Energy 48 (2012) 314–322

Contents lists available at SciVerse ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Evaluation of offshore wind resources by scale of development

Bernd Möller [a,*], Lixuan Hong [a], Reinhard Lonsing [b,1], Frede Hvelplund [a]

[a] Department of Planning and Development, Aalborg University, Denmark
[b] Winsen, Germany

ARTICLE INFO

Article history:
Received 28 October 2011
Accepted 13 January 2012
Available online 12 February 2012

Keywords:
Offshore wind
Denmark
GIS
Spatial analysis
Resource economics

ABSTRACT

Offshore wind energy has developed rapidly in terms of turbine and project size, and currently undergoes a significant up-scaling to turbines and parks at greater distance to shore and deeper waters. Expectations to the positive effect of economies of scale on power production costs, however, have not materialized as yet. On the contrary, anticipated electricity generation costs have been on the increase for each increment of technology scale. Moreover, the cost reductions anticipated for progressing along a technological learning curve have are not apparent, and it seems that not all the additional costs can be explained by deeper water, higher distance to shore, bottlenecks in supply or higher raw material costs.

The present paper addresses the scale of offshore wind parks for Denmark and invites to reconsider the technological and institutional choices made. Based on a continuous resource-economic model operating in a geographical information systems (GIS) environment, which describes resources, costs and area constraints in a spatially explicit way, the relation between project size, location, costs and ownership is analysed. Two scenarios are presented, which describe a state-of-the-art development as well as a sketch of smaller, locally owned parks that may have several economic advantages but require a greater planning and acceptance because of higher visual impact and area competition.

1. Introduction

Offshore wind energy was first developed in the early 1990s and has since expanded at a significant pace. Development has further accelerated since the year 2003, when larger turbines became available, experience was gained with greater water depths and distances to shore, and the confidence of developers grew [1]. There seems to be a law of scale, which directs development to ever larger turbines located at greater distances to shore, at greater water depths and in larger parks [2]. This law initially is driven by the facts that better wind resources exist further away from land; that one should have the largest possible power output per turbine foundation; and that collective infrastructure investments pay off better with larger installed park capacities. This scaling should eventually ensure that power production costs decrease and offshore wind energy becomes competitive with onshore wind energy and other forms of power production. Looking at the figures so far, this is not the case.

Currently there seems to be no limit to the increase of investment costs per MW of offshore wind energy. While early but influential studies from the year 2007 and before quote investment costs of 1.2–2.4 M€/MW [3], this figure increased to 3 M€/MW in 2007 [2]. The recently opened Thanet park in the UK cost 3.5 M€/MW [4]. A recent analysis form Scotland indicates investment levels of 3.2–3.8 M€/MW [5]. Near future installations are likely to cost 5 M€/MW. Albeit there has been a progression towards more efficient turbines located in better wind regimes, and one has to acknowledge the fact that offshore wind energy still is at the beginning of a long learning curve, it does not seem that the scaling law works properly.

Already in 2007 the German government [6] noticed an increase in costs driven primarily by the following factors: a) underestimation of risks and the necessary replacement of parts or entire early installations, b) developers' migration to countries with better feed-in tariffs, c) higher costs of turbines driven by a high demand and production bottlenecks, and d) the transition of offshore wind energy projects from medium scale businesses on a national level to pan-European projects run by multinational utilities, which necessarily have higher expectations to profit than the smaller companies, who have carried along the many projects while they were in their design phase. Furthermore it seems that investment costs generally have been underestimated for parks currently developed. The scaling that is witnessed is clearly expressed by the large utility E.ON [7], who speaks of a 20:20 threshold: moving beyond 20 m sea depth and 20 km distance to

---

[*] Corresponding author. Post: Vestre Havnepromenade 7, DK-9000 Aalborg, Denmark. Tel.: +45 9940 8407.
E-mail address: berndm@plan.aau.dk (B. Möller).
[1] Independent researcher

0360-5442/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.energy.2012.01.029

shore (this is where almost all current wind parks are located) requires even larger turbines, stronger foundations, and new logistics. This means a considerable increase in costs compared to the first Danish and British parks located within the 20:20 threshold.

Wind turbine manufacturers may be shy to admit that there are great potentials of cost reductions while demand exceeds supply. And while the cost shares of turbines are reduced from 70% to a mere 40% [8], this leaves the necessary cost reductions to foundations, cabling and installation. There is little reason to believe that these new technologies will see substantial cost reductions while still in exponential growth. And as long as the technological risk is substantial, and ever larger conglomerates of companies drive the development, there is not much hope for cheap offshore wind generation within the next 10 years, when the basic planning of offshore wind energy is going to be carried out and the best locations available are going to be exploited.

The objective of this paper is to evaluate the meaning of scale by carrying out resource-economic analyses for two development scenarios: one where the installation of offshore wind energy follows the trend; and another where the same amount of wind energy is produced in smaller parks near shore. Costs and a series of other parameters are then compared, and policy implications discussed. For this purpose two databases for the SCREAM model (Spatially Continuous Resource Economic Analysis Model [9,10],) are being built, which include a spatial model of the Danish exclusive economic zone (EEZ) with most of the natural, technical and planning parameters that determine the availability of areas for offshore wind energy, the utilizable wind resource, and its marginal costs in a continuous manner.

Questions to be answered by this analysis are:

1. Is there space for sufficient amounts of smaller scale offshore wind energy in Danish waters?
2. Will a step back to smaller scale offshore wind energy lead to higher or lower generation costs?
3. Which scale of development is more robust to changes in technical, economic, environmental and social conditions?

2. Materials and methods

The SCREAM model is built using a raster-based geographical information system (GIS) [11], which divides the EEZ area into uniform square cells of 1 km^2 size, which form the smallest entities where choices are made on area availability, where the wind resource is calculated in MWh/a, and costs computed in €/MWh. Point of departure is the entire area of the Danish EEZ, see Figs. 1 and 2, and no areas are excluded to begin with other than, in this paper, the waters around the island of Bornholm, for which no usable wind resource map could be sourced. Wind energy potential is calculated using a WAsP/KAMM model prepared by Risø [12], measuring wind energy potential as power density in W/m^2. Power production is calculated using wind power density, specifications for a given choice of turbine, and a park configuration, which results in an installed power density map. Costs are computed using specific investments costs for turbines, foundations, grid connections and installation, which all or partly depend on spatial parameters such as water depth and distance to shore. Operation and maintenance costs are a function of distance to service harbour. Areas excluded for the development of offshore wind energy are derived from legislation (Natura 2000, Danish conservation), navigation charts (impure ground, anchorages, pipelines and offshore installations) [13] and by other planning data (gravel extraction, infrastructure, radar and communication). Areas sensitive to visual impact are modelled using an intervisibility model of coastal stretches, which takes into account the higher visibility from elevated coasts and their hinterland. Finally, areas used for shipping are excluded using data from AIS (Automatic Identification System) [14], which has been converted to a shipping density theme used to exclude areas and specify a safety buffer to navigation corridors. The remaining areas available for wind power development have been further scrutinised for coherent and sufficient geometry to exclude areas too small and too dispersed. All three model aspects: available areas, power production potentials, and the associated power production costs, are then used to model the cumulative available wind power resource and its marginal production costs, plotted in cost-supply curves for

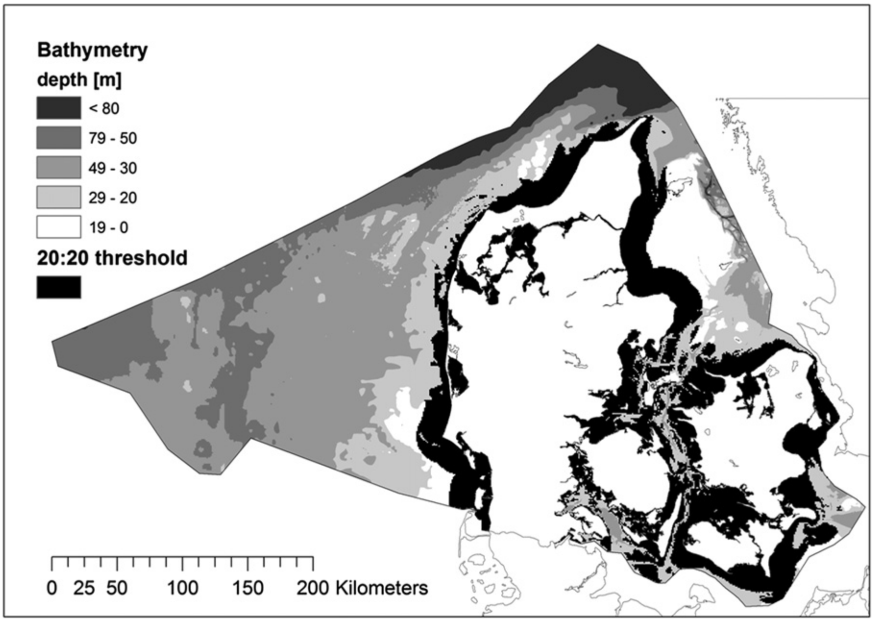

Fig. 1. The study area of 93,800 km^2 comprises the Danish EEZ excluding the island of Bornholm. The map visualises the so-called 20:20 threshold, areas nearer than 20 km to any mainland or large island coast, and with water depths of less than 20 m.