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Evaluation of greenhouse gas emissions avoided by wind generation in the Brazilian energetic matrix: A retroactive analysis and future potential

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ABSTRACT

In recent years, wind power generation has grown exponentially in Brazil. The Brazilian Ten-Year Plan for Energy Expansion predicts an installed wind capacity about of 22.4 GW by 2023. This study evaluates the potential of avoided carbon dioxide emissions due to wind power development in Brazil. First, the emissions avoided by using wind power until the year 2017 were analyzed retrospectively. The future growth projections of wind power in Brazil were then analyzed, using magnitude growth projection models, and the impact of avoided carbon dioxide emissions on the energy matrix was assessed, under various scenarios. The results show that the avoided emissions may correspond to 5.8% of the carbon dioxide emissions in 2030 for the entire Brazilian energy matrix.

1. Introduction

There is growing concern about global warming and what humanity will leave for future generations. This has inspired research on alternative methods of energy production and has encouraged thinking about sustainability and environmental conservation. In this context wind power becomes relevant, since it is a renewable and clean source of energy (Carvalho, 2017). A wind turbine operates within a range of wind speeds. Very low speeds are not enough to move the turbines. On the other hand, very high speeds above the nominal speed make the wind turbine operate in constant power-up mode until a cut-off limit, where the turbine stops operating in order to avoid structural damages (Raimundo and Santos, 2015). Fig. 1 shows an example of a working curve of a wind turbine.

Wind energy uses an inexhaustible natural resource, generates no waste during operation, and has very low levels of greenhouse gas emissions. Several authors have studied the life cycle emission factor of a wind farm in different locations obtaining values that vary from 7.1 to 34.1 gCO_2eq/kWh (Rajaei and Tinjum, 2013; Oebels and Pacca, 2013; Nugent and Sovacool, 2014). These values are well below the average values of other energy sources (obtained from IPCC, 2012), such as coal (1.001 gCO_2eq/kWh), natural gas (469 gCO_2eq/kWh) and Solar Photovoltaic (46 gCO_2eq/kWh). The differences between the emissions of wind power and other energy sources demonstrate the potential of this kind of energy in benefit of CO_2 emissions reduction. In 2016, wind power prevented more than 637 $MtCO_2$ emissions globally (Global Wind Energy Council - GWEC, 2017).

The energy balance of a wind turbine is also highly positive. Uddin and Kumar (2014) found that the time required for repayment of the energy consumed in the production (Energy Payback Time - EPBT) of turbines varies according to the wind speed, installed power, place of operation, among others. Tremeac and Meunier (2009) analyzed the EPBT of two wind turbines (250 W and 4.5 MW) in France. The authors obtained values equal respectively to 0.58 and 2.29 years for the 4.5 MW and the 250 W wind turbines. In Brazil, Carvalho (2017) obtained values of 0.33 years for 2 MW wind turbines. At all cases the EPBT values were less than the lifetime of the wind farm.

One of the major factors in the cost of electricity generated from wind is the capacity factor (CF). The CF of a wind park varies with the type of wind generator and with the distribution of the winds in the region throughout the year. The CF is defined as the ratio between energy production from wind turbines in a certain period of time and the energy that would be produced by the same if operated at maximum power during the same period (Khahro et al., 2014). As shown in Eq. (1) (Lima and Bezerra Filho, 2012), the production of electricity is directly proportional to the CF of the enterprise, which will directly impact its economic attractiveness (as shown by Liu et al., 2017). In Brazil, the annual average CF for wind farms has grown from approximately 25% in 2004 to 38% by 2015 (Brazilian Ministry of Mines and Energy - MME, 2015), although it varies significantly between months and

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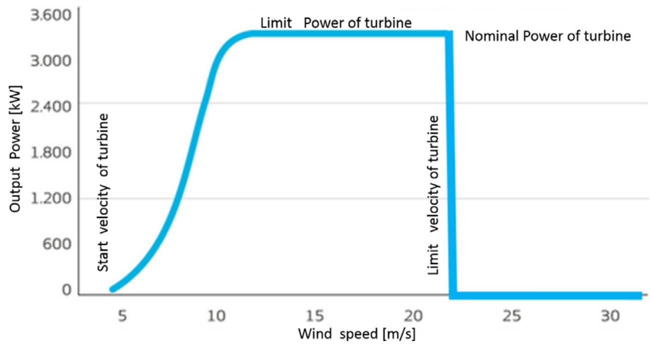

Fig. 1. Example of the working curve of a wind turbine. Power curve of the Vestas wind turbine, model V126, 3.3 MW.
Source: VESTAS (2015).

regions of the country.

$$E = P \cdot CF \cdot 8{,}760 \tag{1}$$

Where: P is the power in kW, and 8760 is the number of hours in a year.

According to the GWEC (2016), the projected global wind energy installation capacity for 2021 is 800 GW. Fig. 2 shows the temporal evolution of the wind power installed around the world between 2001 and 2016. Wind energy has also gained importance in Brazil in recent years, as predicted by Filgueiras and Silva (2003). Currently, Brazil is the largest producer of wind energy in Latin America (Brazilian Communication Enterprise - EBC, 2017). The main region of wind energy production is Northeast Brazil (EBC, 2017). De Jong et al. (2017) estimates that by 2020, 57% of the energy consumed in Northeast Brazil will be produced by wind power generation.

Fig. 3 shows the percentage of participation of each country in the increase of wind power installed in 2014 around the world. This figure shows that 7% of the world's wind energy (17.6 GW) occurred in Brazil. Fig. 4 shows the evolution of Brazilian wind power capacity. There was a trend of exponential growth in wind power between the years 2005 and 2015 (as observed by Melo, 2013). In 2015, wind energy was responsible for 3.5% of all electricity in Brazil, totaling 21.6 TW h (Brazilian Energy Enterprise - EPE, 2016). Table 1 presents the variation of installed power in Brazil during 2014 and 2015. The data demonstrate the huge growth of wind energy in this period (56.2%), which is far greater than other sources' growth.

Despite the recent growth, there is still much wind potential to be developed in Brazil. The 10-year national plan for energy expansion includes 22.4 GW of wind power by 2023 (EPE, 2014). The total potential available in Brazil is estimated at 143.5 GW for wind turbines operating at a height of 50 m (Amarante et al., 2001a). There is still the offshore potential, virtually unexploited in the Brazil. Lima et al. (2015) studied the offshore wind potential of the state of Ceará, Brazil and obtained a potential of 720 W/m^2 and an average speed exceeding 8 m/s in all analyzed scenarios during the dry period.

In the Brazilian scenario, wind energy is advantageous for complementary usage with hydraulic power, a source with a higher rate of generation in the Brazilian matrix (EPE, 2016). Furthermore, such complementary generation could be established in different regions of the country (Amarante et al., 2001b; Silva et al., 2016). Due to this feature, studies have examined the possibility of installing wind turbines in reservoirs of large hydroelectric plants or even around small plants (Assireu et al., 2011; Leite et al., 2014). The wind power job generation potential in Brazil is 13.5 persons/y for each MW between the manufacturing of components and the first year of the plant. The total potential is 24.5 persons/y for each MW during the lifetime of the wind farm (Simas and Pacca, 2014).

The future development of renewable energy sources such as wind power is one of the key factors for the reduction of greenhouse gas emissions, which can assist in achieving targets assumed by the country in the Paris Agreement for the reduction of greenhouse gas emissions by 43%, with respect to the total emissions from 2005 by 2030 (MMA, 2016). Due to the importance of the theme, several models and scenarios, in an attempt to quantify and control CO_2 emissions, and to estimate avoided emissions due to the insertion of renewable sources or the implementation of energy management programs, have also been developed. These actions were encouraged by compliance with global targets as in the case of the Paris Agreement.

The International Energy Agency (IEA, 2017), in its document entitled Energy Technology Perspectives (2017), presents three (3) scenarios, based on combinations of prognosis, trends and short-term analyzes that seek to address the future of the energy sector and assist in decision making. These scenarios consider different cases of global average temperature increase and economic growth until the years of 2060 and 2100. In addition to these scenarios, there are also methodologies that assist in the estimation of emissions from the energy sector. In 2006, the IPCC Guidelines for National Greenhouse

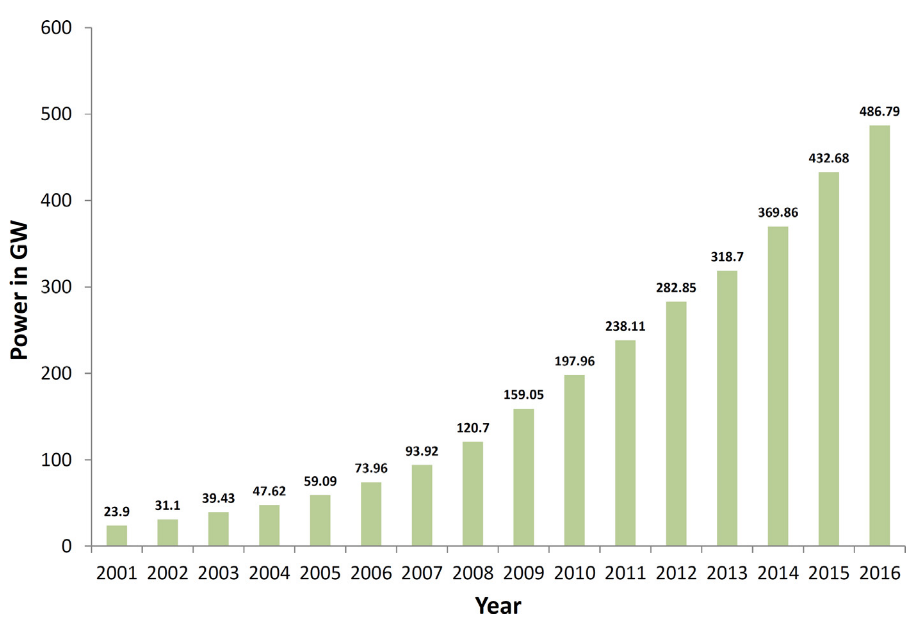

Fig. 2. Global growth of wind power in recent years. Source: GWEC (2016).