, the rate of electrification is better in the national scenario. Fewer waves results in better site conditions in the national scenario. Effects on the component affordability: the effects on the balancing costs are negative, because the supply of electricity will get more variable. The effects on construction costs are positive, because of the predicted cost reductions. The effects on investment risk are more negative in the international scenario, because there are more investments in the grid necessary. Grid and windfarm investments require high upfront costs. The effect on the marginal costs of electricity power generation are the same, because in both scenarios it is for wind energy almost zero and the amount of wind energy that is brought to the grid is the same for both scenarios. Effects on transmission costs are negative, because the costs for grid expansion are very high. Overall, for affordability the effects on energy security are better in the international scenario.

The effects on the dimension technology development & efficiency: effects on innovation & research are positive, because a clear roll-out creates more budgets for innovation and research, which results in more efficiency and innovation. There is a positive effect on the energy intensity. Innovations create more efficiency. More innovations are in the international scenario, so this is more positive. More variability in supply has a negative effect on safety and reliability. This is better in the international scenario, because interconnections facilitate a more stable supply. There is also a negative effect on resilience, as a result of more variability in supply. An increase in production in the market has a positive effect on investment an employment. Overall, for technology development & efficiency the effects on energy security are better in the international scenario.

Effects on environmental & social sustainability: The effects on land/water use are positive in the international scenario, because areas far-offshore are included in the available areas, resulting in more available areas in the international scenario. In both scenarios, it affects other North Sea users and nature and ecology, because it requires a lot of space and it can affect the habitat of species. In the national scenario, there are less available areas, so the effects are negative here. Increasing wind energy reduces the CO_2 emissions and this has a positive effect on the climate change indicator.

Effects on regulation and governance: In an international scenario, there will be more regulation on a European level. In the national scenario, this will stay the same. There will be more permits in both scenarios. Priority access will not be necessary when large-scale wind energy is constructed. Effects on the responsibilities will be negative in the national scenario and positive in the international scenario, because there are more programme responsible parties in both scenarios. The increase is higher in the international scenario, because international parties are allowed in the market also. Effects on trade & regional interconnectivity will be positive, because there will be an increase in export of electricity. The effects on competition and markets will be positive, because there will be more players in the market, which results in more competition. Less subsidies are necessary, because there are more cost reductions in the international scenario. This leads to a more positive effect in the international scenario. Overall, the comprehensive energy security effects are positive.

7.4 Recommendations for the Ministry of Economic Affairs

The recommendations for the Ministry of Economic Affairs result from the policy implications that are discussed in chapter 5. The recommendations are given first and an elaboration on the recommendations follows.

The Ministry of Economic Affairs should:

- Create an integrated system view, to create a more flexible energy system that can better match supply and demand and reduce overinvestments and underinvestments;
- Give a timely signal for a clear roll-out of wind energy to decrease investment risks for stakeholders, create cost reductions, and increase employment opportunities in the Netherlands;
- Stimulate international cooperation to harmonize rules and regulations and create efficiencies on a European level;
- Take measures to prevent negative impacts on nature and ecology.

The focus of the Ministry of Economic Affairs should be shifting from a project level to a more integrated system level. The view should include decisions on the technical elements of the system to make it more flexible, and on the responsibilities within the system. This does not mean that the government should lay out every detail of the future energy system, because some factors are still uncertain, but the government should nudge actors in a certain direction. These technical elements are related to making the system more flexible, through grid extension and better match supply and demand. This will help reduce the problems with grid congestions and mismatches in supply and demand. Technical elements that are important are: energy storage, electrification, power-to-X, and demand-response technologies. The Ministry should keep in mind that these elements can be combined, but they influence each other's importance: when there is energy storage, there is less need for interconnections and vice versa, but they can be both implemented. The integrated system perspective can create more efficient investments, and reduce overinvestments. For example: a lot of interconnections and a lot of storage at the same time make it harder to make a return on all investments. This also means, that in a national scenario, energy storage might be an attractive option, due to little interconnection capacity.

A timely signal from the government for a clear roll-out of offshore wind in this period is needed. This increases the security in the market and decreases the investment risks for stakeholders, resulting in more investments in the offshore wind sector and cost reductions for offshore wind energy. Also, this increases the employment opportunities and gives an economic boost in the regions where it is developed.

Ministry of Economic Affairs should stimulate more international cooperation between the North Sea countries to make a European roll-out of offshore wind farms possible. This could create more efficiency on a European level. Measures need to be taken to facilitate this: energy systems of the North Sea countries that are connected to the offshore grid need to be harmonized, distribution of the costs and benefits of constructing such a system needs to be organized, subsidy schemes, regulatory schemes, legislation, and rules should be harmonized between the participating countries.

The limits for the impact on ecology are reached soon and the Ministry of Economic Affairs should take measures to prevent this. Timely announcing the reduction in noise limits for construction will increase innovations in construction technologies, because companies have enough time to invest in this and develop this. Other measures that could be taken are closing the wind farms for other sectors, and improve ecology after construction, by actively stimulating under water nature. To prevent reaching limits from the birds and bats, the government could protect more breeding grounds of birds and bats, and when there is large migration stop the turbines. Another measure to protect the birds and bats is placing the turbines further apart, but the effects of this are not yet certain.

7.5 Recommendations for future research

Recommendations can be made for future research. On the one hand, they can be made for the Ministry of Economic Affairs and the offshore industry, and on the other hand recommendations can be made to researchers in the academic field. The recommendations are given first, and an elaboration on the recommendations follows.

7.5.1 Recommendations for future research for the Ministry of Economic Affairs

The Ministry of Economic Affairs should research:

- The comprehensive energy security effects of offshore wind energy on a North-Western European level;
- The comprehensive energy security effects of offshore wind energy in a quantitative study;
- The effects of multiple combinations of shared use of offshore wind farms;
- The economic impact of offshore wind energy on other North Sea users.

The framework is used for a large-scale wind energy development in the Dutch EEZ. It could be interesting to see the comprehensive energy security effects for North-Western Europe, the North Sea countries. The framework can be used to research the comprehensive energy security effects for the North Sea countries, when large-scale offshore wind energy is developed in the North Sea. By taking the other countries into account, and especially the interactions between these countries, a better view is given on the comprehensive effects of energy security.

The research that is done in this study is a qualitative study. When more quantitative data becomes available for the period 2030-2050, it would be very interesting to use the new comprehensive energy security framework for a quantitative energy security analysis. Changes need to be made into the ranges, because some of them are now qualitative. A quantitative argumentation will better show the implications of the large-scale wind energy development. Therefore, more and/or better measures can be taken to prepare for these comprehensive energy security effects and to give them a positive effect.

More research in shared use of wind parks is necessary when there is a lot of extra offshore wind energy. 30 GW uses a lot of space, around 5,000 km^2, and this influences other sectors. By combining these functions, the negative effects might decrease. Future research is necessary, to find out which areas are suited for shared use, and which combinations have the best chances in certain areas. These combinations might differ in effect. Some areas might be better to combine wind with nature, some might be better with aquaculture, some might be better with fishing, and some might not be suitable for combinations at all.

More research should also be done in the economic impact of offshore wind energy in the North Sea on other sectors in the North Sea, to explore if they will have economic losses as the result of less available space and if so, what the size of this impact will be. If there are expected losses, it could be researched if is still beneficial to implement large-scale offshore wind energy or that these sectors can be or need to be compensated.

7.5.2 Recommendations for future research in the academic field

Recommendations for future research are:

- Develop a comprehensive energy security with weighted indicators;
- Add more indicators to the comprehensive energy security framework.

As discussed in chapter 6, the indicators all have the same level of importance. As a result, the effects all have the same level of importance. For future research, it could be very interesting to adjust the framework and give all the indicators weights. Important or crucial indicators would get a higher weight than the less important indicators. Then, the implications of the comprehensive energy security effects would become clearer and it would be easier to take measures.

Another point of discussion was that there should be some additional indicators added to the framework. For future research, the comprehensive energy security framework could be adapted by implementing the indicators that are related to education on all levels, and training of employees in the offshore sector. There should also be more indicators for nature and ecology, because during this research it became clear that this can be limiting for the development of offshore wind energy. The level of noise that is made during the construction of energy facilities and the effects on habitat of birds, sea mammals, bats, and plants are limiting. Cost of financing projects would be an interesting indicator to add to the framework, because this shows the maturity of the market and the thrust of the financial sector in the market. This also indicates the investment risks for the developers. The last indicator that would be interesting to implement in the framework would be the share of renewables per source; this could show the impact of large-scale offshore wind on solar energy and vice versa. This would show the impact of an increase in production capacity in one energy sector on other renewable energy sectors. These should be included as well.

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Appendices

Appendix I: Indicators Sovacool et al (2011).

Appendix II: Energy security indicators

Appendix II: System analysis indicators

Appendix IV: Indicators per source

Appendix V: New comprehensive energy security assessment framework

Appendix VI: Results of the comprehensive energy security analysis

Appendix VII: Interviews.

Appendix VIII: Wind Map

Appendix IX: Water depth North Sea

Appendix X: Ranges indicators

Appendix I: Indicators Sovacool et al. (2011)

Dimension	*Component*	*Indicator*
Availability	*Security of supply*	Total primary energy supply per capita
	Production	Average reserve-to-production ratio for the three primary energy fuels (coal, natural gas, and oil).
	Dependency	Self-sufficiency
	Diversification	Share of renewable energy in total primary energy supply
Affordability	*Stability*	Stability of electricity prices
	Access	% population with high quality connections to the electricity grid
	Equity	Households dependent on traditional fuels
	Affordability	Retail prices of gasoline/petrol
Technology development & efficiency	*Innovation & research*	Research intensity
	Energy efficiency	Energy intensity
	Safety & reliability	Grid efficiency
	Resilience	Energy resources and stockpiles
Environmental &social sustainability	*Land use*	Forest cover
	Water use	Water use
	Pollution	Per capita sulphur dioxide emissions
	Climate change	Per capita related carbon dioxide emissions
Regulation & governance	*Governance*	Worldwide governance rating
	Trade & regional interconnectivity	Energy exports
	Competition & markets	Per capita energy subsidies
	Information	Quality of energy information

Appendix II: Energy security indicators

Dimension	Component	Indicator
Availability	*Security of supply*	Total primary energy supply per capita Total electricity demand Annual electricity consumption per capita
	Production	Total installed electricity generation capacity
	Dependency	Self-sufficiency
	Diversification	Share of renewable energy in total primary energy supply
		Geographic dispersion of energy facilities Diversification of ownership of energy companies
Affordability	*Price stability*	End-use energy prices by fuel Electricity price volatility
	Access & equity	Rate of electrification
	Affordability	Marginal cost of electricity power generation Transmission costs for electricity
Technology development & efficiency	*Innovation & research*	Research budgets for renewable sources of energy
	Efficiency	Energy intensity
	Safety & reliability	Frequency of interruption of supply
	Resilience	Generation adequacy System adequacy
	Investment & employment	Direct employment Indirect employment Induced employment Investment in electricity transmission capacity Average rate of return on energy investments
Environmental &social sustainability	*Land / water use*	Required space Water use
	Climate change	Presence of climate change goals and targets CO_2 emissions from electricity sector
Regulation & governance	*Governance*	Number of electricity system regulators Provision of priority grid access to renewable energy
	Trade & regional interconnectivity	Amount of transnational electricity trading Total interconnection capacity
	Competition & markets	Market share of largest three electricity suppliers Total amount of annual public energy subsidies

Table 48: Energy security indicators (Sovacool & Mukherjee, 2011)

Appendix III: System analysis indicators

Political	Economic
Renewable energy targets	
CO_2 reduction targets	Electricity market design
Renewable energy generation capacity	Total energy supply
Responsibilities	Total energy demand
Increase rate of renewable energy generation capacity	CO_2 price
Regulatory uncertainty	Balancing costs
Permit procedures	Cross-border electricity trade
Renewable energy subsidy	Construction costs
International cooperation	Operation and maintenance costs
	Investment risk
	Size of industry
	Indirect effect on related industries
	Employment in industry
	Energy price

Technical	Social
Availability of renewable energy resource	Safety
Site conditions	Available areas
Technological innovation	Required space for renewable energy option
Generation capacity	
Size of installation	
Construction technique	
Operation and maintenance strategies	
Grid connection	
Network stability	
Predictability of power supply	

TABLE 49: SYSTEM ANALYSIS INDICATORS

Appendix IV: Indicators per source

This table shows the indicators per source and the overlap between the indicators. When there is overlap, the most comprehensive indicator is chosen as the indicator for the new comprehensive energy security framework, in the right column.

Indicator from Sovacool et al. (2011)	*Indicator from Sovacool & Mukherjee (2011)*	*Indicator from system analysis*	*New comprehensive energy security framework indicator*
-	-	Total energy demand	**Total energy demand**
Total energy supply	Total primary energy supply	Total energy supply	**Total energy supply**
-	-	Total electricity demand	**Total electricity demand**
-	-	Total electricity supply	**Total electricity supply**
-	-	Availability of renewable energy resource	**Availability of renewable energy resource**
-	-	Increase rate of renewable energy generation capacity	**Increase rate of renewable energy generation capacity**
-	Total installed electricity generation capacity	Generation capacity	**Total installed electricity generation capacity**
Self-sufficiency	-	-	**Self-sufficiency**
	Diversification of ownership of energy companies		**Diversification of ownership of energy companies**
	Geographic dispersion of energy facilities		**Geographic dispersion of energy facilities**
Share of renewable energy in total primary energy supply		Renewable energy generation capacity	**Share of renewable energy in total primary energy supply**
		CO2 price	**CO_2 price**
Stability of electricity prices	Electricity price volatility		**Electricity price volatility**
Retail price of gasoline/petrol	End-use prices by fuel	Energy price	**End-use energy prices by fuel**
		Electricity price	**Electricity price**
		Grid connection	**Grid connection**
	Rate of electrification		**Rate of electrification**
		Site conditions	**Site conditions**
		Balancing costs	**Balancing costs**
		Construction costs	**Construction costs**
		Investment risk	**Investment risk**
	Marginal cost of electricity power generation		**Marginal cost of electricity power generation**
	Transmission costs for electricity		**Transmission costs for electricity**
		Construction technique	**Construction technique**
Research intensity	Research budgets for renewable sources of energy		**Research budgets for renewable sources of energy**
		Technological innovation	**Technological innovation**
Energy intensity			**Energy intensity**
	Frequency of interruption of supply		**Frequency of interruption of supply**
		Operation and maintenance strategies	**Operation and maintenance strategies**

		Predictability of power supply	**Predictability of power supply**
	Generation adequacy		**Generation adequacy**
Grid efficiency	System adequacy	Network stability	**System adequacy**
	Average rate of return on energy investments		**Average rate of return on energy investments**
Size of industry	Direct employment	Employment in industry	**Direct employment**
	Indirect effect on related industries	Employment in industry	**Indirect and induced employment in the industry**
Grid efficiency		Investment in electricity transmission capacity	**Investment in electricity transmission capacity**
		Operation and maintenance cost	**Operation and maintenance costs**
Water availability		Available areas	**Available areas**
	Required space, water use	Required space for renewable energy option	**Required space for renewable energy option**
		Size of installation	**Size of installation**
Per capita energy related carbon dioxide emissions	CO_2 emissions from electricity sector		**CO_2 emissions from electricity sector**
		CO_2 reduction targets	**CO_2 reduction targets**
	Presence of climate change goals and targets	Renewable energy targets	**Presence of climate change goals and targets**
	Number of electricity system regulators	Regulatory uncertainty	**Number of electricity system regulators**
		Permit procedures	**Permit procedures**
	Provision of priority grid access to renewable energy		**Provision of priority grid access to renewable energy**
		Responsibilities	**Responsibilities**
Energy exports	Amount of transnational electricity trading	Cross-border electricity trade	**Amount of transnational electricity trading**
		International cooperation	**International cooperation**
	Total interconnection capacity		**Total interconnection capacity**
		Electricity market design	**Electricity market design**
	Market share of largest three electricity suppliers		**Market share of largest three electricity suppliers**
Per capita energy subsidies		Renewable energy subsidy	**Renewable energy subsidy**

TABLE 50: COMBINING INDICATORS TO THE NEW COMPREHENSIVE ENERGY SECURITY FRAMEWORK INDICATORS

Appendix V: Comprehensive energy security assessment framework

Dimension	*Component*	*Indicator*
Availability	*Security of supply*	Total energy demand Total energy supply Total electricity demand Total electricity supply
	Production	Availability of renewable energy resource Increase rate of renewable energy generation capacity Total installed electricity generation capacity
	Dependency	Self-sufficiency
	Diversification	Diversification of ownership of energy companies Geographic dispersion of energy facilities Share of renewable energy in total primary energy supply
Affordability	*Price stability*	CO_2 price Electricity price volatility End-use energy prices by fuel Electricity price
	Access & equity	Grid connection Rate of electrification Site conditions
	Affordability	Balancing costs Construction costs Investment risk Marginal cost of electricity power generation Transmission costs for electricity
Technology development & efficiency	*Innovation & research*	Construction technique Research budgets for renewable sources of energy Technological innovation
	Efficiency	Energy intensity
	Safety & reliability	Frequency of interruption of supply Operation and maintenance strategies Predictability of power supply
	Resilience	Generation adequacy System adequacy
	Investment & employment	Average rate of return on energy investments Direct employment Indirect and induced employment in the industry Investment in electricity transmission capacity Operation and maintenance costs
Environmental & social sustainability	*Land / water use*	Available areas Required space for renewable energy option Size of installation
	Climate change	CO_2 emissions from electricity sector CO_2 reduction targets Presence of climate change goals and targets
Regulation & governance	*Governance*	Number of electricity system regulators Permit procedures Provision of priority grid access to renewable energy Responsibilities
	Trade & regional interconnectivity	Amount of transnational electricity trading International cooperation Total interconnection capacity
	Competition & markets	Electricity market design Market share of largest three electricity suppliers Renewable energy subsidy

TABLE 51: NEW COMPREHENSIVE ENERGY SECURITY ASSESSMENT FRAMEWORK

Appendix VI: Results of the comprehensive energy security analysis

Dimension	Component	Indicator	National scenario	International scenario
Availability	Security of supply	Total energy demand	--	-
		Total energy supply	+	+
		Total electricity demand	++	++
		Total electricity supply	++	++
	Production	Availability of renewable energy resource	0	+
		Increase rate of renewable energy generation capacity	+	+
		Total installed electricity generation capacity	++	+
	Dependency	Self-sufficiency	++	+
	Diversification	Diversification of ownership of energy companies	0	++
		Geographic dispersion of energy facilities	+	++
		Share of renewable energy in total primary energy supply	++	++
Affordability	Price stability	CO2 price	-	++
		Electricity price volatility	--	-
		End-use energy prices by fuel	-	++
		Electricity price	+	++
	Access & equity	Grid connection	0	++
		Rate of electrification	++	+
		Site conditions	0	-
	Affordability	Balancing costs	--	-
		Construction costs	+	++
		Investment risk	-	--
		Marginal cost of electricity power generation	-	-
		Transmission costs for electricity	-	--
Technology Development & efficiency	Innovation & research	Construction technique	++	++
		Research budgets for renewable sources of energy	0	+
		Technological innovation	++	++
	Efficiency	Energy intensity	+	++
	Safety & reliability	Frequency of interruption of supply	--	-
		Operation and maintenance strategies	+	++
		Predictability of power supply	-	+
	Resilience	Generation adequacy	-	-
		System adequacy	-	+
	Investment & employment	Average rate of return on energy investments	-	+
		Direct employment	+	++
		Indirect and induced employment in the industry	+	++
		Investment in electricity transmission capacity	0	++
		Operation and maintenance costs	+	++
Environmental & social sustainability	Land / water use	Available areas	-	+
		Required space for renewable energy option	+	-
		Size of installation	+	+
	Climate change	CO2 emissions from electricity sector	+	++
		CO2 reduction targets	+	+
		Presence of climate change goals and targets	+	++
Regulation & governance	Governance	Number of electricity system regulators	-	++
		Permit procedures	+	+
		Provision of priority grid access to renewable energy	0	0
		Responsibilities	-	++
	Trade & regional interconnectivity	Amount of transnational electricity trading	+	++
		International cooperation	-	++
		Total interconnection capacity	0	++
	Competition & markets	Electricity market design	0	+
		Market share of largest three electricity suppliers	+	+
		Renewable energy subsidy	0	++

Table 52: Results of comprehensive energy security analysis in two scenarios

Appendix VII: Interviews

Questions interviews:

<u>General questions</u>

1. What are expected long-term developments for offshore wind energy (2030-2050)?
2. What are the developments in both scenarios for the offshore sector?
   - Technological: innovation
   - Economic: employment opportunities, size of industry
   - Political: policy, governance, international cooperation
   - Environmental: ecology / nature
3. What are the effects of large-scale (30GW) offshore wind in the Dutch EEZ in both scenarios?
   - Technological: innovation
   - Economic: employment opportunities, size of industry
   - Political: policy, governance, international cooperation
   - Environmental: ecology / nature
4. What are the risks of developing large-scale offshore wind in both scenarios?
   - Technological;
   - Economic;
   - Political;
   - Environmental.
5. What are the opportunities of developing large-scale offshore wind in both scenarios?
   - Technological;
   - Economic;
   - Political;
   - Environmental.

<u>Questions related to cooperation</u>

6. How to deal with the oversupply in electricity?
   - Storage / interconnections / power-to-X / electrification / etc.
7. In what ways can cooperation contribute to the development of offshore wind energy?
   - Which countries / sectors / activities
8. What are the biggest challenges for cooperation?
   - National and international

Report interview Boskalis
Marcel van Bergen, Director offshore wind
24 July 2017, Papendrecht

Beleid
Tot nu toe heeft Nederland concurrentie tussen de aanbieders weten uit te lokken door de manier waarop er getenderd wordt. Tot nu toe was er een goede, voorspelbare pijplijn, met projecten achter elkaar, georganiseerd door RVO en het ministerie van Economische Zaken.

Ondersteuning vanuit de overheid geeft partijen vertrouwen dat het risico beheerst is. Daarnaast geeft het aan dat subsidies en de ruimte goed verdeeld wordt, door concurrentie te introduceren.

Langetermijn en continu beleid zijn voor bedrijven belangrijk, want de investeringen die gedaan worden voor bijvoorbeeld schepen of ander materieel is altijd voor 15-20 jaar. Dit zal ook leiden tot kostenreducties, omdat het dan over een langere periode en meerdere projecten afgeschreven kan worden.

Technische ontwikkelingen
De belangrijkste technische ontwikkeling zal grotere turbines zijn, want dat is de grootste kostenreductiefactor. De windturbine zal wel duurder worden als hij groter wordt, maar de kostenreductie volgt uit minder kabels, fundering en installatie.

Verder zal het efficiënter worden, de techniek zal beter worden en de turbines zullen minder snel kapotgaan, dus dan hoeft men er minder vaak naartoe en wordt het ook betrouwbaarder.

Leereffecten bij wind op zee zullen steeds minder een rol spelen tijdens projecten. Aan het begin bij nieuwe technieken wel, maar ondertussen steeds minder. Wat wel nog een rol speelt waardoor versnelling/vertraging kan optreden is het weer, of wanneer er dingen kapotgaan.

Werkgelegenheid
De bouwbedrijven, zoals Boskalis, worden al betrokken in de fase voor de tendering. Ze worden benaderd door bedrijven die meedoen aan tenders om te adviseren en zo tot optimale ontwerpen en kostenoverzichten te komen.

Hoe verder er vooruitgekeken wordt met betrekking tot de planning van projecten, hoe meer er geïnvesteerd zal worden door bedrijven, hoe meer bedrijven durven doen en er wordt meer werkgelegenheid gecreëerd. Anders nemen bedrijven een te afwachtende houding.

De eerste paar jaar valt onderhoud en reparaties onder de garantie van de leveranciers, daarna zijn het de aparte onderhoudsbedrijven en monteurs die dit doen. De mensen die dan nodig zijn hebben een lagere opleiding nodig, omdat dit simpeler werk is.

Vanuit de staff, mensen op kantoor, werken er ongeveer 200 mensen op de offshore wind tak bij Boskalis. Dit is nog zonder de mensen op zee.

Internationale samenwerking
Boskalis is een internationaal bedrijf, met kantoren over de hele wereld en verwacht dus niet veel last te hebben van de Brexit of soortgelijke ontwikkelingen. Het kan er wel voor zorgen dat het lastiger is om werkvergunningen te krijgen voor werknemers die over de grens werken. Risico's die optreden door wetgevingswijzigingen worden vaak opgenomen in de contracten.

Voor Boskalis is Europa een markt. Het is erg internationaal georiënteerd, bijna alle bedrijven die een rol spelen zijn niet-Nederlands: Nuon/Vattenfall, Dong, Essent/Innogy/RWE. Shell is dan nog Brits-Nederlands en Eneco is Nederlands.

De omstandigheden op de Noordzee zijn ongeveer gelijk verdeeld. Grondcondities, golven en wind zijn belangrijk. Hoe dieper de zee is, hoe meer grote golven er ook zijn en er is ook meer wind. Dit is per zee/oceaan verschillend.

Voor ontwikkeling van windparken moet een locatie aan een aantal eisen voldoen. Er moet voldoende wind zijn, er moet niet te veel zon zijn, want dan wordt dat een aantrekkelijkere optie en er moet vraag van energie zijn, dus dichtbevolkte gebieden met veel energie zijn aantrekkelijker. Dan is de westerse wereld, Azië, en Noord-Amerika interessant. Dan kijk je naar niet te dicht bij de evenaar, want daar is zonne-energie erg interessant. Dan zijn interessante groeimarkten: Taiwan, Zuid-Korea, Japan en de oostkust van de VS. Een nieuwe groeimarkt is Zuid-Amerika. Zo is de regio rond de middellandse zee veel ongunstiger voor wind op zee: diepe wateren maakt de techniek duurder en zonne-energie is daar een betere oplossing.

Europese bedrijven hebben dankzij de ervaringen die ze in Europa hebben opgedaan een voorsprong op de lokale bedrijven in de nieuwe markten, in bijvoorbeeld Azië. Zij zijn al verder in de leercurve, hebben meer ervaring, weten goed wat dingen kunnen kosten door het repeterend karakter van wind. Hierdoor kunnen zij gunstigere biedingen doen voor projecten en dat is gunstig voor de Europese bedrijven. Er wordt wel veel samengewerkt met lokale bedrijven en lokale werknemers, omdat veel landen ook hun eigen markt beschermen en regels opstellen om de eigen markt en economie te laten groeien.

Het grootste risico is de onzekerheid van de energieprijs. Deze is namelijk erg volatiel. Daarnaast komen er misschien de nu biedingen op de tenders. Dit kan ervoor zorgen dat bedrijven moeilijker de financiering rondkrijgen, want hierdoor is er niet meer een minimum elektriciteitsprijs die ze krijgen per eenheid elektriciteit die geleverd is. Dat is een zekerheid die wordt weggenomen. Omdat de prijs extreem gevoelig is voor vraag en aanbod, is de elektriciteitsprijs zo volatiel en daardoor lastig te voorspellen. Hierdoor is het uiteindelijk dus lastig te voorspellen wat het windpark oplevert en of de investering terugverdiend kan worden.

De lage biedingen en de biedingen van nul zijn gebaseerd op een speculatie van de stroomprijs. De ontwikkelaars gaan ervanuit dat de elektriciteitsprijs een bepaalde waarde zal krijgen en dat ze die subsidie dus uiteindelijk niet nodig hebben. Het risico is hier dat ze het niet kunnen waarmaken als de elektriciteitsprijs gelijk of lager is dan hun bieding. Het is namelijk lastig om te voorspellen wat deze prijs is, veel bedrijven hebben de olieprijs namelijk ook verkeerd ingeschat en dat heeft veel invloed gehad op de olie en gassector.

Report interview Dong
28 July 2017, by phone
Caro de Brouwer, Market development
Stefan de Bruijn

De verwachting hoe wind op zee zich zal ontwikkelen na 2030 is afhankelijk van hoe het beleid zich zal ontwikkelen in de komende jaren. Een belangrijk element hierbij is de aanpassing van het net op land en hoe de ontwikkelingen hiervan verlopen. Dit gaat dan vooral over de versterking van het net op land. De ontwikkeling hiervan is van belang, wanneer 1 tot 2 GW uitrol wind op zee plaatsvindt.

Bovendien zijn goede interconnectors, goede geïntegreerde elektriciteitsmarkten, flexibiliteit van producenten en consumenten en goede planning van de TSO's, die ook samenwerken met TSO's van de buurlanden, zijn belangrijkste parameters om ervoor te zorgen dat hernieuwbare energie goed geïntegreerd kan worden in het systeem.

Technische ontwikkelingen

Offshore wind is een intermitterende elektriciteitsbron. Als er flexibiliteit aan de generatiekant ingebracht wordt in het systeem, dan moet er ook flexibiliteit komen aan de vraagkant van het energiesysteem om vraag en aanbod te balanceren. Daar zijn twee belangrijke trends in: aan de ene kant is er energieopslag en aan de andere kant is demand-response een belangrijke trend op Europees niveau. Net als bij de ontwikkeling van meer hernieuwbare energie, zijn dit trends die stimulatie nodig hebben in de vorm van beleid en doelstellingen, omdat ze vandaag nog niet helemaal kostenefficient zijn. Er zal de komende jaren waarschijnlijk veel ontwikkeling zijn in de hele range aan diensten om vraag en aanbod te balanceren.

De offshore windindustrie zelf zal ook moeten innoveren. Turbines worden steeds groter, en er wordt onderzoek gedaan naar nieuwe types funderingen.

Politiek

Nederland heeft voldoende ruimte op de Noordzee om een belangrijke markt voor offshore wind te worden. De aanwijzing van zones voor wind op zee is hiervan van groot belang. Er is voldoende plaats voor de uitrol van 1 GW wind op zee per jaar, en zelfs 2 GW maar dan komen de gebieden veel verder van de kust te liggen.

De aanpassingen aan het net op land moet niet alleen door Nederland beslist worden, maar ook op Europees niveau. Want als er zo veel windenergie van Nederland op het elektriciteitsnet komt, dan moeten de markten met omringende landen ook sterk gekoppeld zijn, bijvoorbeeld met interconnectors.

Doordat er verspreid over heel Europa meer hernieuwbare energie opgewekt wordt en op de netten komt, moeten de bijbehorende markten goed met elkaar communiceren. Dit betekent dat er Europese afspraken gemaakt moeten worden over interconnectie. Deze interconnecties zijn dan nodig om de schommelingen in vraag en aanbod, die ontstaan door de hernieuwbare bronnen, te kunnen opvangen op Europees niveau. De verwachting is dat het aantal interconnecties zal gaan groeien, want hoe meer hernieuwbare energie er wordt opgewekt, des te meer interconnecties landen aangaan met omringende landen. Deze ontwikkelingen zijn al te zien bij landen zoals Denemarken en het VK. Dit beleid moet opgenomen worden in het lange termijnbeleid, want interconnecties maken duurt heel lang.

Het grote succes van windenergie in Nederland tot nu toe is grotendeels te danken aan een voorspelbare en duidelijke rol die de overheid heeft gespeeld. Dit heeft bijgedragen aan de enorme kostenreductie die gerealiseerd is. Ook voor de toekomst is het cruciaal dat er een stabiel beleid is, om duidelijk te hebben wat de uitrol wordt en om verdere kostenreducties te kunnen realiseren.

Economisch
Om wind op zee rendabel te maken wanneer de gebieden verder op zee komen te liggen, zullen de kosten omlaag moeten gaan. Dit geldt niet alleen voor de turbine zelf, maar ook voor het hele systeem er omheen, zoals de transportkabels. Uiteindelijk treedt hier misschien ook meer competitie in op. Om als industrie competitief te blijven is het nodig dat er innovatie blijft plaatsvinden, om de kosten omlaag te krijgen. Hierin ligt ook een rol voor de ontwikkelaars, zoals Dong.

Wind op zee moet bekeken worden vanuit het Europese ontwikkelingskader, want dit is belangrijk om de industrie te laten verbeteren op kostenniveau. Om de kosten te laten dalen moet er een minimale roll-out van Europese wind op zee projecten duidelijk zijn voor de industrie. Het maakt dan niet zo veel uit hoeveel er per land wordt geïnstalleerd, want bijna alle grote spelers op het gebied van wind op zee zijn internationaal actief. Het totaal wat geïnstalleerd wordt in de regio is wel belangrijk.

Kansen en risico's
De grote kansen voor Nederland bij grootschalige wind op zee is dat Nederland een duurzaam energiesysteem kan ontwikkelen. De energieopbrengst kan namelijk erg groot zijn.

Het grootste risico voor Nederland is dat het net op land niet snel genoeg ontwikkeld wordt, om de ontwikkelingen van wind op zee en andere fluctuerende bronnen op te kunnen vangen.

Samenvatting
Nederland heeft een enorm potentieel voor wind op zee, en kan dit potentieel inzetten om te schakelen naar een duurzaam energiesysteem. De eerste stap is gezet, en het vervolgbeleid moet ook transparant en stabiel zijn. Echter, het grote risico is dat het net op land niet snel genoeg ontwikkeld wordt om dit mogelijk te maken. Op langere termijn is er ook de uitdaging van een goede samenwerking met de Europese buurlanden.

Report interview Ecofys
7 August 2017, Utrecht
Michiel Müller, Managing partner

Ontwikkelingen offshore sector
Vanaf 2030 moet er in alle Noordzeelanden ongeveer 10 GW wind op zee uitgerold worden. Dit komt voort uit het Parijsakkoord. Bij Nederland moet er dan ongeveer 33 GW tot 2045 bijgebouwd worden. De offshore sector wordt hierbij een grote industrie, met een lange pijplijn. De industrie zal dan volwassener worden. Op alle vlakken van het construeren en het beheren zal het doorgroeien tot de meest efficiënte oplossingen zijn gevonden. Naar mate er meer ervaringen worden opgebouwd, efficiëntere processen worden doorlopen, efficiëntere bouwtechnieken worden gebruikt en efficiëntere materialen worden gebruikt.

De turbinemarkt wordt op dit moment vooral gedomineerd door Siemens en Vestas. Bij de projectontwikkelaars is voornamelijk Dong dominant. Op het moment dat de pijplijn van projecten duidelijk wordt, zullen er meerdere grote spelers zich gaan focussen op wind op zee. Een voorbeeld hiervan is Shell die dit nu al doet, maar bijvoorbeeld andere utility-bedrijven zoals Engie en EDF zullen dan volgen en dan zal er meer concurrentie ontstaan. Uiteindelijk wordt het dan een markt met veel grote spelers. Hetzelfde geldt voor de toeleveringskant, dit zal op een andere schaal plaatsvinden. De grote spelers zullen de grote risico's nemen en de grote investeringen doen en daarnaast zullen er ook veel grote en kleinere partijen zijn die in de toeleverings- en componenten industrie zitten.

Het onderhoud staat nu nog helemaal in de kinderschoenen. Een vergelijking kan hier gemaakt worden met de olie- en gassector: eerst waren de boorplatforms bemand, nu kan het op afstand beheerd worden en gaat er periodiek een onderhoudsploeg naartoe. Dit soort ontwikkelingen is bij wind op zee ook te verwachten.

De grote kans voor Nederland is dat de nu al sterke offshore-industrie een grote groei kan doormaken. Lange termijnbeleid is hierbij belangrijk, zodat internationale bedrijven die hier nog niet zitten zich kunnen vestigen en voor de positie van de zeehavens. Bij een duidelijke horizon met projecten, zal er bedrijvigheid naar Nederland komen. Dat kan een turbinefabrikant zijn, constructiebedrijven, of iets anders, omdat het handig is om in de buurt van windparken te produceren als er voldoende producten nodig zijn. Dit is een kans voor Nederland om deze bedrijven dan hierheen te halen.

Het grote risico is hiervan de keerzijde: zodra er geen thuismarkt is voor Nederlandse bedrijven, dan is het voor deze bedrijven aanzienlijk moeilijker om ook in het buitenland te blijven doen wat zij nu doen, of zij zullen de overstap maken naar andere landen om zich te vestigen.

Technische ontwikkelingen
Wat een interessante bijdrage moet leveren is niet meer los kijken naar een fundering en een turbine, maar als een geheel. Dit kan door verticale integratie van bedrijven, waarbij 1 bedrijf de verantwoordelijkheid heeft en de overige bedrijven contracteert voor de losse onderdelen.

Op het gebied van interconnectie gaat het waarschijnlijk naar een hybride concept. Een deel van de infrastructuur wordt gebruikt voor de opgewekte stroom uit de windparken en voor interconnectie wordt het gebruikt. De twee uitersten zijn radiale connecties van de windparken naar het land en dan een losse interconnectiekabel en een volledig geïntegreerd grid waarbij alles met elkaar verbonden is. Deze zijn allebei niet voor de hand liggend, doordat het eerste te duur is en het tweede technisch heel lastig is.

Daarnaast zal opslag zich gaan ontwikkelen en dit is weer van invloed op de interconnecties. Als er heel veel opslagmogelijkheden zijn, dan is interconnectie minder aantrekkelijk. Dit geldt voor korte en lange termijn opslag.

Ook zullen andere technieken door ontwikkelen. Wind op land heeft vooral problemen met de ruimte op het land met voldoende wind en zonder te veel weerstand. Zonne-energie zal nog zal vooral in de gebouwde omgeving nog een vlucht nemen, maar er is niet voldoende zon in Nederland om alle benodigde energie te leveren voor Nederland.

Samenwerking
Internationale samenwerking is noodzakelijk bij de ontwikkeling van wind op zee op de Noordzee. De industrie werkt al voornamelijk internationaal. De internationale samenwerking zit dan in twee aspecten: de verdere integratie van energiemarkten door interconnecties en dan vanuit het netwerk samen te werken, omdat het dan één systeem is. Het andere aspect is dat niet alle landen even veel en genoeg ruimte hebben voor voldoende wind op zee.

Bij de ontwikkeling van een eiland moet er hoogstwaarschijnlijk ook internationale afstemming met de buurlanden plaatsvinden, ook als deze volledig op het Nederlandse continentaal plat ligt.

De systeem operator rol zal wel gaan veranderen en er zal een meer overkoepelende systeem operator nodig zijn. Een samenwerkingsverband, zoals de ENTSO-E, is er al, maar zal een actievere rol krijgen. De rollen van de TSO's verschillen per land, maar deze verschillen zijn tot op zekere hoogte wel te overbruggen. Belangrijk is ook weer het lange termijnperspectief.

Nederland zou geschikt zijn om een actieve en volwaardige trekkersrol spelen in de ontwikkeling van de Noordzee. Ze zijn in die zin gelijkwaardig aan het VK en Denemarken, doordat ze allen een volwassen windindustrie hebben en ervaring hebben met offshore wind hebben en een continentaal plat hebben waar veel windenergie kan worden neergezet. Al Nederland inderdaad grootschalig 30-40 GW aan windturbines neerzet en het totale vermogen wat dan in de Noordzee staat op ongeveer 180 GW uitkomt, heeft het een groot aandeel hierin, meer dan bijvoorbeeld België.

De Brexit zal zeker een rol spelen, maar voor het VK is het dusdanig belangrijk voor het energiesysteem om een verbinding te houden met het continentaal plat en Scandinavië, dat zij hier zeker in mee zullen gaan. Andersom is het voor de rest van Europa ook een stuk lastiger om doelen te halen als Engeland niet meedoet, want Engeland vangt een deel van de tekorten uit andere landen op. Dit zal dan betekenen dat wanneer Engeland niet meedoet, Nederland of Denemarken dit waarschijnlijk zal moeten opvangen. Er zal ook veel meer gebalanceerd moeten worden dan op het elektriciteitsnet op land.

Nederland moet ook in internationaal verband meer aanwezigheid en initiatief tonen. Europees beleid en nationaal beleid van de lidstaten gaan vaak niet hand in hand. Dit moet veranderen en landen, ook Nederland, moet erkennen dat het een gezamenlijk internationaal probleem is en verantwoordelijk is. Vooral het tempo moet ook hier opgeschroefd worden. Er moet een gemeenschappelijke visie komen over hoe de roll-out, een planningsstrategie, van wind op zee er op de Noordzee eruit moet komen te zien. Dit met betrekking ook tot kosten en ecologie.

Politiek
Er komt steeds meer een geluid dat wind op zee er moet komen, of het nou duurder is dan andere technologieën of niet, om klimaatverandering tegen te gaan. Dus als de CO_2 prijs laag is, dan zal de ontwikkeling door blijven gaan. Een hogere CO_2 prijs zal wel helpen om de overgang sneller te maken, ervoor zorgen dat de marktpositie beter wordt voor wind op zee door kolen en gas uit de markt te prijzen. Dit zal ervoor zorgen dat er ook meer draagkracht is onder de mensen die alleen kijken naar de markt en de prijs. Op de lange termijn zullen deze allebei een rol spelen in de versnelling van wind op zee. Aan de andere kant is wind op zee al waarschijnlijk snel competitief door prijsdalingen.

Publieke opinie is van grote invloed op hoe wind op zee of andere vormen van duurzame energie zich kunnen ontwikkelen. Door slim hiermee om te gaan, kan de hele perceptie van iets veranderen over acceptabel gedrag. Dit kan veel tijd kosten. Goede voorbeelden hiervan uit het verleden zijn de BOB-campagnes en het anti-rookbeleid. De moraal van mensen kan hierdoor veranderen en dit kan bij duurzame energie ook, als acceptabel gedrag.

Report interview Port of Rotterdam
25 July 2017, Rotterdam
Twan Romeijn, Business Analysts Maritime and Offshore Industry
Rotterdam Offshore Wind Coalition

Ontwikkelingen offshore sector
Een uitrol van 1 GW per jaar zorgt voor bedrijvigheid en voor duidelijkheid. Het havenbedrijf geeft uitgiftes voor 25 jaar of langer, dus hoe verder de visie is voor wind op zee, hoe beter het is voor bedrijven die in deze sector actief zijn. Hoe meer GW uitrol per jaar erbij komt, hoe meer zekerheid bedrijven hebben en hoe meer zekerheid de haven aan deze bedrijven kan bieden. Bedrijven hebben deze zekerheid nodig, voor de zekerheid van hun investeringen, want dit gaat over enorme bedragen.

Als er meer zekerheid is over de visie, hoopt de haven van Rotterdam de offshore-industrie compleet te kunnen maken. Er is nu al een fundatiebouwer, maar een turbinefabrikant en een kabelbouwer is er nog niet. Er kan dan een “one-stop-shop” gecreëerd worden in de haven van Rotterdam, waar verschillende offshore schepen hun producten op kunnen halen in één rotatie. Zo kan ten behoeve van een windpark dan alles in één keer opgehaald worden.

Op een lange termijn zullen er ook onderhouds- en operatiediensten nodig zijn. In eerste instantie heeft de haven van Rotterdam hier niet een hele gunstige ligging voor, omdat er altijd wel een haven is die dichter bij een windpark ligt. Als er verschillende windparken door een beheerder beheerd wordt, dan kan de Rotterdamse haven hier wel een rol in gaan spelen, omdat het dan een centraal punt kan zijn van waaruit de offshore windparken bediend worden, waarbij onderhouds- en operatiediensten gecentraliseerd zijn. Dit kan resulteren in meer scheepsbewegingen voor de Rotterdamse haven, waar de haven dan weer aan kan verdienen.

Olie- en gasbedrijven gaan zich ook steeds meer richten op de offshore wind sector. Dit gebeurt bijvoorbeeld met de modificatie van schepen voor de offshore wind sector. De verwachting is dat zij daarnaast op hun kades binnen de have ook jackets kunnen bouwen voor de windturbines. Sommige grote olie- en gasbedrijven kunnen deze omschakeling snel genoeg doen, andere hebben er meer moeite mee. Het havenbedrijf speelt hier een faciliterende rol in, maar de keuze blijft bij de bedrijven. De verwachting is wel dat veel olie- en gasbedrijven in ieder geval deels een omschakeling zullen maken naar offshore wind.

Ontwikkelingen haven bij grootschalige wind op zee
Er komt in de Rotterdamse haven 70 hectare aan land bij, door middel van landwinning, met nog extra landaanwinningsgebieden binnen de haven, dat beschikbaar is voor de offshore wind sector. Dit zal echter afhangen van hoe "booming" de sector zal worden.

De Rotterdamse haven heeft van oudsher een focus op de fossiele industrie. Hier zal ook een omschakeling in gaan plaatsvinden. Power to gas, power to liquid, elektrificatie of een combinatie hiervan zal een rol gaan spelen. Er is nu ook een aanlanding van TenneT naar de Maasvlakte. Als de capaciteit van wind enorm groot wordt, dan moet de stroom die hieruit voort komt omgezet worden. De haven is hierin een schakel, om ervoor te zorgen dat het product, liquid of gas, gebruikt kan worden verder in de keten, als bijvoorbeeld brandstof voor schepen of in het chemische cluster in de Rotterdamse haven. Om het rendabel te maken moet dit wel op grote schaal gebeuren. Het is gunstig om opslag of omzetting van elektriciteit te doen in een haven, want hiermee reduceer je de transportkosten die gemaakt worden bij het transporteren van elektriciteit en daarnaast zijn er ook veel grote afnemers ven elektriciteit, of de producten die hiervan gemaakt worden.

Werkgelegenheid
Het verdienmodel van de haven was eerst overslag gebonden, dus hoe meer overslag er in de haven plaatsvond, hoe meer de haven en de regio verdienden. Dit verandert met de offshore wind sector. Door het opspuiten van nieuwe grond voor het "offshore wind center" is dat eigenlijk al niet meer rendabel voor de haven, als je kijkt naar hoeveel overslag het oplevert. Nu wordt er daarom naar gekeken hoeveel banen het genereert voor de haven en de spin-off voor regio. Projecten die daar landen, hebben de bedrijven die al gevestigd zijn nodig voor aanvullende diensten. Het wordt gezien als een investering van het havenbedrijf waar de regio van kan profiteren. Hoe meer de regio bedrijvigheid heeft, hoe meer het havenbedrijf weer kan verdienen en hoe beter het voor de stad Rotterdam is qua werkgelegenheid, weinig werkeloosheid en nieuwe trainingen ontstaan.

Er zijn verschillende initiatieven die de werkgelegenheid kunnen stimuleren. Een onderdeel hiervan is het zorgen voor goede opleidingen in de offshore windindustrie. Een deel van de mensen die nu in de olie- en gassector werken, zullen moeten worden omgeschoold om in de windsector te kunnen werken.

Er is heel veel vraag naar goede mensen in de offshore windsector. Als er in een bepaalde regio, bijvoorbeeld Rotterdam, veel goed geschoolde mensen wonen die zijn opgeleid voor de offshore windsector, dan is het voor bedrijven die hierin actief zijn aantrekkelijk om zich in deze regio te vestigen, omdat zij dan altijd toegang hebben tot een "werkgelegenheidspool" die er dan is.

Er zijn verschillende havens nodig om de offshore windparken te kunnen bedienen. Deels is er wel concurrentie tussen havenbedrijven, maar er zijn veel activiteiten die gefaciliteerd kunnen worden. Diepe vaargeulen en sterke kades voor offshore boten en grote ruimtes of hallen voor het ontwikkelen van turbine onderdelen zijn nodig voor bedrijven binnen een haven. Hoe dichter bij de zee het ligt, dus verder uit de stad, hoe gunstiger het is.

Een sterk cluster van bedrijven die actief zijn in de offshore windsector in een bepaalde regio trekken andere offshore windbedrijven en dus ook meer bedrijvigheid aan in de regio, want het is dan aantrekkelijk voor bedrijven om zich bij dat cluster aan te sluiten of hiervan gebruik te maken. Kennisdelen, samenwerken en elkaar ontmoeten spelen hierbij een belangrijke rol en zorgt voor het genereren van werkgelegenheid.

De meeste turbinefabrikanten zijn al gevestigd. Deze zijn buiten Nederland gevestigd. Bij een vooruitzicht van grootschalige ontwikkeling van wind op zee, bestaat er een grote kans dat er een turbinefabrikant zich gaat vestigen in Nederland, omdat het dan voor deze bedrijven ongunstig is om ze vanuit het buitenland te verschepen naar Nederland.

Vanuit de gemeente Rotterdam is er ook een vraag naar grote projecten die opgezet kunnen worden over de energietransitie. Dit kan bijvoorbeeld gaan om projecten rond energieopslag. Zij merken dat offshore wind een belangrijke push zal kunnen geven in de werkgelegenheid. Door innovaties kan op den duur de werkgelegenheid in offshore wind weer naar beneden gaan, hierdoor is het lastig in te schatten hoeveel werkgelegenheid het uiteindelijk oplevert. Uiteindelijk zou het rond de 10.000 fte werkgelegenheid kunnen bieden in de regio rondom Rotterdam.

Samenwerking
Bedrijven in de haven bedienen bijna altijd een internationale markt. Zij bedienen ook Belgische en Duitse windparken. Qua internationale regelgeving wordt het nu waarschijnlijk lastiger om Engelse windparken te gaan bedienen vanuit Nederland.

Technische ontwikkelingen
De huidige manier van windturbines maken vereist veel scheepvaartbewegingen en dit kost veel geld. Een verwachte innovatie is dat de turbines volledig aan land produceert worden en dan met complete molens wordt er naar de locatie van het windpark gevaren, de turbines kunnen dan in een keer geplaatst worden.

Report interview Siemens
18 July 2017, The Hague
David-Pieter Molenaar, CEO Siemens Wind Power B.V.

Technische ontwikkelingen
In 2006 is de ontwikkeling van offshore wind begonnen en toen waren er vooral windturbines in de categorie 2-3 MW, met een rotordiameter van 90-112 meter.

In de komende jaren zal de ontwikkeling in Nederland verder gaan volgens het Energieakkoord, met ongeveer 700 MW per jaar. In de eerste jaren zullen de windturbines in de 8 MW-categorie vallen, met een rotordiameter van 150 meter en dit zal oplopen tot ongeveer 10 MW turbine met een rotordiameter van 200 meter.

Als dit doorgetrokken wordt naar 2030, dan zal naar verwachting het aantal MW per turbine stabiliseren, vooral om economische redenen. Het zal maximaal richting de 20 MW per turbine gaan, want dan krijg je te maken met een bepaalde grootte van de rotor, ander soort schepen die nodig zijn en met minder windturbines per park. Als er minder windmolens per park zijn, voor hetzelfde aantal MW, dan betekent het dat als er 1 windturbine stilstaat, dat het effect en de impact hiervan groter is. Er zal een balans komen tussen het aantal en de impact op je beschikbaarheid en productie. De vraag is ook als er een nog grotere turbine komt, kan die nog geïnstalleerd worden?

Technisch zou het wel kunnen, maar dan worden de molens te groot en te uniek. Er worden dan te weinig aantallen geproduceerd om te kunnen standaardiseren.

Wat betreft turbine innovaties: voorlopig ligt de monopile nog voor de hand in de Noordzee, vooral qua waterdiepte. Het is makkelijk te produceren, makkelijk te installeren en makkelijk te ontwerpen. Op een gegeven moment wordt wel de belasting in de diameter te groot en moet er een ontwikkeling komen in hoe om te gaan met de golven, maar voor de Noordzee valt dit mee.

Innovaties en onderzoek zullen plaatsvinden op het bouwen met lichter materiaal en bouwen met een kleinere diameter door beter te ontwerpen, om tot kostenbesparingen te komen.

De ontwikkeling zal vooral plaatsvinden door andere productietechnieken, bijvoorbeeld bladen ontwikkelen met 3D technologieën, bladen die zich aan kunnen passen aan de wind, big data uit de turbines gebruiken om betere voorspellingen te kunnen doen. Vooral Nederland kan heel sterk zijn in deze data analyseren en voorspellingen te doen. Voorspellingen kunnen dan zijn op wanneer onderdelen vervangen moeten worden en de opbrengst van de windturbines. Een voorwaarde hiervoor is wel standaardisatie van de turbines en de omstandigheden waarin zij opereren. Door de snelle ontwikkeling in de turbines tot nu toe is die standaardisatie er nog niet

Ontwikkeling van projectniveau

Een andere ontwikkeling die zal plaatsvinden is van het werken op turbineniveau, naar projectniveau en later naar portfolioniveau. Wat een belangrijke ontwikkeling is die hiervoor bij de sector nodig is, is duidelijkheid wat betreft de outlook. Het aantal GW dat per jaar wordt uitgerold is niet heel relevant, zolang het maar vroeg duidelijk is hoeveel er wanneer nodig is, zodat iedereen zijn productie daarop kan inrichten, havens inrichten, mensen trainen en voorzieningen treffen. Als bedrijven weten dat ze een portfolio aan projecten kunnen inrichten, dan gaan zij anders te werk met bijvoorbeeld inkoop en onderhoud. Dit gaat dan niet over één project, maar over een heel portfolio.

Er kan dan gekeken worde of er projecten gecombineerd kunnen worden. Het wordt dan veel aantrekkelijker als er meerdere projecten vanuit een locatie gefaciliteerd kunnen worden.

Internationale parken bedienen vanuit een locatie is nu nog lastig, dan heb je nog te maken met customs, tussen bijvoorbeeld Nederland en Duitsland. Als hier afspraken over gemaakt worden, dan kunnen er bijvoorbeeld vanuit de Eemshaven landgrensoverschrijdende projecten plaatsvinden. Dit zal bijdragen aan kostenreductie en efficiency. Qua werkgelegenheid zal dit zorgen voor een sterke werkgelegenheidsbasis. Dit zal een belangrijke stap zijn. Er moet gekeken worden of Nederland, Duitsland, Engeland en België gecombineerd kunnen worden.

Continuïteit van uitrol van projecten en portfolio denken met de outlook zijn ontwikkelingen die belangrijk zijn voor de sector. Het risico voor bedrijven wordt lager en er kan gestandaardiseerd worden.

Werkgelegenheid offshore windsector

Een belangrijk aspect hierbij is dat Nederland een vestigingsplaats wordt voor de windindustrie, dat is belangrijk voor de windindustrie. Driekwart van de werkgelegenheid in de windindustrie komt uit de onderhoudsfase, dit is meestal lokaal. Dus windparken bouwen is goed voor de werkgelegenheid en dan krijg je nog veel meer extra werkgelegenheid door het onderhoud van parken. Daarnaast is er nog export van kennis en kundigheid.

Om offshore windturbines te kunnen plaatsen, moeten werknemers gecertificeerd zijn en bepaalde trainingen gevolgd hebben om onder die omstandigheden te kunnen werken.

Hierbij is een zorg dat relatief weinig jongeren een technische opleiding volgen. Wat nodig is, is een nationale opleiding in offshore wind, waarvan het curriculum bekend is bij bedrijven. Het moet internationaal gelinkt zijn en Engelstalig. Dit is belangrijk als wij ons als Nederland willen onderscheiden en om werkgelegenheid te stimuleren. Het moet bekend zijn van de opleidingen wat deze mensen te bieden hebben. Dat is nog te langzaam aan het ontwikkelen op dit moment. Ze moeten voorbereid worden op zowel de technische uitdagingen van de turbine, als op de levensstijl van twee weken op zee, twee weken thuis. Uiteindelijk zijn ze dan ook internationaal inzetbaar, wat wel de werkgelegenheid in Nederland stimuleert.

Voor Gemini zijn 40-45 mensen aangenomen bij Siemens. Nieuwe mensen kunnen aangetrokken worden door herscholing van wind op land of vanuit de offshore olie en gassector.

Samenwerking

Samenwerking, zowel internationaal als nationaal op projecten, kan eigenlijk alleen als er een lang termijn outlook is.

Bij grootschalige windparken is er ook combinatie met andere functies mogelijk. Hierbij kan gedacht worden aan een eiland met havens, hotels en natuurontwikkeling. Dit moet dan vooraf gepland worden, achteraf is het veel duurder.

Een eventuele andere belangrijke vervolgstap is de koppeling van wind met gas, want het gaat om de voorspelbaarheid van de stroom die beschikbaar is. Het gaat niet om de prijs maar om de waarde van de stroom. Hierbij spelen gas en opslag een rol. Door een groot park hiermee te combineren, kan er gegarandeerd een continue stroom geleverd worden. Bij een portfolio aan projecten wordt dit makkelijker om in te investeren. Dan kunnen de vaste kosten voor een fabriek, opslag of eiland worden afgeschreven over meerdere projecten, waardoor dit aantrekkelijker wordt.

Voorwaarden zijn dat er een duidelijke richting geschetst moet worden en dat er competitie gecreëerd moet worden, door de juiste prikkels te geven. Hoe meer landen en projecten gecombineerd worden, hoe moeilijker het is om projecten op elkaar af te stemmen, maar dit is zeker haalbaar bij een duidelijke richting.

De volgende stap is de koppeling met andere landen. Koppeling van de infrastructuur met andere landen is erg belangrijk.

Beleid
Een goede ontwikkeling is geweest dat er een aparte categorie van subsidies is voor wind op zee. Dit geeft zekerheid en duidelijkheid aan de ondernemer.

Er moeten duidelijke randvoorwaarden geschept worden vanuit de overheid. Binnen deze randvoorwaarden kunnen ontwikkelaars windparken ontwikkelen. Deze randvoorwaarden zijn bijvoorbeeld: maximale toegestane hoeveelheid geluid, maximale toegestane overlast voor dieren in de omgeving. Als de ondernemer niet voldoet aan deze randvoorwaarden, dan heeft de overheid een "exit" en kunnen ze de subsidie en vergunning intrekken. Dit prikkelt de ondernemer.

De belangrijke stap is nu internationale samenwerking, cross-border projecten, portfolio denken bij projecten en duidelijke doelen stellen.

Kansen overheid: door het clusteren van projecten, duidelijke randvoorwaarden en kaders te zetten en het focussen op TWh, in plaats van op geïnstalleerde MW, dan zijn de doelstellingen makkelijker te behalen.

Report interview TNO
8 August 2017, The Hague
Ir. Sjoerd van der Putten, Project manager - Structural Dynamics
Grootschalige windenergie biedt grote kansen voor Nederland, doordat het geografisch een goede ligging heeft en doordat het een goede basis heeft om de technologieën door te ontwikkelen. En dan vooral de offshore technologie voor de balance of plant en niet de turbine ontwikkeling. De offshore diensten en de onderzoeksdiensten zijn aspecten waar Nederland sterk is.

Technische ontwikkelingen
De hoofdontwikkeling op technisch vlak zal zijn dat de windturbines steeds groter worden en dit is ook leidend voor de andere technische ontwikkelingen die zullen plaatsvinden. De offshore markt is dus ook afhankelijk van wat de grote windturbine fabrikanten verwachten aan ontwikkelingen in de jaren die erna volgen. De echte technologische ontwikkelingen in turbines vinden vooral plaats in Duitsland en Denemarken.

Er wordt verwacht dat sensoren een grote rol gaan spelen. Dit zorgt ervoor dat op afstand veel informatie verkregen kan worden om operaties te optimaliseren. Dit kan opgesplitst worden in informatie voor de kosten en de baten. Aan de batenkant kan het helpen bij de optimalisatie en voorspelling van de opbrengst van windenergie. Een belangrijk idee is dat hieruit duidelijk kan worden wat de relatie is van de omgevingscondities en de opgewekte stroom. Dit kan op het niveau van een enkele windturbine of van een heel park. Aan de kostenkant kan de degradatie van het systeem nauwkeuriger bijgehouden worden, om deze zo te kunnen beheersen. De snelheid van degradatie kan hierin bijgehouden worden, maar er kan ook gekeken worden naar wanneer er bepaalde acties ondernomen worden, zoals onderhoud en inspectie. Er kan ook gekeken worden naar hoe onderhoud en inspectie de status van een windpark beïnvloeden.

Innovatie vindt plaats in een matrix: op de verticale as is de mate van vernieuwing van de technologie en op de horizontale as is de mate van vernieuwing van de omgeving. Wanneer je een bestaande technologie in een nieuwe omgeving wilt gebruiken, dan vindt er innovatie plaats. Bij wind op zee speelt dat bij het gebruik van staal en kabels. De omgeving verandert doordat er verschil in krachten door water en wind en grotere turbines plaatsvindt.

Hiervoor is dan nieuwe kennis nodig om hiermee om te gaan. Afstand tot de kust en waterdiepte is dit van invloed op onderhouds- en inspectiekosten. Dit zal dus nieuwe concepten nodig hebben, misschien is het op den duur dan mogelijk dat er onderhoudsvrije windparken komen. Dit zal ook weer leiden tot andere kosten in de constructie.

Ontwikkelingen op projectniveau
Daarnaast worden ook te windparken zelfs steeds groter. De aanbestedingen vinden nu op 700 MW plaats, maar de verwachting is dat het naar een aantal GW per tender gaat.

Ontwikkelingen in onderzoek
De Nederlandse onderzoeksmarkt richt zich ook vooral op de offshore technologie en minder op de turbine zelf. Dit gaat dus vooral over balance of plant. Materiaaltechnologie voor de turbine zelf en voor de ondersteuningsconstructie wordt ook veel onderzocht in Nederland. Het materiaal staat op zee onder extreme omstandigheden. Bij grotere schaal van wind op zee, zal er ook hier meer gekeken worden naar hoe het beter kan.

TNO heeft verschillende onderzoekslijnen met betrekking tot wind op zee. De bijdrage is tot nu toe vooral in materiaalontwikkeling, logistieke optimalisatie rondom windparken en sensorontwikkeling.

Ontwikkelingen offshore sector
De offshore sector bestaat uit de supply chain die ervoor zorgt dat het ontwerp, de installatie en de operatie van windparken gerealiseerd kan worden. Dat zijn ook de disciplines die voornamelijk in Nederland te vinden zijn, waar Nederland ook sterk in is. Deze disciplines zijn uiteindelijk ook weer verder op te delen in componenten en handelingen die bepaalde bedrijven uitvoeren. Op lange termijn kunnen er ook extra dingen bij komen, zoals de ontwikkeling van een energie-eiland. De verwachting is dat de sector complexer en groter wordt.

Het onderhoud is meer een lokale markt dan het ontwerp en het transport en installatie. Nederland heeft de afgelopen jaren minder vooropgelopen op het gebied van wind op zee in vergelijking met Denemarken, Duitsland en Engeland en is daarom geen koploper doordat bedrijven minder ervaring hebben kunnen opbouwen in Nederland. Bij het ontwerp, transport en installatie zijn er wel partijen die ook internationaal actief zijn en die zijn minder afhankelijk geweest van de ontwikkelingen in Nederland. Er zijn nog veel transport en installatiebedrijven in Nederland die zich nog niet gefocust hebben op offshore wind, maar die hier wel succesvol in zouden kunnen zijn en een belangrijk aandeel in de ontwikkeling in Nederland zal hebben.

Economisch
Als de subsidie wegvalt, dan is de business case van windparken anders, want er valt een stuk zekerheid van inkomsten weg. Dan zullen de kosten beter in kaart gebracht moeten worden. Daar is data voor nodig, waarbij sensoren een grote rol kunnen spelen, zeker omdat verder op zee het lastiger is om langs te gaan voor controle. Er moet nog meer onderzoek gedaan worden naar wat er allemaal met deze data gedaan kan worden door de industrie. Voorbeelden zijn beter voorspellen van de opbrengst en voor het ontwerpen van een park. Dit kan bijvoorbeeld gebruikt worden om nieuwe turbines en logistieke oplossingen te ontwerpen.

Samenwerking
In de Noordzee zijn op veel verschillende plekken de omstandigheden hetzelfde. Dit draagt bij aan kennisuitwisseling tussen landen. Daarnaast zijn er juist wel veel nationale ontwikkelingen bij de landen rondom de Noordzee, omdat dit gedreven wordt door nationale subsidies. Onderzoek wordt gefinancierd door de overheid en door de offshore sector. Op dit moment zijn de nationale subsidies voor onderzoek veel aantrekkelijker dan de Europese subsidies. Dit zorgt er ook voor dat het onderzoek wordt gedaan voor Nederlandse partijen. Dit kan leiden tot concurrentie. Als er nieuwe standaarden worden ontwikkeld, dan is er wel internationale afstemming nodig tussen de verschillende partijen.

In Europese onderzoeksverbanden wordt een onderzoeksagenda opgesteld met verschillende partijen in Europa. Hier wordt gepraat over gedeelde belangen en belangen die verder van elkaar afliggen. Onderzoek wordt enerzijds gedaan om de overheid te ondersteunen in beleid en anderzijds om de Nederlandse offshore-industrie te ondersteunen in het verkrijgen van een goede wereldwijde positie. Dit heeft voornamelijk een nationaal karakter. Onderzoeksinstituten worden beter door samen te werk met buitenlandse instituten.

De ontwikkeling van projecten wordt uiteindelijk meer Europees. Hier moeten ook tussen verschillende overheden afspraken over gemaakt worden. Het delen van infrastructuur zal hier een grote rol in spelen. Europese samenwerking en schaalvergroting van windparken is heel erg belangrijk om grote stappen te kunnen zetten, om de wereldwijde ontwikkelingen bij te kunnen houden en om een goede concurrentiepositie te houden voor de Nederlandse offshore sector. Grote en kleine Nederlandse partijen kunnen hierin een rol spelen. Snelheid is hiervan belang in Europa, om niet voorbijgegaan te worden door andere regio's, Azië en Amerika, ter wereld.

Andere gebruikers van de Noordzee zijn: visserij, olie- en gassector, defensie, zandwinning en scheepvaart. Op het moment dat er echt grootschalige wind op zee gerealiseerd wordt in Nederland moet naar multifunctioneel ruimtegebruik gekeken worden en naar de combinatie met deze andere sectoren en de ecologie. Infrastructuur delen met de olie- en gassector, boten delen en personeel delen zijn hier enkele voorbeelden van. Een eiland bouwen zou hiervan een ander voorbeeld kunnen zijn van multifunctioneel gebruik van ruimte. Hier zitten technische risico's aan, zoals meer aanvaringen of materieel krijgt te maken met andere krachten. Dit kan van invloed zijn op de faalfrequentie.

Interview Van Oord
Dolf Elsevier van Griethuysen
Business Development
Ontwikkeling offshore sector
Er is bij een deel van de ontwikkeling van wind op zee gebeurd wat de sector verwachtte. Het was eerst een kleinschalige, veelbelovende techniek. Op dit moment is het een ver ontwikkelde techniek voor duurzame energie, zeker voor Nederland, en de afgelopen jaren zijn er kosten gereduceerd.

Beleid
Beleid over hoeveel projecten er nog komen en hoe groot de verwachtte projecten zijn, vergroot het vertrouwen van de industrie dat er voldoende omzet gemaakt kan worden om investeringen te rechtvaardigen. Een langere inzet van materieel, zorgt voor lagere prijzen per project. Stabiel beleid en volume zorgt voor vertrouwen in de ontwikkeling in wind op zee. Bij te veel onzekerheid kan dit leiden tot vertraging.

De huidige wetgeving voor subsidies is niet geschikt voor de nulbiedingen op subsidie-tenders. Er zijn in Duitsland al nulbiedingen geweest en de overheid wil onderzoeken of dit in Nederland ook mogelijk is. In Duitsland gaan de ontwikkelaars ervan uit dat in 2025 de investeringskosten lager zijn, de elektriciteitsprijs hoger is dan nu en dat de turbines groter zijn. Door deze ontwikkelingen wordt er door de Nederlandse overheid gedacht aan het veilen van kavels op zee. Een mogelijk risico is hierbij dat het systeem minder stabiel wordt, met als gevolg dat het minder zeker is dat parken daadwerkelijk gebouwd worden. De verwachte energieprijs is hierbij van groot belang.

Op zee is er veel meer ruimte voor windturbines dan op land. Het is op zee wel duurder om windturbines te plaatsen dan op land, onder andere omdat er meer nodig is voor de funderingen.

Economische ontwikkelingen
Lage rente, lage staalprijzen en volume in het vooruitzicht kunnen zorgen voor lage investeringskosten. Daarnaast speelt de ervaring en kennis die bedrijven steeds meer krijgen ook een rol, wat tot minder kosten kan leiden.

Door volume in het vooruitzicht te stellen kan een stabiel systeem gecreëerd worden door de overheid. Het is dan mogelijk dat er meer partijen toetreden en de sector kan meer gaan investeren in bijvoorbeeld schepen of fabrieken. Dit zal zorgen voor meer concurrentie. Door concurrentie gaat de prijs omlaag. Met een stabiele markt, genoeg concurrentie en goede spelers, wordt er geïnvesteerd en zal de prijs dalen. Bij turbinefabrikanten zijn er op dit moment maar drie grote fabrikanten, maar mogelijk komen anderen erbij.

Een goed werkend ETS-systeem of een CO2 belasting kan helpen bij de ontwikkeling van wind op zee. Daarnaast kan capaciteit meer gewaardeerd worden. De essentie is dan dat de geplaatste capaciteit belangrijker is dan de geleverde energie. De marginale kosten van duurzame energie zijn (bijna) nul en het gaat dus vooral om de investering. Economisch hangt de ontwikkeling van wind op zee niet meer in hoofdzaak af van de technische ontwikkelingen.

Technische ontwikkelingen
De windindustrie kan een uitrol van 2 GW wind op zee in Nederland per jaar aan. Een probleem wat dan speelt is de capaciteit van elektriciteitsnet op land. Een dermate grote toename van wind op zee, kan congestie op het net op land veroorzaken. Een ander probleem wat op termijn gaat spelen is dat Nederland een stroomoverschot krijgt. Er moeten afnemers zijn om de stroom te gebruiken of het moet geëxporteerd kunnen worden.

Projectontwikkeling
Van Oord is ook aandeelhouder in wind op zee projecten, om vroeg betrokken te zijn bij projecten. Hierdoor kan een project efficiënter worden, dan wanneer een opdrachtgever Van Oord er later bij betrekt, want er kan in een vroeg stadium geoptimaliseerd worden.

Werkgelegenheid
Leereffecten van projecten zorgen ervoor dat projecten sneller kunnen gaan. Het aantal werknemers per MW gaat ook verder omlaag bij projecten, maar omdat projecten vaak groter worden gaat het aantal werknemers per project wel omhoog. De meeste werknemers zijn nodig in de bouwfase van een project.

Van Oord heeft door KPMG laten uitzoeken wat de toegevoegde waarde is van het Geminipark voor Nederland. Hierin is CO2-reductie, werkgelegenheid, belastingen, subsidies, veilig werken, etc. meegenomen. Hier komt een zeer positieve balans uit naar voren.

Internationale samenwerking
Van Oord maakt geen onderscheid tussen Nederlandse of internationale parken. Bij meer dan de helft van de Europese windparken is Van Oord betrokken. Het is nog onbekend of de Brexit veel invloed zal hebben.

Het is van belang dat er een open Europese energiemarkt ontstaat. Daarnaast is het van belang dat de Europese stimuleringsregelingen worden geharmoniseerd, zolang deze er nog zijn. Het helpt als stimuleringsregelingen op zo een manier aangepast worden dat windparken ook aangesloten kunnen worden op buurlanden, bijvoorbeeld een Duits park laten aansluiten op Groningen, wat efficiënter is dan het op Duitsland aan te sluiten.

Nederlandse Windenergie Associatie (NWEA)
Guido Hommel
21 juli 2017, Utrecht

Beleid
Partijen hebben verschillende meningen over de snelheid van de uitrol van wind op zee en over de tenders. Deze verschillen op 1 of 2 GW per jaar en de grootte van tenders. De markt zegt dat 2 GW per jaar haalbaar is om te produceren, mits er een duidelijk overheidsbeleid is. Het grootste knelpunt is dan de invoeding op het net op land. Er zijn verschillende mogelijkheden om dit op te lossen:

- Het versterken van de kuststations, de aanlandingspunten;
- Verder op het land invoeden.

Ontwikkelingen offshore sector
Bij kostenreductie is een vaak gehoorde zorg dat supply chain in de knel kan komen, doordat zij het wel waar moeten maken voor die lage prijs, terwijl ze ook steeds minder verdienen aan de olie- en gassector. Hierbij kunnen wel partijen omvallen, maar andere kunnen ook weer ontstaan.

Ontwikkelingen ecologie
Ecologische ruimte is ook een belangrijk knelpunt. Dat knelpunt zal snel opspelen. Er is een risico dat er uiteindelijk een keus moet komen. Windenergie is goed om klimaatverandering tegen te gaan en klimaatverandering heeft juist weer effect op het milieu en de ecologie als bijvoorbeeld de watertemperatuur stijgt. Op die vlakken helpt windenergie ecologie. Dat neemt niet weg dat op lokaal niveau tijdens de bouwfase het heien er verstorend werkt en in de operationele fase hebben de vogels er last van. De discussie is hier tussen lokaal korte termijneffecten en globaal lange termijneffecten.

Lokaal kan er ook weer een bijdrage geleverd worden aan de natuur. Het is namelijk mogelijk dat er rondom de windturbines nieuwe natuurontwikkeling zal plaatvinden.

Technologische ontwikkelingen
Innovatie speelt hierbij een rol om dit tegen te gaan, met andere bouwtechnieken. Bluepiling technologie werkt met waterdruk om windturbines te plaatsen, wat veel minder geluidsoverlast veroorzaakt. Andere technieken worden aangejaagd als er steeds strengere geluidsnormen worden vastgesteld. Dit zal zeker mogelijk zijn bij een vraag vanuit de markt. Tot die tijd kunnen de mitigerende maatregelen versterkt worden. De techniek zal gedreven worden door de strengere normen. Ook grotere windturbines zijn gunstig voor de vogels. Dan staan de turbines verder uit elkaar en kunnen de vogels ze beter ontwijken.

Werkgelegenheid
Werkgelegenheid zal alleen maar toenemen met de 1 a 2 GW windenergie op zee uitrol. Er bestaat dan ook een reële kans dat er een windturbine fabrikant een productielocatie vestigt in Nederland. Op dit moment zijn die er nog niet, dus wanneer zij genoeg productie verwachten zullen zij dit doen. Dit creëert werkgelegenheid. Hetzelfde geldt voor een kabelfabrikant. De arbeidskrachten moeten er dan ook wel zijn in Nederland, met opleidingen.

Internationale samenwerking
Gemini grenst aan een Duits park. Bij verdere uitbreiding hiervan of bij de ontwikkeling van het gebied ten noorden van de Wadden is er mogelijkheid tot samenwerking met Duitsland. Dit zal dan vooral in de operationele fase zijn.

Vanuit Den Helder airport zijn ze bezig met een samenwerkingsovereenkomst met vliegvelden in omringende landen, om ervoor te zorgen dat ze niet in concurrentie met elkaar zijn. Geen van deze vliegvelden kan het totaalpakket aanbieden in voorzieningen, dus er wordt samengewerkt om in kaart te brengen wie waar sterk in is.

Daarnaast wordt ook de samenwerking gezocht in de Political Declaration.

Ook in de doorvaart en medegebruik de samenwerking gezocht. Ervaringen worden hierin gedeeld met andere landen, zoals Denemarken. Harmonisatie hierin zou goed zijn.

Op een gegeven moment moeten er politieke keuzes gemaakt worden op doorvaart en medegebruik. Op een gegeven moment moeten er misschien keuzes gemaakt worden. Het zou dan kunnen dat er wordt besloten dat dit niet kan. Dit kan weerstand opwekken.

Internationale samenwerking is voordehand liggend bij interconnectie. Iedereen heeft te maken met dezelfde problemen bij variabiliteit in vraag en aanbod. Dit draagt bij aan de leveringszekerheid.

Het koppelen van voorspellingssystemen zal beter werken bij internationale samenwerking. Dit zal bijdragen aan een betere voorspelling van wanneer het waar waait en wat dus de oplevering zal zijn per park. Hoe beter de koppeling en het delen, hoe meer er gebruik gemaakt zal worden van elkaars kennis en diensten.

De verwachting is dat het alleen maar internationaler wordt. Brexit of iets soortgelijks zal hier geen "show stopper" voor zijn.

Economische ontwikkelingen
Er is een risico dat elektriciteitsprijzen zich zo ontwikkelen en lager worden dat er wel nog subsidie nodig blijft voor de ontwikkeling van wind op zee. Het grootste risico is bij de tenders dat er wel een winnaar is, maar dat er toch geen windpark komt. Dit kan als de elektriciteitsprijs te laag is, of wanneer de staalprijs plotseling sterk omhoog gaat.

Op politiek vlak is er een risico dat er niet een beleid komt wat over de kabinetsperiode heen gaat. Hierdoor kan het beleid wisselen per kabinet, wat ongunstig is voor mensen die willen investeren en die duidelijkheid op de lange termijn willen hebben.

Report interview TenneT

10 July 2017, The Hague
Thomas Aksan – Public Affairs
Infrastructuur
Het huidige hoogspanningsnet is vrij robuust (n-1) in Nederland en op het land is het in een bijna volbrachte toestand. Met de huidige ontwikkeling van wind op zee tot 2030 en 2050, waarbij er een mogelijkheid is dat er 1 of 2 GW wind op zee per jaar erbij komt, zal het net wel degelijk uitgebreid moeten worden. Dit zal dan vooral wat dieper landinwaarts moeten zijn, maar is afhankelijk van welke keuzes er gemaakt worden.

Internationale samenwerking
Het huidige beleid is nog erg nationaal gericht. Nu er meer windenergie en zonne-energie op het net komt, is het logisch vanuit het oogpunt van de kosten, dat er samenwerking gaat plaatsvinden. Internationale planning is hierbij van belang. Dit gaat dan over de ontwikkeling van het grid. Zo een internationale setting is vooral nodig bij een situatie waarbij Nederland meer produceert dan dat het nodig heeft.

Het is vele malen voordeliger om vraag en aanbod over de landsgrens te optimaliseren. Vanuit TenneT is internationale samenwerking noodzakelijk voor de efficiëntie. TenneT gelooft in het internationale scenario.

Ondanks dat Nederland nu een nationale focus heeft, is het toch een land met veel interconnecties, het behoort tot de landen die het best verbonden zijn met de buurlanden. Dit heeft effecten op de leveringszekerheid en de prijsontwikkeling van elektriciteit.

In een internationaal scenario, dan komt erbij dat de dingen die TenneT nu ziet, en de ontwikkelingen die TenneT nu doet, dat die ook besproken worden met de buurlanden, omdat het wenselijk is dat voordat de plannen worden gemaakt, de afstemming al heeft plaatsgevonden en dus in een vroeg stadium al geoptimaliseerd worden. Door in een vroeg stadium contact te zoeken, af te stemmen met elkaar en te beginnen met het samenwerken. Meest voor de hand liggende landen zijn hierbij Duitsland, België en het VK.

Vooral voor de langere termijn wordt er ook verder gekeken naar Frankrijk, Oostenrijk en Denemarken. Wanneer kernenergie niet meer toegepast wordt in Frankrijk, dan kan er ook nagedacht worden om via de zeeverbindingen tussen Nederland en Frankrijk aan te leggen.

Economische ontwikkelingen
Het is nog niet helemaal duidelijk of en wanneer het punt wordt bereikt dat er zo veel wind op zee is dat de marginale prijs naar nul gaat, of zelfs negatief wordt, en wat dit dan zou betekenen is ook nog onzeker. Het kan onzekerheid veroorzaken bij investeerders. De vraag is of er dan methoden zijn om ervoor te zorgen dat prijsmechanismen nog interessant zijn om te blijven ontwikkelen en te investeren.

In een internationale setting is het onduidelijk wat er gaat gebeuren als zowel Nederland als Duitsland te veel stroom produceert. De vraag is dan waar het heen getransporteerd gaat worden en of daar genoeg capaciteit voor is. Een andere mogelijkheid die dan een rol kan gaan spelen is opslag.

Technologische ontwikkelingen
Technologische innovaties zijn er genoeg en TenneT is hier voldoende mee bezig. Voorbeelden hiervan zijn 66 kV kabels en de standaardisatie van de platforms heeft tot kostenreducties geleid. Voor toekomstige innovaties wordt er nu ook gekeken naar HVDC-oplossingen in plaats van HVAC en naar het energie-eiland, wat nog nergens is gedaan in de wereld.

TenneT is een dermate grote partij wat betreft verbindingen, dat wanneer TenneT interesse toont in een bepaalde techniek, dat de markt hier dan in meegaat en hierin verder gaat innoveren. Dit is zowel nationaal en internationaal. Internationaal kennis exporteren is hierbij een onderdeel. Kennis delen zorgt ervoor dat er ook kennis verkregen kan worden van uit het buitenland.

Kansen en risico's
Een risico dat altijd speelt voor TenneT, is dat er besluiteloosheid heerst. Het vraagstuk is er complex en dit kan ervoor zorgen dat er dingen vooruitgeschoven worden. Dit kan ervoor zorgen dat tempo verloren gaat. Tijd is

belangrijk. Om de afspraken uit Parijs te kunnen waarmaken, en binnen de 1,5 graden opwarming te blijven, moet er gigantisch hard gewerkt worden in een beperkte tijd. Een goede planning en niet te lang besluiteloos blijven is hierbij cruciaal.

Een grote kans die er nu is, is het momentum dat er nu is. Er is heel veel vertrouwen in de markt, in de sector en binnen de overheid. Resultaten worden gehaald. Er is een generatie opgestaan die zich echt hardmaakt voor het tegengaan van klimaatverandering en inzet op duurzame energie.

Er is wel durf nodig. Het gaat om grote belangen. Besluiten die genomen worden, gaan grote effecten hebben.

TenneT moet hierin zijn rol vervullen. Infrastructuur is namelijk een belangrijke randvoorwaarde. Het kost veel geld en het duurt lang en het is uitdagend. Tegelijkertijd moet er geanticipeerd worden op de veranderingen, door middel van lang termijn visies. TenneT moet hierbij goed afstemmen met stakeholders en altijd een paar stappen vooruit blijven kijken.

Report TKI Wind op Zee
17 July 2017, Utrecht
Ernst van Zuijlen, Director TKI Wind op Zee

Beleid
In de offshore sector wordt een hele snelle groei verwacht tot 2030. Dit is nog afhankelijk van het beleid of er 1 GW of 2 GW uitrol van wind op zee per jaar is. Dit brengt ook een enorme uitdaging met zich mee voor de sector om dit waar te maken. Een logischere manier zou zijn om hier een opbouw in aan te brengen: beginnen met 1 GW wind per jaar en dit opbouwen naar 4 GW per jaar in deze periode.

Infrastructuur
Er zijn een aantal grenzen waar je tegenaan loopt bij deze ambitieuze plannen. Een hiervan is het net op het land, met de vraag of de stroom voldoende aan land te krijgen is en de stap erna of we de stroom kunnen transporteren naar waar het gebruikt wordt. De stroom die dan wordt geproduceerd 25-30 GW, kan niet allemaal gebruikt worden in de vorm van elektriciteit, want de vraag zal ongeveer 11/12 GW zijn. Wat overblijft, zal dan geëxporteerd moeten worden naar andere landen, of omgezet worden naar andere energievormen, opslag en gasproductie. Het energiesysteem moet dan veranderd worden en dat is een enorme uitdaging.

Gebruikers Noordzee
Qua ruimte is er ook een uitdaging. Wat betreft milieu, natuur en randvoorwaardes zit wind op zee nu al aan de grens. Door technisch verstandige keuzes te maken moet dit op te lossen zijn, maar wind op zee neemt veel ruimte in. Er moet opgepast worden dat er geen weerstand gecreëerd wordt, wat snel gebeurd bij ingrijpende veranderingen.

Wat betreft andere sectoren:
- Scheepvaart: redelijk gedefinieerde paden waarmee goed rekening gehouden kan worden;
- Olie & gas: hierbij is samenwerking mogelijk: door levering van stroom;
- Visserij: de sector staat onderdruk en ziet wind op zee als bedreiging;
- Natuur: De vraag blijft of er gebouwd gaat worden in de Natura2000 gebieden, Doggersbank en Bruine bank. Dit kan waarschijnlijk wel, maar als dat niet zorgvuldig gedaan wordt ontstaat er schade en weerstand.

Ontwikkelingen offshore windsector
Technisch, qua windturbine productie, is 4 GW wind op zee voor Nederland geen probleem. Er moeten dan wel meer productielocaties komen, er moeten meer productielijnen zijn van grote windturbines. Dit is een enorme kans voor Nederland. De Maasvlakte en de Eemshaven zouden hier geschikt voor kunnen zijn.

Daarnaast zijn er voldoende installatieschepen nodig, maar deze markt kan zich snel aanpassen en daarnaast kunnen er schepen die nu voor de olie en gassector gebruikt worden omgebouwd worden voor de offshore wind sector.

Technologische ontwikkelingen
Innovaties in het slimmer bouwen van windturbines en het makkelijker installeren zal plaatsvinden. Een voorbeeld hiervan is dat de turbine al volledig in de haven geproduceerd wordt en dat de volledige windmolen in een keer wordt getransporteerd en geïnstalleerd op de locatie door het te laten zinken. Desnoods kan het ook volledig teruggehaald worden voor onderhoud.

Bij de installatie betreft het overlast voor de natuur vooral het heien. Zeezoogdieren hebben hier bovenmatig veel last van. Dit geluid kan met schermen en andere heitechnieken gereduceerd worden. Monopiles kunnen ook in de grond getrild worden en er is ook een waterhamer (Fistuka) die een minder lawaai maakt en minder belastend is voor de omgeving. Boren in plaats van heien en met gravity based technieken zijn ook nog oplossingen waarnaar gekeken wordt. Al deze oplossingen maken minder lawaai dan heien.

Werkgelegenheid
Er moet voldoende personeel zijn, ruimte voor productie zijn, ruimte voor de turbines en ruimte voor de stroom op land zijn. Dit vergt lange termijnplanning.

Voldoende mensen met de juiste opleiding kan een bottleneck zijn voor de uitrol van wind op zee. In Nederland zullen er 30.000-40.000 mensen nodig zijn in 2030, in heel Europa zal dit ongeveer 300.000-400.000 mensen zijn. Nu zijn het er in Nederland tussen de 5.000-10.000.

Er komen veel mensen beschikbaar vanuit de olie- en gassector. Als zij in de windsector gaan werken zullen ze wel minder gaan verdienen dan in de olie- en gassector. Hierdoor kan het lastig zijn om mensen te vinden die dat wel willen, want de omstandigheden zijn zwaar op zee en de mensen zijn lang van huis.

Bij de opleidingen is er een opschaling nodig om aan de arbeidsvraag te voldoen. Er zijn 5 tot 7 keer zo veel wetenschappelijk opgeleiden nodig, 10 keer zo veel hbo-opgeleiden en ook 10 keer zo veel arbeidsplaatsen op het mbo-niveau. Bij de mbo-opleidingen zal het meeste nodig zijn. Vooral voor het onderhoud van de windturbines, wat niet eenmalig is maar voor jaren achter elkaar.

Ecologie
Tijdens het beheer zijn de vogels en vleermuizen (meeuwen en Jan van Gent) een probleem. Er is een kans dat dit wel meevalt, doordat er hier nog veel over onbekend is en dat er te voorzichtig wordt gedaan met de voorspellingen. Er wordt gekeken naar oplossingen met afschrikken door licht en geluid of ze er omheen leiden. Er moet ook nog gekeken worden naar betere modellen en voorspellingen voor deze diersoorten.

Ontwikkelingen en effecten van de energieprijzen
In de periode 2030-2050 zal de elektriciteit op sommige tijden erg goedkoop worden. Wanneer de CO_2 geprijsd wordt zullen de fossiele bronnen dan erg onaantrekkelijk worden, behalve op momenten van schaarste. Als elektriciteit zo goedkoop wordt, dan zullen allerlei industrieën hun productieproces aanpassen. Die gaan dan producten maken als het hard waait. Als de elektriciteitsprijs gemiddeld omlaag gaat, dan kan het welvaartsniveau en het welzijnsniveau van Nederlanders omhooggaan. Van grootschalige gasimporteur kan Nederland grootschalige elektriciteitsproducten exporteur worden. Dit kan bijvoorbeeld kunstmatig gas zijn.

De vraag is of bestaande bedrijven op tijd de omschakeling kunnen en durven maken. Veel nieuwe innovatieve bedrijven staan ook op om te werken met waterstof. Het zal ook impact hebben op mobiliteit, zoals de elektrische auto. Ook hier moeten bedrijven op tijd de omschakeling maken. Dit zal op sommige plaatsen pijn doen, maar anderen kunnen de kansen wel oppakken en innovatieve bedrijven kunnen opstaan.

Kansen en risico's
Er zijn veel kansen in innovatieve startups en mkb-ers die hierin snel kunnen schakelen en productie kunnen aanpassen naar elektrificatie en naar gebruik van waterstof.

Nederland heeft wel kansen laten liggen. Dit had al eerder moeten beginnen om op tijd te kunnen voldoen aan de doelstellingen te voldoen. Er is wel veel kennis en kunde om snel te kunnen schakelen. Kijk naar het verleden, toen Nederland snel schakelde naar gas. Voor deze snelle schakeling zijn de juiste incentives nodig. Met de kostendaling van wind op zee en zon gaan er processen opeens versnellen in deze omschakeling.

Overschakelen naar een infrastructuur voor bijvoorbeeld waterstofgas zou technisch wel kunnen, maar dit vraagt hoge investeringen en veel mensen die hieraan mee moeten werken en dat kan nog wel een probleem zijn. Veel systemen overhoop halen leidt wel ook tot maatschappelijke onrust en weerstand, want veel mensen zijn hierin nog onwetend en dit leidt tot angst over deze veranderingen. Het beste is het om het uit te leggen, wat de voor- en nadelen zijn en hoe hiermee wordt omgegaan, door middel van nieuwe terreinen van werkgelegenheid en omscholing.

Internationale samenwerking
Samenwerking met de buurlanden is nu voornamelijk over de beperkte connectiecapaciteit. Dit is nodig voor de regelbaarheid, opslag en leveringszekerheid. Het net zal nog behoorlijk door moeten ontwikkelen om een volwaardig transportnet te komen. Een ontwikkeling die hierbij kan plaatvinden is om in plaats van een wisselstroom verbinding een langere gelijkstroom verbinding aan te leggen naar Duitsland, bijvoorbeeld het Ruhrgebied.

Verder weg zullen er ontwikkelingen ontstaan van grote projecten buiten Europa die van invloed zijn op Europa. In de Sahara kan er bijvoorbeeld en groot windpark zonne-energie gaan leveren aan Europa. Dan zullen hiervoor grote DC-verbindingen ontstaan tussen Europa en de Sahara, die zijn weer van invloed op de rest van het Europese netwerk, doordat de stromen van energie veranderen. Het net zal veel meer “meshed” zijn.

De productie van energie wordt veel nationaler en regionaler, met vertakkingen naar de buurlanden voor de leveringszekerheid. Nederland wordt veel minder afhankelijk van Saoedi- Arabië en Rusland, met mogelijk minder geopolitieke spanningen tot gevolg. Afhankelijkheid is minder op globaal niveau, maar meer op Europees niveau.

Report interview Shell
11 August 2017, Den Haag
Floris van Hövell, Government relations
Shell kijkt naar de energietransitie wereldwijd en heeft hier analyses over gemaakt. Hieruit blijkt dat die transitie zich op nationaal niveau afspeelt. Toen is er vanuit Shell een focus gekomen op een aantal landen, waaronder Nederland, omdat het zowel upstream als downstream en in de retail in het energiesysteem aanwezig is.

Vanuit Shell is het de overtuiging dat de besluiten in de energietransitie op systeemniveau genomen moeten worden. Er moet dan naar het “grote plaatje” gekeken worden. Het wordt dan heel duidelijk dat elektrificatie gaat gebeuren en een belangrijke rol gaat spelen. Daarnaast krijgt, gelet op de geografie van Nederland en de Noordzee, wind op zee een belangrijke rol. Gericht beleid voor de uitrol van wind op zee is belangrijk voor de energietransitie in Nederland en voor de economie van Nederland.

Als gericht beleid wordt gevoerd op het ruimtelijke ordeningsvraagstuk en naar meerjarig beleid, dan worden er meer investeringen naar Nederland getrokken. Die gaan naar de havens, met aanleverstations, er kan een turbinebouwer komen naar een haven, bijvoorbeeld Rotterdam, Den Helder of de Eemshaven. Deze ontwikkelingen scheppen werkgelegenheid en zorgen voor innovatie.

De andere grote vraag gaat over wat er gedaan moet worden met de opgewekte stroom. Er moet beleid komen dat ervoor zorgt dat het energiesysteem dit aankan, zodat de stroom of meteen geëxporteerd kan worden, of omgezet kan worden in bijvoorbeeld warmte voor de industrie of voor mobiliteit. Dit levert economische kansen op.

De hele energiesector is afhankelijk van het beleid. Het type beleid en energiebron wat het meest gunstig is verschild per regio in de wereld. In Nederland is dan wind op zee belangrijk. Ondanks de energietransitie zal de wereld nog lang afhankelijk zijn van olie en gas.

Shell heeft de ambitie om snel te groeien in de Noordzee regio wat betreft wind op zee. In Duitsland, VK, Denemarken en Frankrijk liggen kansen voor Shell.

Shell wil graag grotere tenders, van enkele gigawatts. Dit kan bijvoorbeeld 5 of 10 gigawatt zijn. Deze tenders worden dan niet gewonnen door 1 partij die 10 GW gaat exploiteren, maar de helft. Deze partij zal dan waarschijnlijk een groot consortium zijn die het risico kan en wil nemen. Daarnaast wordt de andere helft in kleinere stukken verdeeld en aan kleinere partijen aanbesteed. Het idee is dat als er in één keer zo een groot volume wordt getenderd, dat er ook een veel aantrekkelijkere prijs ontstaat door de toeleveringsindustrie, omdat er volume in productie is. Deze kostendaling komt dan doordat er meerjarige opdrachten ontstaat en er meer zekerheid in de markt is. Dit kan oplopen tot 25% kostendaling opleveren.

Daarnaast trekt dit ook veel meer investeringen naar Nederland toe, omdat er meer geproduceerd moet worden.

Volgens Shell zijn deze grote tenders ook nodig om de doelstellingen van rond de 100 GW voor de Noordzee wat betreft windenergie te halen. De huidige hoeveelheid van tenderen is daar niet toereikend voor.

Een risico hier is dat er niet zoveel grote consortia zijn die dit risico kunnen dragen en dat zorgt voor minder concurrentie. Shell en Statoil zijn bijvoorbeeld bedrijven die dit kunnen, maar kleinere bedrijven zijn hier niet altijd even positief over.

Bij dit soort grote projecten moet ook de infrastructuur hier klaar voor zijn, door bijvoorbeeld internationale handel van stroom te faciliteren.

Als tenders internationaler worden, dan zou dit een goede ontwikkeling zijn. Het kan hier dan gaan om bijvoorbeeld een internationale tender, waarbij een windpark van meerdere landen is. Dit is aantrekkelijk omdat het dan over grotere schaal van projecten gaat. Er kunnen wel nog wat hindernissen zijn tussen verschillende landen om dit te realiseren.

Niet alleen wind op zee is van invloed op het energiesysteem. Wat er daarnaast gebeurd met het kolen- en gasgebruik is hier ook van invloed op. Hier moet rekening gehouden worden bij de ontwikkeling van wind op zee, want dit is van invloed of de geproduceerde stroom erbij komt in het aanbod of in plaats van de stroom die is opgewekt door kolen en gas.

Demand-response, opslag en omzet van stroom naar warmte of gas zijn energievormen waar Shell naar kijkt. Dit is voornamelijk de vraagkant van de keten. Bij een grote ontwikkeling in de opwekkingskant, zal dit ook van invloed zijn in de vraagkant van de keten. Hoe meer geïntegreerd dit wordt, hoe interessanter het is voor een bedrijf als Shell.

Een technologische trend die gezien wordt is het ontwikkelen van grotere turbines. Dit heeft ook invloed op de funderingen en de kabels. Van het type funderingen en dynamo's wordt ook nog een ontwikkeling verwacht. Turbines van de wind af (2B-energy) en floating turbines zijn technologieën waar nog veel van wordt verwacht.

Als er geen subsidie meer is en de elektriciteitsprijs is laag, dan zijn er kleine marges bij de opgewekte elektriciteit. Dan wordt het risico groter dat als de kosten stijgen dat het niet meer aantrekkelijk is om het windpark in bedrijf te hebben. Dit kan van invloed zijn op doorvaart en medegebruik, want dit kan ervoor zorgen dat er dingen kapotgaan, door bijvoorbeeld aanvaringen en door ankers. Dit veroorzaakt dan hogere kosten.

Hoe drukker het wordt op de Noordzee, hoe meer rekening gehouden moet worden met doorvaart en medegebruik. Dit moet van tevoren meegenomen worden in het ontwerp, zodat er maatregelen genomen kunnen worden. Er is veel druk op de kosten en kostenverlaging. Door medegebruik en doorvaart kunnen dus de kosten weer omhooggaan.

Aan de andere kant zorgt het ontwikkelen van wind op zee op grote schaal er weer voor dat de kosten omlaaggaan.

Een grote kans voor Nederland is dat als er in Nederland een slimme oplossing wordt gevonden van hoe er met veel stroom omgegaan kan worden, dat deze kennis geëxporteerd kan worden en dat het kan bijdragen aan handel. Nederland is hier een geschikt land voor, want het is een land met een klein oppervlak wat dichtbevolkt is.

Een andere kans is er op het gebied van de elektriciteitsprijs. Als deze laag is, dan kan het ongunstig zijn voor de ontwikkelaars, maar het is wel interessant aan de gebruikerskant.

Een energie-eiland is een erg aantrekkelijke optie, maar dat wordt wel pas aantrekkelijk rond 2050.

Verslag interview Stichting de Noordzee
Guido Schild
17 augustus 2017
Bij de huidige plannen zal tot 2023 zo'n 2% en tot 2030 zo'n 5% van de Noordzee voor windenergie wordt gebruikt. Schattingen voor de lange termijn liggen tussen 10 en 15 procent Tussen de windturbines is nog wel veel ruimte dan. Er is een risico dat als er aan alle gevestigde belangen van scheepvaart, olie- en gas, visserij, tegemoet wordt gekomen dat windparken dan alleen nog gebouwd kunnen worden op plekken die vanwege bijzondere ecologische waarden worden beschermd.

Mitigerende maatregelen
Op lange termijn spelen er ook effecten die er nu ook al zijn, zoals geluid voor zeezoogdieren, aanvaringen van zeevogels en habitatverlies. Een aantal van deze effecten zijn technisch te verhelpen. De verwachting is dat voor onderwatergeluid de geluidsnorm steeds strenger wordt, naarmate er meer wind op zee komt. Dit zal op termijn resulteren in een overstap op methoden waarbij nauwelijks of helemaal geen geluid wordt geproduceerd. Er zijn nu al een aantal vogelsoorten die in de knel komen door de ontwikkeling van wind op zee. Naarmate er meer wind op zee komt, kunnen er ook anderevogelsoorten problemen ondervinden. Het is nog niet bekend of vogels die nu vermijdingsgedrag vertonen op termijn gewend zullen gaan vertonen of dat ze gewend raken aan de windturbines.

Wanneer mitigatie van effecten niet meer mogelijk is, maar de uitrol van wind op zee toch doorgaat, dan zal er misschien compensatie moeten plaatsvinden. Hoe dit eruit kan zien verschilt per soort, maar voor vogels kan bijvoorbeeld gedacht worden aan het beter beschermen van broedkolonies beschermen of het nemen van maatregelen die de voedselbeschikbaarheid verbeteren. Dit kan ervoor zorgen dat een soort weerbaarder wordt.

Er zijn ook effecten die plaatsvinden door de schaalvergroting van wind op zee en niet zozeer door de techniek. Als er op heel veel plaatsen hard substraat neergezet wordt, dan kan het zo zijn dat soorten zich meer gaan verspreiden en hun habitat uitbreiden in andere delen van de Noordzee. Dit kan positief of negatief zijn, afhankelijk van of de soort gewenst is of juist een invasieve exoot.

Samenwerking
Het zal goed zijn om op dit gebied meer Europees samen te werken en de Noordzee als een geheel te zien. De effecten kunnen dan beter in kaart gebracht worden. Voorbeelden hiervan zijn de verspreiding van exoten en de verandering van de visgronden voor de visserij. Op dit moment zijn de meeste natuurorganisatie zoals Stichting de Noordzee vooral nationaal gericht. Er zijn wel onderzoeksinstituten die internationaal en Europees gericht zijn.

Op Europees niveau gelden er nu ook verschillende regels tussen de landen. Het zou goed zijn als de regels van de verschillende landen geharmoniseerd worden voor de Noordzee. Meer samenwerking op gebied van onderzoek, beleid en techniek is zeker nodig.

Er is bij de totstandkoming van de huidige routekaart tot 2023 een enorme stap gezet om te komen tot besluitvorming die gebaseerd is op de ecologie en de hieraan verbonden maatregelen die nu voorgeschreven zijn. De meeste mitigerende maatregelen, zoals geluid beperkende maatregelen, zijn kostbaar. Dit verhoogt de kosten voor installatie, maar is nodig om binnen de ecologische draagkracht van het systeem te blijven.

Technische ontwikkelingen wind op zee
Het installeren van grotere turbines is een trend die speelt. Dit levert voor de ontwikkelaars schaalvoordelen op, maar leidt ook tot minder vogels die aanvaringen hebben met turbines. Dit komt doordat er minder molens nodig

zijn om dezelfde hoeveelheid stroom op te wekken, de turbines staan verder uit elkaar en ze draaien langzamer. Als er meer windmolens komen, dan wordt de kans weer groter dat er vogels tegenaan vliegen.

Een andere interessante technologische oplossing is het stilstandsmechanisme. Dit kan in werking treden bij grote migratie van vogels. Dit moet wel door de overheid bepaald worden.

Er is ook een maatregel dat er een minimale "cut-in speed" is. Dit houdt in dat bij lage snelheden de windturbine stilstaat. Zo worden de vleermuizen beschermd, die juist bij lage snelheden vliegen over de Noordzee.

Naar mate er meer onderzoek gedaan wordt, zullen sommige mitigerende maatregelen wellicht minder streng kunnen worden. Aan de andere kant zal de geluidsnorm alleen maar strenger worden, want die is gebaseerd op een bepaald aantal turbines dat geïnstalleerd wordt in een bepaalde tijd. Naarmate dit tempo en het aantal turbines omhoog zal gaan, zal de geluidsnorm aangescherpt worden, want in kortere tijd zal er meer geluid geproduceerd worden. Dit is nodig om de bruinvis te beschermen.

Als redelijkerwijs verwacht kan worden dat dit in de toekomst aangescherpt zal worden door de overheid, dan moet dit op tijd doorgegeven worden aan het bedrijfsleven, zodat zij hier rekening mee houden. Door hier zekerheid over te geven, dan kan hierop geïnnoveerd worden en materieel aangepast worden.

Cumulatieve effecten
Cumulatieve effecten zullen vooral optreden bij de bruinvis. Deze soort is verspreid over de hele Noordzee en legt grote afstanden af. Op het moment dat er op veel plekken gebouwd wordt in de Noordzee met veel geluid, dan is er tijdelijk een groot deel van de Noordzee ongeschikt als habitat. Dit kost ze veel energie en ze moeten misschien naar plekken waar minder voedsel is en waar meer bijvangst risico's zijn.

Daarnaast cumuleert onderwatergeluid van wind op zee met geluid van andere sectoren: seismisch onderzoek, militaire sonar en scheepvaart.

Cumulatieve effecten treden ook op bij vogels. Bij meer windparken zullen er steeds meer vogels sterven door botsingen met windturbines. Op een gegeven moment komt er dan een kritiek punt, met mogelijk uitsterving van (lokale) populaties tot gevolg.

Om cumulatieve effecten tegen te gaan is een systeembenadering nodig, waarbij verschillende vormen van beleid en effecten op elkaar afgestemd zijn.

In de operationele fase zijn er voornamelijk boven water problemen met de ecologie, met name dus met de vogels. Onder water zou elektromagnetische straling van de exportkabels van windparken een probleem kunnen vormen voor haaien, roggen en bepaalde vissoorten. Hier is nog niet veel over bekend. Mocht dit inderdaad een groot probleem zijn, dan kan dit opgelost worden door de kabel dieper onder de grond te leggen. Dit leidt wel tot hogere kosten.

Kansen natuur en wind
Windparken op zee bieden unieke kansen voor de natuurontwikkeling. Dit komt doordat er geen bodemberoerende visserij mag plaatsvinden, er wordt dus niet met sleepnetten gevist. Dus na de bouw van een windpark wordt de bodem 20-25 jaar met rust gelaten in een windpark. Er is nu minder dan 1% van de Noordzee het hele jaar door beschermd tegen bodemberoering. Windparken bieden dus kansen om meer gebieden te beschermen tegen bodemberoering. Dit beschermt met name de soorten die zich in en op de bodem vestigen, maar biedt ook kansen voor vissoorten als kabeljauw en zeebaars en voor verschillende haaien- en roggensoorten.

Daarnaast is er door de windturbines meer hard substraat, de palen en de steenbestortingen van windturbines. Deze bieden habitat en aanhechtingkansen voor soorten. Onderzoek naar aanhechting bij olie- en gasplatforms en scheepswrakken tonen aan dat er een enorme biodiversiteit rondom deze installaties ontstaat. Soorten die niet op zand voorkomen, maar wel op hard substraat gaan zich er dan vestigen zoals schelpdieren, anemonen en koud water koraal. Daarnaast bieden deze structuren ook schuilplaatsen voor vissoorten. Zeezoogdieren kunnen dan ook weer profiteren van een verhoogd voedselaanbod.

Om deze kansen optimaal te benutten kan er actieve natuurontwikkeling plaatsvinden in windparken. Er kan in de ontwerpfase al rekening gehouden worden met de habitatfunctie van de steenbestorting. Materiaalkeuze en de vorm kunnen hierin meegenomen worden. Als het windpark er staat, dan kunnen er tussen de windparken nog extra harde structuren geplaatst worden in de vorm van kunstriffen.

De grootste kans ligt bij de platte oester. Deze bouwen complexe riffen, ze zijn voedsel voor andere soorten: vissen en vogels en deze kunnen in de Noordzee leven. Qua kosten, kansrijkheid en toegevoegde waarde voor het ecosysteem is dit een van de meest aantrekkelijke opties voor natuurontwikkeling.

Windparken kunnen ook gebruikt worden voor bepaalde experimentele vormen van gebruik die dan later buiten de windparken commercieel toegepast kunnen worden. Dit zou bijvoorbeeld voor de duurzame visserij van toepassing kunnen zijn. Visserij op krabben en kreeften met passieve kooien of vallen is hier een voorbeeld van. Met schelpdierkweek en zeewierkweek kan ook geëxperimenteerd worden. Dit kan gunstig zijn voor de voedselvoorziening en heeft een lage impact op het ecosysteem. Hier is ambitie en regie vanuit de overheid voor nodig en veel samenwerking tussen de stakeholders.

Report interview Eneco
19 August 2017, Rotterdam
Gerard Harder, Sr. Advisor Regulatory Affairs

In het verleden is er een "hogedrukpan proces" geweest, om de ontwikkeling van wind op zee te bevorderen en een nieuw systeem te ontwikkelingen om de doelstellingen te halen. Dat is toen gelukt. Toen ging de ontwikkeling van wind op zee snel, zoals met de kostprijsreductie. Deze ontwikkeling kan doorzetten in de toekomst, met de kostprijsreducties als driver.

Er is hierdoor een nieuwe sector ontstaan in Nederland, met een heel concreet perspectief. Hierdoor zal de kostprijsreductie doorzetten, maar in welke snelheid is onduidelijk. Het is hierdoor nog onduidelijk of een nulsubsidie-situatie er komt. Door de ontwikkelingen rondom de kostprijsreducties, kan er eerder gesproken worden over een volwassen industrie dan in eerste instantie werd gedacht. Dit is ook te merken aan bedrijven die eerst niks met wind op zee te maken hadden, die toch gaan omschakelen naar die sector.

Het draagvlak in de maatschappij is hierdoor ook veel beter. Zowel binnen de industrie, de overheden, de bedrijven en burgers. Hierdoor ontstaat er meer steun voor gericht overheidsbeleid. Bij een stabiele uitrol zal dit alleen maar toenemen. De burger bij de energietransitie betrekken kan zorgen voor meer draagvlak onder de bevolking.

Bij een toename van windenergie op zee, zal het ruimtelijke vraagstuk een steeds grotere rol gaan spelen, zoals bij de vissers. Medegebruik bij windparken is een risico. Bodemvisserij kan ervoor zorgen dat de kabels van de windparken losgetrokken worden. Bij de komende parken moet hiernaar gekeken worden en op welke manier.

De vraag of er nulbiedingen komen, is ook afhankelijk van rente, staalprijzen, bouwtermijnen en turbine innovaties. Dit zijn lastige parameters om te voorspellen voor ontwikkelaars.

Eneco heeft al ervaring met meerdere windparken op de Noordzee. Eneco wil deze ervaring benutten en dus heeft het een strategisch doel om meer wind op zee te ontwikkelen. De rol van Eneco is niet alleen assets bouwen, maar ook de elektriciteit naar de markt brengen. Het vraagstuk wat er met die elektriciteit gedaan wordt is belangrijk. Elektrificatie, koppeling met warmte, opslag, netverzwaring, prijsontwikkelingen spelen hierbij een grote rol en deze ontwikkelingen worden versterkt door grootschalige wind op zee.

Andere duurzame technieken: wind op land en warmte, die komen door grootschalige wind op zee onder druk te staan, want het NIMBY-effect speelt minder een rol bij wind op zee. Bij zon-pv installaties valt dit effect mee. Participatie speelt hierbij een grote rol. Niet alleen in overleg, maar ook bij financiële participatie van burgers. Dit creëert meer draagvlak bij de burgers voor de energietransitie in het algemeen.

De Noordzee is een unieke plek, druk vaarverkeer, veel haveninfrastructuur en een ondiepe zee. Vanuit deze regio kan de wereldmarkt bediend worden en dit iets wat nagestreefd moet worden bij de industrie en de overheid.

Het markt ontwerp moet veranderen. Prijsfluctuaties en de neergaande lijn in de prijs moet beheersbaar blijven. Power-to-gas en opslag kunnen hier een rol in spelen. Nieuwe marktintegratiemodellen zijn belangrijk. Hier wordt ook naar gekeken in de EU. Een zorg is hier dat het een overgangsperiode zal kennen met ups en downs.

Het grootste risico is de politieke instabiliteit, hierdoor is er geen zekerheid voor een robuust beleid voor wind op zee en de uitrol hiervan. De uitrol hangt nog steeds sterk aan de coalitie die in de regering zit.

Appendix VIII: Wind map

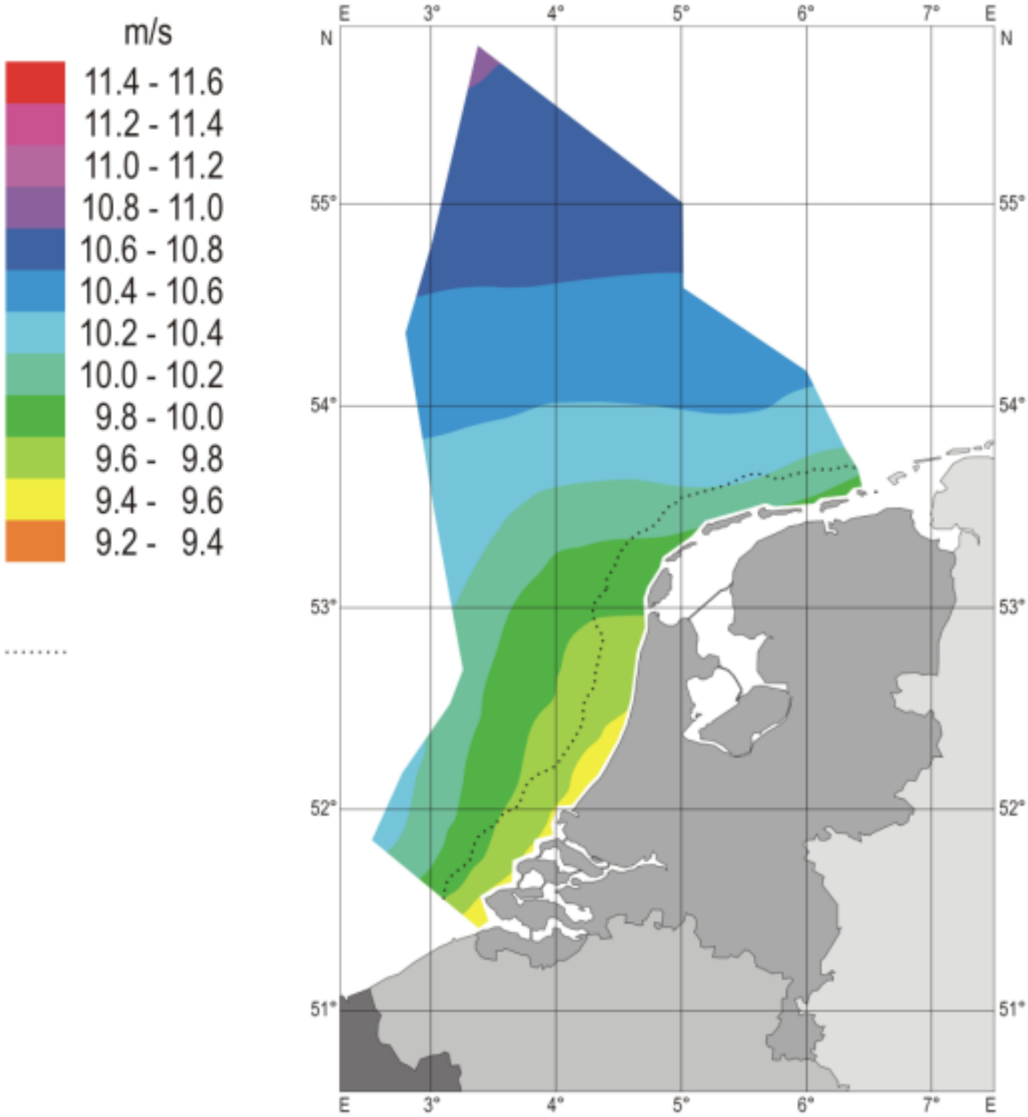

Figure 12 Average wind speed Dutch EEZ (source: ECN, 2017)

Appendix IX: Water depth North Sea

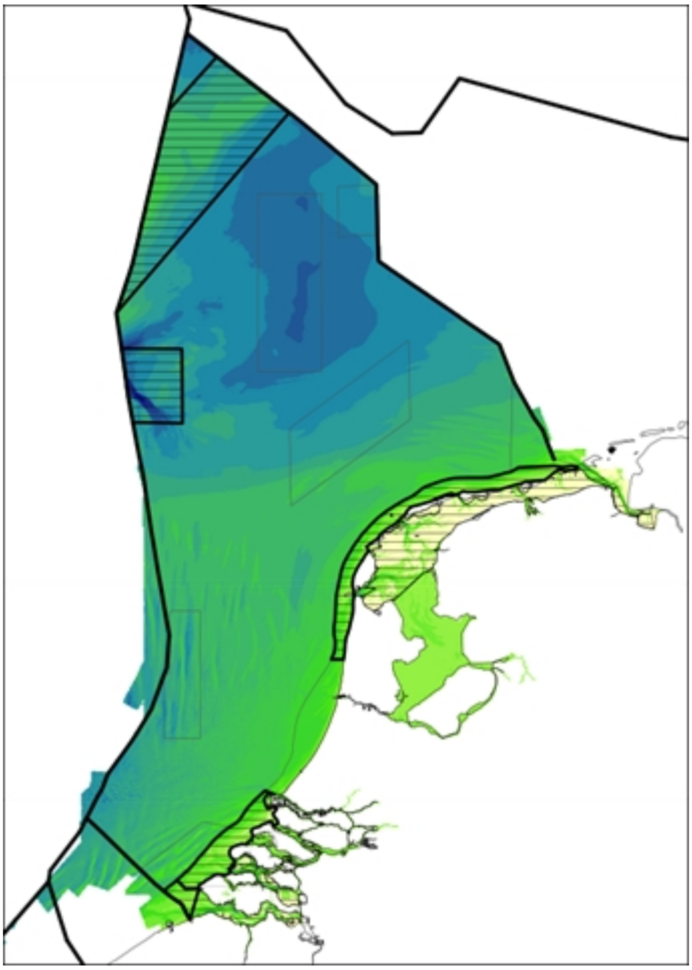

Figure 13 Water depth Dutch EEZ (source: Stichting Anemoon, 2017

Legend:

Yellow: 0-5 meters

Green: 5-35 meters

Blue: 35-60 Meters

Appendix X: Ranges indicators

Ranges	--	-	0	+	++
Availability					
Security of supply					
Total energy demand	< 1850 PJ	1850 – < 1979 PJ	1979 PJ	>1979 – 2195 PJ	>2195 PJ
In the NEV2016 a range is given for the final energy use. 1979 PJ is the projection of the final energy use. Minimum of the range is 1850 PJ. Everything between 1850 and 1979 PJ is negative. Everything below that is very negative. The maximum in the range is 2195 PJ. Everything between 1979 and 2195 is positive. Everything above is very positive (Schoots et al., 2016).					
Total energy supply	< 1500 PJ	1500 – <2052 PJ	2052 PJ	>2052 – 2500 PJ	>2500 PJ
The range is based on the energy use in the year 2015. The total energy supply is derived from the total energetic energy use. The 0-effect is based on the current Dutch energy policies. The negative effect is based on the more ambitious policies. The very negative is everything below that. The positive effect is based on the difference between the zero effect and the negative effect. This is about 100 PJ, so the same amount is used for the positive effect. Everything above that is very positive (Centraal Bureau voor de Statistiek, 2016).					
Total electricity demand	< 355 PJ	355 – <385 PJ	385 PJ	>385 - 415 PJ	> 415 PJ
The range is based on projections in the NEV 2016. In the NEV2016 a range is given for the final electricity use. 385 PJ is the projection of the final electricity use. The minimum of the range is 355 PJ. Everything that is between 355 and 385 PJ is negative. Everything below that is very negative. The maximum in the range is 415 PJ. Everything between 385 and 415 PJ is positive. Everything above that is very positive (Schoots et al., 2016).					
Total electricity supply	< 322 PJ	322 PJ – <422 PJ	422 PJ	>422 - 525 PJ	> 525 PJ
The range is based on projections in the NEV 2016. The 0-effect is based on the current Dutch energy policies. The negative effect is based on the more ambitious policies (Schoots et al, 2016). The very negative is everything below that. The positive effect is based on the difference between the 0-effect and the negative effect, about 100 PJ, the same amount is used for the positive effect. Everything above that is very positive.					
Production					
Availability of renewable energy resource	0-3 Bft. And 9-12 Bft	>3-4.5 Bft.	>4.5-6 Bft.	>6-7.5 Bft.	>7.5-9 Bft.
The availability of renewable energy source relates to the average wind power. When higher than 3 Bft. and lower than 9 Bft., turbines can generate electricity. Higher wind speeds result in more electricity generation. So, higher wind speeds are more positive. When turbines cannot generate, it is very negative (Deltawind, 2017).					
Increase rate of renewable energy generation capacity	<0.5 % per year	0.5 - <1% per year	1% per year	>1 - 1.5% per year	>1.5% per year
The negative effect is based on the current Dutch energy policies, the very negative effect is below that, and the positive effect is based on the ambitious energy policies (Schoots et al., 2016). The very positive effect is everything above that.					
Total installed electricity generation capacity	< 40 GW	40 – <55 GW	55 GW	>55-70 GW	>70 GW
Projections in the NEV2016 are until 2035. In 2030-2035, the projected capacity is increases to 55 GW. The increase is around 1 GW per year. This is extrapolated until 2050. If the increase is between 0-1 GW per year it is positive, if it is more than that, it is very positive. A same amount is used for the negative effect, when the generation capacity decreases (Schoots et al., 2016).					
Dependency					

Ranges	--	-	0	+	++
Self-sufficiency	Only import	Net import: more import than export	Import and export are balanced	Net export: more export than import	Only export.
A country can import energy, but it can also export energy. It is very negative if there is only energy import in a country, negative when it is a net importer, but when there is also sometimes export of energy, and zero when the imports are about the same as the exports in energy, or when there is no import or export in a country. It is positive, when there is net export, but also sometimes import. It is very positive when there is only export.					
Diversification					
Diversification of ownership of energy companies	Only national operating companies	Mainly national companies, and local initiatives	National operating companies, European companies and local initiatives.	Mainly national operating energy companies that also operate international, and EU companies, local initiatives.	National companies that operate nationally or internationally, international companies, EU companies, and local initiatives.
Local initiatives are only regional operating, such as energy cooperations. National operating companies are companies that only operate in the Netherlands and the Dutch EEZ. National companies that also operate internationally are Dutch companies that also have business outside of the Netherlands. International companies are companies from outside the EU. At the moment there are national and international energy companies in the Netherlands, that also operate international and there are local initiatives. It is expected that this will stay about the same for 2030-2050, but that the local initiatives will increase (Schoots et al., 2016). This is the 0-effect. If it becomes more diversified, it is positive, less diversified is negative.					
Geographic dispersion of energy facilities	Centralized and onshore	Mostly centralized, a bit decentralized, and mostly onshore	Mostly centralized, also decentralized, onshore, and offshore close to shore.	Decentralized, onshore, and offshore close to shore	Decentralized, onshore, and offshore close to shore and far-offshore
Geographic dispersion can be onshore and offshore. The 0- effect is based on the plans until 2030 (Schoots et al, 2016). More geographic dispersion is positive, less dispersion is negative.					
Share of renewable energy in total primary energy supply	0 - <25%	25 - <50%	50%	>50 - 75%	>75 - 100%
The share of renewable energy can be between 0 and 100%. The percentages are evenly distributed across the ranges. The higher the share, the better					
Affordability					
Price stability					
CO_2 price	<20 euros per tonne	20 - <40 euros per tonne	40 euros per tonne	>40 - 120 euros per tonne	>120 euros per tonne
The projection in the NEV2016 is a price of 40 euros per tonne CO_2, but it has a bandwidth with a minimum of 20 euros per tonne and a maximum of 120 euros per tonne (Schoots et al, 2016). This is also the chosen bandwidth for this price indicator. Above 120 euros will be a very positive effect, below 20 euros will be a very negative effect					

Ranges	--	-	0	+	++
Electricity price volatility	High peaks, and low peaks: sometimes negative, sometimes extremely high prices.	High volatility: High peaks and low peaks, always positive.	Current level of volatility	Decrease in volatility	Predictable electricity price.
Electricity price volatility creates uncertainties for investors. When the volatility increases, uncertainty increases and this is negative. A decrease, it is positive (World Energy Council, 2015).					
End-use energy prices by fuel	Oil: >145 $/barrel Gas: >0.51 $\$/m^3$ Coal: >140 $/tonne	Oil: >101-145 $/barrel Gas: >0.36-0.51$\$/m^3$ Coal: >95-140 $/tonne	Oil: 101 $/barrel Gas: 0.36 $\$/m^3$ Coal: 95 $/tonne	Oil: 56 - <101$/barrel Gas: 0.21 – <0.36$/m3 Coal: 50 - <95 $/tonne	Oil: <56 $/barrel Gas: <0.21 $\$/m^3$ Coal: <50 $/tonne
When the prices increase, it is expensive in a country to buy fuels, so that is negative. A decrease is positive. For the decrease the prices for 2020 are used from the NEV2016 (Schoots et al., 2016). A higher decrease is very positive. The same amount is used for the decrease of the prices.					
Electricity price	< 40 euros per MWh	40 – <65 euros per MWh	65 euros per MWh	>65 – 110 euros per MWh	> 110 euros per MWh
The projection in the NEV2016 is 65 euros per MWh in 2035, but it has a bandwidth with a minimum of 40 euros per tonne and a maximum of 110 euros per tonne. This is also the chosen bandwidth for this price indicator. Above 110 euros will be a very positive effect, below 40 euros will be a very negative effect.					
Access & equity					
Grid connection	Grid connection is not guaranteed for suppliers	Only radial connections	Radial connections and interconnectors	Hybrid infrastructure: radial connections to shore, connections to an offshore grid	Fully integrated offshore grid
The range is based on how advanced the system is, especially how advanced the offshore grid is and the interconnections. It is expected that an offshore grid will bring financial and technical benefits to the EU power system (North Sea Grid, 2017). Therefore, the more the system moves to an integrated offshore grid, the better it is.					
Rate of electrification	No electrification in all three sectors.	Little electrification in 2 out of 3 sectors.	Electrification in 2/3 out of three sectors	Electrification in all three sectors.	High electrification rate in all three sectors.
The ranges of the rate of electrification are based on the different sectors that can be electrified. These are the industry, transport and heating. In the NEV 2016 is expected that heating and transport will have electrification (Schoots et al., 2016). High rates are positive .If all three have electrification it is also positive, if none of these have electrification it is very negative.					
Site conditions	> 120 meters	>50 - 120 meters	50 meters	25 - < 50 meters	0 -< 25 meters
Site conditions are based on the water depth. The size of the waves increase, when the water depth increases, making it more difficult to reach the site by boat and different turbine support structures are needed. The bandwidths are based on types of offshore wind turbine foundations, see figure 8 (Roland Berger, 2013). The monopile is the current technique and is to a maximum of 50 meters. Therefore, this is the 0- effect.					

Ranges	--	-	0	+	++
Affordability					
Balancing costs	>6 euros/MWh wind	4-6 euros/ MWh wind	2-<4 euros/MWh wind	0-<2 euros/MWh wind	<0 euros/MWh wind
The balancing costs are based on the results of from estimates for the increase in balancing costs due to wind power, with a maximum of 6 euros/MWh wind (EWEA, 2015). Everything above is very negative. An increase of 4-6 euros is the upper part, and is negative. 2-4 euros is expected to be the increase for many countries, this is the 0. Everything below that is positive. If the costs decrease it is very positive.					
Construction costs	> 20% increase	>0 – 20% increase	No increase/decrease	>0 – 20% decrease	>20% decrease
Ranges of the rates are based on the study of clean energy pipeline and are in MW. The maximum range for 5 years is a decrease or increase of 20%. It is expected that in the long term the increase or decrease will flatten (Clean Energy Pipeline, 2014). There is no data for the expected construction costs in 2030-2050. Therefore, the assumption is made for the benchmark that has no increase or decrease. Decrease in costs is positive, increase is negative.					
Investment risk	High upfront cost, high operational costs	High upfront cost, low operational costs	Medium upfront cost, medium operational cost	Low upfront cost, high operational costs	Low upfront cost, low operational costs
The range is based on the CAPEX and OPEX of energy projects. The CAPEX are made upfront. The OPEX are related to the working/operating capital (Noothout et al., 2016).					
Marginal cost of electricity power generation	Decrease without price spikes	Decrease with price spikes	No increase or decrease	Increase without price spikes	Increase with price spikes
Marginal costs can increase, decrease or stay the same. Price spikes can also increase or decrease. Price spikes and increase in the price both make it more attractive to invest in electricity generation capacity. No price spikes and a decrease in the marginal price make it less attractive to invest in generation capacity, because it is difficult to make a return on the investments. Investments in generation capacity are important for the energy security in a country.					
Transmission costs for electricity	> 250,000.00 euros/MW for 1 km cable	250,000.00 – > 179,500.00 euros/MW for 1 km cable	179,500.00 euros /MW for 1km cable	109,000.00 - < 179,500.00 euros / MW for 1 km cable	<109,000.00 euros / MW for 1 km cable
There is no data on the transmission costs for the period of 2030-2050 for offshore energy. The range is based on the investment costs in the connection from an offshore wind farm to the shore as presented by Jepma & Schot (2017). There are two cases. For one case the costs are 109,000.00 euros per km for 1 MW. This is the positive amount. For the other case, it is 250,000.00 euros per km for 1 MW. This is chosen as the negative amount. The neutral will be the average of these two.					
Technology Development & efficiency					
Innovation & research					
Construction technique	Current techniques	1 out of 4	2 out of 4	3 out of 4	All
Needed improvements in the construction technique are: reduction of noise during the construction phase, assembling the wind turbines onshore, building nature inclusive, construct for shared use of wind farms is possible. The highest score is when there is an improvement in all 4 elements or more. The lowest score is when it stays the same and there is no improvement.					

Ranges	--	-	0	+	++
Research budgets for renewable sources of energy	< 65 million euros	65 – 130 million euros	130 million euros	130 – 260 million euros	> 260 million euros
Currently, the most important programme for renewable energy research and energy innovation is from the Topsector Energie for the Netherlands. It gives around 130 million euros of subsidy for projects annually (RVO, 2017d). An increase is positive. If it doubles, it is considered very positive. A decrease is negative. Less than half the amount it is now, is very negative.					
Technological innovation	No innovation	Innovation in 1-2 aspects	Innovation in 3-4 aspects	Innovation in 5-6 aspects	Innovation in >6 aspects
Innovations can take place in several parts of the system. Innovations can take place in the following aspects: capacity of wind turbines, wind farms, transmission grid, construction technique, predictability of wind power, materials, power-to-X, energy storage, flexibility of the system etc. Innovation in more aspects of the system is positive.					
Efficiency					
Energy intensity	> 2% increase per year	>0 – 2% increase per year	0% change per year	2 – >0% decrease per year	> 2% decrease per year
The expected change in energy intensity is between 0 and 2 % increase or decrease for OECD countries. This range is chosen, because all countries of the OECD fall within this range with their current policies (Centraal Planbureau, 2011). It is positive when it decreases, because there is less energy needed to create the same, or more economic value in a country. It is very positive when the decrease is above 2%. An increase is negative, because there is more energy needed to create the same economic value. It is very negative when it is more than 2%.					
Safety & reliability					
Frequency of interruption of supply	> 15 per year	11-15 per year	6-10 per year	1-5 per year	0 per year
The frequency of interruption of supply per year in the Netherlands is based on the number of interruptions of supply between 2009-2012. The frequency decreases and the best year is 2012, with only 8 interruptions in supply, this is in the 0-effect. Steps of 5 are chosen for the frequency in interruptions, because the range varies between 8 and 18 in the years of 2009-2012 (IEA, 2014c). 1-5 interruptions per year is better than the period 2009-2012, and if there are no interruptions this is very positive. Between 11-15 is negative. More is very negative.					
Operation and maintenance strategies	Separate O&M per wind farm	Combined O&M per wind farm	Combined O&M for the wind farms in the portfolio of the operator.	Clusters for O&M in the Dutch EEZ.	Clusters for O&M in the North Sea, international.
O&M costs are ~30% of the LCOE costs for offshore wind. More efficient concepts reduce the LCOE. Geographical clustering of offshore wind farms creates synergies (Roland Berger, 2013)					
Predictability of power supply	Intermittent sources, no curtailing possibilities	Intermittent sources, curtailing possibilities	Intermittent sources, but constant power supply	Constant power supply source, slow response	Constant power supply source, quick response
Predictability is important to match supply and demand. Intermittent sources make it difficult to predict the supply. Curtailing is possible when there is an oversupply, to match supply and demand. A quick response to match supply and demand is desired (IEA, 2013).					
Resilience					

Ranges	--	-	0	+	++
Generation adequacy	0 - <25%	25 - <50%	51 - <75%	75 - <84%	84% - 100%
Ranges in generation adequacy are represented by the maximum generation reserve capacity as a percentage of peak demand. Import capacity is also considered in this percentage. In 2012 the reserve margins with interconnection are 84 %, which is "very healthy" according to the IEA. This is within the range of very positive. The benchmark will decrease in generation capacity compared to 2012, due to more renewable energy implementation (IEA, 2014c).					
System adequacy	<8%	8 - <17%	17%	>17 - 34%	>34 %
Ranges in system adequacy are based on the interconnection capacity as a percentage of the domestic generating capacity. In 2012, this was 17% (IEA, 2014c). It is very positive if it doubles. It is very negative when it decreases to half that percentage. In 2050 the benchmark is 9800 MW interconnection capacity and 55 GW production capacity, so 17% system adequacy.					
Investment & employment					
Average rate of return on energy investments	> 15 years	13 – 15 years	12 years	8 – <12 years	< 8 years
The ranges in the average rate of return are based on the subsidy time of the SDE+. This can be 8, 12, or 15 years. The more years it takes to make the return on investments, the higher the investment risk is. Therefore, a shorter time is positive and a longer time is negative (RVO, 2017e).					
Direct employment	<6500 fte per year	6500 – <11.000 fte per year	11.000 fte per year	>11.000 - 22.000 fte per year	>22.000 fte per year
Expected direct employment opportunities are around 11.000 fte per year in 2020. This will be used as the 0 effect for the benchmark (NWEA, 2017a). More than double per year between 2030-2050 will be very positive and when it is in between that it is positive. Less than half of that, 6500 or lower, will be very negative. Everything in between that will be negative.					
Indirect and induced employment in the industry	< 20.000 fte per year.	20.000 – <40.000 fte per year	40.000 fte per year	>40.000 - 80.000 fte per year	>80.000 fte per year
Expected indirect and induced employment opportunities are around 40.000 fte per year in 2020. This is used as the benchmark (NWEA, 2017a). When it is more than double per year between 2030-2050, it is very positive and when it is in between that it is positive. When it is less than half of that, 20.000 or lower, it will be very negative. Everything in between that will be negative.					
Investment in electricity transmission capacity	No investments in grid	Investments in connecting wind farms to shore	Investments in connecting wind farms to shore & in interconnections	Investments in Dutch onshore & offshore grid & interconnections	Investments in international offshore grid & in onshore grid
In the benchmark, it is expected that the interconnection capacity will increase and that there will be more wind farms connected to the grid. Therefore, this is the 0. More investments in the grid are better for the implementation of offshore wind and to deal with the variability, therefore, this is positive.					
Operation and maintenance costs	Very high O&M costs	High O&M costs	Medium O&M costs	Low O&M costs	Very low O&M costs
This is related to: technology development, efficiency in maintenance, and offshore conditions (Roland Berger, 2013). Very positive: when all these elements are good, very low O&M costs. Positive: 2/3 are good: low O&M costs. Neutral: 2 of these elements score medium, 1 scores good. This will be the benchmark. Negative: 1 scores badly, the others medium. Very negative when 2 of these elements score badly or all of them score badly, this results in high O&M costs.					

Ranges	--	-	0	+	++
Environmental & social sustainability					
Land / water use					
Available areas	5.000 – <10.000 km^2	10.000 – <15.000 km^2	15.000 – <20.000 km^2	20.000 – <25.000 km^2	25.000 - 30.000 km^2
The Dutch EEZ is approximately 58.000 km^2, of which approximately 28.000 km^2 is used for functions other than wind energy. In a very positive situation all remaining space will available for wind energy. This is 30.000 km^2. When using the indicator of 6 MW/km^2 for required space, as it is now, the minimum required space is 5.000 km^2 for 30 GW (Noordzeeloket, 2017e). The ranges of available space will be evenly distributed between 5.000 – 30.000 km^2. The assumption for the benchmark is that 15.000-19.999 can be used.					
Required space for renewable energy option	< 3 MW/km2	3 – <6 MW/km^2	6 MW/km^2	>6 – 12 MW/km^2	> 12 MW/km^2
Currently, the required space is 6 MW/ km^2. If the MW/ km^2 go down, it is negative, because more space is needed (Noordzeeloket, 2017e). If they increase, it is positive. It is very positive if they more than double the MW/ km^2. It is very negative when they decrease to less than half of it.					
Size of installation	300 m	250 m	220 m	200 m	150 m
The size of the installation is related to the rotor diameter. Currently, it is expected that the largest will be around 220 m (IPCC, 2012). This is the benchmark. Smaller turbines with the same capacity are more efficient, therefore that is positive.					
Climate change					
CO_2 emissions from electricity sector	>64.8 – 48.6 Mton	<48.6-32.4 Mton	<32.4-16.2 Mton	<16.2 - >0 Mton	0 - <0 Mton
For the 0 effect of the NEV2016 in 2035 will be used, which is 32.4 Mton (Schoots et al, 2016). The very positive effect is when there are 0Mton CO_2-emissions. The positive scenario, will be in the middle of those: that will be 16.2 Mton. For the very negative effect it is double the number of NEV2016: 64.8 Mton. The negative scenario is in between: 48.6 Mton CO_2-emissions.					
CO_2 reduction targets	<40% CO_2-reduction	41 – 79% CO_2-reduction	80 – 95% CO_2-reduction	95 – 100% CO_2-reduction	>100% CO_2-reduction
The 0-effect is based on ambitious of the Dutch government and the EU, 80-95% CO_2-reduction by 2050. In an ambitious setting this can increase to 100% reduction, this is the positive effect. In a very ambitious setting, this can be more than 100%, using by CCS. It is very negative when the reduction targets stop after 2030. The reduction target for 2030 is 40%; everything below this target is very negative. Everything in between 40% and the 80-95% target that is the current policy, is negative (Ministry of Economic Affairs, 2016a).					
Presence of climate change goals and targets	No climate agreements are respected	Only national climate agreements or only international agreements are respected.	Current international + national agreements are respected (lower limit of targets)	Ambitious current international + national climate agreements are respected	New, more ambitious international climate goals and targets after the Paris agreement
National and international goals and targets are set in the Paris Agreement, Energy Agreement for Sustainable Growth, Energy Report, and Energy Agenda. They present ranges: for example 80 – 95% reduction (Government of the Netherlands, 2013b; Ministry of Economic Affairs, 2016b; Ministry of Economic Affairs, 2016a). It is positive when the ambition is 95% reduction and 0 if the ambition is 80% reduction. Additional, more ambitious, targets will be very positive. It is negative when not both national and international agreements are respected. It is very negative when neither are respected.					

Ranges	--	-	0	+	++
Regulation & governance					
Governance					
Number of electricity system regulators	No regulators	Only national regulator	National regulator and international cooperation of national regulators	National regulator and international regulator	International EU regulator
The ranges vary from no regulation in countries to regulation on an EU level, in an integrated market. The benchmark is the situation as it is currently. International regulation will be positive, the markets will be fairer.					
Permit procedures	No development permits after 2030	Only national small-scale development permits	Medium-scale and small-scale national development permits.	Large-, medium-, and small-scale national development permits.	Large-, medium-, and small-scale international and national development permits
Small-scale is permits of 350 MW each. This based on the permits now (RVO, 2017f). Medium permits is between 350 MW and 1 GW. Large-scale is >1GW permits.					
Provision of priority grid access to renewable energy	Only renewable energy access when conventional is too expensive	Conventional energy gets priority	Grid access according to merit order	Priority access based on sort of renewable source	Priority access all renewable sources.
The benchmark is the merit order, because that is the situation currently (Mulder, 2017). It is not likely that it will change for the benchmark.					
Ranges	**--**	**-**	**0**	**+**	**++**
Responsibilities	There is no responsibility	National responsibility	North Sea countries responsibility	North-West European responsibility	European responsibility
The development of offshore wind in the North Sea can have different levels of responsibility. Only national responsibility is negative, because there is no international alignment between projects. North Sea countries are the countries that are developing offshore wind in the North Sea: UK, Belgium, France, the Netherlands, Germany, Denmark, and Norway. North-West European countries are also the North Sea countries, and Luxembourg, Austria, and Sweden. European responsibility is for the whole EU.					
Trade & regional interconnectivity					
Amount of transnational electricity trading	<30 TWh/year	30 - <60 TWh/year	60-<80 TWh/year	80 – 160 TWh/year	>160 TWh/year
Export of electricity will be between 40 – 50 TWh per year for the benchmark. Import will be between 20 – 30 TWh per year. (Schoots et al., 2016). This means that there will be 60-80 TWh/year. An increase is positive, and a decrease is negative. For this, double and half are used.					

Ranges	--	-	0	+	++
International cooperation	No cooperation	Cooperation on 1-3 elements	Cooperation on 4-6 elements	Cooperation on 6-9 elements	Cooperation on >9 elements
Several elements of international cooperation are: harmonization of legislative procedures and regulatory procedures, planning and coordination of wind farms in the North Sea, international system operations, construction, interconnection, system integration, maintenance & operation of wind farms, ecology, shared use, dealing with other North Sea users, etc. As the benchmark is chosen to use a situation where international cooperation is on half of these elements.					
Total interconnection capacity	< 8250 MW	8250 MW – <9800 MW	9800 MW	> 9800 MW	> 9800 MW + connection to other countries
In 2030, interconnection capacity will facilitate electricity trade between the Netherlands and: Germany, Belgium, Denmark, UK, and Norway. If it increases between the Netherlands and these countries, it is positive. If there will also be a connection to another country, it will be very positive. If it stays on the level of interconnection capacity of 2020, it will be negative. If it stays below that, interconnection capacity it will be very negative, because this means that interconnection projects under construction will stop (Schoots et al., 2016).					
Competition & markets					
Electricity market design	National market	National market + market coupling: volume only	National market + market coupling: volume & price	North-Western European electricity market	European electricity market
Ranges of the electricity market design are based on the integration of the EU market. A more integrated market is better for integration of renewable energy in a system and to create more stable electricity prices (IEA, 2014c). The benchmark will have the same situation as it is now: a national market, with market coupling in volume and price.					
Market share of largest three electricity suppliers	> 70%	60 – 70%	50 – <60%	40- <50%	<40%
The market share of the three largest electricity suppliers was 59% in 2009 (IEA, 2014c). This is the benchmark. A higher percentage leads to less competition in the market and is therefore negative. The range is divided by steps of ten percent.					
Renewable energy subsidy	No subsidy or tax incentives	National subsidy or tax incentives	National subsidy and tax incentives	National+EU subsidy & tax incentives	International European support scheme
The benchmark has a national subsidy and tax incentives. This is based on the current situation and there this will probably no change in the near future. EU subsidies are positive, this gives the offshore sector, renewable energy generation, and technology development a boost. International coordination creates more efficient research and developments.					

TABLE 53: OPERATIONALIZATION OF THE RANGES OF THE INDICATORS