REPORT

Large scale development of wind energy in the Netherlands, far offshore and after 2023

Results of sector consultation and input for policy agenda

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Author(s): Suzan Tack, Erik Zigterman, Joris Truijens, Patrick van Dijk, Michiel Muller and Huygen van Steen

Drafted by: Suzan Tack

Checked by: Erik Zigterman

Date / initials: EZi, 19/6/2016

Approved by: Erik Zigterman

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<thead>
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<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>AEP</td>
<td>Annual Energy Production</td>
</tr>
<tr>
<td>CAPEX</td>
<td>Capital expenditure</td>
</tr>
<tr>
<td>DBFMO</td>
<td>Design, Build, Finance, Maintain and Operate</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DNB</td>
<td>De Nederlandse Bank</td>
</tr>
<tr>
<td>EEZ</td>
<td>Exclusive Economic Zone</td>
</tr>
<tr>
<td>ETS</td>
<td>Emission Trading System</td>
</tr>
<tr>
<td>FID</td>
<td>Financial Investment Decision</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GW</td>
<td>Giga Watt</td>
</tr>
<tr>
<td>LCoE</td>
<td>Levelized Cost of Energy</td>
</tr>
<tr>
<td>LFAC</td>
<td>Low Frequency Alternating Current</td>
</tr>
<tr>
<td>MW</td>
<td>Mega Watt</td>
</tr>
<tr>
<td>SER</td>
<td>Sociaal Economische Raad</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Operation &amp; Maintenance</td>
</tr>
<tr>
<td>OPEX</td>
<td>Operational expenditure</td>
</tr>
<tr>
<td>OWF</td>
<td>Offshore Wind Farm</td>
</tr>
<tr>
<td>PPP</td>
<td>Public Private Partnership</td>
</tr>
<tr>
<td>RES</td>
<td>Renewable Energy Sources</td>
</tr>
<tr>
<td>RVO</td>
<td>Netherlands Enterprise Agency</td>
</tr>
<tr>
<td>TKI Wind op Zee</td>
<td>Top consortium for Knowledge and Innovation Offshore Wind</td>
</tr>
<tr>
<td>TSO</td>
<td>Transmission System Operator</td>
</tr>
<tr>
<td>VRE</td>
<td>Variable renewable energy</td>
</tr>
<tr>
<td>WTG</td>
<td>Wind Turbine Generator</td>
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</table>
Executive Summary

Offshore wind energy is one of the renewable energy sources for the Netherlands with large potential. Currently the Levelized Cost of Energy (LCoE) of offshore wind energy is much higher than the market price of energy. In order to develop (part of) this large potential in offshore wind, identifying the optimal way to generate further reduction of the LCoE is key. That requires vision and setting policies for developing larger scale offshore wind for the period 2023-2030/50.

In this setting, the Netherlands Enterprise Agency (RVO-Ministry of Economic Affairs) and TKI Wind op Zee have commissioned Royal HaskoningDHV and Ecofys Consultancy to conduct an Offshore Wind Sector Consultation. The consultation focussed on assessing the possibilities for further and continued cost reduction. The objective is to outline the (political) offshore wind agenda for the coming years and to determine the required actions in the short and medium term.

The Netherlands has established in its National Water Plan several wind energy areas in the Dutch Economic Zone of the North Sea (see Figure 4). One of these wind energy areas is named IJmuiden Ver and is located about 80 to 100 km from the west coast of The Netherlands. The wind energy area IJmuiden Ver has the potential for large scale implementation; the area is sufficient large for more than 5000 MW.

The offshore wind sector is a relative young sector. As the industry matures, competition and standardisation are expected across the value chain. Standardisation is expected to serve as cost lever in the same way as it has done for onshore wind. Construction of more than 100 offshore wind turbines per year in the Dutch EEZ is expected to influence investment decisions in the supply chain in the Netherlands to build additional production capacity.

Currently the Netherlands Government is executing a coordinated and stable roll-out wherein the Government organises the required studies (i.e. geotechnical study), the permits (Kavelbesluit) and the grid connection. Continuity of this roll-out as well as a significant project pipeline are a precondition for cost reduction of offshore wind in the Netherlands. The Dutch government should ensure a stable roll-out program both in capacity (MW) as in planning (years). This is needed to increase competition in the market and to ensure scale and growth effects. A stable roll-out program will eventually reduce the day-rates and the risk premium, which will accordingly reduce the LCoE.

At the start of this Sector Consultation the following tender scenarios were considered: (1) continuing with 2*350MW per year for 7 years; 4 tenders of 1250MW for 4 years and 1 tender of 5000MW for 4 years. When comparing the three scenarios:

- The base case, or business-as-usual, with 2*350 MW tenders each year, for a period of 7 years, is considered too small to utilize the economies of scale.

- Phased-approach, with four tenders of 1250 MW, to be constructed in the following 4 years, is considered optimal, because it allows for learning effects, standardization, competition, incremental improvement, mass production effects and continued cost reduction.

- Single-approach, where 5000 MW is tendered to one large consortium at once to be constructed in 4 years, is considered too large, due to uneven factory loading in the market.

During the consultation process a fourth roll-out scenario is suggested:

- Anchor tenant model. This model transferred to the IJmuiden Ver area would mean a roll-out of 1250 MW per year over a period of 4 years: a large consortium could be responsible for 625 MW per year,
developing the industrial infrastructure. While the rest of industry can piggy bag from smaller tenders dividing the other 300 to 350 MW per year.

Project size will increase with large scale implementation of offshore wind. When the size of a project increases, the risk profile increases accordingly. However, a stable roll-out program will lower the risk profile. On the other hand, larger projects create increased advantages of economies of scale and growth in the market and supply chain. Most respondents in the Sector Consultation agreed that anything less than 1250 MW per year will be too small to capture the economies of scale and cost savings on current and future technologies. The mitigation of the risks will depend on the structure of the subsidy and the agreements between developers and the government, e.g. requirements regarding the construction period. A stable, low risk legal framework will result in cost reduction due to financing advantages and competition for financing.

It is expected that a potential LCoE reduction of 6% can be realised when a roll-out of 1250 MW annually for a period of four years is applied in large scale development of offshore wind energy in, for instance, IJmuiden Ver. The cost reduction potential of the Wind Turbine Generator (WTG) and foundation costs have the largest impact, since these are relatively large contributors to the LCoE.

A detailed long term vision should be developed on the most cost efficient way to integrate large scale additional production of offshore wind energy into a high voltage grid on the North Sea connected to the surrounding countries and the required means (including interconnection) to ensure grid stability.

A hub- or work island for may lead to considerable cost reduction for grid development and wind farm development (CAPEX and OPEX). The government would need to designate a specific spatial offshore area to allow for the construction of such an island. This could become part of a wind energy area already designated, such as IJmuiden Ver.

Collaboration with our neighbouring countries (United Kingdom, Belgium and Germany) is essential to achieve large scale implementation of offshore wind in the North Sea and the required cost reduction. In particular, collaboration related to the electrical grid (interconnectors), the construction of a work island in IJmuiden Ver and the harmonization of subsidy regimes could result in a substantial cost reduction which may not be possible when each country acts on its own. However, inappropriate regulations and political willingness were mentioned as limiting factors for cooperation.

A political decision on the future pipeline and tender process should be taken as soon as possible as it allows for optimal planning, the necessary preparations in the supply chain, options for standardization and accordingly cost reduction. There is also an urgent need to formulate a broader policy on the Dutch energy transition beyond the horizon of the current Energy Agreement. Policy development is therefore required on two levels:

- Energy Agreement 2.0, providing a plan on how the construction of offshore wind will continue after the end of the current Energy Agreement in 2023 without a gap. This would mean that before the end of 2017 the Energy Agreement 2.0 should be approved to arrange for new offshore tenders by 2019.

- A longer term policy towards 2030/2050 providing a wider vision on the Dutch approach to the transition towards a low carbon economy.
1 Setting the scene

1.1 Offshore wind energy essential for Dutch energy transition

In 2023 16% of the total Dutch energy demand is to be provided by renewable sources. By 2030 the Netherlands has to meet the European climate target for sustainable energy of 27%. By 2050 the European Union aims to phase out coal, oil and later on natural gas. The Netherlands supports this strategy towards the energy transition (Ministerie van Economische Zaken, 2016). For this energy transition toward 2050, it is in the political, economic and public interest of the Netherlands to fully develop the domestic renewable energy sources:

- on a scale and pace that meets the required CO₂ objectives,
- maximizes the pace at which technology becomes competitive, and
- maximizes socio-economic benefits, such as jobs and industrial production.

The Dutch energy transition will come at significant cost. The question for Dutch policy makers is how to smartly shape the energy transition; how can the Netherlands meet the climate targets and at the same time generate economic development? As identified by De Nederlandse Bank (DNB) the optimal approach would be focus on (i) investment in renewable energy sources, (ii) energy savings, and (iii) investment in bridge technology (Schotten et all, 2016).

Offshore wind energy is one of the renewable energy sources for the Netherlands with large investment potential. The Dutch part of the North Sea is particularly well endowed for largescale offshore wind development, due to relative low water depths, sound wind availability and closeness to the market. The Dutch part of the North Sea has a potential of >50GW installed power. In order to develop (part of) this large potential in offshore wind, identifying the optimal way to generate further reduction of the Levelized Cost of Energy (LCOE) is key, because currently market prices are much lower. That requires vision and setting policies for developing larger scale offshore wind for the period 2023-2030/50.

1.2 Offshore wind sector consultation into large scale development of wind energy far offshore after 2023

1.2.1 Objective

The offshore wind sector consultation into large scale development of wind energy far offshore after 2023 has been commissioned by RVO and TKI Wind op Zee. The consultation has been conducted by Royal HaskoningDHV and Ecofys Consultancy, assessing possibilities for continued cost reduction. The objective is to outline the (political) offshore wind agenda for the coming years and to determine the required actions in the short and medium term.

As defined in the Agreement on Energy for Sustainable Growth (2013), hereafter called the Energy Agreement
RVO
Netherlands Enterprise Agency (RVO) encourages entrepreneurs in renewable, agrarian, innovative and international business. It helps with grants, finding business partners, know-how and compliance with laws and regulations. The aim of RVO is to improve opportunities for entrepreneurs and strengthen their position. The Agency works at the instigation of ministries and the European Union.

Royal HaskoningDHV
Royal HaskoningDHV takes great pride in being a leading consultancy in the renewable energy industry for nearly 30 years. We work on a large variety of projects, from large and technically challenging offshore wind projects to community onshore wind and tidal development giving us a unique appreciation of the priorities and needs of different scale projects.

Ecofys
Ecofys is a leading consultancy in renewable energy, energy & carbon efficiency, energy systems & markets and energy & climate policy. The unique synergy among these areas of expertise is the key to its success. Ecofys creates smart, effective, practical and sustainable solutions for and with public and corporate clients all over the world.

1.2.2 Approach
This sector consultation investigates the potential for large scale implementation of offshore wind in locations further offshore and its impact on the LCoE. The basic assumptions of this consultation are summarized in Table 1.

Table 1: Basic assumptions

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Basic assumptions of sector consultation</th>
</tr>
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<tbody>
<tr>
<td>Large scale</td>
<td>4 to 5 GW</td>
</tr>
<tr>
<td>Location</td>
<td>Dutch Exclusive Economic Zone</td>
</tr>
<tr>
<td>Far offshore</td>
<td>Distance of at least 80 km from shore</td>
</tr>
<tr>
<td>Designated wind energy area</td>
<td>To continue the roll-out directly after the current Energy Agreement a legally destined offshore wind energy area is available for 4 to 5 GW, e.g. wind energy area IJmuiden Ver (IJmuiden Ver is roughly 1000 km²)</td>
</tr>
</tbody>
</table>

Royal HaskoningDHV and Ecofys conducted an offshore wind sector consultation to tap into the large amount of knowledge and expertise available in the offshore wind sector and other sectors with relevant expertise. The consultation was conducted via the Delphi method, for more detail on this approach, reference is made to Appendix 1. The sector consultation existed of two written rounds of consultation, which allowed participating organisations to discuss and prepare internally, before sending in their response. This was followed by an integration workshop, where the outcomes of the consultation were presented and followed by more detailed discussions.

The consultation brought together a broad group of experts; a number of 46 organisations participated, ranging from offshore wind developers, manufacturers, constructing companies, to investors and policy makers. The consultation resulted in valuable and enthusiastic response throughout the offshore wind sector. This shows the right timing of this sector consultation and the need for constructive measures in the short and medium term.
Under the current Energy Agreement a cost reduction of 40% is foreseen. After 2023 autonomous innovation in technology and learning effects are expected to continue to bring costs down. Figure 1 presents the LCoE of an wind farm with a Financial Investment Decision (FID) in 2010.

This sector consultation is looking for the differentiators in cost reduction as a result of large scale roll-out of wind energy far offshore. In the consultation three scenarios were compared:

- The base case, or business-as-usual, with 2*350 MW tenders each year, for a period of 7 years, according to the current way of tendering where the contract is awarded to the lowest bidder.
- Future phased-approach, with four tenders of 1250 MW, to be constructed in the following 4 years.
- Future single-approach, where 5000 MW is tendered to one large consortium at once to be constructed in 4 years.

The options for cost reduction could materialise due to

- Technological changes
- Market and supply chain developments
- Changes in financing of the wind farm
- Policy.

The sector consultation focussed on these four aspects.

### 1.3 Readers guide

This report presents the outcomes of the sector consultation into large scale development of wind energy far offshore after 2023. This first chapter provides the background to the sector consultation, its objective and approach. Chapter 2 presents the results of the consultation for technology as driver for cost reduction. In Chapter 3 the results are presented for market & supply chain as driver for cost reduction. In Chapter 4 finance aspects are included. Chapter 5 gives the results for the policy aspects. The paragraphs in
Chapter 2 to 5 each focus on a different cost reduction aspects relevant for subsequently technology, market & supply chain, finance and policy. Each paragraph starts with the indication whether or not the respective cost reduction aspect is a key differentiator of large scale development of offshore wind far offshore. Chapter 6 concludes with the key input for the policy agenda.
2 Technology as driver for cost reduction

Technology development and innovation in a relatively young and fast growing market is an ongoing process and will continue independently of strategic choices in policy, legislation or specific roll-out scenarios. In a recent TKI Wind op Zee study (TKI Wind op Zee, 2015) five cost reduction drivers have been identified within the offshore wind technology: wind turbines, transportation & installation, foundations, operations & maintenance and electrical infrastructure. These could lead to a combined 35% reduction of the LCoE by 2020. The question in this sector consultation is how much cost reduction potential could be created after 2023 by these five cost reduction drivers?

2.1 Wind turbines and farm

Cost reduction differentiator
Large scale development of offshore wind in the Netherlands is no differentiator for cost reduction related to wind turbines.

Consultation outcomes
Worldwide there is an autonomous general trend towards larger turbines and this is expected to continue with or without the Dutch offshore development. There is an autonomous trend towards larger turbine sizes (>10MW), which will increase the trade-off between annual energy production (AEP) and loads; reliability and serviceability. This is expected to further reduce operation & maintenance (O&M) and wind turbine generation (WTG) costs, being equal or lower for larger turbines. To this end, research is focussing on: blade structure design, bearing technologies and electrical systems within the turbine.

Figure 2: Technology development: from 30kW to 7MW in 35 years. Source: Siemens Wind Power

2.2 Transportation and installation

Cost reduction differentiator
Large scale development of offshore wind in the Netherlands is a differentiator for cost reduction related to transportation and installation. Cost reduction is expected in the range of 2 to 5% on WTG and foundation installation.
Consultation outcomes

The outcomes of the consultation show that there are opportunities to optimize the logistical process of installation through standardization, interface management, and increased efficiency. More specifically, the outcome shows that cost reduction could be achieved through:

- When a stable roll-out is guaranteed, harbours will increase their investment in multipurpose facilities or dedicated terminals. The offshore wind sector is now considered a short-term client for harbour facilities; work is often completed within 6 months. It was indicated that each of the three scenarios (base case, 4*1250 MW and 1*5000 MW) would be an interesting scenario for the investments in multipurpose facilities or dedicated terminals. A cost reduction potential of 20% on harbour costs was mentioned.

- Usage of the same installation vessel with barges for various components.

- Feeding of the installation vessel instead of using the installation vessel for transportation.

- Ability to work between 6 and 6 instead of 24 hours a day allows for optimal planning of transportation and installation which increases efficiency.

- Management of interface risks2 and planning can be optimized and started earlier in the process of offshore wind farm (OWF) development. This will reduce waiting time and will allow for cost savings.

All these aspects will reduce the installation time per foundation/turbine and accordingly reduces costs. Scale is needed for optimization (coordination and structuring) of the installation flow. The more positions/foundations/turbines are included in one project, the more efficient the installation process becomes and the more cost reduction is achieved. The installation of larger projects will require more manning and equipment. There will be savings in relation to one-off costs (mobilization, demobilization) and there will be benefits from a larger learning curve and the possibilities to maintain trained staff.

The future developments towards larger turbines, requires larger foundations, and accordingly larger equipment which is able to transport and install these larger turbines, e.g. roll-on roll-off technique. The market will be able to supply this equipment, but requires 1 or 2 years to respond with the necessary development and production. To determine the required investment it is necessary for developers to look 3 to 5 years ahead.

Quote from sector consultation:

“It is important to bear in mind that a 1250 MW wind farm in 2023 will consist of more or less the same number of positions as for instance Gemini does today. Furthermore, from an installation perspective construction in 2023 will have limited challenges compared to installation to date. Building a 5000MW wind farm over a period of 4 to 5 years, after 2023, is doable, while taking installation risk into consideration.”

A number of consulted organizations indicated that scale is needed for optimization, but up to a certain limit. Congestion and supply shortage may occur (temporary 1 or 2 years) during the time that suppliers are making the necessary investments required for increased production.

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2 Interface risks arise where a project depends on interaction between two or more stakeholders. Physical interfaces will often occur on the same or adjoining construction sites where different contractors are engaged in the design and construction of works that ultimately connect or closely interact on completion. Relationship interfaces may arise from interactions between stakeholders in a construction project, such as contractors on site, the local community, utilities, regulatory bodies and governments. Relationship interfaces between project participants may relate to site access and work conditions, while community stakeholders may be concerned with environmental impacts on for instance ecology or landscape.
Aspects for further study
Based on the outcomes of the consultation the following aspects related to transportation and installation have been identified for further study:

- Opportunities for upgrading one of the Dutch harbours to a multipurpose harbour.
- One of the organizations consulted indicated that the delaying factor of current offshore wind farm development is the construction of sea cables, which is a cost increasing factor that should be looked into.

2.3 Foundations

Cost reduction differentiator
Large scale development of offshore wind in the Netherlands is no differentiator for cost reduction related to the development and construction of foundations.

Consultation outcome
The general trend expected to continue, independent of large scale roll-out of offshore wind in the Netherlands, is the development of XL monopiles or jackets. The monopile is considered as the less expensive option for the Dutch situation. Small improvements are expected to drive the cost further down, such as the connection between the monopile and the transition piece. The jacket technology is younger than the monopile and expected to become more competitive in the future. Compared to the current prices of jacket foundations a cost reduction of 40% is expected for an installed jacket, but this is a development independent of large scale roll-out of offshore wind in the Netherlands.

Large scale development of offshore wind might however allow for site specific technologies. For instance the development of new foundation techniques might become feasible with large scale implementation of offshore wind in the Netherlands.

Other general trends, independent of large scale roll-out of offshore wind in the Netherlands, which are expected to lower the costs of foundation and benefit competition include:

- Certification of alternative installation techniques (vibrating; drilling) and adoption of more economical certified design rules (e.g. by lower noise levels)
- Increased tailoring of environmental precaution measures.

The type of foundations has a high impact on the final investment case and will also influence the tower cost, the installation time, the risk related to installation, etc. However, it is important to stress that it is impossible to foresee the actual foundation demand after 2023. This demand depends on interlinked uncertainties including cost, supply chain, technological development of foundation types and installation methods and development of wind turbines.

2.4 Operations & Maintenance

Cost reduction differentiator
Large scale development of offshore wind in the Netherlands is a differentiator for cost reduction related to operation & maintenance (O&M). Cost reduction is expected in the range of 1 to 5% on O&M related costs.
Consultation outcome

O&M costs are mainly driven by the scheduled service activities and unscheduled maintenance activities per wind turbine generator (WTG). In the current situation, each wind park owner has its own O&M system and dedicated staff.

The results of the consultation show that there are opportunities to optimize O&M resulting in cost savings. More specifically the outcomes of the consultation show that cost reduction could be achieved through:

- Sharing costs, when projects become larger it is expected that the overhead cost (crew vessels, spare part stock, operating centres, etc.) can be shared among owners.
- Services can be combined, interface management optimized both resulting in more efficient planning and cost reduction.

Quote from sector consultation:

“From an O&M perspective a 5000 MW wind farm with one developer could maximize output of investment, e.g. related to the procurement of helicopters and vessels.”

Furthermore, the consultation looked into the potential for extended life design. Some consulted organizations suggest that foundations could be designed to allow for two turbine lifespans (2*25 years), accordingly reducing the CAPEX\(^3\) of an offshore wind farm (OWF) substantially. However, others indicate that foundations are unlikely to be used for 50 years or more. Due to the progress in turbine technology, it is unlikely that turbines 25 years out in the future can be built on the same substructures as the ones being built in the near future, as loads and weight of the turbines might change. It was mentioned that offshore substations, export cables and onshore substations have more potential for extended life design, and accordingly large scale roll-out of offshore wind could be beneficial to drive the costs of these elements of the electrical grid down.

Aspects for further study

Based on the outcomes of the consultation the following aspects related to O&M have been identified for further study:

- The cost reduction potential of O&M aspects is hard to quantify, as it depends on number and size of turbines, site and turbine maturity. It is recommended to conduct case specific LCoE calculations on the potential future sites with assumptions related to turbine technology and maturity, size of the wind farms etc., to determine the potential.
- Potential of extended life design for on- and offshore substations and exports cables.

2.5 Electrical infrastructure

Cost reduction differentiator

Large scale development of offshore wind in the Netherlands is a differentiator for cost reduction related to electrical infrastructure. The cost reduction potential is dependent on new technologies and therefore hard to quantify.

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\(^3\) Capital expenditure (CAPEX) is the cost of developing or providing non-consumable parts for the product or system. Its counterpart, operational expenditure OPEX is an ongoing cost for running a product, business, or system.
Consultation outcome

TenneT is since 1 April 2016 legally responsible for the construction and maintenance of the offshore grid, provide offshore connections to wind farms and transport the electricity to shore\(^4\). In the current situation TenneT is using standard offshore substations of 700 MW and AC-technology\(^5\) for the shore connections.

Once the development of the offshore wind farms under the current Energy Agreement is completed (by the end of 2023 producing roughly 3800 MW), the receiving capacity of the 380kV onshore grid and its sub-stations in the west of the Netherlands (Borsele, Tweede Maasvlakte, Wateringen, Vijfhuizen en Beverwijk) has almost reached its maximum.

Figure 3: Connection of offshore wind farms to onshore grid, current situation in the Netherlands. Source: TenneT

The outcomes of the consultation confirm that, when considering large scale roll-out of offshore wind, the key challenge is where to and how to transport the electrical power. The onshore grid in the western part of in the Netherlands has limited additional capacity to allow for transport of 4000 or 5000 additional MW offshore wind capacity after 2023. Key elements in the onshore grid development are:

- Planning of the closure of the coal power plants\(^6\)
- Increased electrification of society (electric cars, electric heating and electric cooking, etc.) and on the other hand increased efficiency, which is expected to result in a stable electricity demand.
- Sharp increase of decentralised power generation (solar, wind farms, thermal storage, etcetera).

Onshore shortage in grid capacity is therefore expected. And hence: the onshore integration of offshore power should have a significant impact in deciding on exact roll out of offshore wind (location and timing).

To achieve minimum costs per MW, the power rating of cables must be as high as technically feasible. To date, cables transporting 1200MW are commercially available, using DC at 320kV. This can be increased further by using higher voltage levels or even gas insulated lines. The outcome of the consultation shows that the use of 380 kV AC and/or 220 kV AC is not optimal for OWFs of 1200 MW or more.

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\(^4\) TK 34401, Wijziging van de Elektriciteitswet 1998 (tijdig realiseren doelstellingen Energieakkoord), as accepted by Parlement on 18 February 2016 (Tweede Kamer) and 22 March 2016 (Eerste Kamer)

\(^5\) Alternating current (AC) versus Direct current (DC), or Low frequency AC (LFAC)

\(^6\) In the Energy Agreement (2013) it has been decided to close down five old coal power plants. Additional closing down of two coal power plants is considered to accelerate the reduction of CO\(_2\) emissions.
In the current situation TenneT uses AC infrastructure to transport the power from the OWFs to shore. When considering large scale roll-out further offshore (4*1250MW or 1*5000MW) the use of second generation DC infrastructure for transportation might be more cost effective. The cost reduction is expected to be in the range of 30 to 40%, due to: lower volumes, less weight, reduced installation time, lower transmission losses and higher transmission capacity.  

Quote from sector consultation:

“Large scale roll-out could create opportunities for:
- Load monitoring equipment: using the dynamic rating on export cables, which results in more installed power and options to operate export cables on higher average loads.
- Peak sharing by buffering / storage of energy at high production and export stored energy at times of lower production, resulting in more production capacity through the same infrastructure.”

It is expected, that the DC transformer stations will have an optimal capacity of up to 1200 MW and consist of several distributed building blocks of e.g. 400 MW, which will provide for redundancy. This implies that from a technical point of view wind farms of up to 1.2 GW will be the best solution, dictated by the next generation transmission technology. DC infrastructure is more expensive compared to AC infrastructure, but as a rule of thumb DC becomes cost-effective at cable lengths of more than 80-100km and can reduce the amount of cable used significantly with approx. 1/3 compared to AC. This could reduce the overall cost in case of longer distances. With a fixed long term and EU wide spatial planning, implementation of a DC based grid might be favourable, while AC remains more beneficial at a shorter planning outlook.

One of the consulted organizations indicated that large scale roll out of offshore wind in European waters would require more interconnectors to mitigate the variable production pattern of wind energy. Opinions differ on how interconnection can best be constructed. The interim results of Synergies at Sea (WP1: feasibility study UK-NL) show that opportunities for interconnection could result in cost reduction due to more efficient power generation. The interim results also show that interconnection through OWFs leads to faster and higher returns, with the additional benefit that it creates more redundancy for the OWF. Suitable technologies for integrated solutions exist, but technological developments are needed to bring cost down. However due to a lack of effective market demand the sector does not undertake the necessary R&D.

Aspects for further study
Based on the outcomes of the consultation the offshore grid operator TenneT should prepare a detailed long term vision on the most cost efficient way to integrate large scale additional power of offshore wind energy into the grid and required means (including interconnection) to ensure grid stability. This should include (but is not limited to):

- Technical and financial tipping points of AC, DC and LFAC;
- Opportunities for additional costs reduction, e.g. standardisation;
- Include onshore grid adjustments in LCoE calculations;
- Turbines producing directly at DC, collect at DC-DC boost station feed in to export infrastructure;

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7 It should be noted that in the current LCoE calculations onshore grid adjustments are not included. This study aligns with similar studies in the past, and therefore does not include onshore investments in the LCoE for offshore wind energy.

8 Synergies at Sea is a consortium that investigates the feasibility of an innovative electricity infrastructure on the North Sea. The consortium examines technical solutions, (required) changes to international legislation and regulations and new financing models. The consortium consists of Nuon/Vattenfall, ECN, RoyalHaskoningDHV, Groningen Centre of Energy Law of the University of Groningen, Delft University of Technology, DC Offshore Energy and Energy Solutions, and is coordinated by Grontmij.
- Benefits of interconnection;
- The grid requirements, especially onshore, including the scenarios to be taken into account considering the closure of the coal power plants and the export to the hinterland.

## 2.6 Technology concluding remarks

Technological developments in the offshore wind sector will continue for a large part independent of large scale roll-out in the Netherlands, e.g. development of larger turbines and optimization of monopile, jacket and gravity based structures. However the current large scale roll-out in the Netherlands and the proposed large scale roll-out in Ijmuiden Ver will also have an impact on technological developments in the offshore wind sector. The key differentiators of large scale development of offshore wind in the Netherlands can be found in transportation & installation, O&M and electrical infrastructure.

Cost reduction is expected in the range of 2 to 5% on WTG and foundation installation due to lower mobilization and demobilization costs and increasing learning curve, and standardization, interface management, and increased efficiency which reduces the installation time per turbine. Furthermore, cost reduction is expected in the range of 1 to 5% on O&M related costs due to combined services, interface management, efficient planning. Another opportunity might be the development of new foundation techniques which might become feasible with large scale implementation, e.g. due to the necessary investments in large port facilities.

The key technological challenge is the on- and offshore grid. Opportunities for DC and interconnection require further study and a vision on the international offshore grid development in the North Sea.
3 Market & supply chain as driver for cost reduction

The market and supply chain in the offshore wind sector is eager to respond to strategic choices in policy, legislation or specific roll-out scenarios. In a recent TKI Wind op Zee study (TKI Wind op Zee, 2015) four cost reduction drivers have been identified within the offshore wind market and supply chain; competition, collaboration, scale & growth effects and project management & development. These could lead to a combined 19% reduction of the LCoE by 2020. The question in this sector consultation is how much cost reduction potential could be created after 2023 by these four cost reduction drivers?

3.1 Competition

Cost reduction differentiator
Large scale development of offshore wind in the Netherlands is a differentiator for cost reduction related to competition. The cost reduction potential could reach 25%.

Consultation outcomes
As the sector matures, competition and standardization across the entire value chain is expected. Within the industry, it is the belief that standardization will serve as an important driver for cost reduction, in the same way as it has for onshore wind. Large scale roll-out of Dutch offshore wind will facilitate and speed up standardization.

Governments can influence (i) the speed at which the industry standardizes and (ii) the extent of competition across the value chain. Governments can achieve this by creating transparency and implementation stability through a set program for roll-out, covering a long time period and large capacity offshore wind. A stable roll-out with more volume will:

- Reduce the risk premiums of the financial sector related to offshore wind (lower interest rates for investments),
- Create comfort for new suppliers and developers to enter and invest in the offshore industry
- Reduce day rates as capacity utilization of equipment and staff increases, and accordingly lower costs
- It will enable a long term value chain planning.

Construction of more than 100 offshore wind turbines per year is expected to influence investment decisions in the supply chain at a large scale to build additional production capacity. With an increasing and stable demand, the supply chain will be able to respond within 1 or 2 years. This means that in the first 1 or 2 years shortages may result in higher prices instead of lower prices, which will act as a pull factor for other suppliers to enter the market.

A long-term outlook on stable and substantial volumes is a precondition for investment decisions in the supply chain. The sector is committed to bring the LCoE down. The key for the offshore wind sector is the extent to which it will be successful in getting its cost base down. Its survival and growth will depend on the long-term cost outlook (meaning lowering LCoE till market rates).
One of the consulted organizations suggested an anchor tenant model\(^9\) for roll-out, in order to create cost benefits for the whole sector. The model works as follows: a large consortium is to develop 1 or 2GW per year, for a longer term period of for instance (minimal) five years. In addition 1 or 2 GW per year is left to the market in smaller tenders. The secure pipeline, ensured by the anchor, creates an industrial infrastructure in the market and supply chain. The rest of the sector will profit/piggy bag on the infrastructure already developed by/for the anchor. This level of industrialization in the sector could have the potential to generate a cost reduction of up to 25%.

### 3.2 Collaboration

**Cost reduction differentiator**

Large scale development of offshore wind in the Netherlands is no differentiator for cost reduction related to collaboration.

**Consultation outcome**

The general trend is expected to continue, where strategic alliances (both within the market & supply chain as well as with costumers) are needed to drive the industry forward. Working offshore in a challenging environment does not allow for stand-alone services. Willingness, dedication and transparency on risks and forecasts are essential for sharing services. Best practices from other offshore industries, such as the oil & gas sector are entering the industry (e.g. regarding health and safety) and have potential for further optimization.

A number of consulted organizations indicated that collaboration with our neighbouring countries (United Kingdom, Belgium and Germany) is essential to achieve large scale implementation of offshore wind and the required cost reduction. Collaboration related to e.g. the construction of a work island for O&M could result in a substantial cost reduction which would not be possible when each country acts on its own. However, inappropriate regulations and political willingness were mentioned as limiting factors for cooperation.

### 3.3 Scale & Growth effects

**Cost reduction differentiator**

Large scale development of offshore wind in the Netherlands is a differentiator for cost reduction related to scale and growth effects. Clustering, scale effects, standardisation and supply chain management are expected to reduce cost by 10 to 15%.

**Consultation outcome**

A cost reduction of 10 to 15% is expected from scale and growth effects in the supply chain. Key contributors to this cost reduction are:

- Increased learning curve in the supply chain, expected reduction of 5%
- Mass production optimization, expected reduction 5%.

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\(^9\) Based on approach in the retail industry: the business who is serving as the primary draw to a commercial property acts as the anchor tenant. For example, a large department store located at the end of a shopping centre may be considered the anchor tenant of the centre.
Crucial to achieve this cost reduction potential is long term market stability and product security, so that the supply chain doesn’t have to change too often. Availability of vessels, logistics etc. is crucial. It is not clear yet when the construction of new specific vessels for OWF construction might be cost effective.

Quote from sector consultation:

“The industry is in a classic “chicken and egg” situation: To reduce the cost base, it needs economies of scale. To achieve economies of scale, it needs to make a convincing case that costs can come down. As such, large scale projects and political clarity for projects beyond 2023 will have a great impact on reducing the LCoE.”

Furthermore, the consultation looked into the potential for a hub- or work island. Some consulted organizations suggest that the use of such an island would significantly reduce costs. On the contrary, others indicated that for the benefit of offshore wind alone such an island will not be cost effective. More functions should be combined to make the investment in such an island cost effective. For instance placing substations for the electrical grid on the island could make the island cost effective. The presence of a hub- or work island in a wind energy area might be feasible when considered “infrastructure” and the government is the main stakeholder.

Aspects for further study
Based on the outcomes of the consultation the following aspects related to scale and growth effects have been identified for further study:

- Further detailing of the cost reduction potential of 10 to 15%, in addition to the 5% caused by increased learning curve and 5% caused by mass production optimization.
- Further detailing of the costs and benefits of a hub- work island and of offshore port facilities.

3.4 Project management & development

Cost reduction differentiator
Large scale development of offshore wind in the Netherlands is a differentiator for cost reduction related to project management and development. The cost reduction potential however is expected to be limited and hard to quantify.

Consultation outcome
Larger projects combined with a significant pipeline are expected to reduce project management and development costs. Large projects will reduce the CAPEX as result of fewer tenders and auctions.

Quote from sector consultation:

“As offshore wind will be more and more considered as a permanent solution instead of one-off projects, stakeholder engagement will become increasingly important.”

When looking at large scale development of wind energy far offshore, a number of consulted organizations suggested to reconsider the extent of the project scope. In the UK the project scope currently also includes the transmission asset as an integrated part of the offshore wind farm. In the Netherlands the TSO is responsible for the construction of transmission assets. A number of benefits of both approaches is included in the table below.
Table 2: Benefits of two approaches to extend of project scope (i) development of offshore grid by TSO or (ii) as part of the scope of offshore wind developers, based on outcomes of sector consultation

<table>
<thead>
<tr>
<th>Development by TSO</th>
<th>Development by offshore wind developers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different links can easily be interconnected to provide redundancy and to harvest monetary synergies</td>
<td>Innovation is accelerated</td>
</tr>
<tr>
<td>The construction of cost efficient high power links is easier, which lowers a market entry barrier</td>
<td>Reduction of interface risks</td>
</tr>
<tr>
<td>Lower risk profile of OWF projects</td>
<td>Openness to competitive pressure</td>
</tr>
<tr>
<td></td>
<td>Future technologies (second generation DC) might reduce the need for central coordination by a Transmission System Operator</td>
</tr>
</tbody>
</table>

Aspects for further study
Based on the outcomes of the consultation the following aspects related to project management & development have been identified for further study:

- Extent of project scope when looking at large scale development of offshore wind, recognizing the difference between the current systems in the UK and NL.

3.5 Market & supply chain concluding remarks

As the industry matures, competition and standardisation are expected across the value chain. Standardisation and scale are expected to lower costs in the same way as it has for onshore wind. Construction of more than 100 offshore wind turbines per year are expected to influence investment decisions in the supply chain to build additional production capacity.

The key differentiator of large scale development of offshore wind in the Netherlands are scale and growth effects in the supply chain. Opinions differ on the optimal project size and roll-out. Cost reduction related to scale and growth effects are expected in the range of 10 to 15%, caused partly by increased learning curve and mass production optimization. Long-term presence of a hub- or work island could reduce aspects of the CAPEX and the OPEX, e.g. increased efficiency in transportation and installation and optimization of O&M.

Competition in the market & supply chain benefits from large scale development of offshore wind in the Netherlands. A suggested model for roll-out would be an anchor tenant model. With a roll-out of 2000 MW per year over a period of 5 years, a large consortium could be responsible for 1000 MW per year, developing the industrial infrastructure. While the rest of industry can piggy bag from smaller tenders dividing the other 1000 MW per year. The key challenge for the market & supply chain is to find the preferred roll-out, in order to create as much cost reduction potential as possible.
4 Finance as driver for cost reduction

The way offshore wind projects are brought to the market creates opportunities for potential cost reductions. Opportunities may exist in the scope of works that is offered to the market, the risk allocation in agreements or the structure of tender procedures. All are factors determining the overall risk-profile of the project. Consequently these affect the key driver in costs of wind farm implementation; the cost of financing. Further, this sector consultation also considers PPP options and other forms of tender procedures.

4.1 Risk

Cost reduction differentiator.
Large scale development of offshore wind in the Netherlands is a differentiator for cost reduction related to risks mitigation. 1250 MW was seen as an optimum project size.

Consultation outcome
The LCoE is (partly) determined by the mitigation of project risks (completion risks, financial risks and project contract/structure risks) and how to best insure the residual risk. The residual risk is best borne by the party who can insure this risk at the lowest price. When a stable roll-out (in MW and years) is guaranteed by the government, the risk profile of projects will reduce and accordingly the LCoE.

Comparing the base case with the two future scenarios (base case, 4*1250 MW and 1*5000 MW), the project size will increase with large scale implementation of offshore wind. When the size of a project increases, the risk profile increases accordingly. The main reasons being:

- Increased singular project risk
- Unnecessary single project burden on balance sheets of contractors, banks and utilities

On the other hand, larger projects bring advantages in economies of scale and growth in the market and supply chain. To gain insight in the risk profile and changes related to increasing project size, the base case is compared to the future scenario of 4*1250MW on a number of risk aspects, see the risk matrix below.

<table>
<thead>
<tr>
<th>Risks</th>
<th>Base case</th>
<th>4*1250MW</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion risks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical/technical (e.g. ground, latent defect, technology and design risk, foundations)</td>
<td>0</td>
<td>-</td>
<td>Advantages due to standardization, reduces risk when a proper PPP is set up, however independent of size of the OWF.</td>
</tr>
<tr>
<td>Legal (e.g. change in law and permitting risk)</td>
<td>0</td>
<td>-</td>
<td>One kavelbesluit for wind energy areas IJmuiden Ver. Reduces legal risks when a proper PPP is set up, however independent of size of the OWF.</td>
</tr>
<tr>
<td>Financial (e.g. cost overrun and delay)</td>
<td>0</td>
<td>0</td>
<td>Remains the same</td>
</tr>
<tr>
<td>Force majeure risk</td>
<td>0</td>
<td>+</td>
<td>Larger projects, larger impact</td>
</tr>
</tbody>
</table>
**Project related**

<table>
<thead>
<tr>
<th>Risks</th>
<th>Base case</th>
<th>4*1250MW</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Financial risks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market price risk</td>
<td>0</td>
<td>+</td>
<td>Will be equal, but volume will increase. Hence, risk will increase</td>
</tr>
<tr>
<td>Exchange rate risk</td>
<td>0</td>
<td>0</td>
<td>Remains the same</td>
</tr>
<tr>
<td>Interest rate risk</td>
<td>0</td>
<td>+</td>
<td>Larger projects, longer time frame, larger risks</td>
</tr>
<tr>
<td>Inflation risk</td>
<td>0</td>
<td>++</td>
<td>Risk will increase due to longer time frame and stress on the market</td>
</tr>
<tr>
<td>Tax risk</td>
<td>0</td>
<td>0</td>
<td>Remains the same</td>
</tr>
<tr>
<td><strong>Project contract/structure risks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-contracts</td>
<td>0</td>
<td>+</td>
<td>Larger, more contracts needed, risk increases</td>
</tr>
<tr>
<td>Design</td>
<td>0</td>
<td>- -</td>
<td>Learning effects reduce risk</td>
</tr>
<tr>
<td>Construction and engineering</td>
<td>0</td>
<td>- -</td>
<td>Learning effects reduce risk</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Interface</td>
<td>0</td>
<td>+</td>
<td>These need to be managed by contracts and if these get bigger effectively interfaces get bigger</td>
</tr>
<tr>
<td>Bankability</td>
<td>0</td>
<td>-</td>
<td>Risk spread across larger number of banks</td>
</tr>
<tr>
<td>Execution/delivery</td>
<td>0</td>
<td>-</td>
<td>Learning effects reduce risk</td>
</tr>
</tbody>
</table>

+ + Risk large increase 0 Risk remains the same - - Risk large reduction
+ Risk small increase - Risk small reduction

Most consulted organizations indicated that a phased approach with projects of 1000MW to 1250MW per year would be preferred to lower the risk profile. The following reasons were mentioned:

- With an increasing project size, the risk profile increases. The liquidity in the market to finance one large project might be an issue, the risk mitigation is surely expected to be an aspect of concern.
- The larger the project, the more equity input is required, limiting the number of eligible parties in the marketplace.
- Projects require guarantees on a company's balance sheet, the larger the project the less companies will be able to allow for its size.
- Since it will take quite some years to fully develop and construct a 5000MW project, it will be very hard to bid the right price at time of tender. Due to lack of visibility on the cost development/technology evolution it is quite likely that the bid price will be too high compared to what it could have been in case of e.g. four consecutive tenders.
- The uncertainties on technological development, from the financial investment decision to actual inauguration of the last turbines, would increase the risk premiums and thus make the financing of a 5000MW windfarm more expensive.
- The larger the projects, the fewer competitors can compete in the bid. Only a very limited number of developers would be able to close a financial investment decision on a 5000MW windfarm. While projects up to 1250MW require companies that are financially solid and that have experience with offshore wind, there are more market players that can meet these requirements. The competition among developers would decrease dramatically.
The government faces the risk that if the winning developer fails, it can be difficult to engage with a new developer. If a 5000MW project would fail, it would have very serious repercussions on the entire offshore wind supply chain.

Quote from sector consultation:
“"A 5 GW project might work: with a two-step system similar as in the UK. In that case several 5 GW zones would be handed out in a short time frame, after which the developers will be able to compete with projects of up to 1.2 GW in auctions. The developers are free to develop the 5 GW zones when they want to (within limits) and where they want to (i.e. similar to the development of the big zones in UK: East Anglia, Hornsea, Dogger Bank etc.) It would be up to the developer to decide when to participate in an auction and with which part of the big zone. This would leave the required flexibility to the developer, the selection of best sites to the market, provide for competition in annual auctions and would incorporate the latest cost evolutions in the bids. However, given the total size of the Dutch offshore wind market and the current spatial planning on the Dutch North Sea it may be unlikely the authorities are willing to hand out several 5 GW zones.""

The optimum project size is a trade-off between harvesting the synergies of having very large-scale offshore wind farms and ensuring an entry barrier sufficiently low to guarantee competition. From a cost perspective it is impossible to tell exactly what the tipping point will be past 2023. Most respondents agree that anything less than 1250MW will be too small to capture the economies of scale and cost savings on current and future technologies.

Additional study
Based on the outcomes of the consultation the following aspects related to finance risks have been identified for further study:

- It needs to be determined what the optimum project size is: increased risk profile vs economies of scale.
- In the base case the government does not act as owner, but as the regulator and concession grantor, hence the government will not bear risks which are borne by asset owners. In case the government will become asset owner in the future the situation will be different. Financial modelling is needed to determine the effects of such a changing situation.

4.2 Public Private Partnerships

Cost reduction differentiator
It could not be concluded that introducing PPPs would have a lowering effect on the LCoE.

Consultation outcomes
Many forms of Public Private Partnerships (PPP) are possible, which are bankable and lead to fair risk allocation, also in the offshore wind sector:

- Current system: long lasting concessions based on permits granted as result of tenders, volume/market risk lays with the concessionaires and the grid connection is provided by the State.
- OWFs made available to the State under a DBFMO-regime (Design, Build, Finance, Maintain en Operate) with strict performance levels, volume/market risk rests with the State, which leads to a different subsidy regime and risk allocation.
The State tenders for the lowest electricity price against cost price, after which the State off takes the electricity generated and uses or sells the electricity. The volume/market risk lays with the concessionaire while the price is guaranteed by the State.

The market itself is best placed to structure the cooperation, and preferred from of PPP. The decision for a type or form of PPP follows a solid business case and risk definition. When private-public cooperation becomes closer, strong forms of governance are required. The success of a PPP is defined by:

- No excessive or double risk pricing by the various parties involved;
- Application of the best available technology;
- The way in which project partners work together and aim for mutual and aligned project objectives.

Financing parties in the offshore wind sector have been able to absorb more risk than previously expected. Lenders agreed to take on some risk, which in other PPP projects they have not done before (e.g. change in interest risk, change in legislation risk).

PPP-experiences from other sectors can provide insight on reduction of transaction costs and innovation drivers. Apart from beating the Public Sector Competitor forecasts the reduced risk of cost and time overruns of PPPs can generate major savings. It was mentioned that larger projects are not necessarily the more successful (e.g. Eurotunnel, Amsterdam metro). The largest offshore PPP’s to date have been max €1bn, apart from the Offshore Transmission Owners (OFTOs) or for example Thames Tideway. In these cases a very strong regulatory regime, including payment guarantees, was introduced.

From a financial perspective the optimal size of an OWF depends on:

- Government’s willingness to step into a PPP.
- Contractor’s willingness to take on singular construction and development risk on one OWF.

When comparing the three scenarios (base case, 4*1250 MW and 1*5000 MW), from a PPP perspective the base case is preferable given the funding requirement (approximately €2.1bn for 2x350MW, €3.7bn for 1250MW and €15bn for 5000MW).

4.3 Tender process

Cost reduction differentiator.
Large scale development of offshore wind in the Netherlands is a differentiator for cost reduction related to the tender process. 1250 MW was seen as an optimum project size.

Consultation outcomes
A suitable tender process should ensure transparent procedures, limited transaction costs and include best practices from the tendering of other PPP-projects. Tender system should constantly be geared to challenge the private sector to develop the best possible solution, including:

- Technical, organisational and financial aspects
- A quality element in the tenders (about 5 to 10% of the price) challenges the private sector, as price is not the only aspect of concern, e.g. reward the quality of the risk mitigation plan or the design philosophy.
- Lowest price for rated capacity vs highest AEP for lowest price
Seek fair balance between price pressure in tender and necessary innovation. For instance by creating a separate site in the tender (like Borssele V) or allow for flexibility to test new innovations within sites.

**Quote from sector consultation:**

“Competitive tendering is good for LCoE reduction in the short run, but will it also create sufficient margin to reinvest in new technology?”

It is expected that the lowest possible cost price (including lowest possible CAPEX and O&M costs) would be achieved when the tendered zones are as big as possible, while at the same time assuring sufficient competition among developers. Hence, when comparing the three scenario’s (base case, 4*1250 MW and 1*5000 MW) from this perspective 4*1250MW is preferred.

**Quote from sector consultation:**

“The implementation of large scale offshore wind energy is expected to reduce cost due to scaling effects. The differences in the Borssele bids for 1x350MW and 2x350MW, and later on Hollandse Kust, will already give a first indication of the potential of scaling effects.”

### 4.4 Finance concluding remarks

Project size will increase with large scale implementation of offshore wind. However, when the size of a project increases, the risk profile increases accordingly. However, a stable roll-out program will lower the risk profile. On the other hand, larger projects create increased advantages of economies of scale and growth in the market and supply chain. When comparing the two future scenarios (4*1250MW vs 1*5000MW) a phased approach with projects of 1000MW to 1250MW would be preferred by most of the consulted organizations. Various PPP options are bankable and lead to fair risk allocation. Improvements in the tender process are suggested, e.g. include a quality element in the tender.

A number of respondents indicated that the mitigation of the risks highlighted in the sector consultation will depend on the structure of the subsidy and the agreements between developers and the government, e.g. requirements regarding the construction period. A stable, low risk legal framework will result in cost reduction due to financing advantages and competition for financing.
5 Policy as diver for cost reduction

The continued cost reduction requires efforts from all stakeholders combined with favourable external factors. A recent TKI Wind op Zee study (TKI Wind op Zee, 2015) identified that government policies contribute to cost reduction in various ways: preventing market costs, reducing offshore wind risk profile, creating a competitive market, stimulating technological innovation, incentivise cost reduction and creating a market for offshore wind. The question in this sector consultation is how much cost reduction potential could be created after 2023 by policy aspects?

5.1 Current Energy Agreement and beyond

Cost reduction differentiator.
Policy continuity in offshore wind development is a strong cost reduction differentiator. A precondition is that in 2017 the Energy Agreement 2.0 should be approved

Consultation outcomes
The consulted organizations commend the Dutch government for the steps undertaken in the current Energy Agreement, including:

- Clear spatial planning
- Offshore grid developed through TenneT
- Organizing tenders and mandating 40% cost reduction
- Reducing risk by providing detailed information for the tender process
- Acceleration of innovation.

Nonetheless, there is an urgent need to formulate a broader policy on the Dutch energy transition beyond the horizon of the current Energy Agreement. The Dutch Energy Report (Ministerie van Economische Zaken, 2016) is an important first step. It advocates a clear long-term (2030/2050) CO2-reduction target and an approach to achieve that target by way of policies for energy ‘functionalities’.

Quote from sector consultation:

“Identifying the optimal way to identify LCoE reduction of offshore wind is critical. But when formulating policy, it is important to place this in the context of the broader energy transition and ensuring optimal economic benefits for the Dutch economy.”

The large potential of the Dutch part of the North Sea of >50GW installed power should play an important role in the energy transition. A roll-out of 1000 to 1250MW per year for the period 2023 to 2030 was suggested by the offshore wind sector, which could be funded by the revenues of continued (offshore) gas production. Such a large-scale focused approach could:

- Generate fast cost-reduction through the effects of industrialization of offshore wind development;
- Contribute significantly toward the CO2 reduction targets for the Netherlands energy supply;
- Create significant spin-off for the Dutch economy (e.g. the offshore industry and harbours).
One consulted organization indicated that a potential of 25% cost reduction could be expected. But it was also mentioned that it would require additional policies to create significant spin-off for the Dutch economy, by:

- Increased electrification of the whole Dutch society
- More realistic CO₂ emission price setting through an Emission Trading System
- The phasing out of coal-generated electricity.

The outcomes of the sector consultation show that there is a need for Energy Agreement 2.0, providing a vision on how the construction of offshore wind will continue without a gap after 2023. This would mean that before the end of 2017 an Energy Agreement should be approved to arrange for new offshore tenders by 2019.

Furthermore, a longer term policy towards 2030/2050 is needed, providing a wider vision on the Dutch approach to the transition towards a low carbon economy. A long term policy is key in creating a sustainable market for offshore wind.

5.2 Stable roll-out

Cost reduction differentiator.
A stable and large offshore wind development programme is a strong cost reduction differentiator.

Consultation outcomes
The Dutch government should ensure a stable roll-out program both in capacity (MW) as in planning (years). This is needed to increase competition in the market and to ensure scale and growth effects. A stable roll-out program will eventually reduce the day-rates and the risk premium, which will accordingly reduce the LCoE. When comparing the three scenarios:

- The base case, or business-as-usual, with 2*350 MW tenders each year, for a period of 7 years, is considered too small to utilize the economies of scale.

- Future phased-approach, with four tenders of 1250 MW, to be constructed in the following 4 years, is considered optimal, because it allows for learning effects, incremental improvements and continued cost reduction.

- Future single-approach, where 5000 MW is tendered to one large consortium at once to be constructed in 4 years, is considered too large, due to uneven factory loading in the market.

A political decision on the future pipeline and tender process should be taken as soon as possible as it allows for optimal planning, the necessary preparations in the supply chain, options for standardization and accordingly cost reduction.

5.3 Spatial planning

Cost reduction differentiator.
Developing large scale designated wind energy areas is a cost reduction differentiator. The best option to realise a possible Energy Agreement 2.0 is in wind energy area IJmuiden Ver.
Consultation outcomes
Offshore wind energy production in the Netherlands is only possible in areas designated by the government for wind energy. These areas are specified in the National Water Plan (Ministerie van Infrastructuur en Milieu, 2009 and 2016). Considering the additional time it takes to designate additional wind energy areas (about 3 years) this sector consultation is based on the assumption that no spatial changes will be approved in the wind energy areas up to 2023. The current spatial situation is as such, that in the remaining space within wind energy area Hollandse Kust large scale implementation of wind energy (>2000 MW) is not expected in the coming 10 to 15 years, due to existing oil and gas extractions and offshore production platform. Hence, large scale wind energy development directly after 2023 may only be possible in IJmuiden Ver, since no other areas large enough have been designated.

As part of the theme Market & Supply chain (see Chapter 3) the benefits of a hub- or work island were discussed. The government would need to designate a specific spatial offshore area to allow for the construction of such an island. This could become part of a wind energy area already designated, such as IJmuiden Ver.

Additional study
Based on the outcomes of the consultation the following aspects related to spatial planning have been identified for further study:

- The ecological impacts and required mitigation measures of large scale implementation are uncertain and require additional research such as the cumulative impacts (current roll-out, future roll-out and projects in neighbouring countries) relevant for birds, bats and sea mammals.
- Scale and impact of new nature conservation plans for instance the harbour porpoise protection plan or the designation of additional Nature 2000 areas such as the Bruine Bank.

![Designated wind energy areas in the Dutch part of the North Sea](image-url)
5.4 Cooperation with other EU countries

Cost reduction differentiator.
Cooperation with neighbouring countries may result in further cost reduction, in particular if interconnections are constructed and a shared work island is constructed. However, large scale development far offshore is a precondition.

Consultation outcomes
Cooperation with our neighbouring countries (United Kingdom, Belgium and Germany) and other countries bordering the North Sea (Norway, Sweden, Denmark, Ireland, France) is essential to achieve large scale implementation of offshore wind and the required cost reduction. The Netherlands and its neighbouring countries are urged to increase cooperation to avoid a gap between the current and future roll-out of offshore wind. Such cooperation should focus on:

- Long term grid stability; interconnection requirements at large variable renewable energy (VRE) penetration levels;
- Alignment or harmonization of subsidy regimes to enable combining offshore wind with interconnectors;
- Regulating pressure on the supply chain, by not having all developments in the same year;
- Construction of a hub- or work island.

Cooperation related to these aspects could result in a substantial cost reduction which may not be possible when each country acts on its own. However, inappropriate regulations and political willingness were mentioned as limiting factors for cooperation.

Additional study
Based on the outcomes of the consultation the following aspects related to cooperation have been identified for further study:

- Costs and benefits of increased cooperation between countries bordering the North Sea, in the field of interconnection, subsidy regimes, work islands, etc.

5.5 Policy concluding remarks

There is general consensus among the consulted organizations that the government is to ensure a future structured and stable roll-out of offshore wind energy. Opinions differ on the optimal size of future projects, but 4*1250MW is considered as having the most potential. Collaboration with neighbouring countries is considered essential to achieve large scale implementation of offshore wind and the required cost reduction, but is hampered by regulations and unwillingness to cooperate. There is an urgent need to formulate a broader policy on the Dutch energy transition beyond the horizon of the current Energy Agreement.
6 LCoE reduction

The sector consultation has resulted in a number of cost reduction differentiators which are expected to lower the LCoE due to large scale roll-out far offshore. These aspects were used as input for LCoE cost reduction modelling. The cost reduction modelling is conducted by Ecofys, using the TKI Wind op Zee Offshore Wind Cost Model. This paragraph summarizes the outcomes, a full description of the modelling and its results are included in Appendix 2.

6.1 Overview of cost reduction potential

The outcomes of the sector consultation indicates that the scenario with a roll-out of 1250MW per year over a period of four years is expected to result in the highest cost reduction. Therefore, the decision\textsuperscript{10} was made to conduct the cost reduction modelling for two variants of this scenario. The 1250MW per year scenario is divided in a lower and higher range variant, together giving the expected bandwidth of cost reduction potential. Table 4 shows the input gathered through the sector consultation per cost component, per scenario, and the reasoning behind the cost reduction.

<table>
<thead>
<tr>
<th>Impact of large scale roll-out</th>
<th>Cost component of LCoE reduction modelling</th>
<th>Lower variant %</th>
<th>Higher variant %</th>
<th>Ref to paragraph</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Learning curve in the supply chain</td>
<td>WTG supply</td>
<td>5</td>
<td>5</td>
<td>3.3</td>
</tr>
<tr>
<td>B Mass production and optimization in the supply chain</td>
<td>WTG supply</td>
<td>5</td>
<td>5</td>
<td>3.3</td>
</tr>
<tr>
<td>C Learning curve in the supply chain</td>
<td>Foundation supply</td>
<td>5</td>
<td>5</td>
<td>3.3</td>
</tr>
<tr>
<td>D Mass production and optimization in the supply chain</td>
<td>Foundation supply</td>
<td>5</td>
<td>5</td>
<td>3.3</td>
</tr>
<tr>
<td>E Lower mobilisation and demobilization costs and increasing learning curve</td>
<td>WTG installation</td>
<td>1</td>
<td>2</td>
<td>2.2</td>
</tr>
<tr>
<td>F Standardization, interface management, and increased efficiency which reduces the installation time per turbine</td>
<td>WTG installation</td>
<td>2</td>
<td>5</td>
<td>2.2</td>
</tr>
<tr>
<td>G Standardization, interface management, and increased efficiency which reduces the installation time per foundation</td>
<td>Foundation installation</td>
<td>2</td>
<td>5</td>
<td>2.2</td>
</tr>
<tr>
<td>H Combined services, interface management, efficient planning</td>
<td>O&amp;M services</td>
<td>1</td>
<td>5</td>
<td>2.4</td>
</tr>
</tbody>
</table>

6.2 Outcomes of cost modelling

Implementing a roll-out of 1250MW annually over a period of four years leads to a significant LCoE reduction of approximately 6%. The difference between the lower and higher variant is small, with the higher range resulting in only a slightly lower LCoE.

\textsuperscript{10} In consultation with TKI Wind op Zee
Table 5: Outcome of cost modelling

<table>
<thead>
<tr>
<th>Case</th>
<th>LCoE reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>0</td>
</tr>
<tr>
<td>Future phased approach, 1250MW annually over period of 4 years, lower variant</td>
<td>-5.8</td>
</tr>
<tr>
<td>Future phased approach, 1250MW annually over period of 4 years, higher variant</td>
<td>-6.4%</td>
</tr>
</tbody>
</table>

The impact of large scale offshore wind roll out on LCoE is significant because most of the expected cost reductions are related to the supply and installation of WTGs and foundations, which account for approximately half of the LCoE. The difference between the scenarios originates from the ranges given for installation costs and O&M services. Since these comprise a relatively small share of the total LCoE (15-20%) the difference between the lower and higher variant is limited.

Figure 5 shows the LCoE impact of the cost reduction on the specific cost reduction components as defined in Table 4. A relatively small difference between the lower and higher variant is shown for the WTG and foundation CAPEX since only the installation cost reduction potential differs between both variants and the CAPEX contribution of installation costs is relatively small.

It should be noted that the OPEX values do not correspond one on one with the O&M services cost reduction input. This is due to the fact that OPEX also include business interruption insurances (based on Energy Yield) and machinery breakdown insurances (based on CAPEX). In the lower and the higher variant the CAPEX decreases significantly which in turn translates into a higher relative contribution of the machinery breakdown insurances on the OPEX value.

Conclusion of the LCoE calculation

It is expected that a potential LCoE reduction of 6% can be realised when a roll-out of 1250MW annually for a period of four years is applied in large scale development of offshore wind energy. The cost reduction potential of the WTG and foundation costs have the largest impact, since these are relatively large contributors to the LCoE.
7 Key input for policy agenda

7.1 Sector consultation main conclusions

The Netherlands has established in its National Water Plan several wind energy areas in the Dutch Economic Zone of the North Sea (see Figure 4). One of these wind energy areas is named IJmuiden Ver and is located about 80 to 100 km from the west coast of The Netherlands.

Currently the Netherlands Government is executing a coordinated and stable roll-out in with the Government organises the required studies (i.e. geotechnical study), the permits (Kavelbesluit) and the grid connection. Continuity of this roll-out as well as a significant project pipeline are a precondition for cost reduction of offshore wind in the Netherlands. The government is to ensure a coordinated and stable roll-out of offshore wind energy very much in line with the current roll-out but at a larger scale. Two scenarios for roll-out are suggested:

- A roll-out of 1250 MW per year over a period of four years. This would allow for competition, standardisation, economies of scale, learning curve and mass production effects. However, when the size of a project increases, the risk profile increases accordingly but a stable roll-out program will lower the risk profile.

- Anchor tenant model. This model transferred to the IJmuiden Ver area would mean a roll-out of 1250 MW per year over a period of 4 years, a large consortium could be responsible for 625 MW per year, developing the industrial infrastructure. While the rest of industry can piggy bag from smaller tenders dividing the other 300 to 350 MW per year.

It is expected that a potential LCoE reduction of 6% can be realised when a roll-out of 1250MW annually for a period of four years is applied in future large scale development of offshore wind energy. The cost reduction potential of the WTG and foundation costs have the largest impact, since these are relatively large contributors to the LCoE.

A detailed long term vision should be developed on the most cost efficient way to integrate large scale additional production of offshore wind energy into a high voltage grid on the North Sea connected to the surrounding countries and the required means (including interconnection) to ensure grid stability.

Collaboration with neighbouring countries is essential to achieve large scale implementation of offshore wind and the required cost reduction. Collaboration related to e.g. the electrical grid (interconnectors), the construction of a work island or the harmonization of the subsidy regime could result in a substantial cost reduction which may not be possible when each country acts on its own.

There is an urgent need to formulate a broader and stable policy on the Dutch energy transition beyond the horizon of the current Energy Agreement, on two levels:

- Energy Agreement 2.0, providing a vision on the planning of offshore wind to continue construction in 2023 directly after the end of the current Energy Agreement without a gap. This would mean that before the end of 2017 the Energy Agreement 2.0 should be approved to arrange for new offshore tenders by 2019.

- A longer term policy towards 2030/2050 providing a wider vision on the Dutch approach to the transition towards a low carbon economy.
7.2 Actions

Based on the sector consultation the following actions are defined for the policy agenda to develop large scale offshore wind after 2023 in the Netherlands.

Technology

- Invest in innovation sites and innovation tenders to prove technology. Action holder: TKI Wind op Zee and RVO
- Invest in demonstration sites. Action holder: TKI Wind op Zee and NWEA
- Reward technological innovation in bids. Action holder: Ministerie van Economische Zaken
- Allow, as much as possible, technological flexibility in the permits. Action holder: Ministerie van Economische Zaken
- Develop a long term vision for the grid, both on- and offshore, in light of strongly increasing variable renewable energy (VRE) penetration levels, the shift to non-synchronous generators and large scale distributed renewable energy sources (RES). Action holder: TenneT

Market & Supply chain

- Create a tender model that allows for large scale tenders: (i) 1250 MW per year over a period of four years, or (ii) an anchor/tenant approach. To maximize the chances of realizing cost reduction and economic opportunity as well as aligning public and private interests in this large scale development. Action holder: Ministerie van Economische Zaken
- Joint exploration by public and private sector on how to develop (multipurpose) harbour facilities or a hub/harbour/work island. Action holder: harbour sector and Ministerie van Economische Zaken

Finance

- Study different tender processes in which financing of OPEX and CAPEX is split up, e.g. power price vs green bonds. Action holder: Ministerie van Economische Zaken and sector
- Lower entry barrier for low risk investors (e.g. pension funds) to invest in the offshore wind energy market. Action holder: Ministerie van Economische Zaken
- Study options for longer contract period to match depreciation of more than 15 years. Action holder: sector and Ministerie van Economische Zaken

Policy

- Develop long term vision on energy transition. Action holder: Ministerie van Economische Zaken and Topsector Energy and sector
- Cooperation between government and key industrial players to develop a vision and approach for the wider energy transition. Action holder: Ministerie van Economische Zaken and NWEA
- Preparation of spatial planning decisions necessary for large scale roll out. Action holder: Ministerie van Infrastructuur en Milieu
- Undertake required studies and decisions to allow for development of OWFs in wind energy area IJmuiden Ver, including:
Specific study on grid connection. **Action holder: TenneT**

Preparation of kavelbesluit. **Action holder: Ministerie van Economische Zaken and sector**

1. **Develop long term policy towards 0% subsidy. Action holder: Ministerie van Economische Zaken and sector**

2. **Development of policies to promote and allow for the entry of institutional investors, cooperatives and public bodies. Action holder: Ministerie van Economische Zaken**

3. **Invest in cooperation with neighbouring countries on large scale development to further reduce costs. Action holder: Ministerie van Economische Zaken**

### 7.3 Overview of aspects for further study

In the previous chapters different aspects were indicated for further study. In this paragraph all aspects are listed together.

<table>
<thead>
<tr>
<th>Aspect for further study</th>
<th>Reference to paragraph</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transportation and installation</strong></td>
<td></td>
</tr>
<tr>
<td>Opportunities for upgrading one of the Dutch harbours to a multipurpose harbour</td>
<td>See paragraph 2.2</td>
</tr>
<tr>
<td>One of the organizations consulted indicated that the delaying factor of current offshore wind farm development is the construction of sea cables, which is a cost increasing factor that should be looked into.</td>
<td></td>
</tr>
<tr>
<td><strong>O&amp;M</strong></td>
<td></td>
</tr>
<tr>
<td>The cost reduction potential of O&amp;M aspects is hard to quantify, as it depends on number and size of turbines, site and turbine maturity. It is recommended to conduct case specific LCoE calculations on the potential future sites with assumptions related to turbine technology and maturity, size of the wind farms etc, to determine the potential.</td>
<td>See paragraph 2.4</td>
</tr>
<tr>
<td>Potential of extended life design for on- and offshore substations and exports cables.</td>
<td></td>
</tr>
<tr>
<td><strong>Electrical infrastructure</strong></td>
<td></td>
</tr>
<tr>
<td>An overall long term ‘offshore grid vision’</td>
<td>See paragraph 2.5</td>
</tr>
<tr>
<td>Technical and financial tipping points of AC, DC and LFAC</td>
<td></td>
</tr>
<tr>
<td>Opportunities for additional costs reduction, e.g. standardisation</td>
<td></td>
</tr>
<tr>
<td>Include onshore grid adjustments in LCoE calculations</td>
<td></td>
</tr>
<tr>
<td>Turbines producing directly at DC, collect at DC-DC boost station feed in to export infrastructure</td>
<td></td>
</tr>
<tr>
<td>Benefits of interconnection</td>
<td></td>
</tr>
<tr>
<td>The grid requirements, especially onshore, including the scenarios to be taken into account considering the closure of the coal power plants and the export to the hinterland.</td>
<td></td>
</tr>
<tr>
<td><strong>Scale and growth effects</strong></td>
<td></td>
</tr>
<tr>
<td>Further detailing of the cost reduction potential of 10 to 15%, in addition to the 5% caused by increased learning curve and 5% caused by mass production optimization.</td>
<td>See paragraph 3.3</td>
</tr>
<tr>
<td>Further detailing of the costs and benefits of a hub- or work island.</td>
<td></td>
</tr>
<tr>
<td><strong>Project management &amp; development</strong></td>
<td></td>
</tr>
<tr>
<td>Extend of project scope when looking at large scale development of offshore wind, recognizing the difference between the current systems in the UK and NL.</td>
<td>See paragraph 3.4</td>
</tr>
<tr>
<td><strong>Finance risks</strong></td>
<td></td>
</tr>
<tr>
<td>It needs to be determined what the optimum project size is: increased risk profile vs economies of scale.</td>
<td></td>
</tr>
<tr>
<td>In the base case the government does not act as owner, but as the regulator and concession</td>
<td>See paragraph 4.1</td>
</tr>
</tbody>
</table>
Aspect for further study

grantor, hence the government will not borne risks which are borne by asset owners. In case the government will become asset owner in the future the situation will be different. Financial modelling is needed to determine the effects of such a changing situation.

Spatial planning
- The ecological impacts and required mitigation measures of large scale implementation are uncertain and require additional research such as the cumulative impacts (current roll-out, future roll-out and projects in neighbouring countries) relevant for birds, bats and sea mammals.
- Scale and impact of new nature conservation plans for instance the harbour porpoise protection plan or the designation of additional Nature 2000 areas such as the Bruine Bank.

Cooperation with other EU countries
- Costs and benefits of increased cooperation between countries bordering the North Sea, in the field of interconnection, subsidy regimes, work islands, etc.

Reference to paragraph
See paragraph 5.3
See paragraph 5.4

7.4 In closing
For any questions or suggestions related to this sector consultation, please do not hesitate to contact Royal HaskoningDHV or Ecofys. The experts are more than happy to provide an answer.

Suzan Tack 06 5396 8981
Joris Truijens 06 1132 3144
Erik Zigterman 06 5156 6268
Patrick van Dijk 06 5201 8557
Michiel Muller 06 1520 9054
Huygen van Steen 06 1589 7842
8 Literature

Ministerie van Economische Zaken, (2016), Energierapport, Transitie naar duurzaam

Ministerie van Infrastructuur en Milieu, (2009), Nationaal Waterplan 2009-2015

Ministerie van Infrastructuur en Milieu, (2016), Nationaal Waterplan 2016-2021

Schotten, G, S. van Ewijk, M. Regelink, D. Dicou, J. Kakes (2016), Tijd voor transitie – een verkenning van de overgang naar een klimaatneutrale economie, Occasional Study DNB

SER, (2013), Energieakkoord voor duurzame groei

Synergies at Sea, (2016), Feasibility of a combined infrastructure for offshore wind and interconnection Draft final report, by: Nuon/Vattenfall (leading Subproject 1), ECN, Delft University of Technology, University of Groningen, Royal HaskoningDHV and DC Offshore Energy

TKI Wind op Zee (2015), Cost reduction options for Offshore wind in the Netherlands FID 2010-2020, by PwC, DNV GL and Ecofys
Appendix 1

Consultation Approach
Appendix 1 | Consultation approach

Delphi methode

De situatie rond grootschalige ontwikkeling van windenergie op zee wordt getypeerd door een veelvoud van belangen en visies. In Nederland zijn in het verleden veel consultaties uitgevoerd, waarin de markt werd gevraagd mee te denken over mogelijk marktbenaderingen voor grote projecten. Omdat de genodigden veelal een strategisch belang hebben en daardoor de kaarten dicht bij de borst houden, valt de oogst van deze sessies vaak tegen. Het creëren van een setting die vertrouwelijkheid en desgewenst anonimiteit kan bieden, kan zeer bijdragen aan de resultaten van de analyse.

Om een brede groep experts op een gestructureerde manier te betrekken bij de analyse is de Delphi-methode toegepast. Hierdoor is effectief, snel en een betrouwbare consensus bereikt over een probleemstelling. De Delphi-methode is bij uitstek een gespreksvorm die helpt om samen zicht te krijgen op complexe toekomstvraagstukken. Bij de Delphi-methode spreken de experts zich vrij uit, denken hardop en worden niet afgeredend op wat zij inbrengen. Voorwaarden voor deelneming is dat mensen mondig en deskundig moeten zijn op het onderwerp dat voorligt.

Het voordeel van de Delphi-methode is dat experts veel meer geneigd zijn te delen, als ze in een aantal ronden op elkaars input kunnen reageren. De kennis en visies die experts onderling delen inspireert en bevorderd gesprekken tijdens een ‘face-to-face’ bijeenkomst. Een bijeenkomst die vooraf is gegaan aan een Delphi-methode kent een hele andere dynamiek dan reguliere marktconsultaties en levert veel meer resultaat, omdat participanten al veel met elkaar hebben gedeeld en daarop verder willen borduren.

In de consultatie rondom windenergie op zee zijn experts betrokken van bedrijven, kennisinstellingen, belangenorganisaties en publieke instellingen. Doordat al deze partijen zijn betrokken is een solide basis gelegd voor toekomstige samenwerking en breed gedragen resultaat.
Appendix 2

Memo Ecofys | LCoE calculations
Include appendix 2, memo Ecofys, LCoE calculations
1 Introduction

Royal HaskoningDHV, together with Ecofys, was contracted by RVO and TKI Offshore Wind to conduct a study into large scale development of offshore wind energy after 2023, looking into possibilities for continued cost reduction after 2023. Under the current Energy Agreement a cost reduction of 40% is foreseen and after 2023 autonomous innovation in technology and learning effects are expected to continue to bring costs down, but other cost reduction levers may be required to arrive at a long-term acceptable cost level. This study aims to investigate the potential of the large scale roll out offshore wind to continue the cost reduction trend after 2023. The cost reduction potential was assessed, based on inputs gathered through an extensive consultation with the offshore wind sector, in comparison to the current roll out scheme of the annual tendering of 700 MW. This study will specifically investigate the cost reduction potential of a large scale phased tendering approach (annual tendering of 1250MW), thereby taking into account the cost reduction potential for several components including supply, installation, and O&M services. These components were identified to be affected by large scale roll out during the consultation rounds.

2 Methodology

This section will describe the methodology of the cost reduction potential study including scenarios, site description, model input, assumptions and a brief model description.

2.1 Scenarios

The scenarios considered in this cost reduction potential study are based on the scenarios as presented in the consultation project scope in which three scenarios were defined:
• Base case (annual tendering of two 350 MW areas, over a period of 7 years)
• Future phased approach (annual tendering of 1250 MW, over a period of 4 years),
• Future single approach (single 5 GW tender).

Based on the feedback provided within the consultation sessions and through consultation with TKI, the decision was made to compare two variants of the future phased approach to the basic approach and to omit the future single approach. The future phased approach is thus divided in a lower and higher range scenario together giving the expected bandwidth of cost reduction potential for the phased large scale roll out of offshore wind. The bandwidth of cost component impacts were defined during the consultation sessions.

**Base case**

The base case, or business-as-usual, is defined as having 2*350 MW tenders each year, for a period of 5 years, in accordance with the current way of tendering where the subsidy is awarded to the lowest bidder.

**Scenario 1a – lower range**

Scenario 1a represents lower range of cost reduction expected for the large scale roll out of offshore wind through annual tendering of 1250 MW. Cost reduction parameters on a component level are defined in section 2.2. Supply costs for WTGs and foundations are identical for scenario 1a and 1b, as only a single cost reduction for these components was defined during the consultation sessions. For this scenario, the minimum expected cost reduction for WTG and foundation installation costs as well as O&M services is taken from the cost reduction potential ranges as defined in the consultation sessions.

**Scenario 1b – higher range**

Scenario 1b represents higher range of cost reduction expected for the large scale roll out of offshore wind through annual tendering of 1250 MW. Cost reduction parameters on a component level are defined in section 2.2. For this scenario, the maximum expected cost reduction for WTG and foundation installation costs as well as O&M services is taken from the cost reduction potential ranges as defined in the consultation sessions.

**Site and project description**

The site that is selected for this study is Ijmuiden Ver which is deemed representative as a site for the post 2023 roll out of offshore wind given its size and current status (already appointed as offshore wind area). The project under consideration is defined as a 700 MW wind farm project; similar to the size of wind farms in the base case. The assessment will assume TenneT as developer of the transmission assets as presented as the basic assumption in the consultation rounds. The cost
reduction potential in scenario 1a and 1b will be determined on the basis of this 700 MW wind farm project.  

2.2 Cost reduction Input

Input for cost reduction on a cost component level, was gathered through a two-round written consultation session and a single workshop session to tap into the large amount of knowledge and expertise within the offshore wind industry sector. Cost reductions on a component level are defined for WTGs (supply and installation), Foundations (supply and installation) and O&M services. The cost reduction parameters are defined relative to the base case scenario. Table 1 shows the input gathered through the sector consultation per cost component per scenario, and the reasoning behind the cost reduction. Note that supply costs (a-d) are similar for scenario 1a and 1b while a cost reduction potential range is given for installation (e-g) and O&M (h) costs between both scenarios.

---

1 We expect that 700MW platforms remain standard for wind farms foreseen in the large scale roll out (when TenneT is assumed as developer of the offshore wind farm transmission assets). The cost reductions on cost component level for the large scale roll out scenario are defined relative to the base case. Defining a new scenario for the large scale roll out (including the effects of large scale) and consecutively imposing the cost reduction parameters as defined in the consultation round would results in accounting twice for the effect of the large scale roll out.
### Table 1 Cost reduction potential of large scale offshore wind roll out

<table>
<thead>
<tr>
<th>#</th>
<th>Impact of large scale roll out</th>
<th>Cost component</th>
<th>Scenario 1a</th>
<th>Scenario 1b</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Learning curve in supply chain</td>
<td>WTG supply</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>b</td>
<td>Mass production and optimization in supply chain</td>
<td>WTG supply</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>c</td>
<td>Learning curve in supply chain</td>
<td>Foundation supply</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>d</td>
<td>Mass production and optimisation in supply chain</td>
<td>Foundation supply</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>e</td>
<td>Lower mobilisation and demobilisation costs and increasing learning curve</td>
<td>WTG installation</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>f</td>
<td>Standardization, interface management, and increased efficiency which reduces the installation time per turbine</td>
<td>WTG installation</td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td>g</td>
<td>Standardization, interface management, and increased efficiency which reduces the installation time per foundation</td>
<td>Foundation installation</td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td>h</td>
<td>Combined services, interface management, efficient planning</td>
<td>O&amp;M services</td>
<td>1%</td>
<td>5%</td>
</tr>
</tbody>
</table>

#### 2.3 Model

The TKI-WoZ Offshore Wind Cost Model has been initially developed by Ecofys as ordered by the research programma Far and Large Offshore Wind (FLOW). Over 2012-2013, the industry partners of FLOW have delivered confidential (cost) data to build up the confidential database which is the backbone of the model. Since the initial development, TKI-WoZ has carried out further data collection and validation and testing of the model with Ecofys’ support. The TKI-WoZ Model is applied in a wide range of applications (ranging from quantification of technical innovation, alternative subsidy schemes, permitting systems) and is under continuous scrutiny. A summary of the calculation methods in the model can be found in Appendix A.

#### 3 Results

The results of the cost impact analysis per scenario are provided in Table 2.
Table 2 LCoE reduction comparison for the different scenarios.

<table>
<thead>
<tr>
<th>Case</th>
<th>LCoE Reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>0%</td>
</tr>
<tr>
<td>Scenario 1a</td>
<td>-5.8%</td>
</tr>
<tr>
<td>Scenario 1b</td>
<td>-6.4%</td>
</tr>
</tbody>
</table>

Implementing the phased tendering approach (1250 MW annually), both the lower (1a) and higher (1b) range cost reduction scenarios lead to a significant LCoE reduction of approximately 6% compared to the base case. The difference between the scenarios is however small, with the higher range resulting in only a slightly lower LCoE. Figure 1 gives the breakdown of the LCoE on a cost component level.

Figure 1 Breakdown of the impact of the different scenarios on the major LCoE cost components.

Figure 1 shows the impact of large scale offshore wind roll out on LCoE is significant because most of the expected cost reductions are related to the supply and installation of WTGs and foundations, which account for approximately half of the LCoE. The difference between the scenarios stems from the ranges given for installation costs and O&M services. Since these comprise a relatively small share of the total LCoE (15-20%) the difference between the low and high cost reduction estimates is limited. Figure 2 shows the resulting LCoE-translated impact of the cost reductions on the specific offshore wind project components as given in...
Table 1.

Figure 2 LCoE reduction impact on specific components for which a potential cost reduction has been identified.

Figure 2 shows a relatively small difference between scenario 1a and 1b for the WTG and foundation CAPEX since only the installation cost reduction potential differs between both scenarios, and the CAPEX contribution of installation costs is relatively small.

In addition, the OPEX values do not correspond one to one with the O&M services cost reduction input.
This is due to the fact that OPEX also include business interruption insurances (based on Energy Yield) and machinery breakdown insurances (based on CAPEX). In scenarios 1a and 1b, the CAPEX decreases significantly which in turn translates into a higher relative contribution of the machinery breakdown insurances on the scenario 1a OPEX value.

4 Conclusion

Based on this analysis, it is expected that a potential LCoE reduction of 6% can be realised when the phased approach (annual tendering of 1250 MW) is applied in future large scale development of offshore wind energy. The cost reduction potential of the WTG and foundation costs have the largest impact, since they are relatively large contributors to the LCoE.
Appendix A: TKI-WoZ Offshore Wind Cost Model

A summary of the calculation methods used in the TKI-WoZ Model is provided below:

- **Development expenditure (devex)**

  This is based on the key cost elements encountered during the development phase of an offshore wind farm: engineering and design, consent and permitting, wind measurement campaigns, geotechnical and geophysical surveys.

- **Capital expenditure (capex)**
  - **Supply costs of wind turbines:**
    
    The model contains four generic wind turbine types, all of which are based on a collection of wind turbines available on the market. Supply costs as modelled for the near future project are based on the current pricing level as observed in the market. For the basecase of this study, a 7 MW wind turbine with a rotor diameter of 164 meters was used.

  - **Supply costs of foundations**

    The supply costs of foundations are calculated based on the weights of the main components. These weights depend on site conditions (such as water depth, soil conditions) as well as wind turbine specifications (such as hub height and top mass). Weights are calculated based on engineering relations taking into account site conditions and wind turbine specifications. In addition, the model contains unit rates for the main components, which describe the price of components per ton of material.

  - **Supply costs of electrical infrastructure**

    The TKI-WoZ model is capable of calculating CAPEX of all assets typically used for HVAC designs. In this case the transmission assets were considered to be developed by TenneT, so only the developer electrical infrastructure assets are calculated by the TKI-WOZ model.

  - **Installation costs**

    For each of the main components, costs for installation are calculated based on specific installation vessels and installation cycles. In addition, costs for mobilisation and demobilisation as well as weather downtime costs are calculated separately.

  - **Construction insurance, management and contingencies**

    Capex includes a separate category in which the costs for construction insurance, management and construction contingencies are calculated. These costs are expressed as a percentage of capex of the supply and installation costs.
• **Energy production**

Gross energy is determined based on a Weibull distribution which describes the wind climate at the site, combined with power curves of the wind turbines applied. Losses (wake, electrical, non-availability) are calculated separately and are subtracted from the gross energy yield to arrive at the net energy yield.

• **Operational costs (OPEX)**

Operational costs (OPEX) include the maintenance costs of wind turbines, foundations and electrical infrastructure, as well as operational insurance and the wind farm operator’s organisation. Within this cost category, the maintenance costs of wind turbines form the largest cost element. These costs are primarily driven by the number of wind turbines and the logistical set-up. The set-up for the basecase assumes the use of Floatels.

• **Decommissioning costs**

Decommissioning costs are calculated based on the initial installation costs of the wind farm, reduced by a price reduction factor as it is expected that the decommissioning process will have a shorter timeline. The costs are accounted as an expense at the end of the lifetime of the wind farm.

• **Financing and cash flow parameters**

The model includes both project and balance financing. In case of project financing, the baseline assumption is amortisation based on annuities. All cash flows are discounted to the year of financial close (‘t=0’ in the cash flow), based on the required return on equity as discount factor. The cash flow uses midpoint discounting.

• **Construction period**

During the construction period, capex is linearly spread over the period, which starts after financial close. The baseline assumption is a construction period of 2.5 years.