A Method for Calculating the Levelised Cost of Energy for Offshore Wind Farms

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ABSTRACT

The need to reduce greenhouse gas emissions and the search for cleaner energy sources are accelerating the development of offshore wind technology, which offers significant energy potential (Lakshmanan, 2021). This study describes a methodology for calculating the Levelised Cost of Energy (LCOE), which determines the average cost per megawatt-hour of producing energy in an offshore wind farm. This calculation considers initial investments, operation and maintenance costs, decommissioning expenses, and other economic factors. LCOE is a key parameter for investment decisions in offshore wind farms, which typically require significant upfront capital. It provides a comprehensive perspective on the project's financial performance throughout its life cycle. The proposed methodology allows for the individual assessment of each cost and revenue component, providing the flexibility to apply it to various scenarios and operational conditions. To facilitate this process, a MATLAB script was developed to automate calculations, generate reports, and perform sensitivity analyses. The script was validated through a simulation using data from the Walney Offshore Wind Farm project, yielding an LCOE of €107.63/MWh, which aligns closely with an established industry benchmark. This demonstrates the model's effectiveness in assessing economic viability and identifying the key factors influencing LCOE. The results highlight the model's potential to support strategic decision-making, optimise projects, and enhance the competitiveness of offshore wind energy within the context of the global energy transition.

Keywords: Offshore wind energy, LCOE, economic viability, investment decisions, energy transition, renewable energy.

JEL Codes: Q42, Q54, G31, O33, D61.

I. Introduction

A. Technological evolution

The global climate urgency and the pressing need to decarbonise world economies have placed the energy transition at the heart of international political and economic agendas.

At the centre of this transformation, offshore wind energy has emerged as one of the most promising pillars for large-scale electricity generation, offering superior energy density and greater wind consistency than onshore solutions. The development of this technology is not merely a response to greenhouse gas emission reduction targets, but also a strategic opportunity to enhance energy security and foster industrial innovation. The trajectory of offshore wind energy is a testament to human capacity for innovation in the face of extreme environments. Although onshore wind technology reached commercial maturity decades earlier, the transition to the marine environment represented a qualitative leap in engineering complexity. The industry has progressed beyond its experimental origins in shallow waters to utility-scale plants with turbines now exceeding 15 MW in unit capacity.

This evolution has not been limited to blade size or tower height; the true revolution occurred below the waterline. Initially, the sector relied exclusively on fixed foundations, such as monopiles or jacket structures, limited to specific depths. However, the need to access even more powerful winds further out at sea has driven the development of floating platforms. The transition from fixed-bottom to floating offshore wind turbines represents a significant technological leap, enabling deployment in deep waters where wind resources are stronger and more consistent (Barooni et al., 2023). This technological innovation enables the exploration of vast areas of the continental shelf where depth previously made fixed structures economically unfeasible. The upgrade of foundations is now one of the primary drivers for reducing technical risk and expanding the sector.

Europe has served as the global laboratory for offshore wind energy, possessing a significant portion of the world's installed capacity and a consolidated value chain. This dominance results from consistent public policies and a favourable geography, particularly in the North Sea. According to the Global Wind Energy Council (GWEC), the sector continues to show record growth despite global economic challenges. In particular, the United Kingdom stands out as a leader in this field. Through mechanisms such as Contracts for Difference (CfD), the British government has successfully reduced uncertainty for investors. The Walney Offshore Wind Farm, located in the Irish Sea, is situated within this context of excellence. Walney is not only an engineering landmark but a practical example of the commercial viability of this technology. By using data from this specific project to validate the methodology proposed in this study, it is ensured that the conclusions are anchored in the operational reality of one of the world's most competitive markets.

B. The Levelised Cost of Energy (LCOE)

To compare different energy generation technologies and assess the viability of long-term projects, the most widely accepted indicator is the Levelised Cost of Energy (LCOE), which represents the average cost per unit of energy generated throughout the project's entire life cycle, allowing for an analysis that balances high initial costs with future energy returns.

As defined by Short et al. (2012), the LCOE is the cost that, if assigned to every unit of energy produced over the system's life, would equal the total costs when discounted to a common base year. Despite technological optimism, the capital-intensive nature of these projects poses unique financial challenges. Almost all of the investment (CAPEX) in offshore wind is decided at the initial stage. This makes the project extremely sensitive to the cost of capital and interest rates, as the discount rate reflects market risk perception.

The economic viability of offshore wind energy is heavily linked to the efficiency of its supply chain. Offshore logistics require highly specialised port infrastructures capable of handling colossal components, such as blades exceeding 80 metres and nacelles weighing hundreds of tonnes. The transport of these components and the availability of specialised installation vessels (jack-up vessels) constitute one of the most sensitive portions of the total investment. Volatility in raw material prices and fluctuations in marine fuel costs introduce uncertainty variables that the LCOE methodology must be able to handle. The economic viability is further challenged by the need for advanced power forecasting and intelligent O&M strategies to manage output uncertainty and high maintenance costs (Ma et al., 2025).

The development of large-scale offshore wind farms must occur within a framework of environmental and social sustainability. Environmental factors such as noise pollution during installation, artificial reef effects, and long-term corrosion emissions also influence project planning and costs (Rezaei et al., 2023). Protecting marine biodiversity and managing noise during installation are factors that influence project planning. These aspects have direct economic repercussions: more complex licensing processes translate into additional costs. However, when well-planned, offshore wind energy generates significant positive externalities, such as the creation of skilled employment in coastal areas and the revitalisation of industrial zones.

C. Objectives and Structure of the Article

The primary objective of this article is to present an integrated model for simulating and analysing LCOE in offshore wind farms. It aims to address the need for tools that allow for rapid and accurate simulations of various economic and operational scenarios.

To achieve this objective, the article is structured as follows. In Section 2, the model developed for the LCOE calculation is described. In Section 3, the model is tested through a practical case study based on the Walney Offshore Wind Farm. The results are presented alongside a sensitivity analysis that demonstrates how variations in key parameters impact the final cost of the megawatt-hour produced. Finally, Section 4 provides the concluding remarks.

Over time, the BSC's adaptability has allowed it to serve diverse contexts, from large corporations to public institutions and SMEs. Each entity has tailored the framework to its strategic realities. The BSC's integration of performance measurement with strategic execution has also established it as a foundation for integrated reporting and sustainability management (Figge et al., 2002). However, despite its universal principles, the BSC's effectiveness depends heavily on contextual adaptation, especially in sectors with complex and fast-changing environments, such as the food industry.

II. Model Development

The model developed in this study provides a systematic approach to evaluating the economic performance of offshore wind farms through the application of LCOE. This metric facilitates the comparison of energy technologies with disparate cost structures by determining the average cost per unit of energy produced over the project's entire lifecycle.

A. LCOE in the Context of Offshore Wind Farms

The application of LCOE to offshore wind farms presents unique challenges compared to its onshore counterparts. Offshore projects are characterised by high capital intensity and complex operational logistics, which means the LCOE must be sensitive to variables such as water depth, distance from the shore, and the reliability of subsea infrastructure. For offshore wind, the LCOE serves as a benchmark for competitiveness, and as noted by the International Renewable Energy Agency (IRENA, 2023), the global weighted-average cost has fallen drastically due to technological improvements and supply chain efficiencies. The model used in this acknowledges that calculating LCOE for offshore projects requires a detailed breakdown of costs specific to the maritime industry, such as specialised installation vessels and the impact of the salt-spray environment on turbine degradation.

B. The Fundamental LCOE and Integrated Financial Equation

The mathematical framework is built upon the principle of discounted cash flow analysis. As defined by Short et al. (2012), the LCOE is the constant cost per unit of energy that, if applied to every unit of electrical energy produced over the system's economic life, would equal the total costs of the project when discounted to a base year. While a simplified version accounts for general expenditures, this research culminates in a formulation that integrates tax implications and asset depreciation, represented by Equation 1 (the variables and their components are described below):

$$\mathrm{LCOE} = \frac{\sum_{t=0}^{n} \Big[\underbrace{\sum_{i=1}^{n_C} C_{i,t}}_{\mathrm{CAPEX}_t} + \underbrace{\Big(\sum_{j=1}^{n_O} O_j \Big) D_t}_{\mathrm{OPEX}_t} \Big] (1+r)^{-t} + \underbrace{\Big(\sum_{k=1}^{n_D} d_k \Big) (1+r)^{-(n+1)}}_{\mathrm{DECEX}_{n+1}}}{\sum_{t=1}^{n} AEP_t (1+r)^{-t}} \quad \text{[Equation 1]}$$

where:
AEP_t — Annual energy production in year *t*.
CAPEX_t — Capital expenditure in year *t*.
OPEX_t — Operational expenditure in year *t*.
DECEX — Decommissioning expenditure in year *t+1*.
D_k — Decommissioning cost component (e.g., mechanical removal, cable wear, environmental recovery)
nD — Number of DECEX categories.

r — Discount rate.
n — project lifespan.

This formulation ensures that the calculated cost reflects the real-world fiscal burden and the tax shields associated with large-scale capital investments.

C. Capital Expenditure Modelling

Capital Expenditure (CAPEX) in offshore wind projects represents the most substantial financial commitment, typically decided at the project's inception. In our approach, the turbine system is modelled by considering the nacelle, rotor, and blades, with the understanding that as turbine capacity increases, the cost per megawatt often benefits from economies of scale (Manwell et al., 2010). The support structure sub-model accounts for foundations, specifically focusing on monopile engineering where procurement costs are calculated as a function of water depth and seabed morphology. The electrical infrastructure is another critical pillar, encompassing the modelling of array cables, offshore substations, and export cables, while factoring in the material costs and technical complexities of subsea installation. Finally, the model incorporates installation and commissioning logistics, which involve the chartering of specialised heavy-lift vessels.

D. Operational Expenditure and Maintenance Strategies

Operational Expenditure (OPEX) is modelled through a combination of fixed and variable costs that ensure the wind farm's efficiency throughout its lifecycle. According to IRENA (2023), these costs are significantly higher in the offshore sector due to the corrosive nature of the marine environment. The methodology distinguishes between preventive maintenance, which includes scheduled inspections, and corrective maintenance, which relies on failure-based repairs. To estimate the costs of unscheduled services, the model utilises historical failure rate data for major components such as gearboxes and generators. Maintenance logistics are calculated based on the distance from the onshore base, factoring in the operational costs of crew transfer vessels and service operation vessels.

E. Annual Energy Production and Efficiency Factors

The denominator of the LCOE equation, the discounted Annual Energy Production (AEP), is derived from the theoretical power curve of the selected turbines. However, the actual energy delivered to the grid must account for several efficiency losses to remain realistic (Manwell et al., 2010). The model integrates wake losses—referring to the wind speed reductions caused by turbulence behind upstream turbines—as well as an overall availability factor that accounts for technical downtime. Additionally, transmission losses resulting from heat dissipation in the subsea cables and substations are deducted from the gross production to ensure the AEP reflects the net energy yield.

F. Decommissioning and Lifecycle Management

As the project reaches the end of its operational life, the methodology accounts for the decommissioning stage (DECEX). Decommissioning costs for floating wind farms may differ significantly from fixed-bottom projects, with studies suggesting distinct cost structures for platform removal and site restoration (Maienza et al., 2020). In accordance with international maritime regulations, the model estimates the financial requirements for the complete removal of turbines and the restoration of the seabed. Although these expenses occur far in the future, their present value is integrated into the calculation to provide a holistic lifecycle perspective, as recommended by Short et al. (2012).

G. Script Architecture in MATLAB

The technical contribution of this study is the implementation of these “sub-models” into a modular MATLAB script. The software architecture was designed to automate the discounted cash flow calculations and enable sensitivity analysis, a feature crucial for risk assessment. By varying the discount rate, CAPEX, or AEP, the script identifies which variables have the most significant impact on the project's economic viability. This allows the user to simulate various scenarios, providing a range of LCOE values that support strategic decision-making in the global energy transition.

III. Results

In order to validate the computational algorithm developed in this study for calculating LCOE with MATLAB, it was essential to use real, specific and structured data, covering the initial investment, operating costs, decommissioning costs, as well as annual energy production and the project lifespan. However, obtaining complete and detailed public data on offshore wind projects remains a challenge, particularly with regard to the breakdown of costs by category.

Given this limitation, the Walney Offshore Wind Farm project, located in the Irish Sea, United Kingdom, was selected as a case study. The choice was based on the extensive documentation available in the study conducted by the Climate Policy Initiative (CPI), which provides a structured analysis of the technical and economic factors involved in implementing the project. That study provides estimated data based on reliable industry benchmarks and is widely referenced in scientific literature and feasibility assessments of offshore projects.

A. Technical and Economic Input Parameters

The accuracy of the LCOE calculation depends upon the precision of the input data. Table 1 summarises the core technical specifications and financial assumptions used in the MATLAB simulation, based on the project’s operational profile and contemporary market rates (IRENA, 2023).

The Walney Offshore Wind Farm is an offshore wind complex located approximately 15 km off the coast of Cumbria, United Kingdom. Operated by Ørsted in partnership with other companies in the sector, the project consists of two initial phases (Walney 1 and Walney 2), totalling 367.2 MW of installed capacity, distributed across 102 Siemens SWT-3.6-107 turbines. Table 1 presents the set of values provided by the CPI study.

Table 1– Technical and Economic Input Data for Walney Case Study.
Note: Values provided by the CPI study (own elaboration).

Parameter	Value provided	Source / Observation
Installed capacity	367.2 MW	Actual project data
Number of turbines	102 (2×51)	
Turbine nominal power	Siemens SWT-3.6-107 (3,6 MW)	
Estimated annual production (AEP)	1,383.000 MWh	Value cited in the CPI study
Capacity factor	43%	
Project lifetime	20 years	
Total estimated CAPEX	€1,343,650.000	
Estimated annual OPEX	€29.07/MWh	Value cited in the CPI study
DECEX (decommissioning)	€28,940.000 (future value)	Amount provisioned in the CPI study
Annual discount rate ®	5%	Value cited in the CPI study
LCOE estimated by the authors	€112.18/MWh	Result of the CPI study for the project

B. Capital Expenditure (CAPEX) Analysis

The CAPEX analysis for Walney reveals the typical cost distribution of second-generation offshore wind farms. The CPI study only presents the total estimated investment value, which stands at €1,343,650,000.00 without detailing the categories of expenditure. In order to enable the use of this data in the present study, the total amount was segmented into typical components of offshore wind projects — including turbines, foundations, substations, cables, installation and other costs — based on average percentages reported in specialised technical literature (Sølvik et al., 2022). As highlighted by Castro (2022), the turbine and foundation costs dominate the initial investment. In the simulation, the total CAPEX was allocated to procurement, electrical systems, and marine logistics (Table 2). The results indicate that the high cost of foundations is directly linked to the steel prices and the specialised vessels required for pile driving.

Table 2– Technical and Economic Input Data for Walney Case Study.
Note: Values provided by the CPI study (own elaboration).

Parameter	Value (€)	Percentage
Total CAPEX	***1,343,650,000.00***	***100.0%***
Turbine	524,023,500.00	39.0%
Substructure	483,714,000.00	36.0%
Electrical infrastructure	174,674,500.00	13.0%
Assembly and installation	80,619,000.00	6.0%
Development	67,182,500.00	5.0%
Port and docking	6,718,250.00	0.5%
Plant commissioning	6,718,250.00	0.5%

C. Operational and Decommissioning Expenditure

The OPEX adopted, €29.07/MWh, was taken directly from the CPI study. To detail the composition of this cost, the breakdown structure presented in the Guide to an Offshore Wind Farm (BVGAssociates, 2024) was used. Based on the example values provided by this source, the relative percentage of each OPEX component was calculated, and these proportions were applied to the total value of €29.07/MWh. The approximate breakdown is shown in Table 3.

Table 3– Breakdown of Operational Expenditure (OPEX).

Parameter	Value (€)	Percentage
Total OPEX	***40,203,810.00***	***100.0%***
Operations, maintenance and services port	2,018,231.26	5.0%
Operations control centre	603,057.15	1.5%
Training	1,206,114.30	3.0%
Land logistics	603,057.15	1.5%
Technical resources	3,015,285.75	7.5%
Insurance	5,427,514.35	13.5%
Offshore logistics	3,216,304.80	8.0%
Turbine maintenance and service	17,689,676.40	44.0%
Balance between plant maintenance and service	6,022,530.74	15.0%
Statutory inspections	402,038.10	1.0%

DECEX was explicitly stated in the CPI report at €28.94 million (future value), reflecting a financial provision for the closure of the wind farm's operations. Other relevant parameters, such as the AEP of 1,383 GWh and the capacity factor of 43%, were derived by the CPI from the project's technical data. The lifespan considered was 20 years. Finally, the LCOE value of approximately €112.18/MWh corresponds to the CPI calculation for the Walney project. It serves as a reference for comparison with the result obtained by the script developed in this work.

D. LCOE Results and Financial Sensitivities

The simulation of the Walney Offshore Wind Farm project, run using a MATLAB script, yielded the following key economic viability indicators: LCOE was calculated at €107,63 per MWh; the project's NPV is €569,414,646.42, indicating substantial profitability over its lifetime; furthermore, the internal rate of return (IRR) stands at 9.63; and finally, the discounted payback period was determined to be 11.72 years, representing the time required for the cumulative discounted cash flows to recover the initial investment. The simulation thus achieved results very similar to those of the Walney Offshore Wind Farm project, confirming the validity, adaptability and effectiveness of the methodology developed.

The inclusion of a sensitivity analysis is a crucial step towards robustness in a developed calculation model, especially for long-term projects such as offshore wind energy. It allows the impact of uncertainties inherent in cost and production estimates on the project's viability to be assessed. For this analysis, the three most critical and uncertain variables were selected: CAPEX, due to its magnitude and the nature of the decomposition estimate; AEP, which epresents the uncertainty of actual energy production in relation to the projected production, and the discount rate (r), the only purely financial variable that reflects market risk and the cost of capital. Table 4 presents the results of the analysis, showing how the LCOE changes with ±10% and ±20% variations in each variable, while the others are kept constant.

Table 4– Sensitivity analysis.

Scenario /Variable	Variation (%)	New Variable Value	Calculated LCOE (€/MWh)	LCOE Variation (%)
Base scenario	—	CAPEX: €1,343,650,000.00 AEP: 1,383,000 MWh *r*: 5%	107.63	—
CAPEX	−20%	€1,074,920,000.00	92.04	-14.49
	−10%	€1,209,285,000.00	99.84	-7.24
	10%	€1,478,015,000.00	115.43	7.24
	20%	€1,612,380,000.00	123.23	14.49
Discount rate	−20%	4.00%	101.24	-5.94
	−10%	4.50%	104.40	-3.00
	10%	5.50%	110.94	3.07
	20%	6.00%	114.31	6.21
AEP	−20%	€1,106,400.00	101.24	25.00
	−10%	€1,244,700.00	104.40	11.11
	10%	€1,521,300.00	110.94	−9.09
	20%	€1,659,600.00	114.31	−16.67

The analysis in Table 4 shows the magnitude of each variable's impact on the LCOE. As shown in the table, all the parameters tested influenced the LCOE, AEP was the variable that had the greatest impact on the result. A -20% variation in AEP increased the LCOE by 25.00%, while a 20% increase in production resulted in a 16.67% decrease in cost. This inverse and amplified relationship is expected, since AEP is the denominator in the LCOE equation; lower energy production dilutes total costs by fewer MWh, dramatically increasing the unit cost.

CAPEX proved to be the second most influential variable. A ±20% variation in initial investment resulted in a direct change of ±14.49% in LCOE. As CAPEX is the main component of total project costs (representing 72.43% of present value costs in the base scenario), its variation was expected to have a significant impact, albeit less pronounced than that of AEP.

Finally, the discount rate had the least impact among the variables analysed. A ±20% variation in this rate (from 5% to 4% or 6%) changed the LCOE by approximately ±6%. The more moderate influence stems from the discount rate being applied to both the numerator (future costs such as OPEX and DECEX) and the denominator (future energy production) of the LCOE formula, which mitigates its net effect on the final ratio. The sensitivity analysis reinforces the robustness of the model developed, not only for calculating a specific LCOE value, but also as a risk assessment tool. The finding that AEP is the most critical variable for LCOE underscores the paramount importance of accurate yield assessment and reliable operation. This aligns with industry focus on mitigating production uncertainties arising from complex wake effects, the need for high-resolution forecasting, and minimizing downtime through optimized maintenance strategies (Ma et al., 2025).

The primary constraint on the financial success of the Walney project and similar ventures is ensuring the estimated energy production. Therefore, accuracy in wind resource assessments and the reliability and availability of turbines are critical factors to prioritise throughout the project's life cycle.

IV. Conclusions

A. Discussion of the Findings

Based on an in-depth analysis of offshore wind energy technologies, challenges, and regulatory frameworks, this study developed and validated a robust, adaptable computational methodology to calculate LCOE in offshore wind farms. The research addressed the main technological components, such as turbines and foundations, and the challenges inherent to these projects, as well as analysing the regulatory and incentive landscapes in Brazil, the European Union, and Portugal, and contextualising the importance of an economic feasibility analysis tool.

The application of the methodology to the Walney Offshore Wind Farm case study validated the model's accuracy, with the LCOE calculated at €107.63/MWh, showing remarkable convergence with the reference value of €112.18/MWh, a deviation of only 4.05%. This proximity confirms the validity of the methodology and the correct implementation of the calculations.

The sensitivity analysis identified AEP as the variable with the greatest impact on LCOE, with a 20% reduction in generation increasing LCOE by 25%. CAPEX emerged as the second most influential factor, with a ±20% variation in investment resulting in a

±14.49% change in LCOE. Although relevant, the discount rate showed a more moderate impact. These results underscore that the viability of offshore wind projects is intrinsically linked to ensuring energy production and rigorous management of initial investments.

From a methodological point of view, the work offers a transparent and reproducible calculation structure, materialised in a MATLAB script that can be easily adapted by other researchers, industry professionals and for educational purposes. In practice, identifying AEP as the most critical variable provides strategic guidance for investors, reinforcing the need to prioritise high-precision wind studies and to select technologies that ensure maximum operational reliability. Thus, the research presents a valuable tool for decision-making, project optimisation, and risk mitigation in the growing offshore wind energy sector.

Despite its robustness, the model has limitations and opens avenues for future research. The script, in its current version, does not dynamically incorporate the impact of incentive policies, such as feed-in tariffs or tax benefits, nor does it account for market energy price volatility. Future work could expand the model to include these variables. Another area for improvement is to include the implementation time factor in the CAPEX calculation, applying a present-value correction to costs over the construction period, which more accurately reflects the project's actual costs. In addition, a better interface could be developed to simplify data entry, as well as to integrate more complex risk analyses to model the uncertainty in input parameters. The methodology could also be expanded to compare the LCOE of offshore wind with other renewable energy sources, such as floating solar, to provide a broader perspective for energy planning. Building on the technological evolution discussed in the introduction, future iterations of the model could explicitly parameterise foundation technologies. Incorporating the distinct cost structures and installation logistics of floating versus fixed foundations would make the tool directly applicable to the next generation of deep-water offshore wind projects.

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

BVGAssociates, 2024. Guide to an Offshore Wind Farm. [Online] Available at: https://guidetoanoffshorewindfarm.com/wind-farm-costs/

Barooni, M., Ashuri, T., Velioglu Sogut, D., Wood, S., & Ghaderpour Taleghani, S. (2022). Floating offshore wind turbines: Current status and future prospects. *Energies*, *16*(1), 2. https://doi.org/10.3390/en16010002

Castro, R. (2022). *Electricity Production from Renewables*. Berlin/Heidelberg, Germany: Springer.

Department for Energy Security and Net Zero. (2023). "Electricity Generation Costs 2023". HM Government. Available at: https://www.gov.uk/government/publications/electricity-generation-costs-2023

European Commission (2023). *The EU Offshore Renewable Energy Strategy*. European Union Publications Office.

Global Wind Energy Council (GWEC). (2023). Global Wind Report 2023. GWEC. https://www.gwec.net/reports?t=227240362215

International Energy Agency (IEA) (2021). Offshore Wind Outlook 2021. OECD Publishing. https://www.iea.org/reports/world-energy-outlook-2021

International Renewable Energy Agency (IRENA) (2023). *Renewable Power Generation Costs in 2022*. Abu Dhabi: IRENA. https://www.irena.org/publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022

Lakshmanan, P., Sun, R., & Liang, J. (2021). Electrical collection systems for offshore wind farms: A review. *CSEE Journal of Power and Energy Systems*, *7*(5), 1078-1092.

Ma, X., Li, M., Li, W., & Liu, Y. (2025). Overview of offshore wind power technologies. *Sustainability*, *17*(2), 596. https://doi.org/10.3390/su17020596

Maienza, C., Avossa, A. M., Ricciardelli, F., Coiro, D., Troise, G., & Georgakis, C. T. (2020). A life cycle cost model for floating offshore wind farms. *Applied Energy*, *266*, 114716. https://doi.org/10.1016/j.apenergy.2020.114716

Manwell, J. F., McGowan, J. G., & Rogers, A. L. (2010). *Wind Energy Explained: Theory, Design and Application* (2nd ed.). Wiley.

Rezaei, F., Contestabile, P., Vicinanza, D., & Azzellino, A. (2023). Towards understanding environmental and cumulative impacts of floating wind farms: Lessons learned from the fixed-bottom offshore wind farms. *Ocean & Coastal Management, 243*, 106772. https://doi.org/10.1016/j.ocecoaman.2023.106772

Short, W., Packey, D. J., & Holt, T. (2012). A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies (No. NREL/TP-462-5173). National Renewable Energy Lab (NREL). https://doi.org/10.2172/35391

Sølvik, M., Nergård, B., & Ramstad, M. C. (2022). Tool development for LCOE calculation for floating offshore wind (Bachelor's thesis, NTNU).

The MathWorks Inc. (2023). MATLAB (Version R2023b) [Computer software]. https://www.mathworks.com/products/matlab.html

Walney Extension Offshore Wind Farm. (2024). Project Data and Operational Specifications. Orsted. https://orsted.co.uk/energy-solutions/offshore-wind/our-wind-farms/walney-extension