



FINAL REPORT

Validation of Studies regarding the Grid
Connection of Windfarm Zone IJmuiden Ver

BLIX Consultancy BV

From: BLIX Consultancy BV

Reference: IUC201804099

To: Ministry of Economic Affairs and Climate Policy
Netherlands Enterprise Agency

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Version: Final Version

Date: 5 November 2018

EXECUTIVE SUMMARY

Based on an advice of the Dutch TSO TenneT, the Ministry of Economic Affairs & Climate Policy (MinEACP) has to decide which grid connection system (GCS) will be used for the approx. 4GW (and possibly more) offshore wind power that will be installed in offshore Wind Farm Zone IJmuiden Ver.

TenneT has commissioned several studies and market consultations to substantiate an advice, based on which MinEACP can make a responsible decision. The decision which GCS concept will be developed, will be based on the Levelized Cost of Energy (LCoE), technical and legal feasibility, compliance with the offshore roadmap of MinEACP and risks.

The MinEACP and the Netherlands Enterprise Agency have given an assignment to BLIX to support this decision-making process by validating the internal TenneT studies and the studies commissioned by TenneT, analyzing the alternatives.

In order to create a structured validation of the TenneT-position, BLIX has formulated the following research questions:

- A. Are the LCoE reports and the underlying reports complete and correct?
- B. Is TenneT's position on the selection of alternatives complete, correct and robust?
- C. Are the TenneT plannings for the most promising options complete, correct and robust? Do they adhere to the roadmap?
- D. Can we validate the TenneT's pre-initiation process (TenneT terminology for preliminary project development) to be complete, correct and robust?
- E. Based on the previous chapters, can we compare the most promising options in a multi-criteria analysis (MCA)?

Answer to research question A: BLIX has been able to validate the LCoE report, since:

- The LCoE-model is correct, and all input parameters can be traced.
- The technical designs of the 8 GCS concepts are correct and complete.
- The CAPEX components of the 8 GCS concepts are in line with our expectations. Based on experience and expert judgement some of the cost components for HVAC and the island solutions could not be completely validated. Therefore, we included them in an extreme sensitivity scenario to see whether this would change the ranking.
- The OPEX components of the 8 GCS concepts are correct and complete.
- Losses and availabilities appear correct, but full traceability has not been provided. Therefore, we included them in an extreme sensitivity scenario to see whether this would change the ranking.
- Extreme sensitivity scenarios for not fully validated starting points do not change the ranking between the options. The worst-case sensitivity of the 2*2GW HVDC island is similar to the base case of the 2*2GW HVDC platforms. Therefore, we have been able to validate that the 2*2GW HVDC island has a lower LCoE than the 2*2GW HVDC platforms.

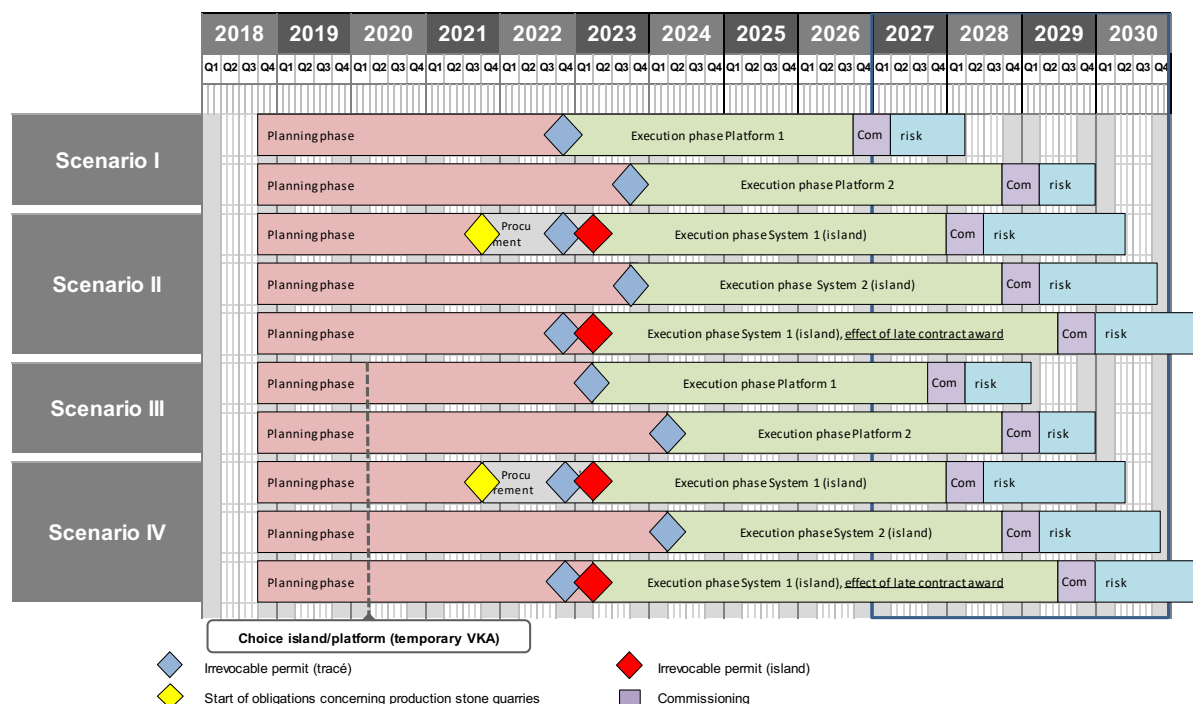
Answer to research question B: BLIX has been able to validate the critical design choices made by TenneT to be optimal for this phase of the project:

- The 8 GCS concepts that have been considered are the most feasible options. Choosing from these options will result in the optimal design.
- TenneT has correctly rejected HVAC, even though we have not been able to provide a validation of all quantified arguments. However, the qualitative arguments to reject HVAC are strong and even in an extreme scenario HVAC is not significantly cheaper.

VALIDATION GRID CONNECTION STUDIES IJMUIDEN VER

- We can validate TenneT's preference for 2GW export cables over 1GW and 1.33GW. TenneT's motivation is correct, complete and robust.
- Infield cables running underground are more advantageous compared to overhead lines for the island-based GCS.
- The 2*2GW HVDC island case has operational advantages and a lower LCoE, while the planning for 2*2GW HVDC platforms is less risky. A more in-depth assessment (see below) has been performed to assess the plannings and adherence to roadmap and coalition agreement.

Answer to research question C: TenneT has provided four scenarios which aim for a 2027-2028 commissioning of the grid connection as shown in the planning below. The GCS under review are the 2*2GW HVDC island ('island') and 2*2GW HVDC platforms ('platforms'). This planning also includes the required onshore connection and the export cables, but these are not on the critical path. Note that this planning does not show the moment when wind farms will become operational.



The prerequisite for the island case is that the island will be monofunctional and that the contract for stone production will be awarded before permit is irrevocable. The following four scenarios have been described:

- Scenario I – Late 2018 selection of platforms – completed in 2027.
- Scenario II – Late 2018 selection of an island – completed in 2028.
- Scenario III – Simultaneous development until 2020 – Selection of platform in Q1-2020 – completed in 2028. Note that a choice for platforms in 2020 leads to one year of delay compared to choosing platforms in 2018.
- Scenario IV – Simultaneous development until 2020 – Selection of island in Q1-2020 – completed in 2028.

BLIX has assessed the 'roadmap' of MinEACP and distilled the following requirements:

- Wind farms will be commissioned from 2027 onward
- 4GW offshore wind at IJmuiden Ver needs to be operational in late 2030

- Wind farms need to be operational at the end of a calendar year. BLIX assumes that the grid connection needs to be finished 9 months before this date to allow for float in the planning and early completion revenues for the offshore wind farms.

We have found that the base case for all scenarios is in line with the roadmap to a certain extent. This is not the case anymore when risks materialize that lead to the delays, which could lead to less competitive bids in tenders and the obligation (under the Electricity Act) for TenneT to compensate the wind farm permit holder(s):

- Only scenario I is fully in line with the roadmap.
- Scenario II has a significant risk not to be completed in 2028, but in 2029 or 2030. This will result in missing the roadmap milestone by one or two years. Moreover, even in the ambitious planning not all aspects of the roadmap are met.
- Scenario III is in line with the roadmap requirement that 4GW needs to be operational in 2030, but not with the requirement that wind farm commissioning needs to start in 2027. Scenario III means choosing a parallel track that will cause a one-year delay when choosing for platforms afterwards, compared to choosing platforms in 2018.
- Scenario IV has a significant risk not to be completed in 2028, but in 2029 or 2030. This will result in missing the roadmap milestone by one or two years. This risk is the same to scenario II, but this scenario IV has scenario III as a fallback option (until 2020).

Choosing the hybrid scenario III/IV has an additional drawback that this might introduce a political and public debate over the choice between island and platform causing possible delays.

Answer to research question D: The pre-initiation phase for TenneT appears complete, correct and robust.

Answer to research question E: BLIX has created a multi-criteria analysis which provides a back-to-back comparison between the 2*2GW HVDC island and 2*2GW HVDC platforms, see table below. The first four criteria are considered major criteria, which, depending on preference, can shift the choice between platform and island. The final three criteria are minor criteria, since they assume other future developments, or have a limited impact.

Criterion	2*2GW HVDC platforms	2*2GW HVDC Island
Technical feasibility	Feasible	Feasible. Even though a HVDC island is new, all components (with similar interfaces) have been built before
LCoE and cost overruns	±82 €/MWh, low variance	±79 €/MWh, higher variance
	Under TenneT-assumptions platforms are 2.8€/MWh more expensive, which corresponds to an NPV of 600 million euro. This difference drops to 1.8€/MWh or 400 million when assuming the RWS design and costing. In a worst-case scenario for island, the difference is negligible. Cost increases due to possible delays are not taken into account.	
Redundancy and grid stability	Medium redundancy, medium availability, can stabilize the grid	High redundancy, higher availability, can stabilize the grid
Risks of delay and adherence to roadmap	Low risk of delay, full adherence to roadmap when choosing platforms in 2018. Choosing platforms in 2020 leads to partial adherence to roadmap.	Higher risk of delay, possibility to miss roadmap goals by years. Mitigating measures limited during construction with no guarantee to remain in line with the roadmap.

Criterion	2*2GW HVDC platforms	2*2GW HVDC Island
Additional capacity	More expensive and harder to achieve in short time duration	Cheaper and slightly easier to achieve in short time duration
Multiple life and decommissioning cost	Limited possibility for multiple life, decommissioning at zero cost. Overall, no clear advantage over island.	Multiple life possible, decommissioning potentially expensive. Overall, no clear advantage over platform.
Upsides (hydrogen, interconnection etc.)	None, or harder and more expensive to realize due to limited space on a platform	Possible, planning in line with roadmap is only possible when assuming a monofunctional island. Therefore, development of other upsides can only start after initial development of the HVDC island.

Conclusion: a design choice between 2*2GW HVDC platforms and 2*2GW HVDC island depends on the relative importance that the Dutch government would give to a robust planning with short time duration (which favors platform) or to the lowest possible LCoE and more operational redundancy (which favors island in an optimistic scenario).

- In case full adherence to the roadmap is required, a choice for a 2*2GW HVDC platform GCS is the only suitable option. The roadmap requires the first 1GW of wind farms to be operational in 2027, and thus requires the first 2GW GCS to be operational in Q1-2027. Worst-case (but highly mitigatable) delays would lead to commissioning in 2028. This is still moderately in line with both roadmap and coalition agreement.
- Immediate choice for an island will lead to the first operational wind farms in 2028 in an optimistic scenario, which is still moderately in line with the roadmap. Delay until 2029 or later is a real risk however, since we have not been able to fully validate the 2028 planning for the island and additional risks might still occur. This can be problematic for the offshore wind supply chain, possibly lead to additional cost, and not be in line with either roadmap or coalition agreement. Mitigating measures during the project are limited. Therefore, an immediate choice for an island is only an option, if the MinEACP has no problem with windfarm commissioning in 2029 (or later).
- The hybrid scenario III/IV, in which both options are developed and the choice between island and platform is delayed to Q1-2020, could be a solution for trying to see if risks materialize and to assess if mitigation is possible. It should be noted that choosing the hybrid scenario III/IV and choosing the platform option afterwards (in 2020) will shift the platform planning with a year. This leads to a completion in 2028, which is not fully in line with the roadmap. Moreover, choosing the hybrid scenario has an additional drawback that this might introduce a political and public debate over the choice between island and platform causing possible delays

If MinEACP chooses this option, the following activities should be undertaken:

1. Determination of the required commissioning date for the TenneT GCS by tracking back from the required dates commissioning dates of the wind farms and the optimal construction time of wind farms (using market consultation)
2. Detailed optimization of the entire island concept to make the planning more robust and with a shorter time duration if possible (since a possible 2029 completion date of the GCS is not in line with the roadmap)

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1 INTRODUCTION

1.1 Background & Assignment

Based on an advice of the Dutch TSO TenneT the Ministry of Economic Affairs & Climate Policy (MinEACP) has to decide which grid connection system (GCS) will be used for the approx. 4GW (and possibly more) offshore wind power that will be installed in offshore Wind Farm Zone IJmuiden Ver.

TenneT has commissioned several studies and market consultations to create an advice, based on which the Dutch government can make a responsible decision. The decision which GCS will be developed, will for a large part be based on the Levelized Cost of Energy (LCoE), technical feasibility, compliance with the offshore roadmap and risks.

The MinEACP and the Netherlands Enterprise Agency have given an assignment to BLIX to support this decision-making process by validating the internal TenneT studies and the studies commissioned by TenneT, analyzing the alternatives.

1.2 Research questions

Based on the Request for Proposal and new insights during the execution of the validation, we formulated the following research questions:

- A. Are the LCoE reports and the underlying reports complete and correct?
with the following sub-questions:
 1. Is the LCoE-model correct and can all input parameters be traced?
 2. Are the technical designs of the 8 GCS correct and complete?
 3. Are the CAPEX components of the 8 GCS correct and complete?
 4. Are the OPEX components of the 8 GCS correct and complete?
 5. Have losses and availabilities been correctly assessed?
 6. What happens to the LCoE when considering best- or worst-case scenarios for unvalidated starting points? In this way, the (financial) impact of an unvalidated starting point can be determined. This determines whether there is an issue or not.
- B. Is TenneT's position on the selection of alternatives correct and robust?
with the following sub-questions:
 1. Are the 8 GCS systems under review in the LCoE-reports the most promising options?
 2. Can we validate the TenneT position that HVAC is technically and economically unfeasible?
 3. Are 2GW export cables preferable to 1.33GW and 1GW cables?
 4. Are 66kV infield cables preferable to 66kV overhead lines in the island scenarios?
 5. How do island solutions compare to DC platform solutions?
- C. Are the TenneT plannings for the most promising options robust, correct and complete? Do they adhere to the roadmap?
- D. Can we validate the TenneT's pre-initiation process to be complete, correct and robust?
- E. Based on the previous chapters, can we compare the most promising options in a SWOT/MCA?

1.3 The eight Grid Connection Systems (GCS) under review

The LCoE report and the TenneT reports contain 8 GCS concepts under review, a list of which can be found below.

#	Description	Export cable type	Inter-array cable type
1	6*667 MW AC clustered	220kV, 33MW	66kV inter-array
2	4*HVDC 1GW (standalone)	320kV, 1GW	66kV inter-array
3	3*HVDC 1.33GW (standalone)	400-450kV, 1.33GW	66kV inter-array
4	2*HVDC 2GW (standalone)	525kV, 2GW	66kV inter-array
5a	3*HVDC 1.33GW Island	400-450kV, 1.33GW	66kV inter-array
5b	3*HVDC 1.33GW Island	525kV, 2GW	66kV overhead
6a	2*HVDC 2GW Island	400-450kV, 1.33GW	66kV inter-array
6b	2*HVDC 2GW Island	525kV, 2GW	66kV overhead

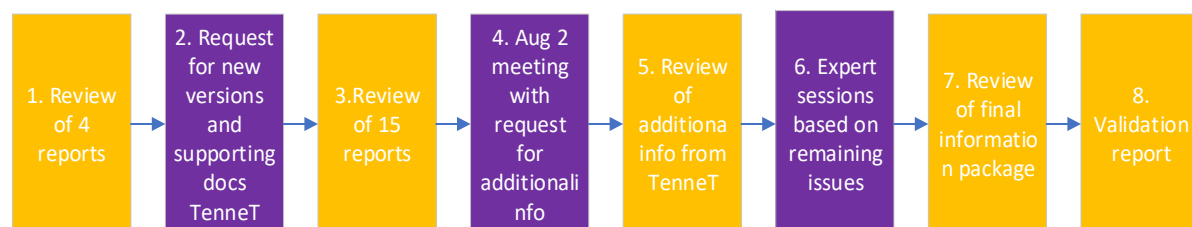
1.4 Structure of the report

The report contains the main findings of important validation issues and is subdivides into chapters, in which the different research questions will be answered:

- Chapter 2: Validation of the LCoE-report results (answer to Question A)
- Chapter 3: Validation of the TenneT position on the selection of alternatives (answer to Question B)
- Chapter 4: Planning and adherence to the roadmap (answer to Question C)
- Chapter 6: Validation of the TenneT pre-initiation process (answer to Question D)
- Chapter 5: Full back-to-back comparison between 2*2GW island and platform and MCA (answer to Question E)
- Chapter 7: Conclusions

1.5 Approach

BLIX has validated the completeness, correctness and robustness of the TenneT proposals for a grid connection system (GCS) for the proposed IJmuiden Ver wind area. We proposed an approach, which was approved by the MinEACP and Netherlands Enterprise Agency in agreement with the Ministry of the Interior (BZK) and Rijkswaterstaat (RWS), as shown in the following figure:



The following steps have been taken:

1. A review of the original information package.
2. This information package was sometimes obsolete and still incomplete; after discussion with TenneT we received additional information.
3. The resulting 15 reports were reviewed.

4. During a meeting at 2nd August 2018, we discussed the current status and requested additional information.
5. BLIX received answers from TenneT to our (high level) questions.
6. Remaining questions were discussed during four expert sessions:
 - a. The financial session contained issues on financial parameters, the LCoE-model, and traceability of the LCoE-model. We chose to perform this digitally due to the limited amount of questions remaining.
 - b. The electrical session (23 August) contained issues on the electrical design of the offshore convertors, the export cables, the power quality issues, etc.
 - c. The risk and planning session (30 August) contained issues on general risks, their mitigation, the planning approach.
 - d. The civil and offshore session (3 September) contained issues on the island construction, offshore construction and their in-depth planning.
7. After these meetings, 13 unresolved questions remained, which have been sent to TenneT in minutes of meeting. TenneT provided an answer to the 13 issues, which included a memo on risk management and a memo with a realistic planning for island and DC platform, to be in line with the '*Routekaart windenergie op zee 2030*', hereafter called "roadmap". This, together with the previous info, was considered the final information package.
8. The abovementioned information, together with publicly available sources, have been the source of our validation.

1.6 List of sources

As mentioned in the previous paragraph, BLIX has used an extensive list of sources. Starting with the original 4 reports, TenneT provided us with additional information, memos and updated documents. Moreover, a significant amount of information was provided as answers to questions and during expert sessions, the minutes of which have been created by BLIX. A complete list of sources is provided separately. Part of the sources are now considered obsolete and have therefore not been included into the assessment.

2 QUESTION A: VALIDATION OF THE LCOE AND UNDERLYING REPORTS

This chapter contains the main findings of the validation of the LCoE report. This chapter contains answers to the following questions:

- 2.1. Is the LCoE-model correct and can all input parameters be traced?
- 2.2. Are the technical designs of the 8 GCS concepts correct and complete?
- 2.3. Are the CAPEX components of the 8 GCS concepts correct and complete?
- 2.4. Are the OPEX components of the 8 GCS concepts correct and complete?
- 2.5. Have losses and availabilities been correctly assessed?
- 2.6. What happens to the LCoE when considering best- or worst-case scenarios for unvalidated starting points? In this way, the (financial) impact of an unvalidated starting point can be determined. This determines whether there is an issue or not.

2.1 BLIX has been able to validate the LCoE-model and traceability of input parameters

2.1.1 The input parameters are traceable from underlying documents or sources, through an overview sheet, into the LCoE-model

- The LCoE-reports did not include a comprehensive break-down of all cost components and their sources in a traceable way. At BLIX's request, TenneT created '*CAPEX reconciliatie 140818.xlsx*' with cost breakdowns and sources.
- BLIX has been able to trace the input parameters from underlying documents or sources, though '*CAPEX reconciliatie 140818.xlsx*' into the LCoE-report and found no inconsistencies.

2.1.2 The LCoE model used by TenneT has been validated by creating a shadow LCoE model that showed similar results

- BLIX has created a shadow LCoE model to assess the following aspects:
 - The correctness of the TenneT LCoE-model, by using similar inputs and checking whether the results are similar.
 - The impact of different scenario's and sensitivities. BLIX uses a sensitivity analysis for starting points that cannot be validated sufficiently. In this way, the impact of a worst-case scenario can be assessed. See later in this chapter for more information.
- The results of the BLIX model and the Ecofys model can be found in Table 1. The results show a similar LCoE difference between the options compared, but the Ecofys numbers are 1.1-1.3€/MWh higher. These differences might be resulting from the phasing of cash, depreciation approach, gearing during the project, etc. In our expert judgement we do not consider this a big risk or one that might alter the ranking of the options.
- Note that the BLIX results are indicative and relatively high level, and therefore only allow for relative comparison.

Table 1: Results of the BLIX LCoE model compared to the Ecofys model for the 8 Grid Connection Systems. A description of the different GCS can be found in the previous chapter.

GCS concept	Description	LCoE Windfarm (Ecofys) (€/MWh)	LCoE GCS (Ecofys) (€/MWh)	LCoE system (Ecofys) (€/MWh)	LCoE system (BLIX) (€/MWh)
1	6*667 MW AC	56.7	36.1	92.8	91.8
2	4*HVDC 1GW	56.5	32.5	89.0	87.9
3	3*HVDC 1.33GW	56.7	28.5	85.2	84.1
4	2*HVDC 2GW	56.9	24.8	81.7	80.5
5a	3*HVDC 1.33GW Island – IA cables	57.9	23.2	81.1	79.8
5b	3*HVDC 1.33GW Island – IA overhead	56.3	25.1	81.4	80.1
6a	2*HVDC 2GW Island – IA cables	57.9	21	78.9	77.6
6b	2*HVDC 2GW Island– IA overhead	56.3	22.9	79.1	77.8

2.2 We have been able to validate the technical feasibility of all relevant GCS.

- We consider all relevant proposed types of platforms and export cables to be technically feasible. The island construction is technically feasible as well.
- The TenneT design for the island solution incorporates the use of long (25km), high capacity (90MW) infield cables. BLIX has been able to validate their technical feasibility and adherence to the Requirements for Generators (RfG) in the new European grid code.
- We do consider the design of the 66kV overhead lines technically underdesigned to cope with severe weather conditions however. This reinforces the TenneT position that overhead lines are not preferable.

2.2.1 We have been unable to validate the technical design and costing of 66kV overhead lines. This reinforces the TenneT position that overhead lines are not preferable, since they were already more expensive.

- TenneT GCS options 5b and 6b contain offshore overhead lines, which have been assessed in a DNV-GL report (*'Feasibility study and cost estimate for 66 kV offshore overhead line'*).
- The technical design proposed in the report cannot be validated; a preliminary review shows that a more robust design is needed.
- Moreover, the required maintenance (especially coating repair) is underestimated.
- Therefore, we expect higher cost estimates for 66kV overhead lines, increasing the LCoE of the option. Since TenneT already concluded that the LCoE of overhead lines are higher than for infields, our findings reinforce this conclusion.

2.2.2 The island construction is technically feasible

- Similar artificial islands consisting of a base of sand, protected by revetments or caissons have been constructed in comparable water depths at various locations around the world. Although these islands are typically built in more sheltered conditions, the currently

anticipated environmental conditions (waves, currents and water levels) can be accounted for by an increased strength of the outer revetment.

- There are various reputable engineering & construction firms capable of designing and realizing such an island. In fact, many of the most renowned firms are established in the Netherlands and Belgium, which have the equipment to construct an artificial island.
- The technical challenges of island construction (wave loads on the revetment, currents, scour, liquefaction, settlements, etc.) are well understood.
- We expect that there will be sufficient sand available in the Dutch part of the North Sea to serve as filling material. The rock volumes needed in the revetments and breakwaters can be easily supplied by rock quarries (mostly from Norway). Furthermore, there are various facilities to produce the concrete armoring elements and quay walls of the ports.
- Connecting the electricity cables will be technically feasible, because there are a range of options available.
- Note that Rijkswaterstaat (RWS) has performed a parallel validation of the technical and economic feasibility of the construction of an island. We have not validated this report and both reports should be considered complementary. We will include the results of the RWS study into our sensitivity analysis however.

2.3 BLIX has performed a sanity check on the CAPEX components of the different grid connection systems. We have found no large anomalies; we will include this in a sensitivity analysis to check impact of differences.

- Breakdowns and calculations can be found in 'CAPEX reconciliatie 140818.xlsx'.
- BLIX has validated that these cost components have been correctly implemented into the LCoE model by using the shadow model (see above).
- We performed a sanity check on all cost components of the different GCS by comparing to known prices and by extrapolation.
- For GCS where we were unable to validate some CAPEX components, we include a scenario into a sensitivity analysis (see later in this chapter).
- BLIX has been able to put the aspects of different options to a different level of scrutiny:

Aspect	Approach and assessment BLIX
AC platforms	These are also procured by customers of BLIX, and therefore BLIX has in-depth knowledge on current EPC-prices from contractors. We found AC export cables and infield cables prices to be highly similar to recent EPC-contracts; AC platforms were found to be 15% more expensive than our most recent quotes. This is within uncertainty margins considering market conditions, location and specific design. We have included a scenario with 15% higher AC CAPEX to see if this has impact on LCoE.
AC export cables	
66kV infield cables	
DC export cables	Prices can be easily converted from AC prices, since cables and their cost drivers are similar. TenneT prices were in line with our expectations.
DC platforms	DC platforms are normally not procured by customers of BLIX and therefore we do not have benchmark EPC-prices, only high-level rules of thumb. TenneT prices were in line with expectations. Since TenneT has experience with 1GW DC platforms in Germany, we expect a low error margin for cost estimations of these platforms.

Island construction	The island construction costing has been put under scrutiny in paragraph 2.3.1, leading to the conclusion that we cannot fully validate the costing. A conservative scenario, in which we increase the island CAPEX by 40%, will be enough to see whether this impacts the LCoE ranking.
Island HV infrastructure	TenneT chose a 25% markup to correct for offshore conditions. BLIX has not been able to validate this number in the absence of a specified design. We will include a scenario in which we will increase this markup from 25% to 50% to see whether this impacts the LCoE ranking.
Onshore DC station	BLIX has only access to rules of thumb. TenneT prices were in line with expectations. Since onshore DC costs do not differ between platform and island, the impact of costing errors to this choice is negligible.

- Conclusion: BLIX has been able to validate the CAPEX for most of the components. Full validation for some components was not possible. We will use a sensitivity analysis to see whether this has a substantial impact on the LCoE-ranking.

2.3.1 The cost of the island is considered a “best-estimate value”. We recommend applying a larger uncertainty margin to see whether this influences the relative LCoE-ranking

- Various marine contractors have been requested by TenneT to compose preliminary designs with cost and planning estimates. We have had highly restricted access to these documents. We conclude that the level of detail varies significantly between the efforts performed. In none of the cases all technical elements have been fully worked out.
- The approach followed by TenneT was to recalculate the given prices to unit rates. The island costs (600 million euro) were determined by averaging the unit rates and multiplying them with the average unit quantities associated with the main island elements (sand, revetment, port, cable landing) while assuming an island with a revetment.
- We consider this a valid first step to determine an “initial best guess estimate” of the island costs without safety factor. A logical follow-up would be to select one promising design as a “reference case” and work out all design elements for this island to further reduce the uncertainty of the costs (and time planning).
- This second step, for which all technical elements are designed and worked out to a level of “basic design” has not yet been performed. The primary elements not fully designed and with potential uncertain costs are: 1) the connection of infield cables, 2) scour protection and 3) risks of weather delay.
- We have identified aspects that (might) change CAPEX compared to the RHDHV market consultation:
 - TenneT confirms that the water depth (23m) was initially taken too optimistically. The additional cost assuming a more representative water depth (25m) was assessed by TenneT to be 15 million euro (mainly additional reclamation of sand). We confirm this estimate.
 - The port and breakwaters have been dimensioned based on the assumption to serve as a basis for operation and maintenance. Removing the requirement of creating sheltered conditions for O&M vessels would significantly simplify the port and breakwater layout. As a lower bound, we estimate that 40% of the costs for port and breakwaters would be saved, leading to a cost reduction of 70 million euro. Without a breakwater, TenneT will still be able to transport goods to the island, albeit not in all wind conditions. O&M activities from the port are not possible anymore however.
- Due to the lack of a basic design for which all technical elements have been worked out, and the associated potential uncertain costs, we recommend applying a high uncertainty margin

on these costs. Since there are also possible CAPEX savings (the net effect of both adjusted water depth and breakwater is -55 million euro), we propose to use 40% as an uncertainty margin instead of the normally used 50% in these instances.

- We consider the uncertainty margin proposed by TenneT (20%) appropriate and in line with industry standards for costs determined based on a basic design for which all elements have been worked out, but inappropriate to apply for an “initial best guess estimate”.
- Rijkswaterstaat (RWS) has performed a second opinion on the CAPEX and OPEX of the island. Even though this second opinion is not within the scope of this validation, BLIX has included the RWS-results into the scenario analysis later in this chapter.

2.3.2 Even though an island will have a good possibility for a second life, complete decommissioning after use will be expensive, possibly 400 million euro. We will include this in a sensitivity analysis.

- Decommissioning of platforms is normally inexpensive, since the decommissioning cost is compensated by the scrap value of the asset.
- Decommissioning of islands can be performed in three ways:
 1. Leaving them be to the elements – no costs.
 2. Removing sea defense (revetment) and allow waves and currents to erode away the sand. This could be done at low cost, but possibly pose risks to the environment (e.g. sand transport towards Bruine Bank).
 3. Complete removal of revetment, port and sand. The concrete armor units and quay walls would have to be removed individually and transported to a disposal location. The rock would have to be excavated but may be used for other construction activities. The sand may be redeposited in nearby dredging locations. We estimate that complete removal of all island elements would require similar equipment, costs and cycle times as the construction minus the cost of producing the armor units, rock and port elements. A conservative estimate of the total decommissioning costs is 80% of the construction cost, so 400 million euro.
- RWS also indicated in their report that decommissioning will be expensive.
- However, even though decommissioning is expensive, it will be after more than 30 years into the lifetime of the island. Due to the time value of money, this has a much lower impact than CAPEX upfront. We will include a sensitivity scenario in which a full decommissioning costing 400 million euro is included after the lifetime of IJmuiden Ver.

2.4 BLIX has performed a sanity check on the OPEX costs of the different grid connection systems. We have found no anomalies.

- TenneT estimated OPEX as a percentage of CAPEX using previous experience and rules of thumb. Breakdowns and calculations can be found in ‘CAPEX reconciliatie 140818.xlsx’.
- A substantial difference between O&M of island and DC-platform is assumed by TenneT. TenneT has further clarified these assumptions (more robust auxiliaries and simpler logistics for the island case). These clarifications are considered acceptable to BLIX.
- Even though we would have expected a more substantiated explanation behind the OPEX, but we do not think this would have made a significant difference when comparing LCoE.

2.4.1 We have been able to validate the conclusion of the O&M report, namely that an O&M port has a limited impact on installation and O&M cost

- We have validated the conclusions of the ECN report *Powerlink Island: Assessment of potential Installation and O&M benefits for developers of offshore wind farms*
- We have been requested to perform a light review of the report. Conclusively we found:
 - The report was lacking clarity on some of the assumptions used.
 - Some assumptions and related conclusions were considered outdated or incorrect.
 - Nonetheless, BLIX does support the conclusion from ECN that an Island will only have a limited effect on any cost LCOE in relation to the O&M of commissioning of the windfarms. Main reason being that size of the windfarms, the distance to shore and limiting conditions would make a Service Operational Vessels (SOV) the most economical solution in all cases, a solution that can operate independent from a port for a large part of the time.
 - We would further support the conclusion from ECN that in case an Island would be chosen, it would be wise to consult the market on any alternative ways an Island could support the construction and operation of the offshore wind farms.

2.5 TenneT has assumed losses and availabilities for the different GCS in the LCoE-model. These losses and availabilities are calculated, but full traceability was not possible.

- BLIX has reviewed 'CAPEX reconciliatie 140818.xlsx', which contained losses and availabilities. A first sanity check shows that losses and availabilities are within bandwidths that are to be expected.
- The losses have been calculated in 'UnavailabilityModel_v20_recalibration_sendoutsheetV3', but full traceability has not been provided, for example using detailed analysis or based on numbers provided by the International Council on Large Electric Systems (CIGRE).
- Availability of AC looks to be underestimated and for DC overestimated. Especially when comparing AC (with high availability) and DC solutions (with low losses when farshore), incorrect availability estimates might lead to significant changes in LCoE. We will include an extreme (or highly conservative) AC scenario for availability into the sensitivity analysis to see whether this impacts the LCoE ranking.

2.6 BLIX has been able to validate the LCoE upsides of double operational lifetime and capacity increase for the island

- The LCoE report includes two sensitivities that determine the LCoE effects for a double operational lifetime and capacity increase. The following assumptions were made:
 - In the double operational lifetime scenario, it was assumed that the island (if applicable), the export cables and transformers, could have a double lifetime. BLIX can validate this technical assumption.
 - The capacity increase scenario included the possibility to build an extra 1GW windfarm to the North of the current area, to be connected to the island using a 380kV export cable. In the case of a platform, a direct shore connection of the 1GW was considered. Both approaches appear technically feasible as well.
- Even though we have not validated this sensitivity by creating a shadow model, we have found no anomalies and results pass the sanity check. Therefore, we can validate that the island solution has additional upsides for a second operational lifetime and capacity increase.

2.7 Even though BLIX has not been able to validate all starting points, extreme sensitivity scenarios for these starting points do not significantly change the ranking between the options.

- The previous paragraphs showed that some of the starting points could not be completely validated. However, incomplete validation is only an issue if this significantly changes the technical feasibility or LCoE ranking.
- To see whether this is the case, we have formulated extreme sensitivity scenario's in which we decreased or increased the expected CAPEX items with a large amount. If even in these scenarios there is no significant change in its LCoE position, we can confirm their relative LCoE even when the starting points have not been fully validated.
- Since an island with overhead lines already has an unfavorable LCoE compared to inter-arrays, we do not include an even more unfavorable scenario to compensate for the underdimensioned overheads.
- The conclusion from this scenario-analysis is that:
 - Even in a best-case scenario HVAC does not have a competitive LCoE.
 - Even in a worst-case scenario HVDC on an island has a similar LCoE to the best performing platform option.
- Overall, we have been able to validate that the 2*2GW HVDC island has the most favorable LCoE.

2.7.1 Extreme scenario's for HVAC do not lead to a favorable LCoE

- We have created a scenario where we calculate the LCoE for a scenario in which non-fully validated aspects are brought to extreme levels:
 - the necessity of compensation – scenario with 70% less CAPEX for compensation
 - HVAC CAPEX – scenario with 15% lower CAPEX
 - HVAC availability – 50% less downtime
 - No necessity to connect land inwards (only 110km export cable needed)

Table 2: Results of an extreme AC scenario, compared to the base cases of the best performing options, with onshore connection distances of 110 km

GCS concept	Description	LCOE system BLIX 110km (€/MWh)
1	6*667 MW AC	67.3
4	2*HVDC 2GW	69.9
6a	2*HVDC 2GW Island – IA cables	67.1

- The analysis in Table 2 shows that, even in an extreme scenario, the LCoE of an HVAC-platform is 67.3 €/MWh at 110km to the onshore connection point, which is still higher than an island solution and slightly lower than the 2*2GW HVDC platforms.
- This result is in line with the rule of thumb that in an unconstrained situation (which we have assumed in the extreme scenario), HVAC is competitive up to 100km from shore compared to HVDC.

2.7.2 An extreme scenario for HVDC on an island using inter-array cables does not make it more expensive than the best performing platform solution

- We have not been able to fully validate the design and LCoE of HVDC on an island. Therefore, we have created four sensitivity scenarios in which these not-fully validated aspects are brought to extreme levels. For comparison reasons, we have also included the LCoE that follows from the RWS CAPEX calculations as well. Note that BLIX has not validated the RWS report:
 - 6a-1: RWS estimate:
 - RWS has estimated the island CAPEX to be 708 instead of 600 million euro.
 - Island OPEX is expected to be 6 instead of 1 million euro per year.
 - 6a-2: High CAPEX for HV systems on island – 50% offshore factor instead of 25% factor used by TenneT.
 - 6a-3: High island CAPEX – Island costs 40% increased to correct for unknown unknowns.
 - 6a-4: Decommissioning needed - The island will be fully decommissioned after 30 years of use, at a conservative cost of 400 million euro.

Table 3: Results of extreme HVDC island scenarios on the LCoE (at 200km to shore)

GCS concept	Description	LCOE system BLIX (€/MWh) ¹	Delta from option 6a (€/MWh)
1	6*667 MW AC	91.8	+14.2
2	4*HVDC 1GW	87.9	+10.3
3	3*HVDC 1.33GW	84.1	+6.5
4	2*HVDC 2GW	80.5	+2.9
5a	3*HVDC 1.33GW Island – IA cables	79.8	+2.2
5b	3*HVDC 1.33GW Island – IA overhead	80.1	+2.5
6a	2*HVDC 2GW Island – IA cables	77.6	0
6b	2*HVDC 2GW Island – IA overhead	77.8	+0.2
6a-1	RWS Estimate ²	78.6	+1.0
6a-2	High Island HV Infra CAPEX	78.5	+0.9
6a-3	High Island CAPEX	79.5	+1.9
6a-2+3	High Island CAPEX + HV infrastructure CAPEX	80.4	+2.8
6a-4	Decommissioning needed	78.2	+0.6

- Conclusion: the analysis in Table 3 shows that, even in an extreme scenario, the LCoE of an HVDC-island is in line with the best performing HVDC-platform solution. Moreover, decommissioning costs of 400 million euro will not significantly increase the LCoE. When comparing an expensive case for the island with the base case for platforms, the difference is negligible (0.1€/MWh). The most extreme scenario, when also taking into account possible decommissioning, platforms will be 0.5€/MWh cheaper.

¹ Note that the BLIX LCoE differs 1.1 – 1.3€/MWh from the Ecofys calculations. Therefore, the BLIX calculations should only be used for a relative comparison.

² We have not validated whether the RWS report uses the same scope as the RHDHV market consultation. Therefore, this LCoE should be viewed with caution.

- This conclusion is in line with the sensitivity analysis of the Ecofys report, in which the worst-case sensitivity of the 2*2GW HVDC island is similar to the base case of the 2*2GW HVDC platforms.

2.8 Conclusion: BLIX has been able to validate the LCoE-report

- In this chapter, we have validated all constituents that lead to the LCoE-ranking. We have concluded:
 - The LCoE-model is correct, and all input parameters can be traced.
 - The technical designs of the 8 GCS concepts are correct and complete.
 - The CAPEX components of the 8 GCS concepts are in line with our expectations. Based on experience and expert judgement some of the cost components for HVAC and the island solutions could not be completely validated. Therefore, we included them in an extreme sensitivity scenario to see whether this would change the ranking.
 - The OPEX components of the 8 GCS concepts are correct and complete.
 - Losses and availabilities appear correct, but full traceability has not been provided. Therefore, we included them in an extreme sensitivity scenario to see whether this would change the ranking and this was not the case.
 - Extreme sensitivity scenarios for not fully validated starting points do not change the ranking between the options. The worst-case sensitivity of the 2*2GW HVDC island is similar to the base case of the 2*2GW HVDC platforms. Therefore, we have been able to validate that the 2*2GW HVDC island has a lower LCoE than the 2*2GW HVDC platforms. Note that possible additional costs that result from delays and non-adherence to the roadmap have not been included into this comparison.
 - Overall, BLIX can validate the conclusions of the LCoE report and underlying assumptions.

3 QUESTION B: VALIDATION OF TENNET'S POSITION ON THE SELECTION OF ALTERNATIVES

TenneT has created a position paper (*NLO-TTB-05179_Advice on the offshore GCS.pdf*), in which it provides a motivated selection of the most promising GCS. TenneT holds the position that a 2*2GW HVDC island is their preferred option from an economic and additional benefits viewpoint. From a planning perspective, the 2*2GW HVDC platforms are preferred. TenneT comes to this conclusion by discussing their different design choices.

In this chapter, we will validate TenneT's choices by answering the following questions:

- 3.1. Are the 8 GCS systems under review in the LCoE-reports the most promising options?
- 3.2. Can we validate the TenneT position that HVAC is technically and economically unfeasible?
- 3.3. Are 2GW export cables preferable to 1.33GW and 1GW cables?
- 3.4. Are 66kV infield cables preferable to 66kV overhead lines in the island GCS concepts?
- 3.5. How do HVDC island GCS concepts compare to HVDC platform GCS concepts?

3.1 The eight GCS considered in the LCoE-report are the most promising options

- TenneT has created a back-to-back comparison between 8 options. Based on a discussion with TenneT, BLIX learned that these 8 options were chosen to be the most promising from a longer list with options.
- The 2017 version of the LCoE-report also contained clustered and interconnected HVDC-platforms and an island solution with collector platforms. Both failed to have a favorable LCoE and did not possess any other significant advantages over alternatives. We have validated that these options were correctly rejected.
- At BLIX's request TenneT has provided an overview of the rationale behind the rejection of alternatives. This rejection is qualitative; no calculations have been presented to support the choice. BLIX can validate the rejection of:
 - LCC (Line-commutated converters)-HVDC - no advantages over VSC (Voltage-source converters)
 - DRU-HVDC - technology risk
 - 380 kV AC - because of the greater need for compensation
 - Low frequency AC – no district advantages given the site conditions
 - GIL (gas insulated line) - technology risk
 - Superconducting Cable - technology risk
- A HVAC solution on an island has not been considered. The reason for this is that the substructure of an AC platform is relatively cheap. The main reason for DC on an island is the immense weight of the DC-converter. In case of an island, this large weight is a smaller issue.
- Another scenario that has not been considered is the use of 275kV, but TenneT has indicated that they are confident that they covered all relevant options with 220kV and 280kV.
- Conclusion: We can validate that TenneT made a multi-stage selection from broad to narrow.

3.2 We follow TenneT's qualitative reasoning that HVAC is not technically feasible, but have been unable to find calculated evidence. However, our sensitivity analysis shows that HVAC has a higher LCoE even when connecting close to shore.

- TenneT rejects a choice to connect 4GW of offshore wind using AC platforms based upon four qualitative reasons:

Criterion	TenneT position	BLIX validation
Grid stability	AC cables have a negative impact on the grid and require significant compensation measures.	Even though we confirm that grid stability will be a major challenge, BLIX cannot fully validate this position, since an underlying calculation has not been provided. However, we do acknowledge that these calculations are time intensive.
Planning flexibility	Since (partial) connection beyond onshore bottlenecks will be necessary, resulting in longer connections (ca. 200km). AC cables are limited in length or require intermediate compensation. Therefore, DC solutions provide more flexibility.	We have not been able to fully validate the need for longer connections. If they are needed, we validate they are indeed more easily realized using DC, due to the lower amount of cables and more flexibility in the routing. Inland permitting procedures for AC and DC have the same timeframe, however. Overall, BLIX can validate this position.
LCoE	Large scale DC solutions have a lower LCOE when assuming longer connections. LCOE is similar for nearshore solutions (up to ca. 110km).	BLIX can validate that DC has a significantly lower LCoE at ca. 200km. An extreme scenario for AC at a. 110km does not show a large advantage for HVAC. Full calculations of the losses and availability for this calculation have not been provided.
Stakeholder issues with Cable routing/corridors.	Connecting IJmuiden Ver with HVAC would result in 12 cable trenches while DC results in 2 cable trenches. From a spatial, permitting and stakeholder acceptance perspective less cable trenches is preferred.	BLIX can validate this position

- Conclusion: We have not been able to provide a full quantitative validation of all points. However, the qualitative arguments to reject HVAC are strong and even in an extreme scenario HVAC is still more expensive than the cheapest option. Therefore, we can validate the TenneT choice to reject HVAC.

3.3 We can validate TenneT's preference for 2GW cables. Market readiness for 2GW cables is expected before 2027, but market risks might still occur.

- 525kV cables, needed to transport 2GW, are currently not market ready, but will be ready in 2027. As TenneT states in *NLO-TTB-05179*: 'According to TenneT for the DC cables an XLPE solution with a conductor size of 2500 mm² is proposed but this is not freely selectable yet. German TSO's are currently in the process of testing several types of 525kV cables. The results are foreseen in Q1 2019. It is expected that the 525kV XLPE cables will be available for the grid connection of IJmuiden Ver.'
- Failure of the tests in Q1 2019 might be still in time to reconsider a choice for 2GW cables. Procurement of a higher number of 1GW capacity cables to be installed in parallel is still a fallback option as well. Note that this scenario is unlikely, but mitigation is possible.
- Due to the novelty of the technology, market risks might still occur. Options that include 2GW export cables have a significantly lower LCoE however, easily offsetting these market risks.
- Compared to 1.3GW cables, the amount of onshore connection points will be reduced from three to two. This will not pose a significant problem for the onshore grid and might have significant advantages for limiting the impact of cable tranching onshore.
- Moreover, when choosing 2GW connections, this will become the greatest single point of failure in the Dutch electricity grid. The current market regime requires TenneT to have reserve capacity available related to this 2GW. We do expect that the market will be different in 2028, mainly because distributed intermittent production will have a larger impact when its penetration rises. Nonetheless, this issue should be solved before 2028 in cooperation with MinEACP.
- Concluding, we can validate TenneT's preference for 2GW cables. Their motivation is correct, complete and robust.

3.4 Subsea Inter-array cables are superior to overhead lines for island solutions.

- The island solution contains only a single HV-location in the entire IJmuiden Ver area. This leads to large distances between remote turbines and the HV-station.
- BLIX validated the technical feasibility of the subsea inter-array cables and their adherence to the Requirements for Generators (RfG) in the new European grid code.
- We have not been able to fully validate the current design of the 66kV inter-array cables. Either additional calculations or minor adjustments to the design will solve this issue however. Moreover, to be expected. We expect a redesign is needed, which will cause a significant increase in LCoE.
- Concluding, since the LCoE of 66kV inter-arrays is already superior to overhead lines, this observation will increase the difference even further. Therefore, BLIX can validate that an island with inter-arrays is superior to an island with overhead lines.

3.5 We can validate the operational and LCoE-advantages of the 2*2GW HVDC-island over HVDC-platforms. The planning for platforms leads to earlier completion however.

- The TenneT position paper (*NLO-TTB-05179 -Advice on the offshore GCS*) prefers a 2*2GW island (GCS Concept 6a) over 2*2GW HVDC platforms (GCS Concept 4) from an economic and additional benefits viewpoint. From a planning perspective, the 2*2GW HVDC platforms are preferred. Therefore, a final choice depends on the weight of the different criteria (or whether they are considered knock-out criteria).
- A preliminary comparison between the two options would result in the following results:
 1. Both concepts are technically feasible.
 2. LCoE for an island is lower for the base case, but in an extreme scenario LCoE is similar.
 3. An island has an upside for additional capacity, to create an interconnector or produce hydrogen. These activities need to be initiated in a later phase when considering the island to be monofunctional during the initial construction phase but require a spatial reservation on the island.
 4. An island is more robust in operation since space is less an issue.
 5. An island has more unmitigable risks. We need more substantiation of these risks.
 6. The planning of platforms shows an earlier commissioning date than for the island.

3.6 Conclusion: BLIX has been able to validate the TenneT advice on the grid connection. More insight in the planning, risks and compliance with the roadmap of 2*2GW HVDC platforms and 2*2GW HVDC island is needed to create a complete multi-criteria analysis.

- BLIX has been able to validate the following answers to the research questions in this chapter, based on a validation of the report *NLO-TTB-05179*:
 - The 8 GCS that have been compared in the LCoE report and *NLO-TTB-05179* are the most feasible options.
 - We can validate the TenneT decision to reject HVAC, even though we have not been able to provide a validation of all quantified arguments. However, the qualitative arguments to reject HVAC are strong and even in an extreme scenario HVAC is not significantly cheaper.
 - We can validate TenneT's preference for 2GW export cables over 1 and 1.33GW. Their motivation is correct, complete and robust.
 - Subsea infield cables are advantageous compared to overhead lines for the island-based GCS.
 - The island case has large operational advantages and a lower LCoE, while the planning for platforms is favorable.
- A full Multi-Criteria analysis (MCA) between 2*2GW HVDC platforms (GCS Concept 4) and a 2*2GW HVDC Island (GCS Concept 6a) would require additional insight in the robustness of the plannings and the ways in which different commissioning dates for wind farms would be compatible with different roll-out plannings. In the next chapter, we will create this overview.

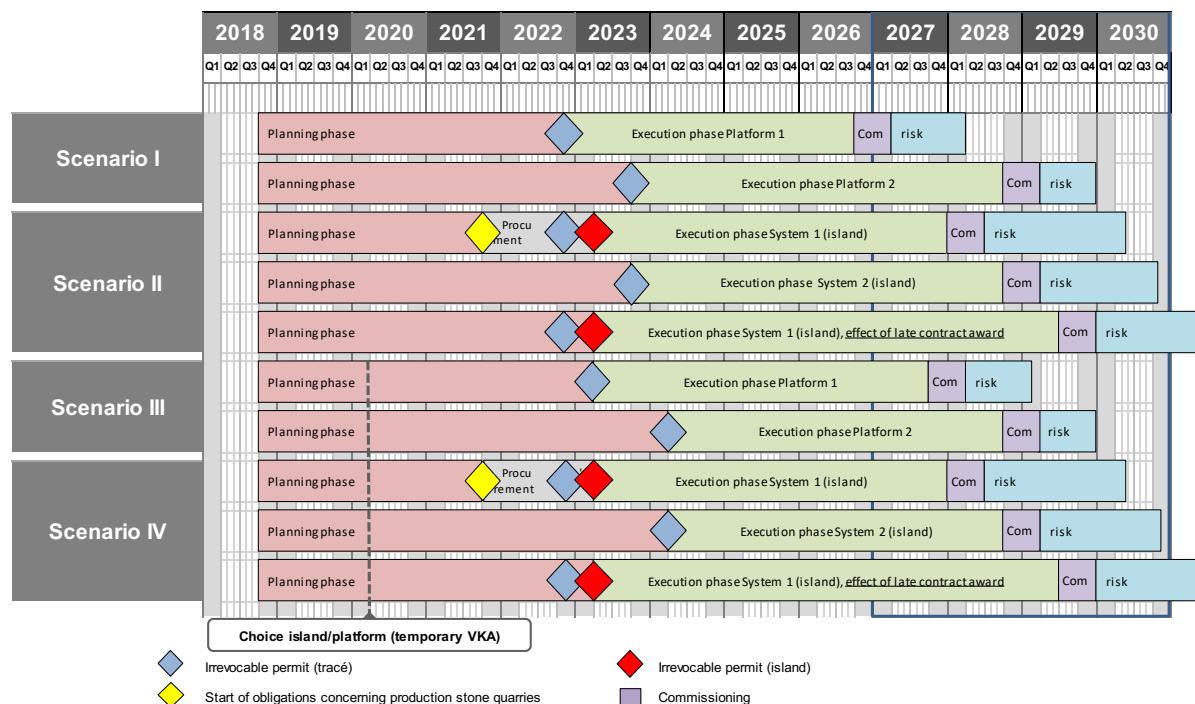
4 QUESTION C: PLANNING AND COMPLIANCE WITH THE ROADMAP – A COMPARISON BETWEEN A 2*2GW HVDC ISLAND AND 2*2GW HVDC PLATFORMS

The previous chapter showed that even though a 2*2GW HVDC island (GCS Concept 6a) has an LCoE advantage over 2*2GW HVDC platforms (GCS Concept 4), planning can become an issue. At request of BLIX, TenneT has formulated four planning scenarios that adhere to the roadmap, (preferably commissioning of the first grid connection in Q1 2027, if this is not possible in Q1 2028). TenneT provided a memo 'Aanvullende notitie 'Uitgangspunten, aannames en beslismomenten, risico's en mitigerende maatregelen behorende bij de planning Ijmuiden Ver' together with four underlying PDFs with an in depth-planning 'Scenario I... IV.pdf'. Specifically for the realization of the island, TenneT provided a detailed execution planning 'Indicative planning_20180908.pdf'.

The memo contains:

- A description of four planning scenario's
- Risks for delays associated with these choices
- Early decision making required by MinEACP to enable these plannings

Scenario I and II in the memo consist of a choice for either platform or island in late 2018. Scenario III/IV is a hybrid scenario, in which the choice between island and platform will be postponed until early 2020, while in the meantime, both options are prepared.



This chapter will perform validations by answering the following questions:

- 4.1. When does a roll-out planning for a GCS for Ijmuiden Ver fully align with the coalition agreement and roadmap and how does this work out for the offshore wind farm developers and the supply chain?
- 4.2. Can we validate the four in-depth deterministic plannings for island and platform?
- 4.3. How do the four scenarios perform when assessing them against the plannings in 4.1?
- 4.4. What early risk mitigation is possible to increase the viability of the island case when choosing a Q1-2020 decision between island or platform (Scenario III/IV)?

4.1 When does a planning fully align with the coalition agreement and roadmap?

4.1.1 The Dutch roadmap towards 11.5 GW of operational offshore wind in 2030 requires the first 1GW of operational offshore wind at IJmuiden Ver in 2027

- The Dutch coalition agreement of 2017 contains a commitment for 11.5GW of operational offshore wind in 2030.
- To facilitate this ambition, the Ministry of Economic Affairs & Climate Policy (MinEACP) created a roadmap 2024-2030 with a proposed roll-out of 6.1GW of offshore wind in the period 2024-2030.
- On 27th March 2018 the Minister of Economic Affairs and Climate Policy has issued the *kamerbrief Routekaart windenergie op zee 2030* (this report uses the term *Roadmap* to refer to this document) to the Dutch Parliament. In this letter the following planning has been communicated on offshore wind windfarm developments in the Netherlands.

Omvang (GW)	Windenergie-gebied	Kortste afstand uit de kust	Start procedure kavelbesluit	Tender	Ingebruik-name
1,4	Hollandse Kust (west)	51 km vanaf Petten	2018	2020/2021	2024 t/m 2025
0,7	Ten noorden van de Wadden-eilanden	56 km vanaf Schiermonnikoog	2019	2022	2026
circa 4,0	IJmuiden Ver	53 km vanaf Den Helder; 80 km vanaf IJmuiden	2020	2023 t/m 2026	2027 t/m 2030
circa 0,9	nader te bepalen				

- Specifically on IJmuiden Ver, the *'kamerbrief Routekaart windenergie op zee 2030'* indicates that:
 - Wind farms will be commissioned from 2027 onward ("de ingebruikname van de windparken vindt plaats vanaf 2027")
 - Tenders are proposed in 2023 and 2025 (assuming 2GW tenders) to ensure a 2027 commissioning. The size of the tenders has not been decided however.
- Wind farms need to be fully commissioned no later than 4 years after an irrevocable permit. When the last permit for IJmuiden Ver will be irrevocable in 2027, developers will have a possibility to commission in 2031. This will not be in line the Dutch coalition agreement.

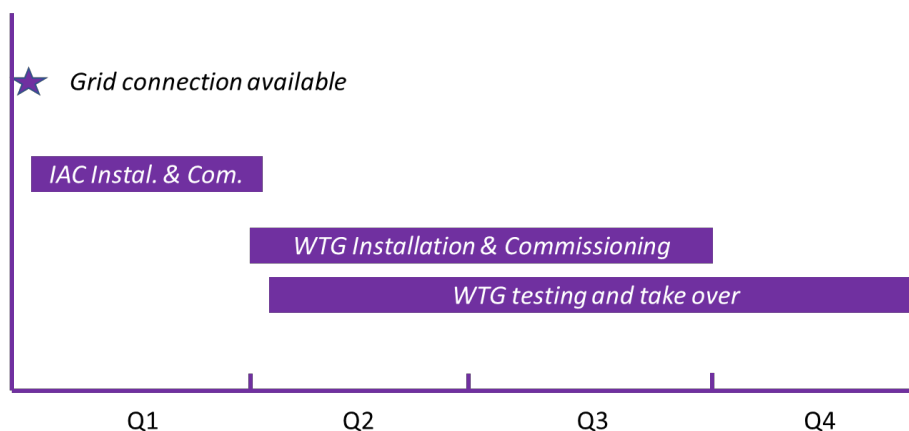
4.1.2 Commissioning of IJmuiden Ver in 2028 could disrupt the supply chain.

- In some of TenneT's planning scenarios the grid connection would only become available in 2028 or later when risks materialize.
- In general, we see it is critical for the supply chain and offshore wind farm developers to have a constant flow of projects and have projects of a manageable size.
- Having a gap in development of offshore wind with no projects becoming operational in 2027 would not be a recommended approach (or at least needs industry consultation). This might lead to less competitive bids in tenders. The solution of having 2GW of grid connection becoming operational in 2028, instead of 1GW in 2027 and 1GW in 2028 would be possible, but is also less ideal.

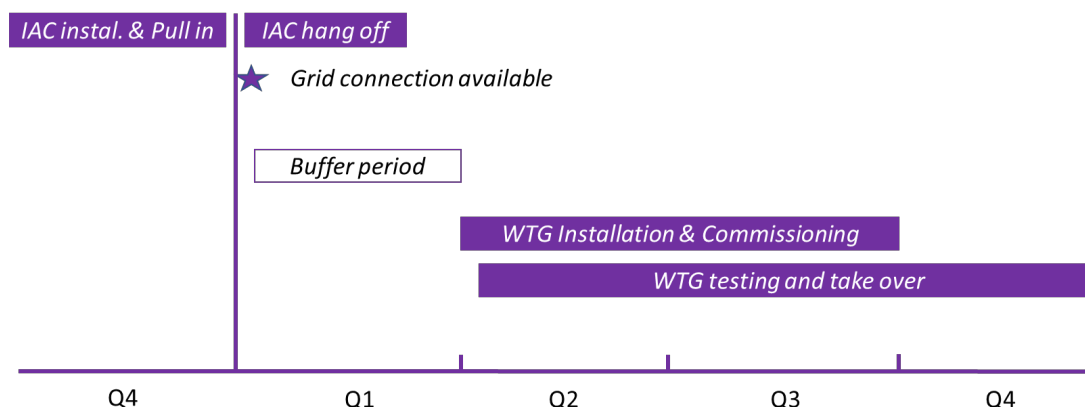
- Based on today's market information, 0.7GW- 1GW per year is considered a workable size for an offshore wind farm development. This size would be making use of economies of scale while still being of an acceptable size in relation to supplier capabilities and balance sheets and for investors and lenders to invest. Some large utilities prefer larger lots however. A market consultation with the sector can shed more light on this preference.
- Further, the strength of the continued flow of projects is key for the supply chain. Only limited offshore projects are built in Europe in any specific year. With concession tenders governments play a key role in ensuring continuity for the supply chain that take significant exposure in taking on large contracts and having their order books filled by only a few offshore wind projects a year. Missing out on one or more projects could become a serious issue for some parties in the supply chain.

4.1.3 From a developer's point of view, a grid connection needs to be ready 9-12 months before the wind farm is fully operational

- In this analysis, we have assumed the planning mentioned in the '*kamerbrief Routekaart windenergie op zee 2030*' to be the reference for our validation.
- Critical in this perspective is defining the difference between the completion and energization of the offshore grid connection, which has been the result of the TenneT planning information that was part of the validation and the actual date wind farms will be operational.
- We would recommend to add 9-12 months on the TenneT planning for each 1GW wind farm to become operational after the grid connection has been completed. This period is built up as follows:



- In this planning approx. 2.5 months buffer is created between the wind turbine generator (WTG) installation and commissioning and the TenneT scheduled energization date as inter-array cables (IAC) installation and commissioning need little head start to the WTG installation as it has a much shorter installation cycle.
- Potentially time could be saved if IAC installation and pull in could be performed prior to energization of the grid connection. This is likely to be feasible in case of an island solution and also in a platform solution if interfaces are managed properly.
- However, in these cases you would ideally still schedule a limited buffer period between the scheduled energization date by TenneT and the WTG installation and commissioning as the actual consequences of a standby of installation spreads, WTG standstill mitigating measures and delayed revenues are substantial and should at first be avoided, despite some comfort provided in the delay compensation scheme provided by TenneT.



- The abovementioned analysis is based on previous BLIX experience with tender preparation in the Netherlands and abroad, and based on current best practices. Based on this analysis, BLIX assumes that at least a 9-month period between commissioning of the GCS and the wind farm is needed. In case a wind farm needs to be operational before the end of a year (which is written in roadmap and coalition agreement), this indicates that the latest commissioning date for TenneT is Q1 of the same year.
- Since planning will be an issue for some of the GCS, a market consultation with offshore wind operators and the supply chain could provide actual and in-depth knowledge on preference. This can lead to an informed decision on what planning approach to take and possibly to update the abovementioned 9 months.

4.1.4 Possible roll-out plannings and their alignment to the roadmap/coalition agreement and impact on the supply chain

The roadmap leaves room for either 1GW or 2GW tenders. Strict alignment to the roadmap, while also keeping in mind the required continuity of the roll-out, would be to issue 1GW tenders starting in 2023, leading to the first operational wind farms in IJmuiden Ver in 2027. However, other plannings are possible that do not fully adhere to the roadmap, which does either leave more time for TenneT to finish their GCS or have other implications.

4.1.4.1 Roll-out planning A: for compliance to coalition agreement and roadmap.

We have created a possible roll-out planning, that adheres to the coalition agreement, roadmap and puts the least stress on the supply chain.

Tender	Tender year	TenneT link ready in year ³	Wind farm operational ⁴
IJmuiden Ver 1 (1GW)	2023	2027	2027-2028
IJmuiden Ver 2 (1GW)	2024	2027	2027-2028
IJmuiden Ver 3 (1GW)	2025	2029	2029-2030
IJmuiden Ver 4 (1GW)	2026	2029	2029-2030

³ Based on the discussion in the previous paragraph, BLIX assumes the GCS needs to be finished in Q1 of a certain year to ensure a possible full commissioning of the wind farm in that same year.

⁴ This time window is between *TenneT link ready* and *4 years after an irrevocable permit*. This window is ideally two summer seasons to allow for an optimal planning window, alleviating stress to the supply chain.

The planning includes the following aspects:

1. TenneT builds the links in 2GW blocks and the first 2GW link to be ready in 2027.
3. 1GW offshore wind farm tenders each year from 2023 to fully align to the roadmap.
4. It allows for windfarms to be built in two summer seasons to enable an optimal planning window, alleviating stress to the supply chain.
5. The last wind farm is commissioned in 2030 to align with the coalition agreement.

4.1.4.2 Roll-out planning B: Compliant to coalition agreement, number of tenders reduced.

This planning adheres to the coalition agreement, but the tenders are (possibly) larger. This approach can be in line with the current roll-out approach, by which tenderers can opt to either go for one lot or both lots at the same time.

Tender	Tender year	TenneT link ready in year	Wind farm operational
IJmuiden Ver 1-2 (2GW or 2*1GW)	2024	2027	2027-2028
IJmuiden Ver 3-4 (2GW or 2*1GW)	2025	2029	2029-2030

The planning includes the following aspects:

1. TenneT builds the links in 2GW blocks and the first 2GW link to be ready in 2027.
2. There is no tender in 2023, but a possibility for a yearly rollout will remain unchanged.
3. It allows for both smaller and larger utilities to issue a bid.
4. Allow for two summer seasons to enable an optimal planning window, alleviating stress to the supply chain.
5. The last wind farm is commissioned in 2030 to align with the coalition agreement

4.1.4.3 Roll-out planning C: Compliant to coalition agreement, no wind farm construction in 2027, TenneT commissioning in Q1-2028 possible

This planning adheres to the coalition agreement, but the tenders are (possibly) larger. This approach will create one extra year for TenneT to commission their GCS, but this means that no wind farm will become operational in 2027. Moreover, there will be no tenders for two years (possibly 2023 and 2024, but this can be optimized).

Tender	Tender year	TenneT link ready in year	Wind farm operational
IJmuiden Ver 1-2 (2GW or 2*1GW)	2024 or 2025	2028	2028-2029
IJmuiden Ver 3-4 (2GW or 2*1GW)	2025 or 2026	2029	2029-2030

The planning includes the following aspects:

1. TenneT builds the links in 2GW blocks and the first 2GW link to be ready in 2028 and the second in 2029.
2. There is no wind farm construction in 2027.
3. TenneT has one extra year to finish their GCS.
4. It allows for both smaller and larger utilities to issue a bid.
5. It allows for two summer seasons to enable an optimal planning window, alleviating stress to the supply chain.
6. The last wind farm is commissioned in 2030 to align with the coalition agreement
7. 4GW of offshore wind will have to be commissioned within 3 years (2028-2030), which can be a challenge for the supply chain.

4.1.4.4 Roll-out planning D: Commissioning of TenneT link in 2029, not compliant to coalition agreement and roadmap or significant stress on supply chain.

This planning is the planning that is still as much in line with the roadmap as possible, but severely hindered by late commissioning of a first TenneT-link in 2029.

Tender	Tender year	TenneT link ready in year	Wind farm operational
IJmuiden Ver 1-2 (2GW or 2*1GW)	2025 or 2026	2029	2029-2030
IJmuiden Ver 3-4 (2GW or 2*1GW)	2026 or 2027	2030	2030 or 2030-2031

This means that:

1. No wind farms will be commissioned in 2027 and 2028, causing significant disruptions to the supply chain.
2. TenneT will have 2 additional years to finish their GCS.
3. One of the possibilities will materialize:
 - a. 4GW will need to be built in 2 years to be in line with the roadmap, putting stress on the capacity of the supply chain.
 - b. The ambition of the coalition agreement will not be met.

As mentioned before, this scenario is undesirable (unless the roadmap is altered), since it disrupts the supply chain and will not be in line with our coalition agreement. Wind developers will include the risks associated with this cramped planning into their financial models, which may decrease the attractiveness of the Dutch offshore wind roll-out and may lead to a significant increase in LCoE of several euro's (or lower cost reductions).

4.2 Validation of in-depth deterministic plannings

4.2.1 We have been able to validate the estimate for the time duration of the platform preparation and construction.

- We have reviewed the two PDFs with a deterministic planning that were provided to BLIX ('Scenario I.pdf' and 'Scenario III.pdf')
- We have been able to validate the completeness and correctness of these plannings for the preparation and construction planning of 2*2GW platforms. The end dates are ambitious, but achievable. A number of risks occur, which will be discussed in a later paragraph.

4.2.2 We have been unable to validate the estimate for the time duration of the island construction.

- We have reviewed the two PDFs with a deterministic planning that were provided to BLIX ('Scenario II.pdf' and 'Scenario IV.pdf'), together with a planning for the construction of an island (*Indicative planning_20180908.pdf*), which was based on plannings that were provided during the market consultation.
- We have been able to validate the completeness and correctness of the plannings for the preparation phase of 2*2GW island. We have not been able to fully validate the construction planning however. TenneT has indicated that these plannings are available but cannot be shared due to NDA. Moreover, MinEACP has commissioned a study by Rijkswaterstaat to assess the cost and time duration of island construction.
- The received time planning of the construction of the island (*Indicative planning_20180908.pdf*) is of a high level:
 - The level of detail was limited to 11 activities. No dependencies were given.

- The phases and sequence of installation was not explained.
- No explanation was given of the basis for the stated durations and underlying assumptions (e.g. quantities, equipment to be used and weather limits, reference projects, etc).
- No workability analyses have been observed. The only reference to workability is that no work is performed in December and January.
- The planning was likely based on a similar approach as costs (averaging the unit rates and multiplying with quantities), not based on a basic design for which all technical elements were worked out.
- No float has been taken along (or it is unclear which float has been taken along).
- The stated duration of island construction is three years. As with the costs, we conclude that this should be considered an "initial best guess estimate". The activities are roughly subdivided into three years. The first year consists of island reclamation and installation activities below to a level of 5m below sea level (to which reference level is unknown). Rock works start only one month after the reclamation works. In year 2 and 3 the revetment is completed. The crown wall, cables and quay walls are constructed in year 3. The planning seems optimistic and it is unclear which float has been taken along.
- We expect the time duration needed for settling of the sand not to be an issue since the underground is all sand. Even though sand does show some settling under stress, this can be induced by applying a force, for example by using the weight of a bulldozer. This process will take no more than a few weeks.
- However, it should also be noted that:
 - Sand reclamation and rock works can be performed more swiftly by using more equipment in parallel. It is unclear to which extent this optimization has been accounted for.
 - An island designed for 4GW (instead of 6GW, which was used in the market consultation) with an assumed 20% lower area, would reduce the reclamation volume with about 15% and the revetment length with about 10%. This could potentially save 15% of reclamation time, and more importantly, 10% of critical revetment installation time.
 - Deciding to removing the O&M base would simplify the port and reduce the breakwaters required, potentially leading to time savings in year 3.
- Overall, given the above uncertainties and without further substantiation or worked out analyses, we see a risk that an additional year of construction may be needed. However, we also see ways to speed up the construction.
- We note that it may be feasible to perform the island construction within three years (or possibly even sooner), but this cannot be validated based on the provided information. We recommend the following steps to reduce the uncertainty regarding the time planning of the construction of the island (and be able to validate the time duration of the island construction):
 - Start with a reassessment of:
 - the required island area based on a target capacity of 4GW and,
 - the requirements for the port and breakwaters in absence of an O&M base;
 - Select one or two representative cases (of the preliminary designs received – e.g. revetment and one caisson) for which to perform a cycle time analysis. Adapt the island area and port requirements.
 - Consult the contractors about their view on potential time optimizations. Assess the activities, necessary equipment, cycle times, workable conditions of each construction phase. Consider the potential for performing activities in parallel.
 - Summarize the results in a detailed P50 and P80 planning for each case.

4.3 Assessment of the four TenneT planning scenarios in relation to the roll-out planning

4.3.1.1 Scenario I – Choice for platforms in Q4 2018

- This scenario consists of a choice for platforms in Q4 2018.
- An early choice for platforms is the only way to be fully in line with the roadmap to assure wind farms will be commissioned from 2027 onward as mentioned in the roadmap (*“de ingebruikname van de windparken vindt plaats vanaf 2027”*). This would be in line with roll-out planning A or B in the previous paragraph, which adhere to the roadmap, the coalition agreement and continuity in the supply chain.
- Early contracting for the platform (before irrevocable permit) could decrease the planning time by 24 months, but this creates a substantial financial exposure for TenneT.
- In case of the maximum amount of delay due to risks materializing, a 2028 commissioning of the first wind farms is still possible. This would imply roll-out planning C, which is still in line with the roadmap and coalition agreement.
- Conclusion: this planning is in line with coalition agreement and roadmap, even when taking risk into account.

4.3.1.2 Scenario II – Choice for an island in Q4 2018

- This scenario consists of the following requirements:
 - The island will be monofunctional. We support the TenneT decision to press for an early decision on mono-functionality. Otherwise, the already challenging planning will acquire additional risks and thus possible delays.
 - Choice for an island in 2018 enables early contractor involvement, lowering risks.
 - Early contracting of stone production (before irrevocable permit) is required.
- Early choice for an island is not fully in line with the roadmap (roll-out planning A or B); roll-out planning C will be possible when no risks materialize. Delays could lead to a completion date in 2029 or 2030. In this case case only roll-out planning D remains possible, causing disruption of the rollout, supply chain problems and possibly inability to adhere to the coalition agreement.
- The following risk remains: The island construction planning has not been fully validated. Worst case this could add a year to the planning, which occurs when not all activities proposed on the second year of construction will be finished within the weather window.
- TenneT states that scenario II has a lower risk of delay than scenario IV (parallel track with platform preparation until 2020) since it lowers the possibility of a Raad van State procedure. We have not been able to validate this position. Even in the case where the Ministry would draft a law that would prepare for an island, this law could be delayed by nature interest groups by arguing that the ecological impact of an island is not yet sufficiently researched to justify an early choice for an island.
- Our assessment is that the small financial gain of this option over the dual track (scenario III/IV) is not worth the risk.
- Conclusion: the planning is partially in line with roadmap, but the roadmap requirement of wind farm commissioning in 2027 cannot be met. When risks materialize, large deviations from roadmap might occur.

4.3.1.3 Scenario III – Parallel track until early 2020, choice for platforms in Q1 2020

- This scenario consists of the following requirements:
 - Island and platform will be developed in parallel and a final choice between the two will be made in Q1-2020, after which only the preparation of the chosen option will continue.
 - HVDC design will be contracted before irrevocable permit, but without large commitments before irrevocable permit.
 - Costs will be an additional 3 million euro compared to scenario I, which we think is a reasonable amount to buy time to alleviate risks and for an “insurance premium”.
- We assume scenario III/IV to be the hybrid scenario where the Ministry does acknowledge the lower LCoE, redundancy and other advantages of the island, but is concerned with the island planning, which could lead to completion of the first GCS in 2030 if major risks occur.
- Scenario III is the backup part of this hybrid scenario. This scenario will be chosen in 2020 in case the island alternative is not feasible due to materialized risks or detailed design or calculations that indicate longer durations.
- Compared to scenario I, the planning will shift a year however. This means that:
 - If no risks materialise, a 2028 commissioning is possible (roll-out planning C).
 - If risks do materialise during the project, only the undesired roll-out planning D is possible. Mitigation will be hard, besides costly early contract award of the platform (gaining 24 months). This possibility should be seen as an insurance possibility, since it contains considerable risks. However, if planning will appear problematic in 2020 or later during the project, this option could still be considered
- Conclusion: the planning is partially in line with the roadmap, but the roadmap requirement of wind farm commissioning in 2027 cannot be met. When risks materialize, large deviations from roadmap might occur. Early contracting for the platform can be used as a mitigating measure.

4.3.1.4 Scenario IV – Parallel track until early 2020, choice for an island in Q1 2020

- This scenario consists of the following requirements:
 - The island will be monofunctional.
 - Island and platform will be developed in parallel and a final choice between the two will be made in Q1-2020, after which only the preparation of the chosen option will continue.
 - Early contract involvement after 2020, which increases risks compared to Scenario II, where involvement is possible in 2019.
 - Early contracting of stone production (before irrevocable permit).
 - HVDC design will be contracted before irrevocable permit, but without large commitments before irrevocable permit.
 - TenneT mentions that a parallel track will cost an additional 3 million euro compared to scenario II.
- We assume scenario III/IV to be the scenario where the Ministry does acknowledge the lower LCoE, redundancy and other advantages of the island, but is concerned with the planning, which could lead to completion of the first GCS in 2030 if all risks materialize.
- Scenario IV will be chosen from the hybrid scenario III/IV i in case certain island risks have not materialized, are sufficiently mitigated and/or detailed design or calculations indicate construction durations are correct or even shorter and/or planning risks till permit are mitigated.
- The following risks remain:
 - Planning delay due to a delayed choice between platform and island.

- Extra delay due to a more complex stakeholder process and later contractor involvements.
- The island construction planning has not been fully validated. Worst case this could add a year to the planning.
- Compared to scenario II, the planning will be similar however:
 - If no risks materialize, a 2028 commissioning is possible (roll-out planning C)
 - If risks do materialize during the project, only the undesired roll-out planning D is possible. Mitigation will be almost impossible.
- Conclusion: the planning is partially in line with the roadmap when no risks occur, but the roadmap requirement of wind farm commissioning in 2027 cannot be met. When risks materialize significant deviations to roadmap occur. The hybrid scenario III/IV still has the possibility to shift to scenario III before Q1-2020.

4.4 Island planning includes the risk of delays until 2031. Mitigating these risks (if possible before 2020) and finding possibilities for design changes is of high importance if scenario III/IV is chosen.

- TenneT included a number of risks to the memo that might cause delays in the island planning. We can validate that these are the risks that are most likely to occur. Some of these risks will occur before 2020 or more information on mitigation is available, so a delayed choice between island and platform will allow these risks to materialize or not. Delays could lead to less competitive bids in tenders and the obligation (under the Electricity Act) for TenneT to compensate the wind farm permit holder(s). The following activities can be undertaken to reduce the risk of an island choice in the hybrid scenario:
 1. Detailed optimization of the entire island concept to make the planning more robust and with a shorter time duration, consisting of the following steps:
 - The reassessment of:
 - the required island area based on a target capacity of 4GW. Note that a choice for 4GW would remove the upsides for additional capacity and other upsides.
 - the requirements for the port and breakwaters in absence of an O&M base;
 - Select one or two representative cases (of the preliminary designs received – e.g. revetment and one caisson) for which to perform a cycle time analysis. Adapt the island area and port requirements.
 - Consult the contractors about their view on potential time optimizations. Assess the activities, necessary equipment, cycle times, workable conditions of each construction phase. Consider the potential for performing activities in parallel.
 - Create in-depth planning to assess possibilities to finish in 2027 or 2028.
 2. Final choice on the required commissioning date for the TenneT GCS, consisting of two parallel tracks:
 - a) A detailed interpretation of the milestones of the roadmap, consisting of the required commissioning dates for wind farms, the size of tenders etc. Currently, these milestones and therefore the required commissioning dates of the GCS are sometimes not clear.
 - b) Market consultation with the offshore wind sector to see how they view larger tenders and a possible year without construction.

Results of the update to the roadmap and the market consultation will lead to planning goals for the commissioning of GCS. If it appears that the completion date of a specific GCS is not within the requirements of MinEACP, this option should be discarded.

4.5 Conclusion

- A choice for 2GW HVDC-platforms adheres to the roadmap (which requires wind farms to be operational in 2027, and thus requires the grid to be operational in Q1-2027) Worst-case (but highly mitigatable) delays would lead to commissioning in 2028. This is still moderately in line with both roadmap and coalition agreement.
- A choice for an island can partially adhere to the roadmap, but the roadmap requirement of wind farm commissioning in 2027 cannot be met. Delay until 2029 or later is a real possibility and will be problematic for the supply chain and not be in line with either roadmap or coalition agreement. Moreover, choosing for an island now is only marginally cheaper than delaying the choice until 2020.
- A hybrid solution, in which the choice between island and platform is delayed, could be a solution:
 - Choice for an island if risks have not materialized, are mitigated or are dissolved.
 - Choice for platforms if the risk of late commissioning is considered too large.

It should be noted that choosing the hybrid scenario III/IV and choosing the platform option afterwards (in 2020) will shift the platform planning with a year, leading to a completion in 2028, which is not in line with the roadmap anymore

5 QUESTION D: VALIDATION OF THE QUALITY AND PROGRESS OF TENNET'S PRE-INITIATION PROCESS

One of the key prerequisites when choosing for the hybrid scenario III/IV is to be able to make an informed decision between III and IV before 2020. This means that TenneT needs to have a smoothly running project preparation ready as soon as possible. During the validation, BLIX has been able to validate the quality of the current status of the pre-initiation process.

5.1 TenneT has created an advanced risk register which has been browsed by BLIX. The risk register is complete and robust.

- During the expert sessions, BLIX has been provided insight into the risk register, which TenneT uses to assess risks, their occurrence and their influence on the probabilistic planning.
- TenneT makes use of a database of ca. 500 known risks collected from their previous offshore projects. From those and an inventory of specific project risks the most important risks for the project in the different scenarios were identified.
- Per planning activity the impact of a risk (severity times chance of occurrence) in a best case, worst case and most likely case has been assessed and added to the planning.
- Conclusion: the risk register and the risk assessment are complete and robust.

5.2 Mitigating measures and swift decision making are needed to adhere to the roadmap. TenneT has created probabilistic plannings which are in-depth and complete

- TenneT has created several probabilistic plannings for both island and platform solutions.
- BLIX has reviewed two unmitigated P10-plannings, both of which would lead to commissioning in 2029, which is out of scope for the roadmap. Strong mitigating measures and early decision making are essential to reach the goals of the roadmap within time.
- Over the next year, we expect TenneT to improve this planning, work together with MinEACP to mitigate planological & construction risks, to allow an informed decision in 2020, in case the Ministry chooses to follow scenario III/IV.

6 QUESTION E: OVERALL MULTI-CRITERIA ANALYSIS BETWEEN 2*2GW ISLAND WITH INTER-ARRAYCABLES (6A) AND 2*2GW PLATFORMS (4)

In the previous chapters, we have performed validations of the LCoE-report (Chapter 2), NLO-TTB-05179 (Chapter 3), a critical assessment of risks, planning and compliance with the roadmap (Chapter 4), and validation of the TenneT pre-initiation process (Chapter 5). This chapter contains a multi-criteria analysis (MCA) of the comparison between 2*2GW island with inter-arraycables (GCS concept 6a) and 2*2GW platforms (GCS concept 4). This analysis is based on the discussion and conclusions of the previous chapters.

6.1 Technical feasibility

We expect that 2GW high voltage systems on an island and on a platform will be technically feasible in 2027. Both use 2GW export cables, which are currently not market ready yet, but this will likely have changed before 2027. Island construction is proven technology, the interface between island construction and civil works will be challenging, but not technically infeasible.

6.2 Levelized cost of energy and risks of cost overruns

The base case for LCoE of the 2*2GW HVDC island solution is 2.8 €/MWh lower than the 2*2GW platform solution when using the Ecofys results. This lower LCoE is the result of lower investment costs, higher availability and lower OPEX. Based on three years of construction and 30 years of operation, this corresponds to a NPV difference between island and platform of 600 million euro. However:

1. When some of the cost estimates that have not been validated, are on the high end of the estimate, this difference will drop to zero.
2. When using the RWS calculations for island construction instead of the RHDHV market consultation, the LCoE difference is calculated by BLIX to be 1.8 €/MWh.

The previous chapters show that island construction is prone to cost overruns due to unknown unknowns. On the other hand, the designs for the islands have not been optimized for 4GW yet and contain a breakwater, which might not be needed. Overall, we expect the cost estimate for the island to be the expected value, but with a higher uncertainty value compared to platforms.

Overall, the LCoE of an island is significantly lower when comparing the base cases. In a worst-case scenario, the difference is negligible. Concluding, there is an expected price advantage for the island. However, cost increases due to possible delays are not taken into account.

6.3 Redundancy & grid stability

A 2*2GW HVDC island will have a higher availability compared to a platform and can therefore be assumed to be a more reliable source to stabilize the grid. Given the Dutch ambition to phase out natural gas and ramp up intermittent production, stability of the grid will become an important issue. The availability of a large and reliable source of energy can be a significant benefit to facilitating the energy transition.

6.4 Risks of delay, planning and adherence to the roadmap

6.4.1 A choice for platforms now is completely in line with the roadmap. Choosing platforms after a parallel track will only partially be in line with the roadmap

The 2*2GW HVDC platform solutions have a challenging but realistic planning, that will lead to the first operational wind farm in late 2027 (TenneT scenario I), or in 2028 when the choice between island/platform will be postponed until 2020 (TenneT scenario III). This will all be within the ambition of coalition agreement and roadmap.

Observed risks (that could lead to a later commissioning) will be mainly during the construction phase, but we can validate that mitigating measures are still possible at that phase. Moreover, when risks do materialize in the beginning of the project, there is an option left for early contracting. Even though this significantly exposes TenneT to financial risk, this can be seen as an insurance to achieve 2028 commissioning at latest. Therefore, we can conclude that a choice for platform (now or in 2020) is in line with the roadmap, since risks are mitigatable.

6.4.2 An early choice for island (scenario II) does not lead to an earlier completion date than decision for island in Q1-2020 (scenario IV). Both have the possibilities of delays until 2029 or 2030 is possible, which is not in line with the roadmap

The 2*2GW HVDC island solution has a challenging planning, that will lead to the first operational wind farm in late 2028 in an optimistic scenario. A choice for island now (compared to decision in 2020) does not lead to a significantly earlier commissioning of the first wind farm however. This will all be within the ambition of coalition agreement and roadmap.

However, when all risks for the island materialize, a 2030 commissioning of the first wind farms might be the result. This is a severe departure from the roadmap and will cause significant supply chain issues. Currently, not all risks are observed to be mitigatable. Therefore, choosing an island now (scenario II) will leave open the possibility of missing the roadmap. Choosing for an island in 2020 (scenario IV) will leave time for some risks to either materialize (which can lead to a choice for platforms in 2020), decrease in chance of occurrence (by additional design or stakeholder management) or dissolve when placed under greater scrutiny. Mitigating measures during the construction of the island are hard to implement however. Therefore, even a choice for an island in 2020 will lead to a possibility that a 2028 commissioning will not be possible. Therefore, as mentioned in chapter 4, the period till early 2020 should also be used to find additional measures to make the design more robust and construction easier, even if this increases cost.

6.5 Possibility for additional capacity

As already mentioned in the Ecofys LCoE recalibration report, there is room for additional capacity in the area. Potentially the IJmuiden Ver area could increase with 1 GW (for example as the location for the still unassigned 0.9GW) towards the north-east of the original area.

- For HVDC platforms, this implies the construction of an additional 1GW platform, with high LCoE. Export cables will need a separate trench, causing additional planning issues.
- For the island solution, a 380kV AC connection is possible to the island; on the island the power will be converted to DC and transported to shore. We have not fully validated the LCoE calculation for this case, but are able to follow the calculation approach and the results pass a sanity check. It would be possible to add the additional cable in a trench that is already used for one of the 2GW cables. It cannot be validated whether the resulting 3GW

can be integrated into the onshore grid in one location. If this is the case, planning differences will still most likely occur.

Concluding, choosing an island will decrease the LCoE of a possibly additional GW in the area. Other advantages are small however.

6.6 Multiple lifetime & decommissioning cost

- HVDC platforms only have limited potential for multiple lifetime, but in case the GCS needs to be decommissioned after the operational lifetime of the wind farm, the net costs are zero (since scrap value is equal to decommissioning costs).
- We have been able to validate that the HVDC Island has large potential for multiple lifetime which will decrease the LCoE of successive offshore wind farms. On the other hand, possible complete decommissioning of an island is expensive.

Concluding, both options have advantages and disadvantages for the long future.

6.7 Upsides for hydrogen, interconnectors, O&M port

HVDC Islands can have many upsides that will be beneficial to society, facilitate the energy transition and reduce cost. However, due to the already challenging planning, TenneT requires a monofunctional island to finish construction in 2028 and therefore has advised against including these upsides into the preliminary design and therefore business case. As mentioned before, we support this decision. However, the possibility remains that, when the island is finished, additional upsides will be realized. This requires an island with dimensions suitable for 6GW however.

6.8 Conclusion

The following table provides an overview of the back-to-back MCA-comparison between platform and island. The first four criteria are considered major criteria, which depending on preference, can shift the choice between platform and island. The final three criteria are minor criteria, since they assume other future development or have a limited impact.

Criterion	2*2GW HVDC platforms	2*2GW HVDC Island
Technical feasibility	Feasible	Feasible. Even though a HVDC island is new, all components (with similar interfaces) have been built before
LCoE and cost overruns	±82 €/MWh, low variance Under TenneT-assumptions platforms are 2.8€/MWh more expensive, which corresponds to an NPV of 600 million euro. This difference drops to 1.8€/MWh or 400 million when assuming the RWS design and costing. In a worst-case scenario for island, the difference is negligible. Cost increases due to possible delays are not taken into account.	±79 €/MWh, higher variance
Redundancy and grid stability	Medium redundancy, medium availability, can stabilize the grid	High redundancy, higher availability, can stabilize the grid
Risks of delay and adherence to roadmap	Low risk of delay, full adherence to roadmap when choosing platforms in 2018. Choosing platforms in 2020 leads to partial adherence to roadmap.	Higher risk of delay, possibility to miss roadmap goals by years. Mitigating measures limited during construction with no guarantee to remain in line with the roadmap.

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Criterion	2*2GW HVDC platforms	2*2GW HVDC Island
Additional capacity	More expensive and harder to achieve in short time duration	Cheaper and slightly easier to achieve in short time duration
Multiple life and decommissioning cost	Limited possibility for multiple life, decommissioning at zero cost. Overall, no clear advantage over island.	Multiple life possible, decommissioning potentially expensive. Overall, no clear advantage over platform.
Upsides (hydrogen, interconnection etc.)	None, or harder and more expensive to realize due to limited space on a platform	Possible, planning in line with roadmap is only possible when assuming a monofunctional island. Therefore, development of other upsides can only start after initial development of the HVDC island.

7 CONCLUSIONS

BLIX has been able to validate the LCoE report, since:

- The LCoE-model is correct, and all input parameters can be traced.
- The technical designs of the 8 GCS concepts are correct and complete.
- The CAPEX components of the 8 GCS concepts are in line with our expectations. Based on experience and expert judgement some of the cost components for HVAC and the island solutions could not be completely validated. Therefore, we included them in an extreme sensitivity scenario to see whether this would change the ranking.
- The OPEX components of the 8 GCS concepts are correct and complete.
- Losses and availabilities appear correct, but full traceability has not been provided. Therefore, we included them in an extreme sensitivity scenario to see whether this would change the ranking.
- Extreme sensitivity scenarios for not fully validated starting points do not change the ranking between the options. The worst-case sensitivity of the 2*2GW HVDC island is similar to the base case of the 2*2GW HVDC platforms. Therefore, we have been able to validate that the 2*2GW HVDC island has a lower LCoE than the 2*2GW HVDC platforms.
- Overall, BLIX can validate the conclusions of the LCoE report and underlying assumptions.

BLIX has been able to validate the majority of design choices made by TenneT to be optimal:

- The 8 GCS concepts that have been considered are the most feasible options. Choosing from these options will result in the optimal design.
- TenneT has correctly rejected HVAC, even though we have not been able to provide a validation of all quantified arguments. However, the qualitative arguments to reject HVAC are strong and even in an extreme scenario HVAC is not significantly cheaper.
- We can validate TenneT's preference for 2GW export cables over 1GW and 1.33GW. TenneT's motivation is correct, complete and robust.
- Infield cables running underground are more advantageous compared to overhead lines for the island-based GCS.
- The 2*2GW HVDC island case has operational advantages and a lower LCoE, while the planning for 2*2GW HVDC platforms is less risky.

Therefore, a design choice between 2*2GW HVDC platforms and 2*2GW HVDC island depends on the relative importance that the Dutch government would give to a robust planning with short time duration (which favors platform) or on the lowest LCoE and more operational redundancy (which favors island).

- In case full adherence to the roadmap is required, the 2*2GW HVDC platform solution is the only suitable option. The roadmap requires the first 1GW of wind farms to be operational in 2027, and thus requires the first 2GW grid link to be operational in Q1-2027. Worst-case (but highly mitigatable) delays would lead to commissioning in 2028. This is still moderately in line with both roadmap and coalition agreement.
- If also a 2028 commissioning of the first wind farms is fully allowed, the choice for an island could fit. However, we have not been able to fully validate the 2028 planning for the island and additional risks might still occur. Delay until 2029 or later is a real risk, which will be problematic for the offshore wind supply chain, possibly lead to additional cost, and not be in line with either roadmap or coalition agreement. Therefore, immediate choice for an island is only an option, if the MinEACP has no problem with commissioning in 2029 or later. Choosing an island now will lead to possible, unmitigable delays without a backup. Delays

could lead to less competitive bids in tenders and the obligation (under the Electricity Act) for TenneT to compensate the wind farm permit holder(s).

A hybrid solution, in which both options are developed and the choice between island and platform is delayed to Q1-2020, could be a solution. It should be noted however, that choosing the hybrid scenario III/IV and choosing the platform option afterwards (in 2020) will shift the platform planning with a year, leading to a completion in 2028, which is not fully in line with the roadmap. Moreover, choosing the hybrid scenario has an additional drawback that this might introduce a political and public debate over the choice between island and platform causing possible delays.

If MinEACP chooses this option, the following activities should be undertaken:

1. Determination of the required commissioning date for the TenneT GCS by tracking back from the required dates the wind farms should be operational and using the size of tenders and the optimal construction time of wind farms (using market consultation)
2. Detailed optimization of the entire island concept to make the planning more robust and with a shorter time duration if possible (since a possible 2029 completion date of the GCS is not in line with the roadmap)