TKI Wind op Zee
Offshore wind cost reduction progress assessment

Authors: Barry Vree and Niels Verkaik
Version: 3.0
Date: 20-02-2017
Summary

This study was commissioned by TKI Wind op Zee (WoZ). Research for this research note was conducted by Ecofys and findings were consulted with representatives the offshore wind industry during a workshop at the Sociaal Economische Raad in The Hague on the 21st of December.

The focus of the study is explaining recent development in offshore wind cost reduction by examining cost reduction trends in the offshore wind market. These trends were modelled by introducing cost reduction levers into the TKI-WoZ cost model.

The cost reduction levers with the largest impact were:
- Design improvements in wind turbines and innovations and improvements in foundation design;
- Reduced financing costs (reduced debt interest and return on equity rates);
- CAPEX reduction through portfolio effects, multi-contracting, purchasing power, increased risk appetite & increased competitiveness, and explicitly excludes technological improvements.
- Policy improvements such as the preparatory work for the projects by the government.

The competitive tender process that was organised by the Dutch and Danish governments materialised these cost reductions in the tender results (in €/MWh). This analysis shows that the cost modelling results approach the tender results for Borssele I&II and the Danish Nearshore tender within a modest margin. The cost reduction impact on Horns Rev III resulted in lower prices than the tender result, indicating an overestimation of the impact of the cost reduction levers. Another explanation could be that the full cost reduction potential of the Horns Rev III tender was not realised, due to a less efficient tender process.

The sensitivity analysis has shown that further cost reductions are feasible under slightly more aggressive (but not unreasonable) assumptions. The resulting cost level is in line with the more recent tender result for Borssele III&IV and Kriegers Flak.

Finally, the role of externalities is investigated showing that even though trends such as steel price and interest rate developments have a significant share in the cost reduction, the majority of the cost reduction is not dependent on these externalities.
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1 Introduction

Recent developments in the cost of offshore wind energy have shown ground breaking winning tender bids in the Netherlands and Denmark. Both winning bids for the Borssele I&II and Borssele III&IV in the Netherlands and the Danish Near Shore (DNS) Wind Tender and Kriegers Flak in Denmark, have seen price levels which are significantly lower compared to tender results in UK, DE and Belgium in previous years. Figure 1 gives an overview of recent developments in offshore wind strike prices for tenders.

Figure 1: Recent developments in levelised cost of energy for offshore wind.

TKI-WoZ commissioned Ecofys to perform a study which aims to provide insight into how current tender prices have been realised. The recent tender outcomes are realised through combination of factors impacting the levelised cost of energy (LCoE) of the projects. In this study these factors were categorised into technology, market and supply chain, policy, and financing conditions, in accordance with the approach previously used by the TKI Wind op Zee studies. To better understand the impact of these influencing factors, their potential LCoE impact was investigated for the three cases mentioned above. The TKI Offshore Wind Cost Model was used for this purpose. Model input was tested and discussed during workshop with key offshore wind sector players on the 21st of December at the Sociaal Economische Raad (SER).

1 TKI Wind op Zee 2015, Cost reduction options for Offshore Wind in the Netherlands FID 2010-2020 (PWC, DNV GL, Ecofys)
2 Approach

The following five step approach was used to investigate the potential impact, and will be further discussed in this section:

1. Case definition
2. Cost reduction trends and impact on costs
3. LCoE Impact analysis
4. Workshop presentation of draft research note
5. Final research note

2.1 Case definition

At the time of study initiation, three cases were defined to further investigate the impact that cost reduction trends have had in these specific cases. The most recent cases at that point were the following, as depicted in Figure 2:

1. Horns Rev III (2015), in Denmark with a strike price of 103 €/MWh
2. Borssele I&II (2016), in the Netherlands, with a strike price of 73 €/MWh
3. Danish Nearshore Tender (2016), in Denmark with a strike price of 64 €/MWh

The Borssele III&IV and Kriegers Flak tender results showed even further cost reduction but were not announced, at the time of the scope definition of this study. The model work required quite some effort as all project details and cost reduction levers had to be determined quite extensively.

Figure 2: Scope definition of this study.
The base case definitions take into consideration of the following aspects:

- For the Borssele I&II case, a site description was available in the TKI Offshore Wind Cost model. This was a site description based on the views and available knowledge level of 2012. Therefore, an updated site definition was created based on the latest insights in water depths and wind climate as made available by RVO.  
- Cost levels for the base cases for Borssele I&II, Horns Rev III and the Danish Nearshore Tender were taken from the TKI Offshore Wind Cost Model and are defined at (FID) 2010 levels. This in particular included a wind turbine with a capacity of 3 MW.  
- Project finance is used as a base case assumption in this model.

2.2 Cost reduction trends and impacts on costs

Four categories of cost reduction trends were identified, in line with earlier cost reduction studies carried out by TKI. All trends were identified and defined compared to the 2010 base case prices levels available in the TKI Offshore Wind Cost Model.

- **Technology**
  - Trends from a technological point of view such as design improvements in wind turbines (e.g. larger turbines) or improved foundation design (resulting in weight reduction in foundations);

- **Market & Supply chain**
  - Trends from market and supply chain effects which include competition, cooperation and externalities such as steel price and interest rate developments;

- **Policy**
  - Policy related developments such as shifting the grid connection responsibility to the TSO, or permit and policy improvements by governments by taking up part of the project development tasks such as investigating the wind climate or soil conditions;

- **Finance**
  - Financing trends such as reduced risks, decreased debt interest rates and reduced required return on equity.

In consultation with TKI-WoZ, a number of cost reduction levers within each category were defined. These are presented in the following tables. An initial estimate of the impact of the levers was based on publicly available data, TKI-WoZ input and Ecofys views on cost reduction developments. During the workshop, cost reduction levers were discussed and a number of parameters were updated. The following tables show the cost impacts as included in the final analysis presented in this research note.

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3 For the presentation of cost reductions categories an, at first sight arbitrary, division is used. For background on this approach please refer to TKI Wind op Zee 2015, Cost reduction options for Offshore Wind in the Netherlands FID 2010-2020 (PWC, DNV GL, Ecofys)
Table 1: Technology related cost reduction levers.

<table>
<thead>
<tr>
<th>Lever indicator</th>
<th>Lever name</th>
<th>Cost component impact</th>
</tr>
</thead>
</table>
| T1              | Design improvements WTGs and innovations and improvements in foundation design | **Borssele, DNS:** Modelled 9 MW WTG, foundations and E-infra recalculated  
**Horns Rev III:** Modelled 8 MW WTG, foundations and E-infra recalculated |
| T2              | Updated site specifications                                                | **Borssele:** Modelled capacity of 700 MW, updated site conditions to 2016 levels. This includes:  
- An update of the water depth and wind speed to the best available wind climate by RVO  
- An update of the wind farm capacity from 300 MW to 700 MW |
| T3              | Switch to 66 kV                                                            | **Borssele:**  
- WTG transformer CAPEX: +45%;  
- WTG Switchgear CAPEX: +50%;  
- Array cable costs: +15%;  
- Array cable length: -20% |
| T4              | Increased availability                                                     | +2% availability (resulting in 96% availability) |
| T5              | Increased experience and innovations in installation                      | Cycle times: -30% (WTG installation, foundation installation) |

4 Note that the cost impact of using 66 kV is expected to materialise over time. Source: TenneT 2015. Position paper: T1 Voltage level.
Table 2: Market and supply chain related cost reduction levers.

<table>
<thead>
<tr>
<th>Lever indicator</th>
<th>Lever name</th>
<th>Cost component impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>Reduced steel pricing(^5)</td>
<td>Steel price -40%</td>
</tr>
<tr>
<td>M2</td>
<td>Third party WTG O&amp;M</td>
<td>WTG OPEX -25%</td>
</tr>
<tr>
<td>M3</td>
<td>Reduced insurance costs</td>
<td>Insurance costs construction -50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insurance cost operations -50%</td>
</tr>
<tr>
<td>M4</td>
<td>Residual lever(^6)</td>
<td><strong>Borssele, DNS:</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• BOP CAPEX -10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• WTG CAPEX -10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Horns Rev III:</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• BOP CAPEX -5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• WTG CAPEX -5%</td>
</tr>
</tbody>
</table>

Table 3: Finance cost reduction levers.

<table>
<thead>
<tr>
<th>Lever indicator</th>
<th>Lever name</th>
<th>Cost component impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Reduced financing costs</td>
<td>Debt interest rate -2.5%-point (absolute value 3%)</td>
</tr>
<tr>
<td>F2</td>
<td>Reduced required return on equity</td>
<td><strong>Borssele, DNS(^8):</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Equity return -30% (absolute value 11%)</td>
</tr>
</tbody>
</table>

\(^5\) Only the steel price developments are considered here. The LCoE sensitivity to e.g. oil and copper prices is considerably lower than steel, as shown in the “Cost reduction options for Offshore wind in the Netherlands FID 2010-2020” study by TKI Wind op Zee (2015, http://www.tki-windopzee.nl/files/2015-10/151028-tki-offshore-wind-cost-reduction-final-stc.pdf).

\(^6\) This lever includes: portfolio effects, multi-contracting, purchasing power, increased risk appetite & increased competitiveness, and explicitly excludes technological improvements. Because of its nature this lever has a relatively high uncertainty.

\(^7\) Reduced impact of M4 assumed for Horns Rev III as the tender took place earlier in time when the impacts of M4 were considered less prominent.

\(^8\) No reduced required return on equity assumed for Horns Rev III as tender took place earlier in time when increased competition and risk appetite were considered less prominent.
Table 4: Policy cost reduction levers.

<table>
<thead>
<tr>
<th>Lever indicator</th>
<th>Lever name</th>
<th>Cost component impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Permit and policy improvements(^9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Combined roll out of concession, subsidy and permit rights</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Wind farm site decisions (Kavelbesluiten)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Flexible permits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Government provides data on soil, waves and wind</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Noise limitation for hammering</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Coordinated research by government for designated areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Construction period: -0.25 yr.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Development period: -4.5 yr.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CAPEX: -4.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Environmental monitoring costs: -50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Structural steel mass: -2.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equity return rate: -0.2% point</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Installation cycle duration: +10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Installation fleet day rate: +10%</td>
</tr>
<tr>
<td>P2</td>
<td>Grid connection responsibility of TSO</td>
<td></td>
</tr>
</tbody>
</table>

**Borssele:**
Shift of transmission asset costs from developer scope to TSO scope. (Note that this is not necessarily a cost reduction from a system point of view, but merely a scope change for the developer.)

2.3 LCoE Impact analysis

As discussed before, the TKI Offshore Wind Cost model was used for calculating the impact of the cost reduction levers on the LCoE for the three cases under consideration. Figure 3 gives a schematic representation of the modelling approach.

The impact of the cost reduction levers was assessed on an individual basis to assess their relative impact and to prevent the order of the cost reduction levers influencing the impact. In addition, a combined case was defined in which the combined LCoE impact of the cost reduction levers was assessed. After the initial analysis was completed, a workshop was held to discuss and challenge the cost reduction levers and initial results.

### 2.4 Workshop presentation of draft research note

The draft research note was presented to a significant number (>25) of representatives from the offshore wind industry at a workshop at the Sociaal Economische Raad (SER) in The Hague on the 21st of December 2016. Participants included representatives from offshore developers, suppliers, government, advisors, associations and financing institutions. Relevant feedback was collected during the session, to sharpen the assumptions and results, and add sensitivity to results were needed.

### 2.5 Final research note

Based on the workshop at the SER, and discussions with TKI-WoZ, a final analysis was performed based on the input parameters as listed earlier in Table 1 to Table 4. The results of this analysis are presented in section 3.
3 Results

This section presents the main results of the analysis for Borssele I&II, Horns Rev III and the Danish Nearshore Tender, based on the final cost reduction levers as defined in Table 1 to Table 4. A sensitivity analysis is presented in section 3.4.
3.1 Borssele I&II

Figure 4 presents an overview of the LCoE impact of individual levers, and the total LCoE impact of the combination of all levers. The following impacts can be identified:

- Updated site specifications (T2) and Grid connection responsibility of TSO (P2) are applied to arrive at a representative base case for the Borssele I&II site conditions (T2: wind speed, water depth, distance to shore) and developer scope (P2<sup>10</sup>) as described earlier in section 2.1.
  - The cost impact of T2 results mainly from an increase in wind speed for the Borssele sites (yield increase of 5%) and economies of scale (e.g. reduced installation costs per MW for WTGs (-12%) and foundations (-5%), reduced E-infra installation per MW (-9%; incl. OHVS), reduced project management costs per MW (-57%), etc.)
  - The cost impact of P2 results from a shift of the transmission assets from the developer scope to the TSO scope.

- The main cost reduction levers relative to the 700 MW base case are respectively design improvements and innovations in WTGs and foundations (T1), reduced equity return rates (F2), reduced financing (interest) costs (F1) and the residual lever representing portfolio effects, multi-contracting, purchasing power, increased risk appetite & increased competitiveness (M4).

- The total impact (combination of all levers) approaches the tender result<sup>11</sup> closely, indicating that the cost reduction levers as presented for this case are able to explain the cost reduction as observed for this case.

![Figure 4: LCoE impact of individual and combined cost reduction levers on the Borssele I&II case.](image)

<sup>10</sup>Note that even though the transmission assets are removed from the developer scope, these are still required for the offshore wind farm and are not directly considered as a cost reduction from a system perspective. However, from a developer’s point of view, a reduction in costs is established by shifting the transmission assets responsibility to the TSO.

<sup>11</sup>Note that the tender results in these analysis are converted to a LCoE level based on a 20-year project lifetime with an assumed after-subsidy income of 30 €/MWh. The sensitivity for the after subsidy income is moderate: after-subsidy income of 60€/MWh would imply an LCoE of 71 €/MWh for the Borssele I&II cases.
3.2 Horns Rev III

Figure 5 presents an overview of the LCoE impact of individual levers, and the total LCoE impact of the combination of all levers, the following impacts can be identified:

- The impact of reduced required return on equity (F2) is absent in this case because no reduced equity return rate was assumed for this case.
- Permit and policy improvements (P1) represent the Danish method of tendering wind farms and is mentioned specifically as cost reduction lever relative to the base case. The Danish tender mechanism was introduced as it was not present in the TKI Offshore Wind Cost model base case.
- The largest contributors to cost reduction for the Horns Rev III case are design improvements and innovations in WTGs and foundations (T1), reduced financing (interest) costs (F1), Third party WTG O&M (M2) and the residual lever representing portfolio effects, multi-contracting, purchasing power, increased risk appetite & increased competitiveness (M4). Note that T1 and M4 were defined specifically for Horns Rev III as indicated in section 2.2.
- A relatively large “delta” remains between the total (combined) impact of all cost reduction levers and the tender result. The identified cost reduction levers result in a larger cost reduction than what the tender result for Horns Rev III demonstrates. One of the explanations could be that some cost reduction levers were overestimated. Another explanation could be that the full cost reduction potential of the Horns Rev III tender was not realised due to a less efficient tender process.

Figure 5: LCoE impact of individual and combined cost reduction levers on the Horns Rev III case.
3.3 Danish Nearshore

Figure 6 presents an overview of the LCoE impact of individual levers, and the total LCoE impact of the combination of all levers, the following impacts can be identified:

- Permit and policy improvements (P1) represent the Danish method of tendering wind farms and is mentioned specifically as cost reduction lever compared to the base case, analogous to the Horns Rev III case.
- The largest contributors to cost reduction for the Horns Rev III case are respectively design improvements and innovations in WTGs and foundations (T1), reduced equity return rates (F2), reduced financing (interest) costs (F1) and the residual lever representing portfolio effects, multi-contracting, purchasing power, increased risk appetite & increased competitiveness (M4).
- The total impact (combination of all levers) approaches the tender result closely, indicating that the cost reduction levers as presented for this case are able to explain the cost reduction as observed for this case.

![Figure 6: LCoE impact of individual and combined cost reduction levers on the Danish Nearshore case.](image-url)
3.4 Sensitivity analysis

A number of sensitivities are defined based on the feedback collected during the workshop and in discussions with TKI. These sensitivities are applied to the “base case 2010 700 MW” for Borssele I&II, as indicated in section 3.1. The sensitivities under consideration are given in Table 5, as well as the base values of the “base case 2010 700 MW” cost level for Borssele I&II.

Table 5: Sensitivity components as defined during the workshop and in discussions with TKI.

<table>
<thead>
<tr>
<th>Sensitivity indicator</th>
<th>Sensitivity name</th>
<th>Cost component impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Increased lifetime</td>
<td>Project operational lifetime of 25 years (base: 20 years)</td>
</tr>
<tr>
<td>S2</td>
<td>Increased WTG capacity 7 MW</td>
<td>7 MW turbine in FLOW Offshore Wind Cost model, recalculation foundation and e-infra</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(base: 3 MW turbine)</td>
</tr>
<tr>
<td>S3</td>
<td>Increased gearing ratio</td>
<td>80% debt share (base: 70% debt share)</td>
</tr>
<tr>
<td>S4</td>
<td>Reduced equity return rate</td>
<td>8% equity return rate (base: 15% equity return rate)</td>
</tr>
<tr>
<td>S5</td>
<td>Balance sheet finance with reduced equity return rate</td>
<td>100% equity share (base: 30% equity share) 8% equity return rate (base: 15% equity return rate)</td>
</tr>
</tbody>
</table>

Figure 7 presents the LCoE impact of the sensitivity components defined in Table 5 on the base case for Borssele I&II. Design improvements and innovations in WTGs and foundations (T1) and a reduced equity return rate of 11% (F2) are shown to present the sensitivity of S2 and S4 relative to their related cost reduction levers.
Figure 7: LCoE impact of individual sensitivity levers (S) put in perspective with T1 and F2.

Figure 8 shows that in case all upsides as defined in Table 5 (S1, S3 & S4) are combined with the Borssele I&II levers, a significantly lower LCoE level can be reached. In fact, the cost level approaches the recent strike price of Borssele III&IV (54.5 €/MWh).

Figure 8: LCoE impact of individual and the combined impact of the individual levers (including upsides from the sensitivity analysis). Total Upside Impact* includes upsides from the sensitivity analysis (S1, S3 and S4) in the Total (combined) Impact on Borssele I&II, from the analysis in section 3.1. Note that F2 has been omitted and substituted by S4.

Note that S5 indeed results a cost reduction compared to the base case. However, this is not an upside compared to project finance based on 80/20 debt/equity ratio, 8% equity return rate and 2.5% debt interest rate.
4 Discussion on external factors and future cost reduction

The cost reduction analysis in section 3 shows that part of the recent cost reduction trends can be explained by external factors such as interest rate (F1) and steel price (M1) developments. One could argue that these externalities are short term economic effects and may prove to be temporary. Figure 9 shows the impact of the evaporation of the interest rate reductions (F1) and the steel price reductions (M1) on the cost reduction for Borssele I&II, indicating a price increase of more than 10%. This shows the majority of cost reduction (>80%) is not based on short term economic effects and could be considered a permanent development.

Figure 9: Impact of externalities on the LCoE reduction for Borssele I&II.

While recent offshore wind developments show a radical drop in LCoE, further cost reductions are still required for offshore wind to become e.g. fully subsidy free and to further lower the energy cost to businesses and consumers. This warrants the question how additional cost reduction for offshore wind could be realised. Aspects to consider include both cost reducing and capacity (or volume) increasing developments:

- Additional innovations, industry scale effects and standardisation
- Capacity increase of wind farms from 700 MW to e.g. 1000 MW
- New offshore wind farm locations, e.g. locations further offshore
- Further improvements in subsidy and permitting regime

The large scale roll-out of offshore wind in the Netherlands introduces other cost related challenges, such as how to create a level playing field where system costs are included in renewable (balancing, merit order) and conventional (CO2-emissions) electricity generation. In addition, an energy system with significantly larger shares of offshore wind, profile (and potentially, imbalance) costs will increase resulting in a relatively larger gap compared to the “grey electricity price”. This development could make participation in other markets such as flexibility attractive for intermittent renewables such as offshore wind.
5 Conclusion

This study has focused on explaining recent development in offshore wind cost reduction by looking deeper into cost reduction trends in the offshore wind market with the use of the TKI-WoZ cost model. The approach and assumptions have been tested during a workshop with the offshore wind industry at the SER in The Hague on the 21st of December. The analysis has shown to approach the tender results for Borssele I&II and the Danish Nearshore Tender within a reasonable margin. The cost reduction impact for Horns Rev III was overestimated, even though more conservative assumptions on cost reduction trends were taken into account. It is not directly possible to explain the cause of this delta, but the analysis shows it is likely that levers for this particular case have been overestimated. Another explanation could be that the full cost reduction potential of the Horns Rev III tender was not realised due to a less efficient tender process.

The sensitivity analysis has shown that the Borssele III&IV tender result can be approached when more optimistic assumptions for the levers are considered. In addition, the role of externalities is investigated showing that even though trends such as steel price and interest rate developments have a significant share in the cost reduction, the majority of the cost reduction is not dependent on these externalities.