Technical study for effects of offshore wind for cost development and cost basis processes

JUNE 2024

Notis:
Følgende vedlegg er fjernet fra rapporten fordi de inneholder forretningshemmeligheter, jf. fvl. § 13 første ledd nr. 2:

- Annex A. Foundation Weights
- Annex B. Production Estimates
- Annex C. Cost Database
- Annex D. Detailed cost breakdown for test case

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CONTACT DETAILS

Name:	Bayram Mercan	Email:	bayram.mercan@afry.com
Address:	AFRY Netherlands		
	2e Daalsedijk 6A, 3551 EJ Utrecht, Netherlands		

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Revision Log

Issue Number	Date	Description	Prepared by	Checked by
1	17/05/2024	Draft Report	Bayram Mercan Hasan Suliankachi David Victoria	Imke Maassen van den Brink
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ABBREVIATION LIST

AC	Alternating Current
AEP	Annual Energy Production
BOP	Balance of Plant
CAPEX	Capital Expenditure
EIA	Environmental Impact Assessment
EYA	Energy Yield Assessment
EXC	Export Cable
FOW	Floating offshore wind
GCS	Grid Connection System
GIS	Geographic Information System
GW	Gigawatt
GWA	Global Wind Atlas
GWh	Gigawatt hour
HVAC	High Voltage Alternative Current
LCoE	Levelized Cost of Energy
LFAC	Low Frequency Alternative Current
MW	Megawatt
O&M	Operations & maintenance
OPEX	Operational Expenditure
OHVS	Offshore High Voltage Substation
OWF	Offshore wind farm
OSS	Offshore Substation
RFQ	Request For Quote
SEA	Strategic Environmental Assessment
SOV	Service Operation Vessel
TLR	Technology Readiness Level
WTG	Wind turbine generator

1 Introduction

The Norwegian Water Resources and Energy Directorate (NVE) is responsible for managing the country’s water and energy resources. On 25 April 2023, NVE submitted proposals for 20 assessment areas that may be suitable for offshore wind power. NVE, which is a subordinate to the Ministry of Petroleum and Energy (MPE) has been commissioned by the MPE to conduct a strategic impact assessment of these 20 assessment areas. On 14 September 2023, the MPE established the investigation programme for the strategic impact assessment and separated the three areas, Southwest F, Vestavind B and Vestavind F from the other areas, because these areas will be used directly in an opening process leading up to a call for tenders in 2025.

The strategic impact assessment requires an accurate and comprehensive evaluations of cost, for that reason, NVE has selected AFRY to develop a cost database and a cost model.

AFRY has built a comprehensive cost database from previous projects and expert input, including emerging technologies such as floating foundations. This database includes costs associated with the construction, operation, and decommissioning of offshore wind farms. For this project, a tailored extract was created to reflect the main components and the most up-to-date data relevant to the Norwegian market. This extract considers factors such as water depths, distance to shore, foundation technology, cable technology, and operation and maintenance.

The cost model is a tool that has been developed to allow NVE to calculate the associated cost of different areas based on the cost database. The cost model has a high degree of flexibility and adaptability which enable analyses of different sensitivities. The output of the model also facilitate comparisons within and between areas for technical suitability and potential conflicts, using the Levelized Cost of Electricity (LCoE) as basis.

The cost database and cost model are both designed to capture and calculate the associated cost for fixed and floating offshore wind farms, taking into account various water depths and designs.

The cost outputs of the model, along with the embedded database and trendlines, enable the calculation of critical components such as foundation weights for monopiles. It's important to note that these outputs are indicative and specifically tailored for the Norwegian market.

1.1 Purpose of this document

The primary purpose of this report is to enable NVE to meet the investigation requirements for assessing the costs associated with wind farms. This report aims to provide a robust and transparent basis for calculating the Levelized Cost of Energy (LCoE) for wind farms, facilitating informed decision-making and planning.

The purpose of this document can be divided into the following main objectives:

- **Describe the methodology for the cost data capture and processing from different projects across relevant markets in Europe**
  This section will outline the approach taken to gather and process cost data from various wind farm projects, ensuring a comprehensive and accurate dataset.
- **Cost & LCoE modelling**
  Here, the report will present the calculations performed to determine the LCoE, accompanied by the resulting outputs using a test case.
- **User guide for the cost model**
  An instructional guide will be included to help users understand and utilize the cost model effectively.
- **Conclusion**
  A summary of the findings and insights gained from the analysis, highlighting key takeaways.
- **Potential for improvements**
  The report will conclude with an assessment of the current model's limitations and suggestions for future enhancements.

By addressing these elements, the report aims to support NVE in effectively responding to investigation requirements and making well-informed decisions regarding wind farm projects.

2 Cost Database Data Collection and Processing

In this chapter, we provide general market cost information. The prices for various components are collected from previous projects where AFRY has participated, helping to create a cost database and allowing for price benchmarking.

2.1 Data Collection

First, all the data is filtered for projects that have achieved or are close to achieving the final investment decision (FID). Then, a second filtering focuses on data relevant to the Norwegian market. For this, data from five different countries in Europe which have been leading the offshore wind development over the last decades and one in Asia. Within this, a variety of projects are able to be documented including those with similar water depth conditions with Norwegian sites, which may require the use of jacket or floating foundations.

Additionally, considering that some of the sites of interest for the Norwegian market are located a considerable distance from shore, it is important to have cost figures for High Voltage Direct Current (HVDC) systems. Due to the very limited data from offshore wind developments, as these are still emerging, data from interconnectors have been gathered to provide a robust benchmark for cables and associated connection systems such as offshore substations and onshore equipment.

To deliver a consistent database, the methodology begins with a cost input sheet, which gathers and classifies the pertinent data from wind farms or interconnector projects. In the following subsections 2.1.1 to 2.1.4, the breakdown of the input sheet is explained along with the averaging methodology for each of the components.

Not all the selected projects have all the required information; some projects only have data for certain components, such as the wind turbine generator cost but not the grid connection system. Therefore, capturing the number of references per item is crucial for ensuring the accuracy of the data processing. This approach also helps identify potential weaknesses in the data and provides an overall view of the market's state. For confidentiality reasons, AFRY reserves the right not to disclose the exact number of references per item; instead, a range is provided in this document.

The input sheet also serves as a standardization tool, accommodating varying levels of detail depending breakdown of the data. AFRY has access to different levels of detail as the information can be inputted by expert advice, from a quotation from a contractor, from a technical due diligence (TDD), a contract management, a tender support, or a performance audit.

2.1.1 Site specific data

For all projects in the database, comprehensive site data are systematically collected and categorized under various headings to ensure a detailed and informative overview of each wind farm. The database encompasses detailed geographical and technical information, such as the location, size, and proximity of the wind farm to shorelines, installation and operational ports, and grid connections. These elements are crucial for assessing the logistical requirements and infrastructure development costs associated with each site.

Technical specifications of the wind turbines, such as manufacturer , model, capacity, rotor diameter, and hub height, are documented alongside the foundation type—whether fixed or floating—and grid type. This also extends to the electrical infrastructure, detailing the number and specifications of export cables and offshore substations, and the grid's voltage ratings.

Additionally, environmental factors are thoroughly recorded, including seabed composition, water depth, average wind speed at hub height, and ice formation risks, which directly influence construction and maintenance costs. This data collection process includes capturing fundamental project details such as the final investment decision year, inflation rates, and currency ratios, which are essential for financial assessments.

Sources of this collected data include direct reports from AFRY projects, external data sources, and country-specific reports, ensuring that the information is accurate and up-to-date. The total number of projects considered for the database ranges between 40 and 50.

2.1.2 Capital Expenditure (CAPEX)

The CAPEX framework is subdivided into the offshore windfarm and grid connection system main components:

Offshore Wind Farm (OWF):

- Wind Turbine Generators
- Foundations
- Inter Array Cables (IAC)

Grid connection System (GCS):

- Export cables
- Offshore substation
- Onshore substation
- Onshore cables

As mentioned Section 2.1.1., the input sheet captures different levels of detail, allowing for the strategic computation of average values that inform both planning and execution phases.

Wind Turbines (WTG)

CAPEX of Wind Turbine Generators (WTGs) is a major contributor to the cost of installing and operating an offshore wind farm, accounting for approximately

20% of the total cost. The CAPEX values in this section are split into three categories:

- Supply cost per WTG: This includes the actual cost of manufacturing the turbine.
- Transport & Installation (T&I) cost per turbine: This covers the expenses related to transporting and installing each turbine.
- Miscellaneous expenses per WTG: This includes any additional costs associated with each turbine.

The projects considered for input range from turbines with capacities of 7 MW up to 18 MW. The data from these projects spans from the final investment decision (FID) in 2011 to 2022, considering a range between 15 and 20 references were considered.

These figures have been used to compute benchmark values by averaging the costs within each category for turbines of varying capacities. To ensure the CAPEX values are accurately averaged, considering the requirements of the NVE sites, it is necessary to avoid averaging all WTG sizes together due to substantial price differences. Therefore, the turbines are divided into two size categories for averaging:

- WTGs between 10 MW and 18 MW
- WTGs above 18 MW

Additionally, in preparing the inputs for the LCoE model, the CAPEX per megawatt of installed capacity is determined. This is further subdivided into the supply cost per megawatt and the transportation and installation (T&I) cost per megawatt.

Foundations (FOU)

Data collection for foundations was primarily divided into two categories: bottom-fixed foundations and floating foundations. The type of foundations were further subdivided into the following categories:

1. Fixed bottom foundations
    - Monopile
    - Jackets
2. Floating foundations
    - Semi-submersible
    - Spar-buoy

Within the overarching categories of fixed-bottom foundations and floating foundations, the subsequent breakdown was similar for both types, a total between 15 and 20 references were considered.

The primary divisions being supply cost per foundation and the transportation and installation (T&I) cost per foundation. The supply cost under fixed bottom foundations were further split into cost headers for supply cost of the foundation itself (monopile, jackets, gravity based structure), transition piece, scour protection and corrosion protection etc.

On the other hand the supply cost under floating foundations were further split into cost headers for supply cost of the floating substructure itself (TLP, semi-submersible, spar-buoy), mooring lines, anchors etc.

AFRY also collects data regarding the actual weight of the foundations in order to use in further calculations. In case of unavailability of credible data regarding foundation weights, we used an in house tool to determine the weights for both floating and fixed foundations with calculation methods unique to the type of foundation being employed.

Based on the weight of the foundations, the supply cost per ton of the foundation was determined for both fixed and floating foundations which was then utilized to compute benchmark values by averaging the costs associated with each type of foundation. Successively, the CAPEX per foundation and CAPEX of foundations for the total wind farm (excluding Offshore Substation) was calculated.

Inter-array Cables (IAC)

The cost sheet of Inter Array Cables (IAC) starts with data point regarding the voltage level of the IAC, a range between 15 and 20 references were considered. It is clear that 66 kV voltage level has become a standard in the offshore wind industry nowadays. Similar to most of the other sections, the primary categorization of expenses for the IAC is divided between the supply cost of the cables and the transportation and installation (T&I) cost of the said cables.

The CAPEX of IAC supply costs can be further subdivided into supply cost of the cable, fixed cable costs, cable protection cost and T&I cost. Fixed cable cost caters for the additional installation CAPEX which is considered for the installation of the internal cabling and static cable connecting each WTG to the network of IAC. These numbers are further added up to arrive at the total CAPEX of the IAC.

The length of cable in the IAC network must be determined in order to calculate the CAPEX of IAC per km of cable length. In cases where the actual length of IAC was unavailable, a theoretical length of IAC was calculated using inputs such as water depth, spacing between each WTG, the rated capacity of the WTG and the complete windfarm.

Subsequently, the CAPEX (including supply and T&I costs) for Inter-Array Cables (IAC) per kilometre was calculated for two voltage levels: 66 kV and 132 kV. The 132 kV technology is expected to become available in the market in the coming years. Therefore, the cost per kilometre for 132 kV cables was estimated using an extrapolation of the costs for export cables, along with the potential additional costs associated with installing this newer technology compared to the mature 66 kV technology.

Offshore Substation (OSS)

Two primary types of substations are pivotal for transmitting generated power to the mainland: High Voltage Direct Current (HVDC) and High Voltage Alternating Current (HVAC) substations. Each type serves a critical role in the efficient and effective transfer of electrical energy over long distances. The

CAPEX of these component are significantly influenced by design decisions and market prices for electrical sub-components and metals. The choice between HVAC and HVDC often hinges on balancing cost, efficiency, and technical feasibility to optimize energy transmission from sea to grid, a range between 15 and 25 references where used for the estimation of this cost input.

The cost database gathers user inputs regarding the type of Offshore Substation System (OSS) being implemented, whether HVDC or HVAC, along with the total number of offshore substations within the wind farm, the capacity of each individual substation, and the voltage rating of the OSS. The primary categorization of expenses for the OSS is divided between the supply cost of the OSS and the transportation and installation (T&I) cost of the OSS.

The supply cost of OSS can be further subdivided into supply cost of electrical systems, facilities, platform, foundations etc. These numbers are further added up to arrive at the total CAPEX of the OSS from which the CAPEX of the OSS per MW of rated capacity can be attained. Similar to the previous sections, these CAPEX values have been utilized to compute benchmark values by averaging the costs associated with each type of OSS (HVDC or HVAC).

Land-station

Following the same approach as the OSS, a benchmark value for the land station is estimated. The cost data includes the type of land station, total capacity, and voltage rating.

The supply cost includes switchgear, converter, transformer and HVAC incomer feeders, and land preparation. These costs are totalled to determine the CAPEX per MW of rated capacity. Similar to the OSS, these CAPEX values are averaged to compute benchmark values for each type of land station where HVDC or HVAC.

Export Cables (EXC)

The cost database sheet for export cable starts with collecting input regarding the voltage level of the cables, total number of cables connecting the OSS to shore and the cross-section of the export cable, a total between 20 and 25 references are considered. Following which, the structure of the cost database for export cables is very similar to that of the IAC. The primary categorization of expenses for the export cable is divided between the supply cost of the cables and the transportation and installation (T&I) cost of the said cables. The CAPEX of export cable supply costs can be further subdivided into supply cost of the cable, cable protection cost and T&I cost. These numbers are further added up to arrive at the total CAPEX per installed export cable.

The length of installed export cable is generally available and in rare cases of data unavailability, the length of export cable is estimated to be 1.2 times the distance of the OSS from shore. The CAPEX of export cable per km of cable length was derived by considering the total CAPEX, length of each export cable and the total number of export cables being used in the respective wind farm.

2.1.3 Development Expenditure (DEVEX)

AFRY categorizes and captures detailed data under specific sub-headers for the development of a comprehensive cost database for DEVEX costs, a renge between 5-10 projects were considered for this item. Here's a summary of our methodology for collecting and analysing DEVEX costs:

- **Cost of Development and Consenting Services**
  Captures expenses related to obtaining necessary permits, consents, and legal compliance for project development stages.
- **Cost of Environmental Surveys + Environmental Impact Assessment (EIA)**
  Documents costs associated with conducting environmental studies and assessments required to evaluate the ecological impact of the project.
- **Cost of Resource and Metocean Assessment**
  This includes expenses related to the assessment of natural resources (like wind, solar irradiance) and meteorological and oceanographic data crucial for project planning.
- **Cost of Geological and Hydrographical Surveys**
  Focuses on the costs incurred in detailed geological and hydrographic surveying, essential for understanding the project site's subsurface and water column characteristics.
- **Cost of Engineering and Consultancy**
  Expenses related to engineering design, project feasibility studies, and consultancy services that guide the project's technical and strategic aspects.
- **Cost of Finance Cost & Legal Advisory**
  These are costs associated with financial planning, fundraising, and legal advice to ensure the project meets all regulatory requirements and is financially viable.
- **Cost of Other Miscellaneous Expenses**
  Includes all other expenditures not categorized above but necessary for the development process, such as preliminary site studies, preliminary project management, and other indirect costs.

2.1.4 Operating Expenditures (OPEX)

In developing a comprehensive cost database for OPEX costs, AFRY adopts a structured methodology to ensure accuracy and relevance of data across various operational categories. This methodology is tailored to systematically capture and analyse costs associated with the operations and maintenance (O&M) of energy infrastructure, arrange between 10-20 projects were considered. Here is a summary of our approach:

Cost of Running Operations:

- **Operations Control Centre**
  Tracking expenses related to the management and monitoring of operations.
- **Training**
  Costs incurred for staff training programs to ensure compliance and efficiency.
- **Onshore Logistics**

Expenses associated with the coordination of land-based operations supporting offshore activities.

- **Technical Resource (Onshore and Offshore**)
  Costs for technical staff, both on land and at sea.
- **Admin and Support Staff (Onshore)**
  Administrative overheads and support staff expenses.
- **Other**
  This includes insurance, environmental studies, health, safety, and environmental (HSE) measures, and compensation payments.

Cost of Running Maintenance Activities:

- Detailed tracking of maintenance expenses for specific components:
  - Turbine, Foundations, Offshore Substation (OSS), Inter-array Cables (IAC), Export Cable, Transmission Systems
  - Other Balance of Plant Systems: Costs associated with other crucial plant components.
  - Statutory Inspections: Expenses related to mandatory inspections required by law.
  - Offshore Logistics and Vessels: Costs for transportation and logistical support for offshore operations.

Additional Specific Costs:

- **O&M Port Costs**
  Expenses related to the port facilities used for O&M activities.
- **Offshore Logistics and Vessels**
  A second, detailed examination of costs specific to the logistical and vessel needs beyond general maintenance.
- **Management Costs**
  Overhead and management-related expenditures.
- **Insurances (Per Year)**
  Annual insurance costs covering all operational risks.
- **Contingency**
  Provision for unforeseen expenses or overruns.

3 Cost & LCoE Modelling

Good knowledge and understanding of the costs of generating electricity is essential in policy design and analysis. In processes to set renewable energy support levels often the economics cost of energy are calculated as a basis for tariff calculation. Levelized costs of energy generation correspond to the cost of an investor assuming the certainty of production costs and the stability of electricity prices. More precisely, it is defined as 'the ratio of the net present value of total capital and operating costs of a generic plant to the net present value of the net electricity generated by that plant over its operating life'. The level of detail in such commissions can differ widely. Sometimes a single formula is used, in other methods a full cash-flow analysis is applied, for instance to address the impact of fiscal regulations.

This chapter details the methodology used to develop a Levelized Cost of Energy (LCoE) model specifically for offshore wind farms. The LCoE is a vital metric used to assess the cost-effectiveness and financial viability of energy generation projects. This model aims to provide a comprehensive framework for evaluating the economic feasibility of offshore wind farms by incorporating various cost components and energy production estimates.

3.1 Calculation of levelized costs of energy –basic principle and requirements

The LCoE approach allows for a comparison between different energy technologies considering the costs occurring during the overall life cycle of a power plant. The LCoE is typically taken as basis for evaluating and comparing alternative options for investments into power plants. The LCoE reflect the minimum price at which electricity has to be sold to ensure that the investment made pays off. Similarly, the LCoE method can be taken as reference to determine a support level for renewable power plants in particular if the objective is to encourage investment without providing overcompensation. As shown in the following formula, the net present value of the investment is divided by the discounted electricity generation of the plant.

$$LCoE = \frac{Total\ Lifecycle\ Cost}{Total\ Lifetime\ Energy\ Production}$$

The above LCoE equation can be disaggregated for offshore wind as follows:

$$LCoE = \frac{CAPEX + DEVEX - \sum_1^N \frac{DR}{1+HR} \times TR + \sum_1^N \frac{OPEX + DECEX}{1+HR} \times (1 - TR)}{\sum_1^N \frac{P50}{1+(HR)} \times (1 - TR)}$$

where;

$$CAPEX = Capital\ Expenditures$$

$$DEVEX = Development\ Expenditures$$

$$OPEX = Operational\ Expenditures$$

$$DECEX = Decomissioning\ Expenditures$$

$$DR = Depreciation\ Rate$$

$$HR = Hurdle\ (Discount)\ Rate$$

$$TR = Tax\ Rate$$

$$P50 = P50\ Net\ Yield\ after\ all\ losses$$

$$N = Technical\ Lifetime\ of\ the\ wind\ farm$$

3.2 Inputs and Calculations

3.2.1 Definition of costs

The total lifetime costs of an offshore wind farm are included in the LCoE model. Costs are defined in four different overall categories. These are Development Expenditures (DEVEX), Capital Expenditures (CAPEX), Operational Expenditures (OPEX) and Decomissioning Expenditures (DECEX).

DEVEX is defined as all costs spent in the period from idea and development to design & planning. CAPEX is defined as all expenditure in the period of construction up to the date the wind farm is commissioned (first power). Costs in the operational period are defined as OPEX. Finally, DECEX is defined as all costs related to abandonment of the wind farm from the wind farm termination date.

Any comparison between different wind farms requires the same starting point. Therefore FID (Final Investment Decision) is selected as the date of comparison.

As discussed in the previous chapter, AFRY has built a comprehensive cost database. For most of the main components, the costs are calculated using this cost database. For OPEX and DECEX, AFRY implemented an engineering approach to be able to estimate the costs. Based on this engineering approach, foundation weights are calculated by using a polynomial formula for each turbine size and different foundation technologies. Also, mooring line weights and ballast weights are calculated using component-specific polynomial formulas.

3.2.2 Definition of production

The estimated production is an important parameter in calculating LCoE values. AFRY used two different level of details when it comes to production estimation:

- Level 1: There is no detailed energy yield assessment. The model estimates the capacity factors based on turbine size and total installed capacity.
- Level 2: The energy yield assessment is available. The user can input the gross and net yield estimates for the offshore wind farm.

3.2.3 Definition overview of input parameters

Table 1. Input parameters for different scenarios

Site Information	Description of input
Area	The total area size of the project
Detailed EYA available	This is a selection to determine the levels described in section 3.3.2
Average Wind Speed	Either, this information comes from the yield assessment or the user gives an input
Gross Yield	If detailed yield assessment exists, the gross yield is calculated, If there is no detailed yield assessment available, this input calculated by AFRY production calculations.
Net Yield	If detailed yield assessment exists, the net yield is calculated, If there is no detailed yield assessment available, this input calculated by AFRY production calculations.
Net Yield after cable losses	The net yield (P50) after the cable losses
Capacity Factor	This value is calculated automatically.
Average water depth	Either, this information comes from the yield assessment or the user gives an input
Distance to Main Port	Distance to main installation port
Distance to O&M Port	Distance to O&M port
Distance to Onshore Connection	Distance to main onshore connection point

Technology Information	
Number of WTGs	Number of wind turbine generators

Rated Power per WTG	Nameplate capacity of one single turbine as a selection: 15 MW 18 MW 20 MW 22 MW 25 MW
Total Capacity	This is calculated based on number of turbines and rated power of the turbines
Foundation Family	The user can select different foundation families: Fixed Floating
Foundation Type	The user can select different technologies: Monopile Jacket Semi-submersible Spar Buoy Concrete Spar Buoy Steel
Average Foundation weight	This value is calculated automatically based on water depths and turbine size
Average Mooring Line Weight	This value is calculated automatically based on water depths and turbine size
Average Ballast Weight	This value is calculated automatically based on turbine size
Inter-Array Cable length – Static	User input for the total length of static inter-array cables
Inter-Array Cable length – Dynamic	User input for the total length of dynamic inter-array cables
Inter-Array Cable Voltage Level	Inter-array cable voltage level as a selection: 66 kV 132 kV
Inter-Array cable loss	Inter-array cable loss in percentages
Export Cable length – Static	User input for the total length of static export cables
Export Cable length – Dynamic	User input for the total length of dynamic export cables
Export Cable loss	Export cable loss in percentages
Offshore Substation Foundation type (if applicable)	The foundation type of the offshore substation as a selection:

	Fixed Floating
Onshore cable length	User input for the total length of onshore transmission cables
Number of crossings	User input for the number of crossings of export cables

LcoE Model Assumptions	
Start date model	Final Investment Decision (FID) date of the project
Start WTG commissioning	Date of commissioning of the first wind turbine generator
COD	Date of commercial operation date of the project
Life-time wind-farm	Technical lifetime of the offshore windfarm
Include production during comissioning	Yes/No selection to include the production during comissioning
Include decomissioning costs	Yes/No selection to include the decomssioning costs
Include inflation in OPEX and power prices	Yes/No selection to include inflation on OPEX and electricity prices
Include taxation	Yes/No selection to include tax on LcoE calculations
Include GCS in cash balance and financing	Yes/No selection to include Grid Coinnection System on financial calculations

Financial Assumptions	
Tax	Tax rate in percentages
Contingency – CAPEX	Contingency in CAPEX in percentages
Contingency – OPEX	Contingency in OPEX in percentages
Inflation	Inflation rate in percentages
Required return on equity	Required rate of return on equity
Equity share in project	Equity share in the project
Electricity Price first year	The expected electricity price at FID
WACC	This is calculated based on other financial assumptions

Use AFRY general assumptions?	For the other financial assumptions, the user can either use AFRY general assumptions or can input independent values

3.2.4 LCoE trends for Offshore wind

As a request from the Client, AFRY also analyzed the trends of LCoE for offshore wind. This will enable to understand the different LCoE levels if the Final Investment Decision date is changed.

AFRY conducted a literature survey to be able to estimate the future LCoE trends however it must be noted that we did not conduct any interviews.

There are several factors that can affect the cost components but also the effectiveness of the wind turbine generators:

- Standardization of foundation technologies
- Availability of installation vessels
- Commercialization of floating offshore wind
- Increased technology readiness levels of different floating substructure designs
- Increased technology readiness levels of dynamic cables
- Construction and operational experience
- Optimized mooring solutions

Based on a DNV study[1], a forecast for LCoE levels are studied for both fixed and floating offshore wind farms. The below table summarizes the LCoE reduction multipliers for different FID dates.

Table 2. Levelized Cost of Energy (LCoE) trends for different Final Investment Decision (FID) dates

FID Year	Trend Multiplier – Fixed	Trend Multiplier – Floating
2030	1,00	1,00
2032	0,97	0,93
2034	0,91	0,71
2036	0,87	0,64
2038	0,85	0,62
2040	0,83	0,57
2042	0,82	0,54
2044	0,78	0,50

[1] Floating Wind: Turning Ambition Into Action, 2023

2046	0,77	0,48
2048	0,77	0,48
2050	0,76	0,47

Rabobank, together with DNV conducted another study[2] to assess the future LCoE trends. This study states that in 2050, the LCoE of floating wind farms might decrease by 45% compared to 2030. By 2040, the drop is forecasted to be 30%. However, it must be noted that this study refers to datasets in 2022, therefore AFRY foresees that the basecase LcoE, which is year 2

030, is higher than anticipated therefore, the forecasted reduction rates might be higher.

Berkeley Lab also conducted a research that includes interviews with industry experts[3]. This study proposes that the LcoE levels for fixed foundation offshore wind farms will face a decrease of 30% by 2050. For floating wind, Berkeley Lab forecasts that the LcoE might reduce up to 56% by 2050.

AFRY concludes that the multipliers that are presented in the above table reflects a reasonable forecast for future LcoE trends for offshore wind.

3.2.5 Test Case: Sørlige Nordsjø II

Norway finalized a tender in previous months and Parkwind has won the tender with a price of 100 EUR/MWh. The proposed project, Sørlige Nordsjø II, has a total area of 540 km2 with a proposed total installed capacity of 1500 MW . It is also understood that the developer will be responsible for the grid connection design, installation and operation. To be able to calculate the costs and LcoE levels, AFRY made assumptions since the details of the project is unknown. We assumed that 20 MW turbines will be used for this project. Based on available public data, the average water depth is 53 meters which might allow to use monopiles. The mean wind speed is 10,8 m/s at 150 m hub height, therefore the estimated capacity factor is 57%. The below table summarizes the inputs for this test case.

Table 3. Input parameters for the test case Sørlige Nordsjø II

Site Information		
Area	*km2*	540,00
Detailed EYA available	*selection*	No
Average Wind Speed	*m/s*	10,80

[2] Floating Offshore Wind Energy: Reaching Beyond the Reachable by Fixed-Bottom Offshore Wind Energy, 2023
[3] Are We Underestimating the Potential for Wind Energy Cost Reductions…and also the Uncertainty?, 2021

Gross Yield	*MWh/yr/WTG*	107.236,82
Net Yield	*MWh/yr/WTG*	90.021,42
Net Yield after cable losses	*MWh/yr/WTG*	87.693,82
Capacity Factor	*%*	57%
Average water depth	*m*	53,00
Distance to Main Port	*km*	200,00
Distance to O&M Port	*km*	200,00
Distance to Onshore Connection	*km*	200,00

Technology Information		
Number of WTGs	*#*	75,00
Rated Power per WTG	*MW*	20,00
Total Capacity	*MW*	1.500,00
Foundation Family	*selection*	Fixed
Foundation Type	*selection*	Monopile
Average Foundation weight	*tonnes*	3.435,44
Average Mooring Line Weight	*tonnes*	-
Average Ballast Weight	*tonnes*	-
Inter-Array Cable length – Static	*km*	290,00
Inter-Array Cable length – Dynamic	*km*	-
Inter-Array Cable Voltage Level	*kV*	66,00
Inter-Array cable loss	*%*	0,80%
Export Cable length – Static	*km*	240,00
Export Cable length – Dynamic	*km*	-
Export Cable loss	*%*	1,80%
Offshore Substation Foundation type	*selection*	Fixed

Onshore cable length	*km*	-
Number of crossings	*#*	-

LCoE Model Assumptions		
Start date model	*dd-mm-yyyy*	1-1-2032
Start WTG commissioning	*dd-mm-yyyy*	1-1-2033
COD	*dd-mm-yyyy*	1-1-2034
Life-time wind-farm	*years*	35
Include production during comissioning	*selection*	Yes
Include Decommissioning costs	*selection*	Yes
Include inflation in OPEX and power prices	*selection*	Yes
Include taxation	*selection*	Yes
Include GCS in cash balance and financing	*selection*	Yes

Financial Assumptions		
Tax	*%*	22%
Contingency – CAPEX	*%*	10%
Contingency – OPEX	*%*	10%
Inflation	*%*	2%
Required return on equity	*%*	10%
Equity share in project	*%*	40%
Electricity Price first year	*EUR/MWh*	100,00
WACC	*%*	5,17%
Use AFRY general assumptions?	*Selection*	Yes

It must be noted that, AFRY assumed that the equity share is 50% and calculated WACC is 5,98% which might change from developer to developer.

The below table summarizes the cost estimates of the project. As requested by the Client, the model selects the most viable (lowest cost) grid connection type automatically. For this project, the model predicts that HVDC connection will be the preferred grid connection technology.

Table 4. Breakdown of costs for the test case Sørlige Nordsjø II

CAPEX		
Offshore Wind Farm (OWF)		
WTG Total CAPEX	***kEUR***	**1.996.666,67**
FOU Total CAPEX	***kEUR***	**987.235,26**
IAC Total CAPEX	***kEUR***	**278.240,00**
DEVEX Total	***kEUR***	**163.107,10**
OWF - Total CAPEX	*kEUR*	3.425.249,02
OWF - CAPEX Contingency	*kEUR*	342.524,90
OWF - Total CAPEX inc contingency	***kEUR***	**3.767.773,93**
Grid Connection System (GCS)		
OSS CAPEX	*kEUR*	890.500,00
Landstation	*kEUR*	337.500,00
EXC Supply	*kEUR*	720.000,00
EXC T&I	*kEUR*	480.000,00
Onshore cable CAPEX	*kEUR*	-
GCS - DEVEX	*kEUR*	254.240,00
GCS - Total CAPEX	*kEUR*	2.682.240,00
GCS - CAPEX Contingency	*kEUR*	268.224,00
GCS - Total CAPEX inc contingency	***kEUR***	**2.950.464,00**
Total project investment	***kEUR***	**6.718.237,93**

OPEX		
Offshore Wind Farm (OWF)		
OPEX - OWF Total	*kEUR/year*	71.248,38
OPEX - OWF Contingency	*kEUR/year*	7.124,84
OWF - Total OPEX inc contingency	*kEUR/year*	78.373,21
Grid Connection System (GCS)		
OPEX - GCS Total	*kEUR/year*	35.405,57
OPEX - GCS Contingency	*kEUR/year*	3.540,56
GCS - Total OPEX inc contingency	*kEUR/year*	38.946,12
Total OPEX	*kEUR/year*	**117.319,34**

Based on these calculations, AFRY calculates the LCoE values as follows:

- Offshore Wind Farm (OWF): 57,31 EUR/MWh
- Grid Connection System (GCS): 39,92 EUR/MWh
- Total LCoE: 97,23 EUR/MWh

Again, we need to mention that the equity share is 40% and calculated WACC is 5,17% which might change from developer to developer. However, the results show strong correlation with the tender results.

Please refer to Annex D for detailed breakdowns of the costs.

4 User Guide

In this section, we provide a high level user guide of the LCoE model that AFRY has developed so the Client can benefit as much as possible from the tool.

4.1 Structure of the Excel

The Excel contains 17 sheets which are summarized in the table below.

Table 5. Sheets included in the LCoE Model Excel file

Sheet name	Block	General Explanation
L	General	Color codes, cell styles
N	General	Conversion units,
COVER	General	Cover
Notes	General	Changes log
Inputs =>	Input	Separator
Site Inputs	Input	Site specific inputs
EYA	Input	Energy Yield Assessment input where applicable
Foundation Weights	Input	Contains the required coefficients to calculate the foundation weights
Production	Input	Contains the required coefficients to calculate the production
Cost Database	Input	Contains the cost database for different main component technologies
LCoE Trends	Input	Contains the LCoE trends coefficients for different final investment decision dates
Calculations =>	Calculation	Separator
Cost Estimates	Calculation	Calculation of cost components for every scenario
WTG commissioning	Calculation	Calculation of production estimates during commissioning of the wind farm
LCoE	Calculation	Calculation of Levelized cost of energy
Outputs =>	Output	Separator
Output - Costs	Output	User dashboard to visualize the cost components and LCoE values

In the following pages, a through description of each excel will be provided.

4.1.1 L

“L” sheet includes a colour guide.

Figure 1. “L” sheet look & feel

Style legend Alt R DE

Style	Design	Comment	Cell styles
Title	Title		AFRY
Heading 1	Heading 1		AFRY
Heading 2	Heading 2		AFRY
Heading 3	Heading 3		AFRY
Heading 4	Heading 4		AFRY
Heading 5	Heading 5		Custom
Assumption	100	A user driven input	Custom
Technical_Input	100	A model input that should not be changed to protect the integrity of the model	Custom
Empty_Cell		A cell that is left intentionally blank to avoid the risk of error	Custom
InSheet	100	A link within the worksheet or an interim calculation step	Custom
OffSheet	100	A link to another worksheet to minimise the number of inter-worksheet references	Custom
Line_SubTotal	100	The sum of elements in the table immediately above	Custom
Line_Total	100	The sum of elements above, including sub-totals	Custom
Total	100	The closing balance of a control account	AFRY
Unit / Info	USD millions	Explanatory text showing helpful information and the units/dimensions of the calculations	Custom
Line_Summary	100	The SUM() of everything to the right	Custom
Table_Header 1	Qtr	Header of a table or of an off-sheet reference	Custom
Table_Header 2	Qtr	Header of a table or of an off-sheet reference	Custom
Flag	1	Binary flag - set up as a 'Style' and updated with conditional formatting	Custom
Warning	0,00	Warnings: Errors or check-required	
Ok_crosscheck	12,00	Ok - cross check	

Please note that in all sheets, cells in yellow serve as input and is where the user of the model can manually write data.

4.1.2 N

“N” sheet includes conversion factors.

Figure 2. "N" sheet look & feel

Names and Constants

Item	Unit	Value
Entity Names		
Model Name	*Name*	AFRY input
Constants		
Days in Year	*Num#*	365
Months per Year	*Num#*	12
Quarters per Year	*Num#*	4
Months per Quarter	*Num#*	3
Hundred	*Num#*	100
Thousand	*Num#*	1000
Million	*Num#*	1000000
Very Small Number	*Num#*	0,0000001
Rounding Tolerance	*Num#*	6
Lists		
Yes	*Choice*	1
No	*Choice*	0
On	*Choice*	1
Off	*Choice*	0

4.1.3 COVER

"COVER" sheet includes general information about the author and AFRY's disclaimer.

Figure 3. "COVER" sheet look & feel

Author	Bayram Mercan
email	bayram.mercan@afry.com
Contact	+31 6 8204 3232
Date	19-Jun-24
Project	Technical study for effects of offshore wind for cost development and cost basis processes
Status	v200
Client	Norges Vassdrags- og Energidirektorat (NVE)

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4.1.4 Notes

"Notes" sheet includes a changes log as well as pending changes in the model (if any)..

Figure 4. "Notes" sheet look & feel

Changes Log comments

Date	Version	Comments / Modifications

Pending changes

#	Item	Solved?
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		

4.1.5 Inputs =>

"Inputs =>" sheet is simply a separator.

4.1.6 Site Inputs

"Site Inputs" sheet includes required inputs from the user for different scenarios. The model can handle up to 40 different scenarios. The inputs are divided into 5 main groups:

- Scenario Information

  This group includes user inputs to define the scenarios. The user can define the site (zone) name, layout name and also the definition of the scenario. It must be noted that the "Scenario Name", i.e. row 10 must be different for every scenario.

- Site Information

  The group includes site information such as area, distance to ports and distance to onshore connection. Also, the user can select whether detailed energy yield assessment (EYA) is available. If there is detailed energy yield assessment for a specific scenario, the user can input the values in "EYA" sheet (please refer to Section 4.1.7). If detailed EYA is not present, then the model automatically calculates the gross yield, net yield and capacity factors. It must be noted that if there is no detailed EYA available, the user also needs to input Average Wind Speed (row 16) and Average Water Depth (row 21) manually.

- Tehcnology Information

  This group includes technological information related to the scenarios. Here, the user needs to make inputs and selections for these items:

  - Number of WTGs
  - Rated Power per WTG, selection
    - 15 MW
    - 18 MW
    - 20 MW
    - 22 MW
    - 25 MW
  - Foundation Family, selection
    - Fixed
    - Floating
  - Foundation Type, selection
    - Monopile
    - Jacket
    - Semi_Sub
    - Spar_Buoy_Concrete
    - Spar_Buoy_Steel
  - Inter-Array Cable length – Static
  - Inter-Array Cable length – Dynamic

- Inter-Array Cable Voltage Level, selection
  - 66 kV
  - 132 kV
- Inter-Array cable loss
- Export Cable length – Static
- Export Cable length – Dynamic
- Export Cable loss
- Offshore Substation Foundation type (if applicable), selection
  - Fixed
  - Floating
- Onshore cable length
- Number of crossings

This group also includes calculations for the foundation weights. The model calculates foundation, mooring line and ballast weights. It is crucial to have an input for the average water depth since this input influences the weight calculations.

- LCoE Model Assumptions

This group includes inputs and selections for modelling assumptions. It is important to have these inputs correct since the "LCoE" sheet refers to these inputs.

- Financial Assumptions

This group includes financial inputs that are required in the LCoE calculations. It also includes detailed financial assumptions. For the sake of simplicity AFRY included basic assumptions for these detailed financial inputs. To be able to calculate the LCoE values, at least, these inputs should be existent:

- Tax
- Contingency – CAPEX
- Contingency – OPEX
- Inflation
- Required return on equity
- Equity share in project

The electricity prices input is important if the user wishes to calculate the financial rate of returns.

Figure 5. "Site Inputs" sheet look & feel

Main Inputs		
Scenario Information		
Scenario ID		1
Site Name		Sørlige Nordsjø II
Layout Name		A
Scenario Name		Sørlige Nordsjø II_A
Description		Sørlige Nordsjø II
Site Information		
Area	km2	540,00
Detailed EYA available	selection	Yes
Average Wind Speed	m/s	10,80
Gross Yield	MWh/yr/WTG	110.000,00
Net Yield	MWh/yr/WTG	99.874,00
Net Yield after cable losses	MWh/yr/WTG	97.291,66
Capacity Factor	%	56%
Average water depth	m	-53,00
Distance to Main Port	km	200,00
Distance to O&M Port	km	200,00
Distance to Onshore Connection	km	140,00
Technology Information		
Number of WTGs	#	75,00
Rated Power per WTG	MW	20,00
Total Capacity	MW	1.500,00
Foundation Family	selection	Fixed
Foundation Type	selection	Monopile
Average Foundation weight	tonnes	3.435,44
Average Mooring Line Weight	tonnes	-
Average Ballast Weight	tonnes	-
Inter-Array Cable length - Static	km	290,00
Inter-Array Cable length - Dynamic	km	-
Inter-Array Cable Voltage Level	kV	66,00
Inter-Array cable loss	%	0,80%
Export Cable length - Static	km	240,00
Export Cable length - Dynamic	km	-
Export Cable loss	%	1,80%
Offshore Substation Foundation type (if applicable	selection	Fixed
Onshore cable length	km	-
Number of crossings	#	-

LCoE Model Assumptions		
Start date model	dd-mm-yyyy	1-1-2032
Start WTG commissioning	dd-mm-yyyy	1-1-2033
COD	dd-mm-yyyy	1-1-2034
Life-time wind-farm	years	35
Include production during comissioning	selection	Yes
Include decomissioning costs	selection	Yes
Include inflation in OPEX and power prices	selection	Yes
Include taxation	selection	Yes
Include GCS in cash balance and financing	selection	Yes

Financial Assumptions		
Tax	%	22%
Contingency - CAPEX	%	10%
Contingency - OPEX	%	10%
Inflation	%	2%
Required return on equity	%	10%
Equity share in project	%	100%
Electricity Price first year	EUR/MWh	100,00
WACC	%	10,00%
Use AFRY general assumptions?	selection	Yes

4.1.7 EYA

Using the "EYA" sheet, the user can input values if a detailed energy yield assessment is available for a specific scenario. First, the user needs to select the scenario correctly at cell D5. Then turbine specific yield assessment results should be entered between columns E-L. This sheet also calculates the related foundation weights for every turbine. These calculations are presented in columns M-O.

Figure 6. "EYA" sheet look & feel

Scenario Name *selection*

Scenario Name	WTG #	Water depth (m)	Wind speed @ hub height (m/s)	Gross yield (MWh/y)	Wake loss (%)	Net yield after wake (other losses	Losses	Net Yield at WTG output (MWh/y)	FOU Steel weight (tonnes)	FOU Ballast weight (tonnes)	Mooring Cable weight (tonnes)
Sørlige Nordsjø II_	1,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	2,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	3,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	4,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	5,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	6,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	7,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	8,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	9,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	10,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	11,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	12,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	13,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	14,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	15,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	16,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	17,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	18,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	19,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	20,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	21,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	22,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	23,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	24,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-
Sørlige Nordsjø II_	25,00	-53,00	10,80	110.000,00				99.874,00	3.435,44	-	-

4.1.8 Foundation Weights

"Foundation Weights" sheet includes coefficients that are required for the weight calculations. The model selects the coefficients based on technological selections presented in Section 4.1.6. It must be noted that these values should not be changed in order to have a robust model. This sheet uses water depth as an input to calculate the weights.

Although AFRY implemented an engineering approach to be able to define these coefficients, there are engineering limitations to these formulas:

- Monopiles: The monopile coefficients will work for every water depth however it must be noted that AFRY did not validate the engineering approach below -60 meters of water depth. Therefore, the monopile calculations will give feasible results if the water depth is between -20 meters and -60 meters.
- Jackets: The jacket coefficients will work for every water depth however it must be noted that AFRY did not validate the engineering approach below -100 meters of water depth. Therefore, the jacket calculations will give feasible results if the water depth is between -40 meters and -100 meters.
- Floating substructures: The floating substructures coefficients will work for every water depth below -90 meters.
- Mooring lines: The mooring line coefficients will work for every water depth below -90 meters. It is assumed that the floaters are connected with 3 mooring lines and the materials used is studless chain.

Please refer to Annex A for the coefficients.

4.1.9 Production

"Production" sheet includes coefficients that are required for the production calculations if detailed energy yield assessment is missing for a scenario. AFRY used PyWake software to be able to determine the high-level production values. Orsted's TurboPark wake model is implemented. To be able to achieve to the net P50 production values, AFRY used a generic 10,4% loss which includes losses due to availability, electrical losses, icing and degradation losses.

Please refer to Annex B for the coefficients.

4.1.10 Cost Database

As detailed in Section 2, AFRY created a comprehensive cost database for the Client. The cost database includes actual numbers that AFRY supported. Since the project specific numbers corresponds to different FID dates, AFRY introduced indexation (EU zone CPI). Therefore the values in the cost database are real 2024 numbers.

The cost database presents the cost parameters for an offshore wind project that will start operation in 2030. This means that the FID of these projects will be 2027-2028. Taking into account that the Client will use the database and the LCoE model for future areas, this representation is feasible.

The below table presents the technological solutions and assumptions made to be able to achieve the cost estimates.

Table 6. Technological solutions and assumptions for the cost database

Main Component	Technological breakdown	Assumptions
Wind Turbines (WTG)	15 MW, 18 MW, 20 MW, 22 MW, 25 MW	The database introduces two different values for supply and transport&installation of WTGs. If the WTg has a capacity higher than 18 MW, the cost estimate changes.
Foundations	Monopiles, Jackets, Semi submersible, Spar Buoy	The database introduces different cost assumptions based on the foundation type.
IAC	66 kv, 132 kV	The database introduces different cost assumptions based on the voltage level.
HVAC		It is assumed that the export cable voltage level is 220 kV. Thus the maximum power that the export cable can transmit is assumed to be limited to 350 MW. The OSS includes transformers, busbar system and auxiliary equipment. It is assumed that there will be one platform. The onshore land station includes power transformers, busbar system, shunt reactors and bays.
HVDC		It is assumed that the export cable voltage level is 525 kV. The OSS includes HVDC and HVAC electrical equipment as well as auxiliary equipment. The onshore land station includes HVDC switchgear, converter, transformer and HVAC incomer feeders.
Direct connection to onshore		It is assumed that the power will be transmitted directly with inter-array cables. It is assumed that the maximum capacity for 66 kV IAC is 120 MW and 200 MW for 132 kV cables. The onshore land station includes power transformers, busbar system, shunt reactors and bays.

4.1.11 LCoE Trends

"LCoE Trends" sheet includes coefficients that are required to estimate the LCoE values for different final investment decision dates. The details of these values are presented in Section 3.2.4.

Figure 7. "LCoE Trends" sheet look & feel

LCoE Trends

FID Year	Trend Multiplier - Fixed	Trend Multiplier - Floating
2030	1,00	1,00
2032	0,97	0,93
2034	0,91	0,71
2036	0,87	0,64
2038	0,85	0,62
2040	0,83	0,57
2042	0,82	0,54
2044	0,78	0,50
2046	0,77	0,48
2048	0,77	0,48
2050	0,76	0,47

4.1.12 Calculations =>

"Calculations =>" sheet is simply a separator.

4.1.13 Cost Estimates

"Cost estimates" sheet calculates the costs of different components based on the inputs. For the sake of robustness, the content of this sheet should not be changed.

As requested by the Client, the model calculates the costs for different grid connection types, i.e. HVAC, HVDC and direct connection. The model selects the cheaper solution.

Figure 8. "Cost Estimates" sheet look & feel

Scenario Information		
Scenario ID		1
Site Name		Sørlige Nordsjø II
Layout Name		A
Scenario Name		Sørlige Nordsjø II_A
Description		Sørlige Nordsjø II
CAPEX		
Offshore Wind Farm (OWF)		
Wind Turbine Generators (WTG)		
WTG Total CAPEX	**kEUR**	**1.996.666,67**
Interarray Cables (IAC)		
IAC Total CAPEX	**kEUR**	**278.240,00**
Foundations (FOU)		
FOU Total CAPEX	**kEUR**	**987.235,26**
DEVEX		
Total DEVEX	**kEUR**	**163.107,10**
OWF - Total CAPEX	kEUR	3.425.249,02
OWF - CAPEX Contingency	kEUR	342.524,90
OWF - Total CAPEX inc contingency	**kEUR**	**3.767.773,93**
Grid Connection System (GCS)		
Grid Connection Type		HVDC
GCS - DEVEX	kEUR	234.120,00
GCS - Total CAPEX	kEUR	2.410.620,00
GCS - CAPEX Contingency	kEUR	241.062,00
GCS - Total CAPEX inc contingency	**kEUR**	**2.651.682,00**
Total project investment	**kEUR**	**6.419.455,93**
Total project investment incl bank fees	**kEUR**	**6.419.455,93**
Total incl bank fees&DSRA&MRA	**kEUR**	**6.419.455,93**
OPEX		
Offshore Wind Farm (OWF)		
OWF - Total OPEX	kEUR	71.248,38
OWF - OPEX Contingency	kEUR	7.124,84
OWF - Total OPEX inc contingency	**kEUR**	78.373,21
Grid Connection System (GCS)		
GCS - Total OPEX	kEUR	31.820,18
GCS - OPEX Contingency	kEUR	3.182,02
GCS - Total OPEX inc contingency	**kEUR**	35.002,20
DECEX		
Total DECEX	**kEUR**	**163.153,72**

4.1.14 WTG commissioning

The offshore wind farm will start to produce power when the first wind turbine is commissioned. This means that there will be production between the first WTG commissioning date and the commercial operation date. "WTG commissioning" sheet calculates the production between these two dates. These production rates are then transferred to the "LCoE" sheet. For the sake of robustness, the content of this sheet should not be changed.

Figure 9. "WTG commissioning" sheet look & feel

	start date of period:	1-1-2032	1-7-2032	1-1-2033	1-7-2033	1-1-2034	1-7-2034
	year:	S2 2032	S1 2032	S2 2033	S1 2033	S2 2034	S1 2034
Windfarm online							
	1-1-2034	-	-	40,78%	97,84%	100,00%	100,00%

		date	1-1-2032	1-2-2032	1-3-2032	1-4-2032	1-5-2032	1-6-2032
			31-1-2032	29-2-2032	31-3-2032	30-4-2032	31-5-2032	30-6-2032
		month #	1	2	3	4	5	6
	Windfarm online							
		1-9-2033	-	-	-	-	-	-
1	WTG #							
1	1	1-1-2033	-	-	-	-	-	-
2	2	4-1-2033	-	-	-	-	-	-
3	3	7-1-2033	-	-	-	-	-	-
4	4	10-1-2033	-	-	-	-	-	-
5	5	13-1-2033	-	-	-	-	-	-
6	6	16-1-2033	-	-	-	-	-	-
7	7	19-1-2033	-	-	-	-	-	-
8	8	22-1-2033	-	-	-	-	-	-
9	9	25-1-2033	-	-	-	-	-	-
10	10	28-1-2033	-	-	-	-	-	-
11	11	31-1-2033	-	-	-	-	-	-
12	12	3-2-2033	-	-	-	-	-	-

4.1.15 LCoE

"LCoE" sheet is the main calculation sheet in which the LCoE values and cash flows are calculated.

This sheet provides the calculation on a semi-annual basis as debt typically follows that pattern.

Figure 10. "LCoE" sheet look & feel

		start date of period:	1-1-2032	1-7-2032	1-1-2033
		year:	S1 2032	S2 2032	S1 2033
Flags					
Indexation & Hurdle Rate Multipliers					
Production	unit				
Profit & Loss	unit				
Debt Structuring	unit				
Cashflow watervall	unit				
Dividends	unit				
Shareholder capital	unit				
IRRs	unit				
LCoE					
Energy yield	*MWh*	76.754.592,06	-	-	1.160.514,25
OWF CAPEX	*kEUR*	3.340.872,98	3.767.773,93	-	-
GCS CAPEX	*kEUR*	2.616.166,91	2.950.464,00	-	-
OWF OPEX	*kEUR*	1.081.095,07	-	-	-12.713,98
GCS OPEX	*kEUR*	537.230,29	-	-	-6.317,98
LCoE OWF	*EUR/MWh*	57,61			
LCoE GCS	*EUR/MWh*	41,08			

4.1.16 Outputs =>

"Outputs =>" sheet is simply a separator.

4.1.17 Output - Costs

"Output - Costs" sheet a dashboard sheet in where the user can review the results for the selected scenario.

In order to be able to achieve results, the user have to select a scenario at cell C5. Without this selection, the model will not work. This sheet also presents LCoE trends for a selected scenario.

Figure 11. "Output - Costs" sheet look & feel

Scenario Name: Sørlige Nordsjø II_A

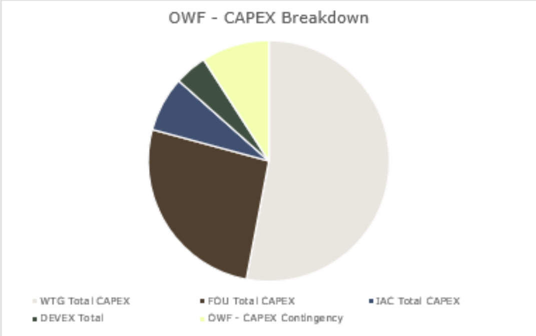
Site Info		
Area		
Number of WTGs		
Rated Power per WTG	MW	
Total Capacity	MW	
Wind Farm power Density	MW/km2	
Average Water depth	m	
Foundation Family		
Foundation Type		
Grid Type		
Distance to Main Port	km	
Distance to O&M Port	km	

CAPEX		
Offshore Wind Farm (OWF)		
Wind Turbines (WTG)		
WTG Supply	kEUR	
WTG T&I	kEUR	
WTG Total CAPEX	kEUR	
Foundations (FOU)		
FOU Supply	kEUR	
FOU fixed	kEUR	
FOU Other	kEUR	
FOU T&I	kEUR	
FOU Mooring Line Supply	kEUR	
FOU Mooring Line T&I	kEUR	
FOU Ballast supply	kEUR	
FOU Total CAPEX	kEUR	
Inter-array Cables (IAC)		
IAC supply costs	kEUR	
IAC crossing costs	kEUR	
IAC installation costs	kEUR	
IAC Fixed	kEUR	
IAC Total CAPEX	kEUR	
DEVEX		
DEVEX Total	kEUR	
OWF - Total CAPEX	kEUR	
OWF - CAPEX Contingency	kEUR	
OWF - Total CAPEX inc contingency	kEUR	
Grid Connection System (GCS)		
OSS CAPEX	kEUR	
Landstation	kEUR	
EXC Supply	kEUR	
EXC T&I	kEUR	
Onshore cable CAPEX	kEUR	
GCS - DEVEX	kEUR	
GCS - Total CAPEX	kEUR	
GCS - CAPEX Contingency	kEUR	
GCS - Total CAPEX inc contingency	kEUR	
Total project investment	kEUR	

OPEX		
Offshore Wind Farm (OWF)		
Vessel costs	kEUR/year	
Staffing	kEUR/year	
Maintenance	kEUR/year	
Service base & Parts	kEUR/year	
Insurance	kEUR/year	
Operator Margin	kEUR/year	
OPEX - OWF Total	kEUR/year	
OPEX - OWF Contingency	kEUR/year	
OWF - Total OPEX inc contingency	kEUR/year	
Grid Connection System (GCS)		
OPEX - GCS Total	kEUR/year	
OPEX - GCS Contingency	kEUR/year	
GCS - Total OPEX inc contingency	kEUR/year	
Total OPEX	kEUR/year	

LCoE		
LCoE - OWF	EUR/MWh	
LCoE - GCS	EUR/MWh	
LCoE - Total	EUR/MWh	

Financials		
Start date model		
Start WTG commissioning		
COD		
Life-time wind-farm	year	
Required return on equity	%	
Equity share in project	%	
WACC	%	
Equity IRR	%	
Project IRR	%	



LCoE Trend		
LCoE - OWF		
2030	EUR/MWh	79,52
2032	EUR/MWh	77,06
2034	EUR/MWh	72,74
2036	EUR/MWh	69,04
2038	EUR/MWh	67,81
2040	EUR/MWh	65,96
2042	EUR/MWh	65,34
2044	EUR/MWh	62,26
2046	EUR/MWh	61,23
2048	EUR/MWh	61,23
2050	EUR/MWh	60,44
LCoE - OWF + GCS		
2030	EUR/MWh	132,05
2032	EUR/MWh	130,42
2034	EUR/MWh	127,57
2036	EUR/MWh	125,13
2038	EUR/MWh	124,31
2040	EUR/MWh	123,09
2042	EUR/MWh	122,69
2044	EUR/MWh	120,65
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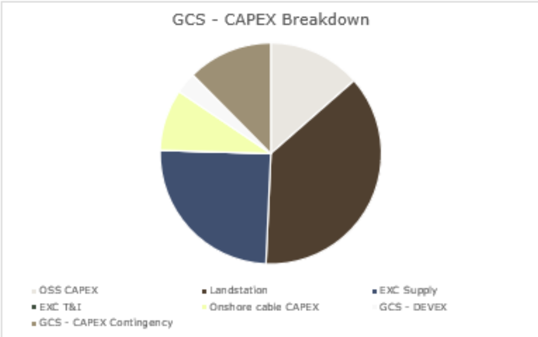

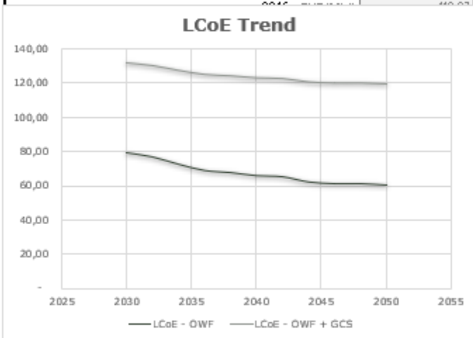

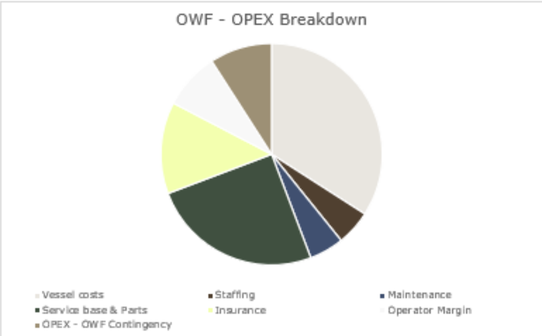

5 Conclusions

In general, the developed Cost Database and LCoE model successfully achieved the target of benchmarking the most up-to-date prices and integrating tools for estimating cost items at NVE project sites. This document provides a thorough analysis of the data collection & processing of cost database and modelling of Levelized Cost of Energy (LCoE).

Section 2 demonstrates that the benchmarking was conducted using the latest available data from projects that have achieved FID, expert inputs, and commercial offers. The averaging of results in the database utilized multiple sources of information, standardizing the data to a common level for use in the LCoE tool.

Section 3 explains the cost modelling process, which involves using the database outputs to develop a flexible model capable of calculating costs for any potential site envisioned by the Norwegian government. This model incorporates several market and engineering trends to accurately calculate crucial parameters for OWFs and GCS costs. It has been calibrated against raw data from AFRY's comprehensive offshore database over the years, yielding accurate results.

Moreover, the model introduces LCoE trends for the offshore wind farm market up to the year 2050, enabling benchmarking for upcoming years and different tenders. The model also allows users to input different levels of detail in the gathered data, such as detailed energy yield assessments or water depth for the calculation of the weight of the foundations.

As presented with the test case, the model successfully breaks down the cost of the Sørlige Nordsjø II site, allowing for future comparisons with potential bids.

6 Potential improvements

The potential improvements of the tool can be divided into two main areas:

Data Acquisition: Acquiring more data to average for the cost database will help fill gaps due to the limited amount of data currently available for components such as floating foundations. This will also allow for better benchmarking of the trendlines used to estimate costs in the model, such as those based on the weight parameter.

Site-Specific Considerations: Conducting a more in-depth analysis of specific site conditions and turbines can enhance the accuracy of the LCoE and its component values. This would involve a detailed study of each site, making the results more accurate and comparable with projects outside Norway. Understanding these comparisons may provide insights into the bidding behavior of potential developers.

ÅF and Pöyry have come together as AFRY. We don’t care much about making history.

We care about making future.

AFRY Netherlands
2e Daalsedijk 6A,
3551 EJ Utrecht, Netherlands

Tel: [Telephone]
afry.com
E-mail: [Email]