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Cost-potentials for large onshore wind turbines in Europe

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ABSTRACT

Against the background of the recent trend towards ever larger wind turbines at higher hub heights, this contribution determines the total technical potential and associated costs for electricity generation in Europe with large turbines, based on a GIS-based methodology employing cost-potential curves. For the EU28 and Europe technical potentials of 15 PWh/a and 20 PWh/a are determined respectively, with associated LCOEs (Levelized Costs of Electricity) of between 6 and 50 €ct/kWh and large variations between countries: the largest potentials and lowest generation costs are to be found in the UK, Poland and Sweden. The approximate required investment to meet national 2020 targets based on the National Renewable Energy Action Plans is estimated based on the model results. A comparison with the results of other studies shows significant deviations in the results, most of which can be explained through the differences in input parameters, and a comparison of the obtained results for Germany with those from a previous study under the same assumptions produced very similar results with a deviation of about 10%. A sensitivity analysis showed that the results are only moderately sensitive to the assumed discount rate as well as the size of turbines available.

1. Introduction, objectives and overview

The European Commission has set a target for 20% primary energy demand from renewable sources by 2020 [1], which is nationally implemented through the Member States' NREAPs (National Renewable Energy Action Plans). As a fraction of the total European (EU28) primary energy demand in 2012 of around 18.4 PWh, this target is about 3.7 PWh. The NREAPs were submitted to the Commission in 2010 and, after being approved following some modifications, are now being implemented. The Directive [1] stipulates the overall goal to be met in each Member State and NREAPs detail the planned expansion of renewable energies until 2020. The national target may be significantly different to the overall 20% goal, the reasoning being that the framework conditions in each country – that is, the renewable resources, political and economic conditions – differ greatly and the target-setting should reflect this.

Electricity generation from wind power in Europe has developed rapidly in recent years. The total installed capacity has roughly increased by a factor of ten since the year 2000, from around 13 GW to 106 GW in 2012 [2,3]. Over half of this total capacity is accounted for by Germany with 31 GW and Spain with 23 GW; together the UK, Italy and France account for about another quarter (with 8 GW each) and the rest is distributed amongst many other Member States [3]. At the time of writing the total electricity generation from wind in Europe accounts for about 7% of the total electricity demand. So it is clear that wind, both on- and offshore, is playing and will continue to play a significant role in making progress towards European and national targets for 2020, as detailed in the NREAPs [4].

Another trend that has been encountered alongside these rapid capacity expansions is the one towards larger turbines. Indeed, turbine sizes, especially rotor diameters and hub heights, and therefore also the nameplate capacities, have increased dramatically in the last few decades. The average new onshore turbine capacity, for example, was below 1 MW in the 1990s but is now of the order of 5 MW. Whilst the average capacity of onshore turbines is expected to increase further in the future, there may well be a techno-economic equilibrium as demonstrated by Ederer [5] for offshore turbines, albeit for different reasons such as social acceptance for example. Despite the higher associated investment, O&M (operation and maintenance) costs, structural and other related challenges, these larger turbines exhibit ceteris paribus lower electricity generation costs. This is mainly due to the higher wind speeds at higher hub heights and the cubic relationship between

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wind speed and power, as well as the much larger swept areas realizable, whereby the area is proportional to the square of the diameter.

These historical and current trends present several research questions relating to the (possible) future developments of wind energy in Europe. For example, the questions arise for large wind turbines of the future where the most suitable locations are in terms of generation costs and what, if any, trade-offs are associated with meeting national as opposed to European generation targets. The general objective of this paper is therefore to quantitatively analyse the potential and costs for large wind turbines across Europe. The specific aims are to determine the cost-potentials for large onshore wind in Europe and to examine the required investments for reaching the national 2020 goals for onshore wind. In this paper a large onshore wind turbine is defined as being larger than or equal to 3 MW because this currently represents the upper end of the capacity scale amongst the installed turbines (e.g. in Germany: 3% of the installed capacity in 2013 consisted of turbines larger than or equal to 3 MW according to http://www.energymap.info).

In order to do this, this paper determines technical potentials and associated costs for large onshore wind in the EU28 plus Norway, Switzerland and Turkey based upon a methodology developed and employed in McKenna et al. [6] and up to date (2013) turbine specifications to reflect the state of the art. The determined cost-potentials are then employed to estimate the investments required to reach the national 2020 targets based on the NREAPS. In the subsequent section 2, a brief literature review is given. In section 3 the data basis and methodology are described and in the following section 4 the results are presented and discussed. There then follows a summary, conclusions and outlook (section 5).

2. Literature review

There is an ongoing discussion about the potential and costs for wind energy, given the continued role it is likely to, or indeed will have to, play in the attainment of the above goals. Several international studies have examined the potential for wind energy in Europe or regions thereof [7–11], which apply an aggregated methodology to determine potentials for large geographical areas. The results of these studies are summarized in Table 1.

Held [7] developed cost-potential curves for wind energy in individual countries within the then EU27, although this was not the focus of her dissertation. Due to the large scope, the available land is derived by employing suitability factors on land use categories, with only natural protection areas and mountainous areas excluded directly. She determined a total potential for onshore wind in the EU27 of 1963 TWh/a at costs in the range 5–13 €ct/kWh.

EEA [8] carried out a similar analysis of the technical potential in each country of the EU27 according to land cover categories and electricity generation costs. The results indicated a technical potential of 45,000 TWh/a, with estimates of 3330 TWh/a and 8919 TWh/a relating to “most likely competitive” and “competitive” scenarios respectively.

In addition, in a study considering biomass, onshore wind and photovoltaic Hoogwijk et al. [9], calculated generation costs and potentials worldwide. For Western and Eastern Europe they determined potentials of 4000 TWh/a and 400 TWh respectively, with generation costs in the range 5–20 $ct/kWh.

One of the most comprehensive recent studies to investigate the potential for renewable electricity generation on a European level was the GreenNet project.[1] The GreenNet-Incentives project is the latest in a series of projects under this heading, having been completed in 2009. Whilst the project remit was much larger, having the overall objective of promoting grid-related incentives for large-scale RES-E integration into different European electricity systems, one part of this project involved the determination of cost-potentials for renewables across Europe.[2] The results have been made available in report format [10] as well as in the form of a tool that is available for download from the website above. Hence within this most recent project the existing database on RES-E potentials and costs has been updated and extended from the EU27, Norway, Switzerland, Croatia, to cover the remaining Balkan countries Albania, Bosnia Herzegovina, Macedonia, Montenegro, Serbia and Turkey. The study determined a medium term potential for onshore wind energy of 400 TWh.

More recently a study by the DLR (German Aerospace Centre) attempted to determine the future potentials and costs for most renewable technologies in Europe out to 2050 [11]. The study had a system boundary of Europe and the MENA countries (40 regions in total, whereby not all regions are individual countries). For this system, Scholz determined technical potential for onshore wind in these 40 regions of around 9000 TWh, with costs that vary from as low as 3.5 €ct/kWh to 20 €ct/kWh (cf. Table 1).

3. Data basis and methodology

3.1. Data basis

The calculation of the potential analysis is based on four data sources, as described in the following subsections.

3.1.1. Average wind-speed

The average wind speed is determined by the use of the data from *the European Centre of Medium Range Weather Forecasts* [12], by name ERA (ECMWF Re-Analysis) Interim. The data includes the average wind speed, which results from the average values of the days of each month in 10 m height from 1980 to 2011. Geographically it is oriented to the European area and a resolution of $0.75° \times 0.75°$ is used.

3.1.2. Available area for wind power generation

The basis for determining the area is the raster dataset *Corine Land Cover 200 – Version 16* (CLC-2000) of the EEA [13]. This dataset divides the European area due to its use into 44 classes (Table 5 in appendix). The used resolution of these data is $100 \text{ m} \times 100 \text{ m}$. An overview of the employed (German) exclusion criteria and offset distances according to the German Federal Ministry of Environment, Nature Conservation and Nuclear Safety is shown in Table 5 in the appendix. Areas are also excluded that need to be protected in a special way or which can't be used because of technical reasons due to too steep gradients ($\geq 20°$). Areas less than 1 ha are not covered by the CLC-2000 and therefore are not considered in this work. For the transport infrastructure data from OpenStreetMap [14] are used. The protected areas are not available in the CLC-2000 data and are taken from the sources of the NATURA 2000 Projects and the CDDA (common database on designated areas) [15,16]. Although there is no uniform regulation, the protected areas are defined as a hard exclusion criterion. Also not available in the CLC 2000 data is the gradient, which is taken from the Website Viewfinder Panaromas [17] and are largely based on the results of the *Shuttle Radar Topography Mission* of NASA, which was done in 2000. In order to account for factors that could not be excluded explicitly, suitability factors are employed based on the Corine

[1] http://www.greennet-europe.org/.

[2] The detailed methodology for the determination of cost-potentials within the GreenNet projects can be found in the PhD thesis of Resch [27].