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Offshore wind installation: Analysing the evidence behind improvements in installation time

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ABSTRACT

The most important single event of the last years in wind energy technology is the reduction in the cost of producing wind electricity offshore, a reduction that can reach 75%, depending on the system boundary considered, for installations commissioned by 2024. Surprisingly, there is very little scientific literature showing how this reduction is being achieved.

The objective of this paper is to analyse the evidence behind cost reduction in one of the most significant cost elements of offshore wind farms, the installation of foundations and turbines. This cost is directly dependent on the daily rates of the installation vessels and on the days it takes to install those wind farm elements. Therefore, we collected installation data from 87 wind farms installed from 2000 to 2017, to establish the exact time for installation in each.

The results show that advances have reached 70% reduction in installation times throughout the period for the whole set, turbine plus foundation. Most of these improvements (and the corresponding impact in reducing costs) relate to the larger size of turbines installed nowadays. There is, therefore, not any leap forward in the installation process, but only incremental improvements applied to turbines that are now four times as large as in 2000.

1. Introduction

Wind energy, both onshore and offshore, is one of the key technological options for a shift to a decarbonised energy supply causing, among other benefits, a reduction in fossil fuel use and in greenhouse gas emissions [1].

It is offshore that wind energy has traditionally most been presented as an energy source with a huge unrealised potential. To date, this is because of the complexity of the technology and project management, the harsh marine environment, and the related high cost of installing wind turbines in the seas. However, this is set to change. The technological developments of the last ten years, among other factors, have led to significant cost reductions that have manifested in recent tender and auction prices.

The analysis of the evolution of offshore wind farm installation time is all but absent in the scientific literature. Schwanitz and Wierling [2] briefly discussed construction time as part of their thorough assessment of offshore wind investment, and showed that wind farm offshore construction time has increased from 2001 to 2016, but it has decreased in unit term (years/MW). One of the data issues shown by this research is the very disperse data set giving $R^2 = 0.05$ (see Fig. 4b in [2]), when construction times are "measured as the period between the beginning of (…) offshore construction and the date of commissioning", perhaps a relatively low level of detail. Interestingly, these authors also discuss the impact of water depth in driving installation costs.

Based on Benders decomposition, Ursavas [3] modelled the optimisation of the renting period of the offshore installation vessels and the scheduling of the operations for building the wind farm. This author provides interesting information on the impact of weather on installation, e.g. "for the Borkum West project the installation of a complete top side of the wind turbine generator that MPI achieved was 25 hours yet some wind turbine generators were under construction for over 3 weeks due to weather conditions". This same purpose, the modelling of the optimisation of transport and installation, was the result of the research by Sarker and Ibn Faiz, concluding that "the total cost is significantly impacted by turbine size and pre-assembly method" [4].

Abbreviations: CapEx, capital expenditure; EU, European Union; GW, gigawatt; IEA, International Energy Agency; MP, monopile; MS, megawatt; OWF, offshore wind farm; TIV, turbine installation vessel; TP, transition piece

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Table 1
Recent offshore wind tenders and auctions, and winning prices in EU countries.

Date announcement	Country	Project name	Size (MW)	Winner	Bid (€/MWh)	(Expected) commissioning
2010/06/22	DK*	Anholt	400	Dong Energy	**140.00**	2012/3
2013/12/30†	UK	Dudgeon	402	Statoil et al.	**186.10‡**	2017
2014/04/23†	UK	Beatrice	588	SSE et al.	**173.70‡**	2019
2015/02/26†	UK	East Anglia One	714	Vattenfall/SSP	**164.72**	2018
2015/02/26†	UK	Neart na Gaoithe	448	Mainstream	**157.17**	2019
2015/02/27	DK*	Horns Rev 3	406.7	Vattenfall	**103.20**	2018
2016/07/05	NL*	Borssele 1 & 2	752	Dong Energy	**72.70**	2020
2016/09/12	DK*	Vesterhav	350	Vattenfall	**63.82**	2020
2016/11/09	DK*	Kriegers Flak	605	Vattenfall	**49.90**	2020
2016/12/12	NL*	Borssele 3 & 4	702	Shell et al.	**54.50**	2021
2017/04/13	DE*	Borkum Riffgrund West 2	240	Ørsted	Market price	2024
2017/04/13	DE*	He Dreiht	900	EnBW	Market price	2025
2017/04/13	DE*	Gode Wind 3	110	Ørsted	60.0	2023
2017/04/13	DE*	OWP West	240	Ørsted	Market price	2024
2017/09/11†	UK	Triton Knoll	860	Innogy	86	2022
2017/09/11†	UK	Hornsea 2	1386	Ørsted	64.1	2023
2017/09/11†	UK	Moray East	950	EDPR, Engie	64.1	2022
2018/03/19	NL*	Hollandse Kust (Zuid)	750	Vattenfall	Market price	2023

Notes: exchange rates to Euro correspond to the day the winner was announced; Dong Energy changed name to Ørsted; *offshore substation and/or HVDC transformer station, and connection to the shore are provided by the transmission system operator and thus not included in the bid price; †date of granting of contract for differences or equivalent. Sources: press releases, offshorewind.biz web site and, for (‡), WindEurope [7].

The objective of this research is to increase scientific knowledge on offshore wind farm installation time and its evolution. This is done by exploring and analysing the installation to a high level of detail, separately focusing on foundation, turbine and whole-set[1] installation. This paper quantifies the improvements for the period 2000 – 2017 in terms of days per foundation and per megawatt rating of the turbine mounted there (megawatt-equivalent or megawatt for short). This article provides actual figures for these parameters that could be necessary for any further research on cost-reduction of the installation of offshore wind energy.

Section 2 extends on specific aspects of the background e.g. giving details of costs and recent cost reductions, whereas Section 3 presents the modelling methodology used in this research and the resulting initial picture. The next three sections present and discuss the results for the three aspects under study: installation of foundations (Section 4), installation of turbines (Section 5) and installation of the set foundation + turbine (Section 6). Finally, Section 7 wraps up the results with a brief summary and conclusion.

2. Background

After a period of cost increases (see Fig. 4 in [5]), the cost of offshore wind energy started to descend even in a very radical way. The evidence for this, as shown in Table 1, is the successive results of tenders and auctions that different European governments used in order to foster the development of offshore wind farms. The tenders involve that the winners will receive their bid price for a number of years, with or without adjustment for inflation depending on the country regulations.

There are significant differences in the period that the bid price will be received and in other key conditions. Also, recent German and Dutch [6] bids at "market price" were awarded without any additional subsidy in addition to the wholesale electricity price.

The significance of the cost reductions shown in Table 1 is even greater when compared to what the wind energy experts expected as recent as two and half years ago. An expert elicitation survey of 163 of the world's foremost wind experts run during late 2015 suggested ***significant opportunities for 24 – 30% reductions by 2030*** [8]. Table 1 shows, for example, that reductions already reached 52% just in the 1.8

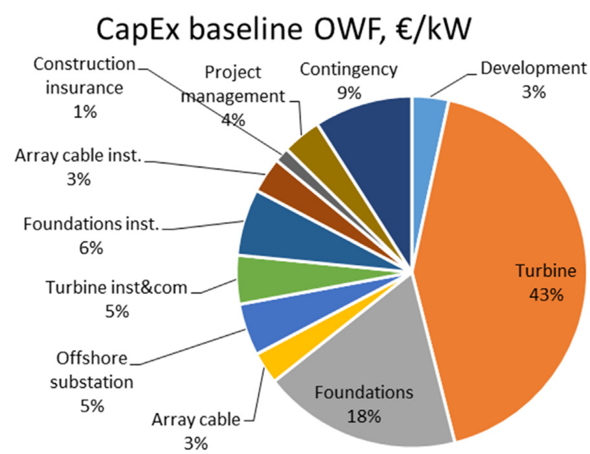

Fig. 1. Estimated breakdown of the capital expenditure of a baseline offshore wind farm in 2015. Source: [9].

years between the Danish Horns Rev 3 and Kriegers Flak OWF tenders.

In order to achieve these prospective cost reductions, offshore wind farm projects need to tackle all the elements that make up their cost. These elements are, in essence, depicted in Fig. 1 copied here from Smart et al. [9]

Costs are highly project-specific. For example, cable connection to the onshore substation used to cost around one million EUR per km [10], and wind farms commissioned in the period 2015–2017 are placed between 1 and 115 km from the coast and required between 6 [11] and 210 [12] km of high-voltage export cable. For different authors wind turbine and foundation installation contributes between 10% and 12% [9] and 16% [13] of capital expenditure (CapEx) of an offshore wind farm. The former figure corresponds to the characteristics of the ones installed in Europe during 2014/2015[2] whereas the latter was reported in 2010 with a focus on the UK.

The installation of foundations and turbines consists essentially of the following actions: (a) adaptation of the vessel for the job (an activity called *mobilisation*); (b) port loading of the turbines/foundations

[1] Throughout this document the term "set" is used to reflect the set of one turbine plus all the elements that constitute its foundation, e.g. monopile/jacket, transition piece, piles fixing jackets, etc.

[2] The baseline data represented in this graph corresponds to a 400-MW, 100-turbine model offshore wind farm as described by IEA Wind Task 26 documentation (see Smart et al. [9]).