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Assessment approaches to logistics for offshore wind energy installation

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ABSTRACT

Offshore wind farm installation planning is highly complex, due to the high dependency on weather and the oversized components that impose specific constraints in areas such as transportation and lifting. Currently, there is very little transparency vis-à-vis the logistics challenges in the industry. We extend the literature by creating an overall view of the coherency between logistical methods and project performance. We develop knowledge about how to use the various approaches by analyzing different logistical solutions. A holistic view of the coherency between the approaches in terms of logistics and project performance, taking into consideration the external influence of weather, is provided through analysis of actual projects in the North Sea region. Case study findings reveal the major factors to be pre-assembly, vessel load, and the distance to shore. We suggest a pre-assembly strategy comprised of a minimum number of components for installation onsite and a maximum number of turbines to be loaded on a vessel. These findings are especially important for the new wind farms being positioned further offshore. We show by means of a case study, with specific characteristics and weather conditions, that the appropriate strategies can be arrived at by using a simulation-based decision-support tool we developed.

Motivation

With today's technological society and with significant developments such as internal combustion engines in transport, our energy consumption has increased more than a hundredfold within the past few decades [1]. Continuing rapid growth is foreseen, and the challenge today is to move away from our heavy dependence on fossil fuels and towards wider use of renewable energy resources. Concerns about sustainability, the environment, and climate change are major reasons driving this shift. The use of fossil and nuclear resources increases the side effects of supplying energy, such as the emission of greenhouse gases and the risk of nuclear accidents. Moreover, the limited supply of fossil-fuel resources and restricted access makes exploitation more and more difficult. In the long run, fossil fuels like oil will become scarce, and more and more expensive. The European Union's commitment to reducing CO_2 emissions, as well as rising oil prices, makes renewable energy increasingly important as an alternative energy source [2].

As a cost-effective and clean way of generating energy with the help of nature, wind energy is seen as one of the most viable options in reducing the ecological footprint [3]. The wind power industry is expected to continue growing in the coming decades. However, the industry is facing another challenge. The possibilities for increased numbers of onshore wind farms are limited as the generation potential in the countryside becomes more restricted [4]. Consequently, the shift from onshore to offshore is inevitable [5].

Compared to onshore, offshore has its advantages, such as the high potential of wind energy over the sea, less visual pollution, and the large availability of space that allows for larger-scale projects [6]. Those countries with coastal areas, especially, are highly interested in developing offshore wind projects. However, the economic aspects of offshore wind projects are currently less favorable compared to onshore. As of 2011, offshore wind projects were at least three times more expensive than onshore wind projects of the same nominal power [7].

Past research on the offshore wind industry has been mainly focused on the technical challenges in the design, manufacturing, installation, and operation of the facilities. A categorization of past research, based on the different phases of wind turbine operations, reveals that studies about the maintenance and operation of offshore wind turbines are denser compared to the installation phase. Within the first category, a plethora of researchers [8–11] have worked on scheduling models for the maintenance of offshore wind turbines. A recent paper in *renewable energy* [12] comprehensively reviews the past research on maintenance logistics. For the daily operation of wind turbines constructed offshore, more scheduling models have been studied in order to minimize cost

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[13–15]. For the second category, that is, logistics operations in the installation phase of a wind farm, the activities involve the port and are related to the pre-assembly of components, transportation to the site, and installation at sea. Relatively little research has focused on the logistics involved in this installation phase of the offshore wind industry. However, in this regard, Scholz-Reiter and colleagues [16] have proposed a mixed-integer linear programming model for the installation of offshore wind turbines. Ait-Alla and colleagues [17] have provided an aggregate planning method for minimizing the installation cost, with capacity and weather conditions being considered as deterministic parameters. Uraz and Emre [18] have identified the factors involved in the offshore turbine installation phase, which is highly necessary in order to understand the ways that installation performance can be improved vis-à-vis various special conditions. This study created an approach for time-wise modeling of the transportation and installation process of offshore wind turbines in order to figure out the effect of different parameters on the overall duration. However, it should be noted that the consideration given to uncertainty and disruptions during the installation remains a vital part of real-life operations and still needs to be addressed [19–21]. Accordingly, Lütjen and colleagues [22] have presented a simulation approach focusing on a different aspect of a wind farm project, which involves inventory control of offshore wind turbines. There is hardly any transparency involved in the logistics of the wind power industry [16]. In particular, the impact of weather conditions on the supply chain complicates any decision regarding a holistic logistical concept, and this is crucial for an economic set-up. Based on these factors and the current research gap, this study fits within the definition of the second category, that is, the installation phase. It adds to the existing literature by considering the disturbances due to weather conditions during the installation phase and provides a decision-support tool that can be used for analyzing the various effects of employing different logistics approaches.

The significance of and need for further studies on the installation phase of wind farms has been underlined by industry facts. Installation at sea is complex, and the equipment necessary is highly expensive. An important challenge for the management of offshore wind projects involves its highly complex planning. The installation of the first wind-power projects was considerably delayed. The influence of weather conditions in terms of restricting time windows for the installation of wind turbines at sea was dramatically underestimated. For example, although the North Sea region has numerous features that make incorporation of renewable energy sources attractive, such as large wind resources and huge hydro reservoirs in the North, installation in the North Sea region is only possible for about 120 days a year [23,24]. The large components of the turbines' structure are highly vulnerable to wind. Hence, installation processes like lifting are restricted to a certain wind speed range. These delays impact project timelines considerably, resulting in huge unforeseen costs [25]. Managing the logistics so that turbines and vessels are in the right place at the right time is a major challenge. Resulting logistical decisions have a significant impact on profitability. The logistics costs of the tower installation phase are estimated at 15–20% of the total cost [26]. The wind power industry is currently facing a new challenge in terms of the planned construction of installations totaling six GW (gigawatt) in capacity to meet the EU target of 20% renewable energy production in 2020 [27]. To be economically feasible, more research needs to be done to develop improved and more efficient handling of logistics activities.

As stated previously, the logistics operations within the installation phase of a wind farm involve the activities at the port related to the pre-assembly of components, transportation to the site, and offshore installation at sea. At sea, the installation of a complete wind turbine structure is divided into two stages: the installation of the foundation and the turbines. The construction of the foundation and its transition pieces are completed first. After this, once the transition piece creates a level connection surface for the turbine, the installation of the turbines can be completed. This study focuses on the turbine installation phase. We will be considering the logistics activities involved in the installation process of turbines, which impacts on the overall project performance. In practice, different logistical methods are used in the offshore wind turbine installation phase. Within these methods, pre-assembly plays an important role in turbine installation. Different levels of pre-assembly of parts onshore instead of assembly onsite can be employed. The purpose of pre-assembly is to partly overcome challenges from the dependency on weather conditions, which is the main cause of project delays [1]. Through the effective and correct use of the pre-assembly concept, installation time can be reduced [28]. However, it is still not yet clear which characteristics of these logistical methods influence project performance and to what extent they influence it. Much may also depend on project specifics such as the distance to shore and local weather conditions. In this study, we will focus on the logistics methods employed during the installation phase of the turbines, which is seen as the key to efficiency in the industry.

This paper contributes to the literature by creating an overview of the relationship between logistical methods and project performance in terms of total installation time and installation costs. As a result, the transparency of the logistics involved in the installation phase in offshore wind can be increased. This matter is of paramount importance in light of the need for greater support in making efficient choices among logistics methods for future projects. This need is made more crucial due to the projects planned in the North Sea region within the next decade. To be able to support decision-makers, an analysis of the influences of the various logistical approaches on project performance for offshore wind projects needs to be undertaken. To accomplish this, first, the specific characteristics of the logistical methods and the influence of weather need to be investigated. Second, it is necessary to know how the different logistics approaches influence project performance. This will provide a more accurate understanding of the use of different logistical approaches and will serve as the basis for the development of a decision-support tool aimed at an efficient supply-chain network design. Finally, a decision-support tool to support assessment of logistics approaches for various project specifications will be developed and will proceed to be implemented in a wind farm installation project in the North Sea.

The remaining parts of this paper are organized as follows. In Section II, the characteristics of the logistics methods used in the offshore wind tower installation will be described. Identification of the essential requirements for offshore network design has primarily been achieved through discussions with experts in the field along with project data. For evaluation and assessment of these consultations with experts, data obtained from the offshore wind project "BARD 1" in the North Sea will be utilized. Section III will then present the structure of the simulation-based decision-support tool. In Section IV, the "BARD 1" project will be described, and the use of the decision-support tool will be illustrated. Following that, the results of additional experiments will be described. Finally, Section V will enumerate the managerial insights and conclude the study.

Offshore wind turbine installation characteristics

This section will provide an in-depth analysis of the problem in order to reveal the characteristics of the various logistics methods. Network characteristics and configurations will be explained, along with the important aspects of the installation phase.