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The right size matters: Investigating the offshore wind turbine market equilibrium

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ABSTRACT

Although early experiences indicate that the maturity of deployed technology might not be sufficient for operating wind farms in large scale far away from shore, the rapid development of offshore wind energy is in full progress. Driven by the demand of customers and the pressure to keep pace with competitors, offshore wind turbine manufacturers continuously develop larger wind turbines instead of improving the present ones which would ensure reliability in harsh offshore environment. Pursuing the logic of larger turbines generating higher energy yield and therefore achieving higher efficiency, this trend is also supported by governmental subsidies under the expectation to bring down the cost of electricity from offshore wind. The aim of this article is to demonstrate that primarily due to the limited wind resource upscaling offshore wind turbines beyond the size of 10 MW (megawatt) is not reasonable. Applying the planning methodology of an offshore wind project developer to a case study wind farm in the German North Sea and assessing energy yield, lifetime project profitability and levelized cost of electricity substantiate this thesis. This is highly interesting for all stakeholders in the offshore wind industry and questions current subsidy policies supporting projects for developing turbines up to 20 MW.
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1. Introduction

The EWEA (European Wind Energy Association) reveals in their annual report about key trends and statistics in the European offshore wind industry 2012 [1], that the average size of wind turbines installed in European waters has continuously increased. During 2012, the average capacity of new wind turbines installed was 4 MW (megawatt) and it is very likely that this trend continues, since EWEA also reports that by the end of 2012 76% of the announced new OWTGs (offshore wind turbine generators) have a rated capacity of over 5 MW. Under the expectation of concomitant cost reductions [2,3], this trend is also fostered by governmental subsidy programs such as the European Wind Initiative [4], which is a ten years research and development programme of the European Union, that grants subsidies for developing and testing large-scale wind turbines (10–20 MW). For example the AZIMUT Offshore Wind Energy 2020 project [5], which has the objective to develop a 15 MW OWTG, and the already completed UpWind project [6] is supported by this European initiative. The latter investigated design limits and solutions for very large wind turbines and showed that even 20 MW wind turbines are feasible from a technical point of view.

As a consequence, upscaling of wind turbines is a research topic with increasing popularity. For example Ref. [7], where this trend is investigated with the aim to provide recommendations for optimal design of large wind turbines [8], where a detailed analysis of costs in relation to upscaling is presented or [9] where an overview of upscaling trends for wind turbine gearboxes is given. This field of study is also related to the problem of finding optimal dimensions for wind turbines, e.g. in Ref. [10] it is argued why wind turbines with a low specific capacity are beneficial, in Ref. [11] an optimizer routine is presented which allows to determine the optimal rotor size for a given wind turbine rating, in Ref. [12] the optimal hub height for onshore wind turbines is investigated and in Ref. [13] the size of rotor/generator is site specific optimized. However, all these publications are written from the turbine designer point of view, whereas this article questions if larger OWTGs can ever be a competitive product assuming reasonable market conditions.

Therefore this article investigates the trend of growing OWTGs from the market point of view and answers the question if 20 MW OWTGs are ever reasonable or if there exists a market equilibrium that lies below this size. This market equilibrium would be of significant interest for stakeholders in the offshore wind industry. Early experiences revealed that the technology has not yet the

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maturity to sustain the harsh offshore environment [14]. Due to the rapid development of this industry, wind turbine manufacturers are faced with tight market conditions and are forced to continuously bring larger turbines onto the market. Supported by the prevailing tendering system of their customers, i.e. offshore wind project developers, where OWTG purchase decisions are mainly based on purchase price rather than future operating costs, improving the technology regarding reliability is therefore often missed out. In addition to that, gaining efficiency and profitability through economies of scale is hard to realize when customers already purchase larger turbines while production of the current generation has started only recently. The intention of this article is to show that there is a market equilibrium that might be reached soon. Hence the focus should be on improving the technology at this level instead of investing in the development of larger turbines. This might also give advice to political decision makers, who intend to bring the cost of electricity from offshore wind to a competitive level, how to optimally design support schemes for offshore wind. A first indication for the actual presence of a market equilibrium is the fact that this seems to be already reached for onshore wind turbines. Since a few years manufacturers have focused on offering a size between 2 and 3 MW for the onshore market [15,16].

This investigation requires the consideration of both economic and technical aspects. Considering offshore wind industry solely from an economic point of view an increasing size of wind turbines seems reasonable. Although larger turbines cost more in terms of acquisition and operation, they generate more energy and consequently also gain more revenues. Hence the growth of turbines would only stop if costs increase disproportional with size or the additional gain in revenues is too little. But physics reveals some additional limitations apart from the engineering challenges that come along with the design of larger turbines. Firstly, a wind turbine transforms the kinetic energy content of the wind into electrical energy, which results in less kinetic energy and reduced wind speed downwind. Hence if a wake intersects with the rotor of a downwind turbine in the plant it is said to be shadowed by the turbine producing the wake and results in less energy output of the downwind turbine. [17] The larger the turbines the larger the wakes and this in turn means that the spacing between the turbines within the farm has to be increased in order to obtain the same energy yield. Based on a predefined planning area this would result in fewer turbines to be optimal within the farm. Secondly, the wind resource, which is the actual long-term kinetic energy content of the wind at a specific location and height, is limited [18]. Thus the size of wind turbines will only grow until the wind resource is not sufficient to efficiently operate the large turbines.

OWF (offshore wind farm) project developers, who determine the demand for OWTGs, are faced with exactly these contrary economic and technical relations when planning a plant. Hence the idea was to use the planning methodology of an OWF project developer and assuming that the only decision criteria for selecting a wind turbine is the profitability of the plant over its whole life cycle. Applying this methodology with different sizes of OWTGs reveals a market equilibrium for OWTGs in terms of size, where OWF developers do not have an incentive to purchase larger wind turbines as this would not increase profitability. In addition to this analysis investigating the demand side, also the optimal size of OWTGs from the view of energy policy planners was analysed assuming that their objective is to exploit sea areas as efficiently as possible. Thus also the LCOE (levelized cost of electricity) for different OWTG sizes was assessed.

In order to generate reasonable and significant results with the developed model the methodology had to be applied to real data. This is why it was assumed to plan an OWF in the EEZ (Exclusive Economic Zone) of the German North Sea. Since Germany has envisaged installing 20–25 GW offshore wind capacity until 2030, the German offshore wind industry is one of the most promising markets for OWTGs in Europe [19]. There was taken particular care about the selection of data, the design of the methodology and assumptions in the sense being as close as possible to reality.

After a short clarification what is exactly understood by wind turbine size and the state of the art OWTG selection process, Section 2 describes the methodology used to identify the market equilibrium and the selected case study data. Section 3 provides the results of the analysis and in Section 4 a critical reflection based on a sensitivity analysis verifies the robustness of the results and individual conclusions for stakeholders in the offshore wind industry are discussed.

1.1. Clarification of wind turbine size and selection process

1.1.1. Wind turbine size

First of all it has to be defined how the size of a wind turbine is specified. As indicated earlier, the size of a wind turbine is usually determined by its rated power (also referred to as installed capacity) specified in kW (kilowatt) or MW. This defines the level of power the turbine and its components is designed for and thus is also the nameplate capacity of the generator. Therefore it is the maximum power a wind turbine is able to produce. The basic equation for power generation P from wind

$$P = \frac{1}{2} \cdot A \cdot \rho \cdot v^3 \cdot C_\mathrm{p} \tag{1}$$

where A designates the swept area of the rotor, v the wind speed, ρ the air density and C_p the rotor power coefficient, reveals that the installed capacity also determines the geometric proportions. In order to ensure efficiency of the turbine the rotor area has to be increased with rated power. In addition to that, also the hub height, which is the distance between ground and rotor centre, has to be raised, because on the one hand a certain distance between rotor tip and ground has to be adhered and on the other hand increasing wind speed with height ensures sufficient power input [20].

1.1.2. OWTG selection process

Prior to developing a research methodology for the OWTG market equilibrium, it is important to understand how a purchase decision concerning the selection of an OWTG type is usually made. Fig. 1 provides a visualisation of the selection process using IDEF0 modelling technique[1] [21] assuming that the main decision criterion is the overall project profitability. For this process basically two models are needed: a spatial planning model and an economic model. The spatial planning model calculates the optimal energy yield based on OWTG data, provided by turbine vendors, wind data of the site and an initial number of turbines. Hence this model uses an optimization algorithm in order to determine the ideal layout of the farm with regards to maximum energy output while observing the constraints of the project area. The optimal energy yield is used as an input for the economic model. This model calculates the profitability of the project using cost and remuneration data. In order to find the most profitable layout of the plant the economic model varies the number of turbines and feeds back the information to the spatial planning model. After some iterations the maximum profitability including

[1] This function modelling language is capable of graphically representing enterprise operations and has the main advantage that additional to input/output relations it is also possible to depict controls, which specify conditions required for the function to produce correct outputs, and mechanisms, which supports the execution of the function such as resources.

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