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Technical note

Cost reductions for offshore wind power: Exploring the balance between scaling, learning and R&D

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ABSTRACT

Offshore wind electricity generation is prospected to increase substantially in the near future at a number of locations, like in the Baltic, Irish and North Sea, and emerge at several others. The global growth of offshore wind technology is likely to be accompanied by reductions in wind park construction costs, both as a result of scaling and learning effects. Since 2005, however, significant cost increases have been observed. A recent surge in commodity prices proves to constitute one of the main drivers of these cost increases. This observation begs the question whether wind turbine manufacturers should return to the laboratory for undertaking R&D that explores the use of alternative materials and bring offshore wind energy closer to competitiveness. It is demonstrated that if one abstracts from material price fluctuations, in particular for metals such as copper and steel, turbine production plus installation cost data publicly available for a series of offshore wind park projects (realized in several European countries since the 1990's) show a cost reduction trend. Hence various other sources of cost increases, such as due to the progressively larger distances from the shore (and correspondingly greater depths at sea) at which wind parks have been (and will be) built, are outshadowed by cost reduction effects. When one expresses the overall cost development for offshore wind energy capacity as an experience curve, a learning rate is found of 3%, which reflects a mixture of economies-of-scale and learning-by-doing mechanisms. Also the impact is quantified on offshore wind power construction costs from the recent tightness in the market for turbine manufacturing and installation services: without the demand-supply response inertia at the origin of this tightness it is estimated that the learning rate would be 5%. Since these learning rates are relatively low – in comparison to those observed for other technologies, and in view of the high current capacity costs of offshore wind in comparison to onshore wind energy – a renewed focus on learning-by-searching or R&D is recommended.

1. Introduction

The global capacity of installed wind power has dramatically increased over the past few years. In 2011 it reached a level of nearly 200 GW and is expected to further expand, with a continuation of the observed average grow rate of some 30%/yr for at least another decade (see e.g. OECD/IEA, 2009) [1]. The vast majority of currently deployed wind energy capacity is onshore, but offshore wind power is gradually catching up. While today only about 1% of wind-generated electricity is produced through off-shore wind turbines, this share is likely to increase over the years to come. At present essentially all offshore wind power capacity is deployed in Northern Europe, but other countries such as China and the USA are increasing their activities in this field. At present among the main challenges regarding the prospects for offshore wind power are its elevated costs.

During the past decade onshore wind power, under optimal conditions and at most favorable locations, has reached competitivity with conventional electricity generation. For offshore wind energy, however, economic breakeven has not yet been reached. Over recent years cost-decreasing effects have coincided and alternated with cost-increasing factors, even while the potential for the competitive improvement of offshore wind parks seemed, and still appears, substantial. The purpose of this short article is to briefly summarize the major mechanisms that so far have created cost reductions, as well as increases, for offshore wind

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power construction. It is also pointed out that the recent cost increase can to a large extent be explained by a surge in prices of commodities such as copper and steel. By attributing much of the recent cost increase for offshore wind power capacity to the price change of specific constituents and materials, a connection is made to recent literature on component-based cost assessments (Ferioli et al., 2009; Ferioli and van der Zwaan, 2009) [2,3].

Particularly in the engineering literature, learning curves are used to express realized cost reductions as function of cumulative manufactured capacity, and have been developed for many technologies and purposes, among which in the field of energy applications (Wright, 1936; OECD/IEA, 2000; McDonald and Schrattenholzer, 2001) [4–6]. The learning curve methodology has been successfully invoked to study the economics of onshore wind power (see e.g. Neij, 2003) [7]. For offshore wind energy, however, the installed capacity has until recently been too limited to determine a learning (or experience) curve (see e.g. DTI, 2007; Smit et al., 2007; UK ERC, 2010) [8–10]. The present study builds on data gathered from several public sources describing recent offshore wind power construction activities (in Denmark, the Netherlands, Sweden and the UK), in an attempt to calculate a learning rate for this emerging technology (EWEA, 2010; 4COffshore, 2010; Garrad Hassan, 2009; Snyder and Kaiser, 2009a and 2009b) [11–15].[1] Mainly data are used from wind parks built with monopole foundations. Since monopoles constitute currently the most frequently employed turbine support, more deployment experience has so far been accumulated with this foundation type than with other kinds like tripods.

2. Capacity cost developments

The growth of offshore wind technology is likely to be accompanied by cost reductions as a result of both scaling and learning effects. For the former one can distinguish between economies-of-scale associated with the capacity of individual turbines and the size of wind energy parks.[2] As for the latter, experience through learning-by-doing will probably be accumulated with regards to at least two major activities: the manufacturing of turbines and foundations, and their installation at sea and connection to the power grid, respectively. There is indirect evidence that these phenomena are at work for offshore wind energy, because they have been observed for onshore wind technology (Neij, 2003) that has many features in common with its offshore equivalent. Likely scaling and learning effects have not yet become apparent for offshore wind power, however, as a result of limited data availability as well as various cost increasing factors that have obscured cost reduction effects.

Since approximately 2005 significant cost increases have been observed for offshore wind power, rather than cost decreases. Essentially four main independent drivers can be discerned for this rise in costs: (1) a surge in prices of commodities such as copper and steel, (2) a tightness in the market of wind turbine manufacturers and installation service providers, (3) an increase in sea depth at which wind turbines are built, and (4) a greater distance from shoreline at which wind parks are located. In order to investigate how large these respective factors are, the cost contributions and their variations are inspected from two constituent materials required for the construction of wind parks. Fig. 1 shows the (inflation-corrected) commodity price development between 1990 and 2010 in €(2010) per metric ton (World Bank, 2008; US Steel, 2009; UNCTAD, 2010) for copper and (structural) steel, both essential metals for wind power deployment [16–18]. They yield particularly high cost shares for offshore wind capacity, through price and volume (for copper and steel, respectively; note the different scales for the left and right y-axes). The market price of these commodities has undergone a substantial increase since 2005, with a peak (reached around 2007–2008) about threefold its average pre-2005 level. While prices of both metals subsequently declined, in 2010 they were still approximately twice as high as they consistently were throughout the 1990's.

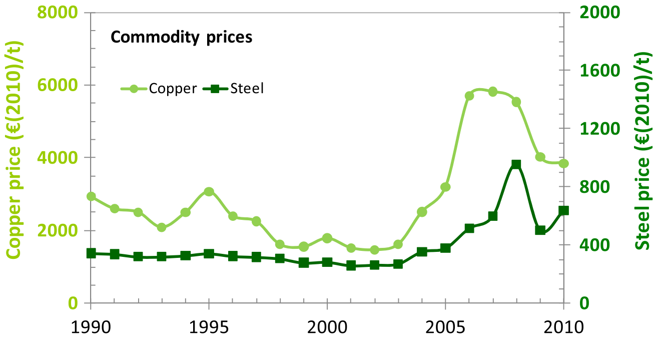

Fig. 1. Price development (in €(2010)/t) between 1990 and 2010 for copper (left y-axis) and steel (right y-axis). Data from World Bank (2008), US Steel (2009) and UNCTAD (2010) [16–18].

What has been the effect of these commodity price increases on the construction costs of offshore wind power? A considerable set of data is now available – from publications such as EWEA (2010), 4COffshore (2010), Garrad Hassan (2009) and Snyder and Kaiser (2009a and 2009b) – on offshore wind power activities over the past two decades [11–15].[3] From these sources a homogeneous series of capacity and cost data is extracted, while corrections are introduced for inflation and conversions to Euros on the basis of factors available from ECB (2010) [19]. Fig. 2 shows that the calculated specific costs (in €(2010)/kW) of offshore wind parks (with monopile turbine foundations) in Europe have increased during the past decade. Since this increase is probably at least partly due to the recent surge in commodity prices depicted in Fig. 1, the original selected data are corrected (homogenized) for price fluctuations of copper and steel, for each data point according to the quantity of these metals involved in the corresponding wind park, and for each year with respect to the average price of these materials between 1990 and 2004. Copper and steel alone contribute to the overall construction costs of offshore wind parks, under pre-2005 conditions, by as much as 20–40% (depending, amongst others, on the turbine type and capacity, as well as the sea depth and distance of the park from land; see e.g. Engels et al., 2009) [20].[4] As evidenced by the specific cost data corrected for copper and steel price variations – that is, with for all these data as constant copper and steel input prices assumed their average between 1990 and 2004 – an indication toward a cost reduction trend can be observed for the 1991–2008 time frame.

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[1] Other countries for which offshore wind data were gathered were Belgium, Finland, Germany, Ireland, Italy and Norway. These were excluded from the data set for the final analysis for reasons of incompleteness.

[2] Unlike for the scaling effects for entire wind parks, specific costs for wind turbines appear to be inversely related to size, so that costs per kW are actually larger with increasing capacity. See, for example,www.renewableenergyfocus.com/view/21781/us-wind-turbine-prices-fallen-by-a-third-since-2008/

[3] We assume that these in principle include cost (rather than price) data, and do not distinguish between whether transformer stations are accounted for or not.

[4] For a typical offshore wind farm, cost component shares are: turbines and ancillaries (51%), support (19%), electrical system (9%), installation turbines and support (9%), installation electrical system (6%), surveying and management (4%), and insurance (2%). Several of these contributions are strongly wind park dependent, which results in a cost share variability from copper and steel by as much as a factor of two.

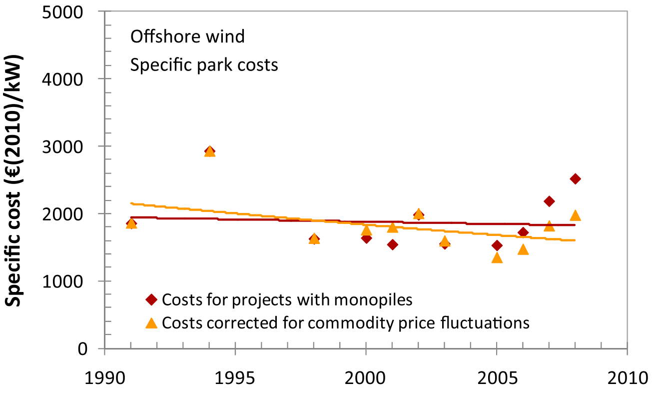

Fig. 2. Specific costs (in €(2010)/kW) of offshore wind parks in Europe over the past two decades for projects with monopile foundations: original data (red diamonds) and data corrected for commodity price fluctuations (orange triangles). Data from EWEA (2010), 4COffshore (2010), Garrad Hassan (2009), Snyder and Kaiser (2009a and 2009b) [11–15]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

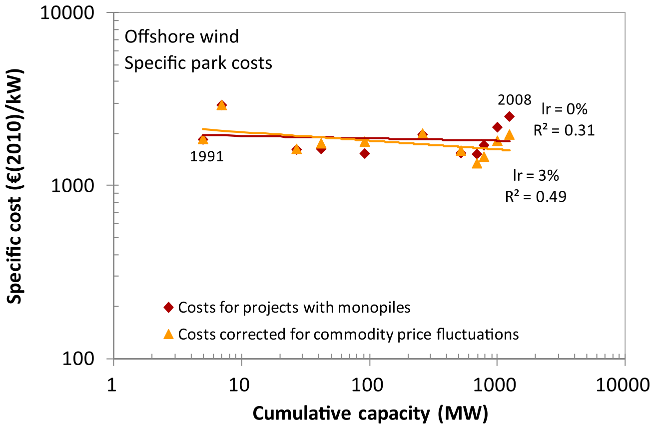

Fig. 3. Learning curves for the specific costs (in €(2010)/kW) of offshore wind parks in Europe for projects with monopile foundations: original data (red diamonds) and data corrected for commodity price fluctuations (orange triangles). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 3 plots the same cost data depicted in Fig. 2, but as function of cumulative installed capacity rather than time. Two learning curves are shown for the specific costs (again in €(2010)/kW) of offshore wind parks in Europe: as obtained through a linear fit around the original data, and as calculated by a regression over these data corrected for commodity price fluctuations, respectively. In the former case no learning-by-doing can be discerned, i.e. the learning rate lr = 0%, since (seen over the entire period) cost reduction phenomena are offset by aforementioned cost increase effects. If, however, cost data are corrected for price fluctuations of copper and steel, and thus amended for the price surge observed for these metals during the past decade, one obtains lr = 3%. The depicted linear regressions yield a fairly low statistical significance (with $R^2 = 0.3–0.5$) because of limited data availability. This statistical deficiency may soon be overcome as new information becomes available for projects that are in the planning phase today and are likely to be realized in the relatively near term.[5]

Fig. 4 repeats the corrected specific offshore wind park cost data of Fig. 3, and adds to the learning curve covering the time series from 1991 to 2008 a similar graph for the interval from 1991 to 2005. By making linear regressions for these two different periods, insight is created in one of the other listed cost increasing phenomena, related to the imbalance between supply and demand during approximately the latter half of the past decade in both the manufacturing of wind turbines and their offshore foundations, on the one hand, and the availability of services to undertake installation and grid-connection activities at sea, on the other hand. By using data between 1991 and 2005 only, that is, from before most of the tightness materialized in this specialized market, one largely abstracts from this effect and obtains lr = 5%. In other words, with this subset of data the learning rate is 2% higher than when one considers the entire data set available to date. This difference can probably be attributed to a modified market, in which demand-supply relations altered after 2005. The additional learning curve plotted in Fig. 4 possesses a better statistical significance (with $R^2 = 0.6$).

3. Prospects and R&D

Through the commodity price correction procedure described above and the subsequent learning curve analysis, two recent cost increase effects for offshore wind energy have been quantified, *grosso modo*: one related to the surge in copper and steel prices and the other associated with the tightness in the market for turbine manufacturing and installation services. What is the likelihood that these effects pertain, exacerbate or reverse, and what will happen if they do in each of these respective cases?

Commodity prices are hard to forecast. Today, one can conclude *ex post* that the commodity price surge since 2005 was strongly correlated with rapid economic growth, and hence high demand for metals such as copper and steel, particularly in developing countries such as China and India. The slight decline in commodity prices after 2008, on the other hand, was largely due to the global financial and economic crisis. Continuous efforts are undertaken to match prevailing demand with adequate supply, for these as with other products. In the present case the scenario that a return to pre-2005 commodity price levels will not soon be attained is a real possibility. Hence, pertaining or exacerbating high commodity prices could also in the future dwarf cost reduction effects for offshore wind power capacity, while the reversal of raw material prices to their values of the 1990's or early 2000's could render these cost reductions more visible than they have recently been.

The wind energy and marine services industry is likely to respond to the tightness in turbine and foundation manufacturing and placement activities by an expansion of commercial activities in this domain, especially when adoption of increasingly stringent national and regional climate policy leads to stable and sufficiently high price tags to CO_2 emissions. If market and policy inertia can be

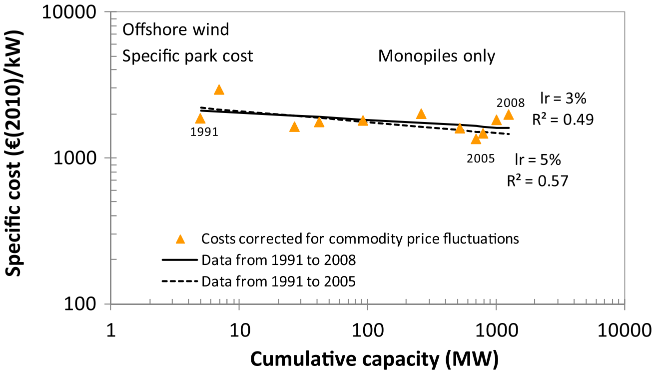

Fig. 4. Learning curves for the specific costs (in €(2010)/kW) of offshore wind parks in Europe for projects with monopile foundations: data corrected for commodity price fluctuations with linear regressions for two different time periods.

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[5] Among the lines of further statistical analysis should also be a testing of the null hypothesis.

addressed and if the future financial environment allows enough investments for the expansion of offshore wind energy, market tightness and associated high turbine manufacturing and installation service prices could be alleviated. The extent to which this materializes will determine whether and how quickly high market price levels can be curbed, and thus whether cost reduction dynamics such as expressed through learning curves can become apparent.

Two cost-increasing effects have not been inspected in this short analysis, related to the distance from shore of wind parks and the depth of turbines at sea – unlike the other two cost-augmenting factors these are both *intrinsic* to offshore wind electricity generation technology. Some of the outliers in the data set probably result from distance and depth effects: understanding of and correction for these factors could improve the statistical significance of the learning curve analysis. It may be possible to determine the relative importance of these factors through an engineering cost assessment. Fundamental for future cost estimates is to realize that these two cost-increasing effects – unlike the other two – are probably not amendable, since for offshore wind park projects depth at sea and distance from coastline are increasing in most countries. The quantification of each of the four cost increasing effects would help determining and disentangling cost decreasing mechanisms and potentials, both as applied to offshore wind power construction in the past and in the future.

What other lessons can be learned from the above? This analysis shows not only that potential exists for cost reductions of offshore wind power and describes the conditions under which these could be realized, but it also demonstrates that there are lower limits to such cost reductions. Minimum prices of copper and steel, in conjunction with the minimum quantities required of these metals, are examples of such lower limits. Through their replacement by other materials (like with similar efforts in the field of photo-voltaic technology) such limits could perhaps be broken, but this is likely to require further R&D. Cost improvements could also be envisaged through enhanced R&D efforts focusing on other components, or on certain turbine techniques, that are employed today. It needs to be carefully contemplated how limited means available for R&D can optimally be directed. For example, also the cost contributions and associated cost reduction limits need to be investigated of innovative components and new materials that can be (or are already) used for wind turbine construction, such as those involving rare earth elements. Today is the right time to study the nature and costs of materials that will be used in future turbine manufacturing, e.g. as possible replacement of these elements.

On the basis of the analysis presented above, it can be concluded that wind turbine manufacturers should return to the laboratory for undertaking R&D that explores the use of alternative materials and bring offshore wind energy closer to competitiveness. The learning rates determined in this analysis constitute backing for this claim: 3% and 5% are relatively low values, both in comparison to those observed for other technologies (where 20% is a typical median number) and in view of the high current costs of offshore wind power (that is readily twice as expensive as onshore wind capacity). A recommendation thus is to renew focus on learning-by-searching, that is, R&D. Alternatively, under scenarios of continued use of copper and steel (and rare earth elements) for wind turbine production, and with estimates of their required amounts and potential market price increases, forecasts can be made with regards to possible future offshore wind capacity cost surges, based on the insights presented above. Another relevant question is whether any of the finite natural resources employed can be recycled after a wind turbine is decommissioned (typically after 20 years of operation), and what the concomitant cost implications would be. Inversely, could materials be employed that allow the extension of their designed lifetime and hence stimulate their profitability? This question too is one that could potentially be answered through intensified directed R&D.

Ultimately of practical relevance would be to know how electricity prices would be affected by the phenomena described above. The generation of electricity from installed offshore wind capacity is another area in which experience can be accumulated – for instance with regards to where and how to optimally exploit the available wind resource. In view of minimizing power generation costs, project developers are increasingly exploiting their degree of freedom in choosing wind park locations with high capital costs but high wind speeds and availability, on the one hand, versus cheaper ones but with a lower wind resource potential, on the other hand. Similar trade-offs can be made between the capital costs of wind parks and their maintenance and operation costs. Since the ultimate goal is achieving cost reductions in electricity prices, rather than in capacity costs, analyzing scaling and learning effects in the latter is perhaps of secondary importance with respect to studying cost improvements in the former. In fact, cost-reducing scaling and learning phenomena for capacity costs may be obscured by efforts to reduce overall power generation costs. The relationship between capacity and electricity costs should be subjected to extensive further research. Exploring these issues has direct practical relevance, given the priority given to offshore wind power in the political agendas of an increasing number of countries today, and since it may simultaneously benefit the policy, industrial and scientific arenas.

It can be concluded that cost-decreasing effects of scaling and learning for offshore wind power can partly or entirely be offset by cost-increasing effects such as commodity price surges. In this paper it is shown that the latter can dominate to such an extent that the former are completely out-shadowed. Capacity cost-reducing effects for offshore wind power could become apparent when copper and steel prices stabilize at their 2010 levels or return to their pre-2005 values. A typical learning rate for offshore wind capacity costs would then be $lr = 3\%$. This value could be increased to $lr = 5\%$, if imbalances between supply and demand in the offshore wind industry can be resolved. It is also pointed out that the costs of certain components – such as copper for electric wiring and steel for turbine and support construction – may constitute an overall lower threshold that cannot be crossed through scaling or learning effects. This short learning curve analysis surely needs to be expanded and refined, but these early and exploratory results on the evolving economics of offshore wind power, and on the delicate balancing act between scaling, learning and R&D drivers for offshore wind cost reductions, should already contribute to improved public policy and private strategy design.

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