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Mismatch of wind power capacity and generation: causing factors, GHG emissions and potential policy responses

Juliana Subtil Lacerda [a,*], Jeroen C.J.M. van den Bergh [a,b,c,d]

[a] Institute for Environmental Science and Technology, Universitat Autònoma de Barcelona, Bellaterra, 08193, Spain
[b] ICREA, Passeig Lluís Companys, 23, Barcelona 08010, Spain
[c] Faculty of Economics and Business Administration, and the Institute for Environmental Studies, VU University Amsterdam, Amsterdam 1081 HV, The Netherlands
[d] Tinbergen Institute, Gustav Mahlerplein 117, Amsterdam 1082 MS, The Netherlands

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ABSTRACT

Policies to assure combatting climate change and realising energy security have stimulated a rapid growth in global installed capacity of renewable energy generation. The expansion of power generation from renewables, though, has so far lagged behind the growth in generation capacity. This indicates missed and relatively cheap opportunities to reduce GHG emissions. This paper sheds light on the mismatch between installed capacity and power generation for the case of wind power. It analyses and compares wind power developments in the four countries that contributed most to the increase in wind power capacity during the last decade: namely, China, the United States, Germany and Spain. We estimate the dynamics of capacity utilisation of wind power installations and identify its drivers. Finally, we identify potential policies to reduce the gap between power capacity and generation, which will contribute to cost-effective reduction of GHG emissions.

1. Introduction

A transition of renewable energy is crucial for making our economies environmentally sustainable. With adequate policy support, renewable energy sources have the potential to meet up to 80% of the world's energy supply by 2050 (IPCC, 2012). In the last decade, renewable energy has experienced a very high rate of expansion. Between 2004 and 2013, power generation capacity of renewables[1] grew by more than 600%, from 85 GW to 560 GW (REN21, 2014). Renewable energy sources have recently surpassed fossil fuels in terms of global capacity additions and investment per year.[2] Nevertheless, the renewables share of total primary energy supply has increased only 0.4% from 2006, when its share was 10.6%, to 11% in 2013 (IEA, 2014b). Most discussions of this rather disappointing development focus on stimulating further diffusion and associated investment in capacity. Nevertheless, the increase of power generation from renewables has traditionally lagged behind the expansion of capacity installation.

Largely due to policy support in the form of subsidies or green certificate systems, renewable energy sources have shown high expansion rates of installations. However, at the same time, there is a serious mismatch betwee2n installed capacity and actual power generation of renewable energy. This is a somewhat overlooked issue in the literature, which is surprising as it suggests a missed opportunity to contribute effectively and relatively cheaply (cost-effectively) to a reduction in GHG emissions.

The mismatch applies particularly to electricity generation from wind power. Wind power has the largest installed capacity among the intermittent renewable energy sources with 318 GW by 2013 (REN21, 2014). Between 2000 and 2012, its globally installed capacity has grown at an average rate of 24% per year (IEA, 2014). In contrast, electricity generation from wind started to rise only from 2008 on, at an average 0.3% per year, resulting in a share of 2% of global electricity production in 2012 (IPCC, 2014). Yet, if all generation capacity then installed had been used, wind power could have

* Corresponding author.
E-mail address: Juliana.Subtil@uab.cat (J.S. Lacerda).

[1] The data presented hereafter on renewable energy exclude hydropower since the focus is on intermittent renewable energy sources.

[2] In 2013, renewables contribute 58% to total global (net) capacity added. For the third consecutive year renewables surpassed fossil fuels and nuclear in terms of investment in new power-generation capacity, comprising US$ 214.4 billion – almost double the net investment in fossil-fuel power, namely US$ 148 billion. This excludes replacement of electricity plants (BNEF, 2014; IRENA, 2014).

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supplied 14.7%[3] of the global electricity consumption in 2012. At the same time, in 2013 alone, an estimated 212 GWh of electricity generated by the existing capacity of wind power were not transmitted to the grid (Li et al., 2015). This is partly explained by the falling prices of coal and gas, but also by low capacity factors[4] and barriers to integration with the broader energy system (Baritaud, 2012; IEA, 2014d; Volk, 2013). So the past decades of policy support have led to extensive deployment of wind power but its capacity of electricity generation has remained under-exploited.

This paper analyses electricity generation from wind power[5] in order to shed light on the mismatch between installed capacity and power generation. In addition, it qualitatively evaluates the consequences for GHG emissions. The study focuses on the four countries with the largest wind power installations in the past decade, namely China, the United States, Germany and Spain. The main contributions of this paper are three: mapping the main drivers of wind power capacity utilisation within the current energetic system; assessing foregone opportunities in terms of GHG emissions reduction; and identifying potential policies to narrow the gap between electricity capacity and generation from wind power.

The remainder of this paper is organised as follows. Section 2 reviews the factors determining electricity generation from wind power within the current system. Section 3 estimates wind power capacity utilisation in the four countries studied, identifies drivers of the gap between capacity and generation, and explains differences found among countries. This is followed in Section 4 by a discussion of foregone opportunities to reduce GHG emissions, and policies to improve wind power generation with given capacity. Section 5 concludes.

2. Wind power: driving forces of capacity utilisation

In this section we examine the main features of electricity generation from wind power followed by discussion of the determinants of its capacity utilisation.

2.1. Electricity generation from wind power

Wind power systems produce electricity by harnessing the kinetic energy of wind and converting it into electric energy. For electricity generation, the dominant design of wind power systems is the utility-scale, the so-called “wind farms”. Normally built in geographical areas characterised by consistent wind flows, wind farms combine several wind turbines with a balance of system of electrical components (such as transformers and grid interconnectors). Each wind farm has a peculiar dynamics that defines its power generation capacity. This dynamics is based on several features, such as the wind farm's capacity factor and connectivity to the power grid.[6] Electricity generated by wind farms is introduced into electric grids by transmission system operators (TSOs) and delivered to consumers by distribution system operators (DSOs).[7]

Since electricity cannot be stored cost-effectively in large quantities, supply and demand must be balanced in real time at all times. This task is normally performed by a grid management system that coordinates TSOs and DSOs. Because electricity networks are highly interconnected, any imbalance between supply and demand in one location may affect the entire network. Hence, electricity provision to consumers depends on the system operators' capacity to guarantee that supply evens demand across the whole network at all times. To this end, a platform is used to allow all electricity producers to communicate in real time with the system operator. In a competitive electricity market, this central platform works also as a bidding market, where the cheapest offers can be identified and dispatched.

Electricity networks are complex systems, with many complementary components and feedbacks. Moreover, each location and each market have different energy mixes, network structures, levels of wind penetration, etc. Here we focus on the current electricity system to analyse the factors considered determinant of the capacity utilisation of wind power installations. Instead of looking at the conditions enabling a future all-renewables system, we recognise fossil fuels as a complementary energy source, and acknowledge the need for redundant capacity of wind power upon this current hybrid system. The following sections briefly review the main determinants of capacity utilisation of wind power installations, namely: capacity factors, system flexibility, and market integration.

2.2. Capacity factor

The capacity factor is an indicator of electricity-generating capacity that specifies the percentage of time that a wind farm produces electricity during a representative year. It is calculated as the ratio of average power delivered in a given period compared to the theoretical maximum power, for a single turbine, a wind farm (covering several turbines) or an entire country (with several wind farms). Capacity factors vary following location and the design of wind turbine and wind farms. The local wind resource is considered the most important factor affecting the performance of wind energy systems (Blanco, 2009). Location influences the capacity factor due to wind conditions. These are rated by capacity of kinetic energy generation (derived from the weather conditions), but also by transmission enabling factors, such as: correlation with peak demand; proximity to end-consumers; and variability and predictability of wind blow (Baritaud, 2012; IEA, 2014d).

Design of wind turbines influences the capacity factor by nameplate capacity (maximum power generation capacity) and suitability to the wind regime. Recently, turbine design has evolved towards higher power capacities by increasing the height of the tower and the length of the blades (IEA, 2014c). On average, however, the average height and rotor diameter of turbines has grown more rapidly than average power capacity. This decrease in the specific power, or ratio of capacity over area, has pushed up capacity factors for the same wind speeds (Wiser and Bolinger, 2013). For lower wind speeds, rotors with high masts and long blades in relation to generator size are the most suitable, and sometimes present even higher capacity factors than high speed designs (Bortolini et al., 2014). Moreover, because lower-wind-speed areas are often closer to consumers than the best wind locations, this offers additional advantages as lower transmission losses and higher flexibility of dispatch. While several designs are in use today, new grid-connected turbines had an average size of 1.8 MW in 2012, up from 1.6 MW in 2008 (Navigant, 2013). The largest commercial wind turbine currently available is 7.5 MW, whereas turbines with a rated capacity between 1.5 MW and 2.5 MW respond for the largest market share

[3] Full capacity refers to maximum power output. The calculation is based on 1625 Mtoe of electricity consumption (IEA, 2014b) and 318 GW of installed capacity (REN21, 2014).

[4] The term “capacity factor” denotes the ratio of average power delivered in a given period compared to the theoretically maximum power that can be generated (further details are provided in Section 2.2).

[5] The analysis is focused on electricity generation from onshore and grid connected wind power installations because this setup is the most widely deployed. Offshore wind power is mentioned whenever relevant for the discussion.

[6] For a comprehensive discussion on wind farms see Chowdhury et al. (2013) and Herbert et al. (2014).

[7] The focus on transmission and/or distribution operators, rather than on vertically integrated utility structure, is given by the fact that these play key roles in markets with significant shares of wind power generation.