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A multi-criteria port suitability assessment for developments in the offshore wind industry

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ABSTRACT

This paper investigates the logistics capabilities of offshore wind ports, namely physical characteristics, connectivity and layout of the port, for supporting the installation and operation and maintenance phases of offshore wind projects. The relative significance of these criteria is determined using the Analytical Hierarchy Process (AHP). The AHP methodology is then applied in a case study as a decision-making tool to enable decision makers to assess the suitability of a number of ports for an offshore wind farm located off the North Sea coast of the United Kingdom (UK).

1. Introduction

Renewable energy sources have gained much attention in light of factors such as surges in the world energy demand, limitation of fossil fuel reserves, fossil fuel price instability and global climate change [1]. Many countries have therefore promoted policies to support the growth of renewable energy sources and continue to increase their installed capacity. Over the past decade, wind power has experienced a sustained and rapid global development [2]. Among the renewable sources (biomass, hydropower, solar, wind, wave, tidal, etc.), wind energy is projected to have the highest share of electricity generation by 2030, providing up to 22% of total electricity generation [3]. In 2012, wind energy alone helped the EU to avoid 9.6 billion Euros of fossil fuel costs [4]. This cost saving is predicted to reach up to 27 billion Euros in 2020 [4]. By the end of 2014, a cumulative amount of 127 GW of onshore wind capacity was installed and grid connected, enough to cover 10.2% of the EU's total electricity consumption in 2014 [5].

While the use of onshore wind for power generation has a long history, offshore wind energy is comparatively a young industry, with the first offshore wind farm established in 1991 in Denmark. The development of the offshore wind industry has been a significant trend in Europe over the past 20 years, due to its contribution to Europe's policy objectives on climate change, energy security, green growth and social progress [6]. Wind turbines placed in the sea benefit from higher speeds and steadier winds, and hence a higher capacity factor [7]. Other important advantages of offshore wind turbines are their relatively low visual impact and the fact that they do not occupy a land area, an important consideration in densely populated regions such as parts of North-Western Europe (e.g. Denmark, UK and Germany) and Japan. Current offshore wind trends show that larger turbines are being deployed (up to 8 MW), and that projects are moving into deeper waters further from shore in order to benefit from stronger wind and fewer user conflicts [8]. Europe is currently in the dominant position in terms of installed capacity with a cumulative installed capacity of over 10 GW in European waters across 82 farms in 11 countries, with the UK holding the leading position [9].

The offshore wind industry is also growing globally. In 2010,

Abbreviations: AHP, analytical hierarchy process; ANP, analytical network process; CAPEX, capital expenditure; CR, consistency ratio; ELECTRE, Elimination and Choice Expressing Reality; GBF, Gravity Based Foundations; HLV, heavy lift vessel; LCOE, levelised cost of energy; Lo-Lo, lift on/ lift off; MADM, multi-attribute decision making; MCDM, multi-criteria decision making; O&M, operations and maintenance; OPEX, operating expenditure; PROMETHEE, Preference Ranking Organisation Method for Enrichment Evaluation; Ro-Ro, roll on/roll off.

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China developed its first offshore wind farm with ambitious plans to reach up to 30 GW by 2020. South Korea has also shown interest in offshore wind power with plans to reach 2.5 GW of installed capacity by 2019. Japan has targets of reaching 10 GW by 2030 and Taiwan has proposed the target of 4 GW by the end of 2030 [10]. The United States has also entered the offshore wind market with the Cape Wind and Deepwater Block Island projects, which are already commencing the construction phase [11] and there are plans for reaching a capacity of up to 54 GW by 2030 [2]. Offshore wind power has also recently been evaluated in Brazil and has been suggested as a complimentary source to the country's hydro and thermal resources [12].

Yet offshore wind is still considered as an expensive source of energy compared to other non-fossil sources. Based on the estimations of UK Department of Energy and Climate Change [13], the Levelised Cost of Energy (LCOE) for Round 3 offshore wind projects, starting in 2019 is £114/MWh. This figure is lower than that of large scale solar PV (£123/MWh) and most biomass technologies that range from £115-£180/MWh. However, the LCOE for offshore wind projects still remains higher compared to that of onshore wind (£99/MWh) and nuclear n^{th}-of-a-kind (NOAK) (£80/MWh). The UK has set the target of reaching £100/MWh for offshore wind by 2020, which should help the industry to become a more competitive source of energy with other established non-fossil fuel sources [13]. The high cost of offshore wind projects is due to several reasons including but not limited to technology uncertainty, turbulent sea conditions, high cost of subsea cables, turbines and foundations and uncertainty related to electricity production especially in the case of failures since immediate repair is not generally an option [14].

Furthermore, the installation, and operations and maintenance (hereafter referred to as O&M) phases of offshore wind projects have a considerable impact on the projects' cost. The installation of the project comprises approximately 26% of the total capital expenditure (CAPEX) and port activities, operations and maintenance comprise almost 85% of the operating expenditure (OPEX) of an offshore wind project [15]. Offshore wind farms typically have a design life of almost 25 years, starting with the process of turbine installation, followed by regular operation and maintenance during the 25 year operating period, and finally decommissioning or in some cases repowering of the turbines. A critical part of the offshore wind supply chain involves ports serving as an on-land base to support the installation as well as the O&M phases of the wind farm.

The current trend of offshore wind farm construction involves the onsite manufacturing or delivery of the components to an installation port where they are assembled and loaded on the installation vessels to be taken offshore. In order to (i) accelerate the expensive offshore installation, (ii) effectively use the limited weather windows, and (iii) reduce the number of required offshore lifts, construction companies tend to minimise the work done offshore by assembling as much of the turbine onshore (at ports) as possible [8]. For the O&M phase, the ports serve as a base from which the offshore wind farms are routinely serviced. Different requirements are placed on the ports' technical and logistical capabilities based on the role that the port plays in the installation and O&M phases of the offshore wind farm [16]. These requirements are numerous and include different criteria. For instance, installation ports preferably must be deep sea ports with a large land area sufficient for the storage and assembly of offshore wind components, whereas O&M ports must be located preferably within 200 km of the site in order to provide a fast and reliable service to the wind farm [17,18].

Therefore, it is envisaged that a port's suitability can have an impact on the offshore wind farm's project cost, since a suitable port that optimally meets the requirements can facilitate the installation and O&M process whereas a sub-optimal port will incur extra costs and/or delays for the developers. Given the remarkable growth in the offshore wind industry, suitable ports and onshore infrastructure are in demand in order to meet the future capacity targets of the industry [19,16].

In this paper, we answer the following questions:

a. What are the appropriate criteria to evaluate the port's suitability for undertaking the installation and operation and maintenance of an offshore wind farm?
b. What are the weights (relative importance) of each criterion/sub-criteria?
c. Which methodology is most appropriate to investigate offshore wind farm ports' suitability?
d. How can this methodology be utilised in order to assess the suitability of ports for a given wind farm?

As the offshore wind industry expands in Europe and worldwide, the ports and onshore bases become strategic hubs in the supply chain from which all the operations of the wind farms are supported. Therefore, the selection of ports, which are logistically suitable for supporting this operation become an important issue. Given the relative immaturity of the offshore wind industry, there is a dearth in the scientific literature concerning decision support models for port selection. In this paper, we provide a detailed overview of the most critical logistical criteria for offshore wind ports. Furthermore, we are interested to understand how these criteria can be used in order to support decision making. Therefore, we first determine the relative importance of these criteria using pairwise comparison of the criteria provided by industry expert judgements. Using these pairwise comparisons, we provide a decision support model for port selection in the offshore wind sector by adopting the analytical hierarchy process (AHP) methodology; it should be noted that the standard form of AHP has been used in this paper and no methodological enhancement to the technique is proposed. The port selection model can be viewed as a generic model and is applicable for the suitability assessment of ports for any offshore wind project.

Two main groups of stakeholders will benefit from this study; the offshore wind developers, and the port owners/operators. The first group can use this model to assess a port's logistics suitability for the installation and O&M phases of their wind farms and hence to shortlist and select suitable ports. The second group can use this model to understand the important criteria for the offshore wind sector, and also to assess their port readiness (competitiveness) for entering this sector. The application of this port selection model is then shown for the West Gabbard Wind Farm located off the east coast of the UK as an example case.

The remainder of the paper is organised as follows: Section 2 presents a brief review on the use of decision-making methods, in particular the applications of Multiple Criteria Decision Making/Analysis (MCDM/A) methods in the offshore wind industry and the port selection literature. Section 3 gives a detailed description of the research methodology. Thereafter, Section 4 presents the weights (relative importance) of each criterion/sub-criterion for the installation and O&M ports, and in Section 5, the West Gabbard case study is presented. Section 6 provides the discussion and conclusion, and suggestions regarding future research paths.

2. Literature review

This section presents an overview of the application of MCDM in the offshore wind industry. Moreover, a literature review on container port selection using MCDM is given. Although container