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A lifecycle techno-economic model of offshore wind energy for different entry and exit instances

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HIGHLIGHTS

- A lifecycle techno-economic model of an offshore wind farm is developed.
- Analytical consideration of OPEX linking latest reliability data to ECN O&M tool.
- Sensitivity analysis specified the most sensitive parameters on the investment NPV.
- The model was applied to different investor clusters in the wind energy market.
- Insights regarding potential minimum asking and maximum offered price are derived.

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ABSTRACT

The offshore wind (OW) industry has reached reasonable maturity over the past decade and the European market currently consists of a diverse pool of investors. Often equity investors buy and sell stakes at different phases of the asset service life with a view to maximize their return on investment. A detailed assessment of the investment returns taking into account the technical parameters of the problem, is pertinent towards understanding the value of new and operational wind farms. This paper develops a high fidelity lifecycle techno-economic model, bringing together the most up-to-date data and parametric equations from databases and literature. Subsequently, based on a realistic case study of an OW farm in the UK, a sensitivity analysis is performed to test how input parameters influence the model output. Sensitivity analysis results highlight that the NPV is considerably sensitive to FinEX and revenue parameters, as well as to some OPEX parameters, i.e. the mean time to failure of the wind turbine components and the workboat significant wave height limit. Application of the model from the perspective of investors with different entry and exit timings derives the temporal return profiles, revealing important insights regarding the potential minimum asking and maximum offered price.

1. Introduction

With 92 wind farms in operation across European countries (including sites with partial grid-connected offshore wind (OW) turbines [1]), the OW market and supply chain have been rapidly expanding, attracting a diverse pool of investors that include Utilities, Original Equipment Manufacturers (OEMs), Independent Power Producers, Japanese Trading Houses, Pension Funds and Banks [2]. Broadly speaking, these investors can be segmented based on their attitude to risk (technology readiness level, track record, portfolio diversity, country, and asset phase), return expectations (Internal Rate of Return (IRR) and yield), holding length, and level of engagement [2,3].

Numerous authors have conducted research in the technical and economic feasibility of OW farms [4–9] and related innovative concepts [10,11], and the development of cost models for OW farms [12–15]. In [4], a feasibility study was performed for the development of an OW farm installed in the Northern Adriatic Sea, in order to test the suitability of the region for the development of the technology, while [9] refers to a feasibility study off the Turkish coast. Another study determining the profitability of an OW energy investment across different areas of Chile was performed in [8]. Kaiser and Snyder have developed models for the installation and decommissioning costs of offshore wind farms, based on existing data in European wind farms [13,16]. Myhr et al. developed a lifecycle cost model with the aim to predict the LCOE of a number of offshore floating wind turbine concepts and compare them with their fixed monopile counterparts [5]. One of their

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conclusion was that LCOE is particularly sensitive to the distance from shore, load factor and availability. Authors in [7] develop a methodology for the life-cycle costing of a floating OW farm and apply it to analyse a location in the North-West of Spain and indicate the best platform option. Dicorato et al. formulated a general model to evaluate the costs in pre-investment and investment stages of OW farms and then employed this method to indicate the most suitable wind farm layout [12]. A review of offshore wind cost components was performed by [17], summarising parametric expressions and data available in literature including the acquisition and installation of wind turbines and foundations, the electrical system, the predevelopment costs, etc. Shaffie et al. have also developed a parametric whole life cost model of offshore wind farms, which requires less input data in relation to other tools available [14], aiming to provide a simple framework for estimating the LCOE of the investment. Data were also trained in order to provide expressions for the estimation of the cost of materials used in a wind turbine, as well as the cost of the offshore substation. Finally, sensitivity analysis was performed in order to indicate the most impactful parameters of the model on LCOE.

Existing literature on the financial returns from renewable energy projects assumes that there is a single investor who owns the asset (e.g. the wind farm) throughout its entire service life [7,9,18,19]. However, recent research [3], as well as market reports [2,20,21] show that equity investors buy and sell their stakes at different phases of the OW farm life, depending on their investment strategy. To this end, a model that predicts returns over time could be useful for investors and policy makers to check the viability of the investment and to predict the temporal return profile of the investment. Additionally, the analytical consideration of the capital expenditure (CAPEX), operational expenditure (OPEX) and financial expenditure (FinEX) variables could contribute to the identification of input parameters that have the highest impact on the feasibility of the project.

This paper aims at addressing this challenge through developing a lifecycle techno-economic assessment framework for the prediction of lifecycle costs of OW farms, which incorporates up-to-date models for the estimation of key cost components, taking into consideration technical aspects associated with the installation and maintenance of the asset. The model developed takes into account the time that expenses occur as well as the time value of money. The high-fidelity model predicts the different costs of a typical OW farm in a lifecycle-phase-sequence pattern, by:

- adopting the most up-to-date parametric equations found in the literature;
- developing new parametric equations where latest data are available;
- including the use of industry standard ECN O&M Tool [22] for the prediction of operation and maintenance costs in conjunction with latest reliability data from [23].

Compared to existing literature related to the life-cycle cost assessment of OW farms, the novelty of this paper lies on, firstly, the consideration of different equity investors with different investment strategies that buy and sell stakes at different time instances during the life of an OW farm project and the development of a relevant tool that enables such investors to assess the viability of their investment [3]; secondly, the prediction of the maintenance cost of the OW farm by linking the latest reliability data published in literature to the industry standard ECN O&M tool, which can account for site specific details (such as the wind profile of the location which affects the available weather window for maintenance interventions); and, finally the derivation of cumulative cost and revenue curves which can reflect the temporal value of the asset, providing a decision support framework to investors and, deriving insights on expected upper and lower bounds for the OW farm price setting.

Although the focus of this study is placed on Europe and especially the UK, a country with significant technical resource [24], as well as a mature market with significant secondary sales activity, the proposed methodology can be applied to other country contexts (such as Japan, Korea and China which are regarded as significant emerging players in the OW market), provided the corresponding policy regime and cost adjustments (personnel cost, material costs, etc.) are taken into consideration. It, thus, needs to be highlighted that results should be treated with caution as input data have been adopted from wind farms mainly installed in North Europe, while no data currently exist for the USA or Asian offshore wind farms. Furthermore, for regions of Asia and the USA (where the frequency of hurricanes and typhoons is much higher than in Europe), existing design standards should also be potentially adjusted to ensure that extreme weather phenomena are properly accounted for.

2. Methodological approach

2.1. Investor profiles in the European offshore wind market

Within the existing market, there is a variety of investors with different investment strategies and appetite for risk. OW power plants are subject to a number of uncertainties of both technical and financial nature [25], which can be encountered across the whole life of the asset by means of variability in the energy performance, capital costs, operational costs, and economics of the LCOE model [26]. As such, during the predevelopment phase, investor faces uncertainties associated with the legal, environmental survey and project management costs, among others. During the procurement phase, there is uncertainty in the prediction of the cost of materials of the different components of the wind farm, while during construction, variability in the cost of labour, availability and cost of installation vessels, weather conditions, along with the duration of the installation operations induce additional risk in the evaluation of the investment. Damages to the wind turbines during the operation and maintenance phase result in uncertain repair costs and loss of revenues due to downtime. Finally, variability in the cost of capital can have a significant effect on the LCOE. Acknowledging above uncertainties within the OW energy sector [27], it becomes pertinent to identify means to systematically assess uncertainty with respect to service life valuation, hence supporting decisions of investors [28]. Each investor develops their bespoke assessment and valuation framework projecting revenues and costs, in order to decide effectively their potential entry and exit strategies.

An analysis [3] of investor strategies, based on data from existing OW farms in the UK indicated the existence of three distinct profiles: (i) Pre-commissioning investors, (ii) Build-Operate-Transfer investors, and (iii) Late entry investors.

Late entry investors comprise third party capital investors, who are investors seeking to contribute equity capital without having an involvement on the core activities of the asset, such as corporate investors, infrastructure funds and institutional investors. They undertake exclusively operational risks, entering after the commissioning of the wind farm, thus avoiding construction risks. This strategy is generally consistent with a low risk profile with stable returns. They principally purchase minority stakes in wind farm assets (mean value of 40.7%).

Pre-commissioning investors principally comprise independent energy companies, EPCI (Engineering, Procurement, Construction and Installation) contractors, and Original Equipment Manufacturers (OEMs). They can be considered as turnkey developers entering the venture at an early phase of its lifecycle to get involved in the construction and installation phase. Further, they tend to sell the majority (if not the entirety) of their stake and exit few years after the project is fully commissioned.

Finally, Build-Operate-Transfer investors comprise major utilities and independent power producers, who build and then keep the operating assets in their balance sheet. Further, they tend to divest part of their stake (minority stakes) during the operating phase of the asset.

Accurate prediction of the temporal returns profile of the investment is useful for the different types of investor clusters to conduct the techno-economic assessment of the asset during the specific year of purchase or divestment. To this end, a parametric life cycle techno-economic model was developed to accommodate the different investor