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Global assessment of onshore wind power resources considering the distance to urban areas☆

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HIGHLIGHTS

- Global onshore wind resources were assessed including the distance to urban areas.
- We evaluate the impact of transmission losses and cost, and visibility restrictions.
- The distance to urban areas' impact was considerable, depending on the supply cost.
- This factor's importance was secondary to economic, land use, and technical factors.
- Neglecting this factor resulted in an overestimation of global wind resources.

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ABSTRACT

This study assessed global onshore wind power resources considering the distance to urban areas in terms of transmission losses and costs, and visibility (landscape impact) restrictions. Including this factor decreased the economic potential considerably depending on the level of supply cost considered (at least 37% and 16% for an economic potential below 10 and 14 US cents/kWh, respectively). Its importance compared to other factors was secondary below 15 US cents/kWh. At higher costs it was secondary only to land use, and was more important than economic and technical factors. The impact of this factor was mixed across all regions of the world, given the heterogeneity of wind resources in remote and proximal areas. Regions where available resources decreased the most included the European Union, Japan, Southeast Asia, the Middle East, and Africa. The supply cost chosen to evaluate the economic potential and uncertainties influencing the estimation of distance to the closest urban area are critical for the assessment. Neglecting the restrictions associated with integration into energy systems and social acceptability resulted in an overestimation of global onshore wind resources. These outcomes are fundamental for global climate policies because they help to clarify the limits of wind energy resource availability.

1. Introduction

Wind energy is considered a major alternative energy supply among the renewable energy technologies, and its use will avoid greenhouse gas (GHG) emissions, diversify energy sources, and reduce the dependence on foreign energy supplies. Wind power generation has experienced considerable growth in recent decades compared to other renewable energy technologies. The global wind power supply increased from 4 to over 400 TWh/yr between 1990 and 2011, with an average growth in annual capacity of around 25%. The outlook for wind power penetration suggests that its share of the total global power supply will increase from 2% to 6–13% (International Energy Agency, 2013c). With this rapid expansion, some issues constraining the practical utilization of wind resources that were absent or not apparent in the past are attracting the attention of policymakers and research communities (EWEA, 2009; GEA, 2012; International Energy Agency, 2013a; Wiser et al., 2011). Examples of such restrictions include the

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capability of power systems to integrate large amounts of electricity that are geographically dispersed and variable within short time frames, acceptability by local communities, the impact on natural environments, and the impact on birds and bats.

Some of these issues are linked to the distance of the wind power supply to urban areas. On the one hand, wind resources far from the main demand centers prevent their integration into existing power systems,[1] in particular, due to the added cost of extending transmission lines (Hoppock and Patiño-Echeverri, 2010). On the other hand, the proximity to populated areas impacts the health of local residents (due to noise and visual annoyance) and landscape values, resulting in opposition to (or low acceptability of) the construction of wind farms (Cohen et al., 2014). These issues may hamper the actual potential for wind power penetration in the future. The implications of the location of wind energy resources with respect to population have been overlooked in global assessments. Although the remoteness of high-quality wind resources and the proximity of wind turbines to populated areas are broadly acknowledged (EWEA, 2009; GEA, 2012; International Energy Agency, 2008; Wiser et al., 2011), their impact on wind resource availability is largely absent from global assessments.[2] Past assessments have focused on physical, geographical, and technical restrictions in the harnessing of wind power (Archer and Jacobson, 2005; de Vries et al., 2007; Grubb and Meyer, 1993; Hoogwijk et al., 2004; Lu et al., 2009; Sorensen and Meibom, 2000; Zhou et al., 2012). In general, they suggest that available wind resources considerably exceed current and future energy consumption, with a wide range of estimates depending on the assumptions made regarding the techno-economic performance of wind farms and land use restrictions, notwithstanding the low spatial resolution of wind speed datasets available at the global scale. Early studies by Grubb and Meyer (1993) and Sorensen and Meibom (2000) used gridded data under a geographic information system (GIS) approach to assess the availability of global resources. Hoogwijk et al. (2004) used a similar approach to evaluate the sensitivity of global energy potential to several parameters related to land use suitability, capacity density and efficiency of wind farms, and cost factors. An extension of this assessment considered several scenarios for the competition of land among wind, solar, and biomass energy supply (de Vries et al., 2007). Using a similar approach, Zhou et al. (2012) provided an updated estimation using more recent wind speed data, introducing transmission costs, and evaluating the variability of the economic potential for three cases. Some studies have focused on accurate estimations of wind speed and power output from wind turbines, and have summarized the availability of wind resources only in terms of technical energy potential, without indicating any economic valuation (Archer and Jacobson, 2005; Lu et al., 2009).

We introduced the distance to urban areas as a new factor in the estimation of the global energy potential of onshore wind energy, and evaluated its importance compared to the other factors in the assessment. A model based on gridded data was used to estimate the global energy potential of onshore wind. The distance to urban areas was used to explicitly introduce power losses and the additional investment costs from electricity transmission, and visibility restrictions in the proximity of urban areas, which represented concerns with respect to negative impacts on the landscape. The impact of including (or neglecting) this factor in the assessment of energy potential was evaluated. A sensitivity analysis was conducted to evaluate the importance of parameters related to the distance to urban areas, with respect to other parameters used in the assessment related to land use, technical, and economic factors. This study extends the scope of previous global wind resource assessments to factors related to the integration of wind power into energy systems, and its social acceptability.

We considered how decision makers and technological developments affect the range of available wind energy resources. More specifically, we assessed these issues with regard to the spatial distribution of wind resources in relation to urban areas. Given that cities are assumed to be the main centers of energy demand and supply of technology, the distance between cities and wind resources can be used to assess how distance and location affects the feasibility of wind power. The distance between potential wind farm sites and urban areas is a matter of concern in studies at the local, regional, and national scale (i.e., a site-specific issue). We highlighted the need for approaching spatial aspects in global studies, at least in an approximate way, when considering a more comprehensive assessment of global wind resources. The remainder of this paper is organized as follows. Section 2 describes the model used for estimating the global energy potential of onshore wind, the main assumptions, and the analytical procedure. Section 3 presents the outcomes from the model with respect to parameters related to the distance to urban areas, and the outcomes of the sensitivity analysis. Section 4 discusses the implications of the study, the uncertainties in the assessment with respect to the quantification of the distance to urban areas and other factors in the assessment. The final section presents the conclusions of the study.

2. Methods

2.1. Outline of the methodology

We assessed global onshore wind resources using a model that estimates the global technical and economic potential of onshore wind energy from large-scale turbines. The distance to urban areas was incorporated into the assessment the power losses and investment costs from electricity transmission, as was the constraint of the visibility of large-scale wind power plants from urban areas. In addition, a sensitivity analysis was conducted by considering low, medium, and high values of several parameters regarding land use and technical and economic factors of the assessment (see Fig. 1).

2.2. Wind resource model

The Renewable Energy Potential Model (REPM) was used to estimate the technical energy potential, the economic energy potential, and the corresponding cost-supply curves of onshore wind using large-scale turbines. The model combines several gridded data and parameters under a geographic information system (GIS) framework (Ikegami, 2009; Silva, 2012). Outputs for energy potential, capacity, total supply cost, and unit supply cost were calculated for grid cells of 0.5 arc-min, and aggregated into 17 world regions. The main inputs to the model include monthly averages of wind speed (Surface meteorology and Solar Energy (SSE), 2005), elevation (Hastings and Dunbar, 1999), slope (Ikegami, 2009), land cover (U.S. Geological Survey (USGS), 2005), protected areas (IUCN and UNEP, 2010), and parameters related to wind turbine

[1] These issues refer mainly to the difficulty for existing electricity supply systems to incorporate large amounts of wind power due to geographic dispersion, and the hourly and daily variability of power output (which results in an unpredictable supply). Technical constraints and costs related to the provision of a variable energy supply depend on the characteristics of the power supply system (availability of a flexible power supply, load duration curves, etc.), and not only on the characteristics of the resource. Therefore, this aspect of wind power integration (providing a variable energy supply) is excluded from this study.

[2] Zhou et al. considered transmission costs in a global assessment of onshore wind resource but did not provide an explicit analysis of the implications of introducing this factor into the estimation.