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A DISCUSSION ON THE CAPACITY FACTOR IN WIND FARMS

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Abstract. *There is a pressing need to accelerate the development of advanced energy technologies in order to address the global challenges of clean energy, climate change and sustainable development. Wind energy, like other power technologies based on renewables resources, is widely available throughout the world and can contribute to reduced energy import dependence. As it entails no fuel price risk or constraints, it also improves security of supply. Wind power enhances energy diversity and hedges against prive volatility of fossil fuels, thus stabilizing costs of electricity generation in long term. Wind power entails no direct greenhouse gas (GHG) emissions and does not emit other pollutants (such as oxides of Sulphur and nitrogen); additionally, it consumes no water. Many economic and environmental benefits are achieved by using renewable sources of energy compared with conventional non-renewable sources. However, the power output of wind farms is intermittent and uncontrollable, with difficulties in integrating the electrical distribution network. This affects the reliability not currently ensuring a steady and sage supply of electricity generation. Currently, it has over 370 GW of installed capacity in wind energy around the world, yet the average effective potential generation is less than half that capacity. The increased use of non-renewable sources will be needed for some time. It is necessary and are being studied various forms of integration between energy generation of wind and hydroelectric, solar and thermal, solar and wind, nuclear and hydroelectric pumped hydroelectric storage, and others, for a generation with security energy and in large scale.*

Keywords: *Wind Farm, Capacity Factor, Onshore, Offshore*

1. INTRODUCTION

Many economic and environmental benefits are achieved by using renewable sources of energy compared with conventional non-renewable sources. Thus, developed and developing countries have invested in this clean form of electricity generation through incentive and subsidy systems (Hebert et al., 2014; Duic et al., 2003; Hosseini et al., 2013; Abbasi et al., 2014).

The systems for generating electricity from wind convert wind energy into electrical energy through wind turbines or wind generators. We call wind farm two or more wind turbines installed. Besides the production of electricity from wind energy systems may also be used for pumping, grinding grain, sawing, etc. (Islam et al., 2014; Yaniktepe et al., 2013).

Wind energy has many advantages such as cost-competitive, clean energy, abundance everywhere in the world, rapid installation and dismantling, no have fuel costs or waste generation. As disadvantages we can mention the intermittence, the network integration challenges, and dependence on subsidies. The competitive cost is motivated by competition, learning, and political support and by defenders of the technology (Kern et al., 2014;).

It is noteworthy that all forms of energy production has an environmental impact, however, the impacts of wind power are low, local, and manageable. These environmental impacts are insignificant when compared with conventional energy sources. The wind farm is currently the cheapest form of renewable energy, justifying large investments in these last two decades (Abbasi et al., 2014; Yaniktepe et al., 2013; Leung and Yang, 2012).

2. ONSHORE AND OFFSHORE

There are two alternatives for generating wind, in onshore or offshore, with horizontal or vertical axis. The turbine of horizontal axis has been the most commonly used. The onshore wind is already well known. On the other hand, the story of offshore wind energy generation is fairly recent and is being driven by the abundance of space, higher average wind speeds and greater constancy of electricity generation on a large scale (Islam et al., 2014).

Offshore wind parks are usually built on the area of the continental shelf, about 10 km away from the coast and up to 10m deep. Compared with terrestrial, marine wind turbines must be fixed on the seabed, needing a strong support structure. It is necessary the use of submarine cable for the transmission of electricity. Also needed are special vessels and equipment for the construction and maintenance work. These factors make the high costs, even to the double or triple the cost on land, mainly by the distance to shore and the water depth.

The size and power of wind turbines has increased rapidly over the last few years. In late 1982, a wind turbine 55 kW had a rotor diameter of 15 m. Nowadays we can find available in the market, models of wind turbines of 5000 kW with rotor diameter of about 126 m.

Offshore wind turbines are considered less impactful than land wind turbines and their size and noise are mitigated by distance. Due to the more constant and higher average speeds winds, the capacity factors are higher in offshore farms than for onshore and nearshore locations. Thus smaller towers are used to support the offshore turbines which ultimately decrease the visual impact. As disadvantages of wind turbines onshore can be mentioned the difficulties in the logistics of large components, and transportation difficulties due to various problems in the assembly, as visual and sound effects. The number of acceptable locations for wind farms may also be limited. The onshore wind farms with larger generating capacities are usually located in remote areas, requiring transmission over long lines for consumer cities. Offshore wind farms may be located closer to the coastal towns requiring transmission lines relatively shorter (Bilgili et al., 2011; Markard,and Petersen, 2009).

3. MAJOR WIND FARMS AND WIND TURBINES

In 2012 the French Alstom inaugurated Haliade 150 of 6 MW, the largest offshore wind turbine of all times (Alstom, 2014). Now in 2014, the magazine Offshore Wind Industry announced that the Danish company Vestas installed the largest offshore wind turbine for testing in Oesterild Denmark 's. The V164-8 has 164 m rotor diameter with a generation capacity of 8 MW, using the wind from an area of 21,124 m^2. With this dimension can be reduced the cabling expenses and maintenance. The support tower has height of 140 m, and a turbine tip with height of 220 m. Most previous V164 -8 turbine has the rotor diameter of 154 m. The V164 - 8 will be available for the market from 2015 (Vestas , 2014). In Latin America, the largest onshore wind farm is located in the state of Bahia - Brazil, in the cities of Caetité Guanambi and Igaporã. The complex had an investment of R$ 1.2 billion and consists of 14 wind farms and 184 turbines with installed capacity of 293.6 MW (Renova Energy, 2012). The increase of wind turbine size are shown in the Figure 1.

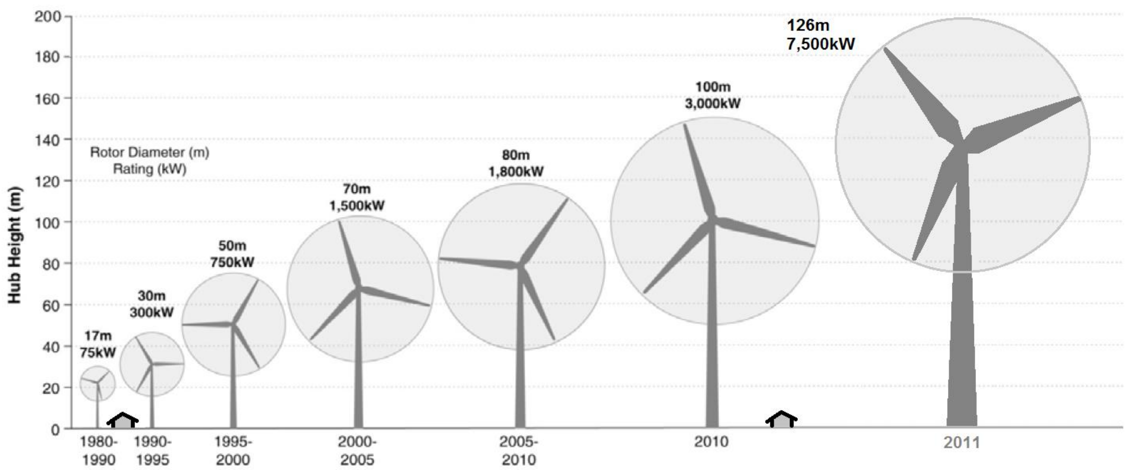

Figure 1 – Evolution on size of wind turbines. Source: Patel (2013)

On July 4, 2013 was inaugurated the largest offshore wind farm in the world. London Array includes 175 wind turbines of 3.6 MW each and rotor diameter of 120 m, manufactured by Siemens, aligned with the southwest wind occupying an area of 100 km$_2$. London Array has a capacity of 630 MW combined generation (Siemens, 2013).

Germany inaugurated on August 26, 2013 the largest offshore wind farm "Bard Offshore 1" in the country. There are 80 turbines with a capacity to produce 400 MW, installed 90 km away from the coast. The park cost three billion euros (AICEP Portugal Global, 2013). Nowadays in China are produced by two wind turbines onshore day. The country currently ranks as the largest generator of onshore wind energy in the world. Has an installed capacity of approximately 75 GW, with pretense to hit 200 GW by 2020. One of the main challenges faced by the Chinese is to integrate supply chain of wind energy (CORE, 2013; BBC News, 2013).

It is estimated that electricity generation based on renewable technologies will grow 25% by 2018, with large share of the wind energy and solar photovoltaics, becoming the second most important global electricity source in countries within and outside the Organization for Economic Co-operation and Development – OECD. The Figure 2 shows this estimate of growth until 2018 (OECD/IEA, 2013).

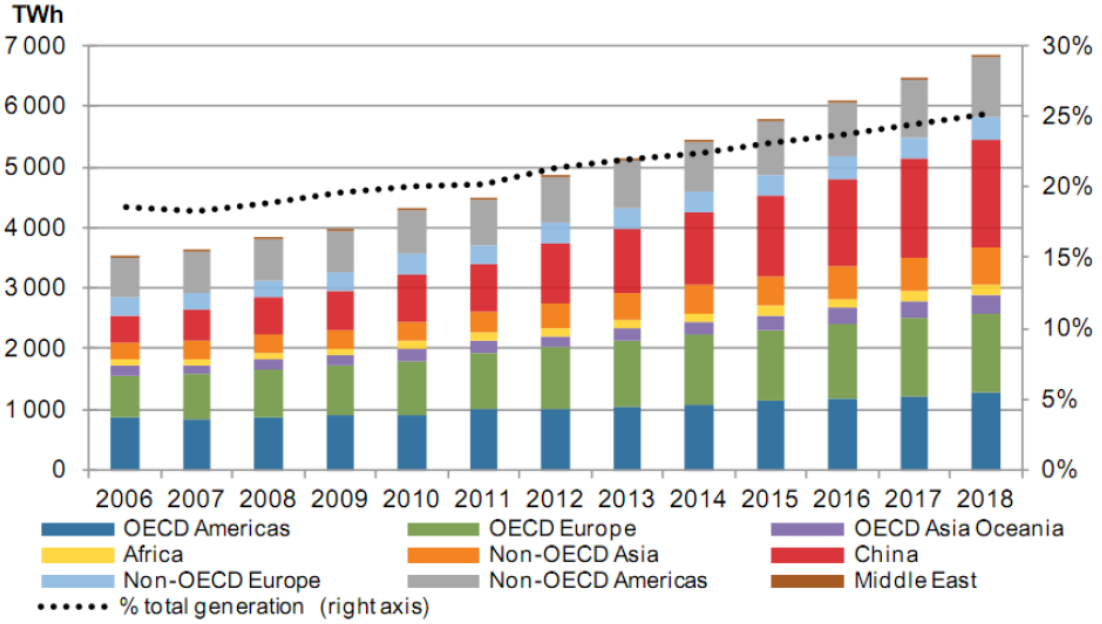

Figure 2 – Global renewable electricity production by region. Souce: OECD/IEA (2013)

However, the increase of installation of new wind farms is surprising. The installed capacity in wind energy during the year 2014 was 52 GW, reaching a total installed capacity of 373 GW worldwide. China leads the world in terms of total installed wind capacity (115 GW), and in 2014 China recorded the largest addition of new wind capacity (23 GW), followed by Germany (6 GW) and the USA (5 GW) according BP (2015). The Figure 3 shows the increase of capacity installed in US, Germany, Spain, China and India, and the rest of World.

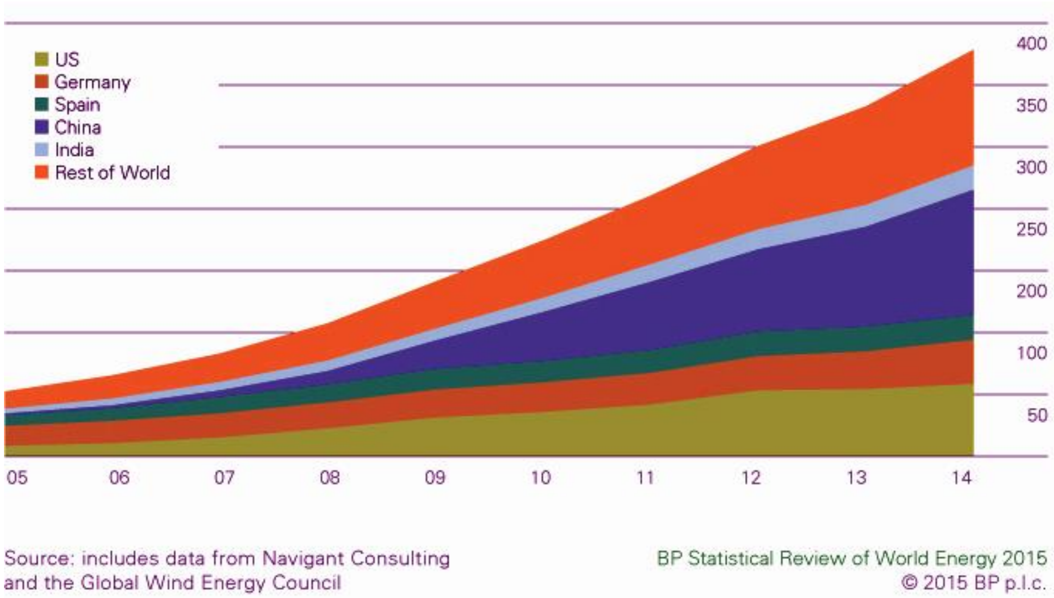

Figure 3 – Installed Wind Generation Capacity in Gigawatts (GW) in end 2014. Souce: BP (2015).

The largest project is to Gansu Wind Farm, in China, with 20,000 MW of installed capacity projected. This project is located in the provence of Gansu, at an altitude of 1800 m, a plateu of 24 km, with a drop of only 200 m. There are largest project in USA, in California with 1548 MW, and other with capacity installed between 200 to 600 MW. Are proposed of wind farm of 2,000 MW in Nebraska, and of 1,000 MW, on New Mexico, in example.

A total of 128.8 GW is now installed in the European Union, a growth of 9.8% on the previous year and lower than the record growth registered in 2012 (+12% compared to 2011). Germany remains the EU country with the largest installed capacity, followed by Spain, the UK, France and Italy. Germany (39.2 GW) and Spain (23 GW) have the largest cumulative installed wind energy capacity in Europe (EWEA, 2015)

4. ANALYSIS OF CAPACITY FACTOR

The capacity factor "FC" of a electrical generation plant is defined as the ratio of the actual output of the plant over a period of time and maximum capacity during the same period . From the capacity values withdrawn from Bazmi and Zahedi (2011) considering works for various technologies of power generation, the lowest values are for renewable sources: solar photovoltaic - 15 %, wind - 20-40 %, and solar thermal 24.5 %, making it clear the high degree of intermittency of these energy sources.

On the other hand, larger capacity factors are for non-renewable sources: coal-fired , oil and nuclear . In relation to the costs of fossil generation technologies, fossil fuels and wind are in the same range .

According to Nagy and Kormendi (2012), the typical capacity factor for a nuclear power is more than 90 % to produce 1,000 MWe continuously during a year, costing approximately $ 2.5 billion , occupying an area of 0.16 km^2. This equates to 2000 wind turbines of 2 MW at a cost of $ 6 billion , occupying an area of 400 km^2.

In Brazil, according to ABEEOLICA (2015), the total installed capacity is 6,560 MW, with 262 wind farms. There are still over 11,000 MW under construction. The Figure 4 shows the wind generation in the National Interconnected System – "SIN" and the average monthly capacity factor for the years 2013, 2014 and first quarter of 2015. It's only considered the values of generation and installed capacity of power plants of type I, those connected to the core network, regardless of net power injected into the system. It is noteworthy that the plants type I are plants connected to the core network - independent of the net power injected into the SIN and the nature of the primary source; or hydraulic power plants whose operation can affect the operation of existing plants Type I; or plants connected outside the core network whose maximum net power injected in SIN helps minimize operating problems and provide greater security for network operation. Therefore, plants are connected at the base of the power system or impacting the safety of the power generation system.

The capacity factor is calculated as the ratio between the average generation and installed capacity. Operational data of wind farms until December 2008 are collected by ONS in Brazil. From these data it is possible to know the behavior of different wind farms installed in the region south and northeast of Brazil.

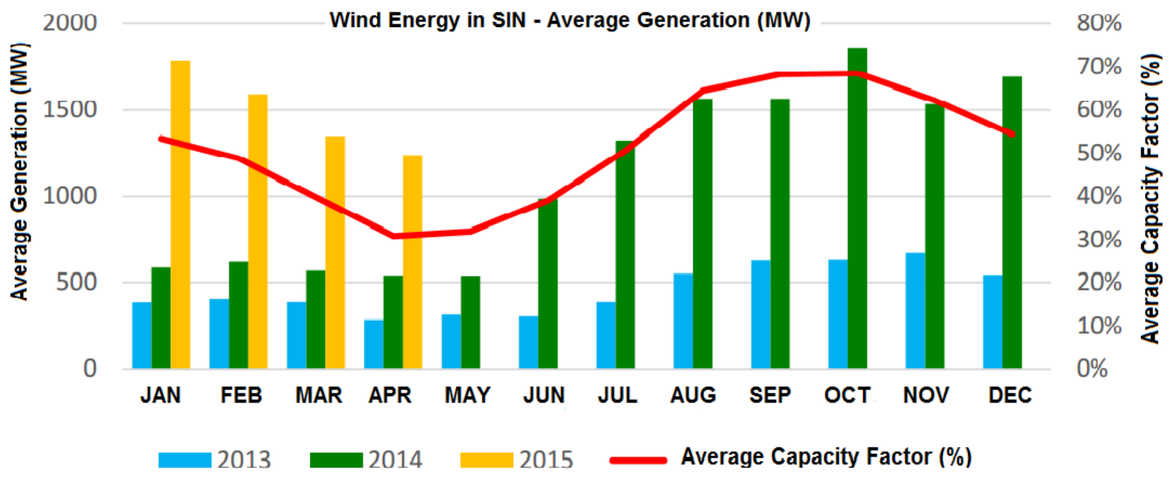

Figure 4 – Average Generation of Wind Energy in Brazil in (MW) and Average Capacity Factor in Last Years. Source: ONS (2015).

In Figure 4 is visible the oscillation of the capacity factor over the months, where is possible to see the capacity falling in the first four months, and then up slightly in May and June and growing more sharply until September and then falling again in the months of October, November and December. Yellow columns indicate a large entry of new wind farms into commercial operation in early 2015.

It is also evident that the average capacity factor has the greatest values in the second half of the year, corresponding to dry periods. Figure 5 shows the average wind generation in the months of May, June and July 2014 by the state (Bahia, Ceará, Rio Grande do Norte and Rio Grande do Sul) for plants of type I.

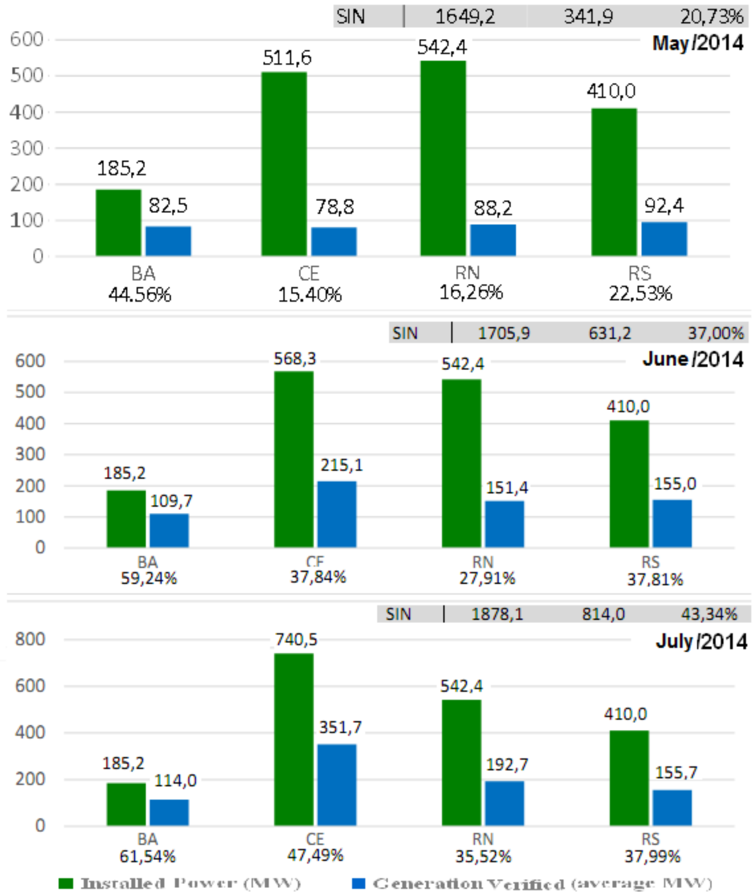

Figure 5. Average wind generation in the months of May, June and July by the state to plant type I.
Source: ONS (2014a).

The power installed in May/2014 was 1649.2 MW and 341.9 MW of average energy actually generated, with an average capacity factor of 20.73%. In June/2014 the installed capacity increased to 1705.9 MW and 631.2 MW generated with a capacity factor of 37.00% and in the month of July/2014, again passing the installed capacity increased to 1878.1 MW, generating 814 MW and capacity factor of 43.34% (ONS, 2014a). Figure 5 clearly shows the intermittency of wind generation and the big difference between installed capacity and power verified. It is noteworthy that the actual generation increased influenced by the increase in installed capacity.

The variability of the capacity factor over the months signals the need for complementarity between renewable sources, particularly wind power and conventional power generation. Figure 6 shows a possible complementarity between wind farms and hydroelectric dam in northeastern Brazil. Integrating the operation of hydroelectric plants and wind sources allow, in some regions, optimization use of water reservoirs by adding larger amounts of energy to the system during periods of drought and seasonal stability enabling the interconnected power system.

The Table 1 shows the average wind generation in April 2015 by state (Bahia, Ceará, Pernambuco, Rio Grande do Norte, Rio Grande do Sul and Santa Catariana) for plants of type I and plant set. The installed capacity in April for this plant was 5349.1 MW and the average generation of 1225.9 MW with an average capacity factor of 22.92 %. According to Fig. 4, the month of April is of lower intensity winds, contributing to a low capacity factor. The Table 2 shows the characteristics of generation and capacity of some wind farms in Brazil. The maximum generations for the month of October 2014 are accompanied with their schedule of occurrence. This month was chosen because it is the largest power generation. It is reported that for these plants presented, the highest capacity factors occurred at a later schedule when energy demanded was low, ie, there are large electricity generation, but consumption is low at these times, except in electro-intensive industries. The capacity factor calculated in Tab. 2 corresponds that moment of generation and does not reflect the average day that is much less.

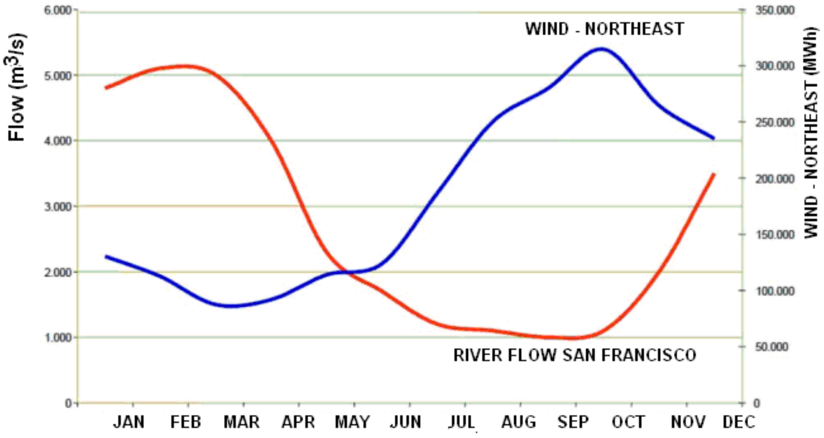

Figure 6 - Northeast wind generation and flow of the river San Francisco. Source: FIEB (2012).

Table 1 – Average Wind Generation to April/2015 by State in Brazil, for plant Type I and plant set.

State	Capacity Instaled (MW)	Average Generation (MW)	Average Capacity Factor (%)
Bahia – BA	911.3	314.6	34.52
Ceará – CE	996.5	147.2	14.77
Pernambuco – PE	79.9	28.9	36.13
R. Grande do Norte - RN	1928.6	439.2	22.77
R. Grande do Sul - RS	1210.9	266.1	21.97
Santa Catarina – SC	222.0	30.0	13.50
SIN	5349.1	1225.9	22.92

Source: adapted of ONS (2015)

Table 2 – Characteristics of maximum generation in some places of Brazil, date of occurrences, and the capacity factors – October/2014.

State	Plant	Nominal Power (MW)	Maximum generation in Month (10/2014)			Historical Maximum Generation		
			Data/hour	Value (MW)	CF (%)	Date/hour	Value (MW)	CF (%)
Ceara	Canoa Quebrada	57	18/10- 23:00	59.29	104.02	18/10/2014- 23:00	59.29	104.02
Ceara	Guajirú	30	17/10- 00:00	23.03	76.76	25/12/2013- 15:00	29.88	99.89
R.G. do Norte	Mangue Seco 2	26	04/10- 20:00	25.91	99.67	10/05/2012- 02:00	26.12	100.46
R.G. do Norte	Rei dos Ventos 3	60.12	02/10- 14:00	55.61	92.50	14/08/2014- 21:00	56.22	93.51
R.G. do Sul	Osório	50	04/10- 15:00	50.53	101.06	26/07/2013- 23:00	50.69	101.38
R.G. do Sul	Sangradouro	50	04/10- 13:00	50.21	100.43	24/09/2013- 05:00	50.62	101.24

Source: ONS (2014b).

5. CONCLUSIONS

Renewables will increase its stake in mainly sources offshore and onshore wind, thermal and solar photovoltaic global energy matrix. However, the power output of wind farms is intermittent and non-controllable. This affects the reliability, not ensuring a steady and safe supplying electric generation. When the wind power generation increases rapidly, other generating technologies must be able to reduce production in order to compensate. When the wind generation falls there must be other able to increase their production to replace the drop in wind technologiesIf this replacement does not occur the system becomes unstable and can generate even his fall. Of more than 373 GW of wind power installed around the world today the effective generation checked is much less, as well as the amount of CO2 avoided, usually reported as a major advantage of this enterprise. Nonrenewable sources will still be necessary until after 2035 to ensure the base load and complementarity between the sources of electricity generation and supply security during peak hours or intermediaries. It is necessary and already several ways of integrating wind and hydro, and solar thermal, solar, wind, nuclear and hydroelectric pumping is being studied, among other possibilities for a firm generation and energy security.

Finally, there are two possible basic technology options for electricity generation with reduced carbon emissions to a world with increasing demand for electricity. One option is to increase generation from sources that do not emit carbon or near zero emissions in its production of electric power, with renewables and nuclear as strong candidates.

The generation through clean technologies to capture carbon dioxide may be the second option. It is worth mentioning that the technology costs, construction time, fuel costs, costs of back-up, available reserves and costs of carbon credits that politics may impose will be determinants in choosing the right technologies that will dominate the future of generation electricity.

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7. REFERENCES

Abbasi, T., Premalatha, M., Abbasi, T., and Abbasi, S.A., 2014. “Wind Energy: Increasing Development, Rising Environmental Concerns”. Renewable and Sustainable Energy Reviews, Vol. 31, pp. 270–288.

ABEEOLICA, 2015. Quem somos. Associação Brasileira de Energia Eólica, Access in: 29 Jun 2015. <www.portalabeeolica.org.br>

Ackermann T., Söder, L., 2000. “Wind Energy Technology and Current Status: A Review”. Renewable and Sustainable Energy Reviews, Vol. 4, pp. 315–374.

Bazmi, A.A., and Zahedi, G., 2011. “Sustainable Energy Systems: Role of Optimization Modeling Techniques in Power Generation and Supply – A Review”. Renewable and Sustainable Energy Reviews, Vol. 15, pp. 3480–3500.

BP, 2015. Wind Energy. Renewable Energy. 29 Jun 2015 <http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy/review-by-energy-type/renewable-energy/wind-energy.html >

Duic, N., Alves, LM., Chen, F., and Carvalho, da G.M., 2003. “Potential of Kyoto Protocol Clean Development Mechanism in Transfer of Clean Energy Technologies to Small Island Developing States: Case Study of Cape Verde”. Renewable and Sustainable Energy Reviews, Vol. 7, pp. 83–98.

EWEA, 2015. Wind in power – 2014 European statistics. The European Wind Energy Association, February/2015.

FIEB, 2012. Energia Eólica – Potencial de Desenvolvimento da Bahia. Federação das Indústrias do Estado da Bahia, Superintendência de Desenvolvimento Industrial, Salvador-BA, Janeiro/2012.

Hebert, G.M. Joselin; Iniyan, S.; Amutha, D., 2014. “A Review of Technical Issues on the Development of Wind Farms”. Renewable and Sustainable Energy Reviews, Vol. 32, 619–641.

Ilkilic, C., 2012. “Wind Energy and Assessment of Wind Energy Potential in Turkey”. Renewable and Sustainable Energy Reviews, Vol. 16, pp. 1165–1173.

Islam, Md R., Guo, Y., and Zhu, J., 2014. “A Review of Offshore Wind Turbine Nacelle: Technical Challenges, and Reserch and Development Trends”. Renewable and Sustainable Energy Reviews, Vol. 33, pp. 161–176.

Jamel, M.S., Abd Rahman, A. and Shumsuddin, A.H., 2013. “Advances in the Integration of Solar Thermal Energy with Conventional and Non-Conventional Power Plants”. Renewable and Sustainable Energy Reviews, Vol. 20, pp. 71–81.

Kaygusuz K., 2010. “Sustainable Energy, Environmental and Agricultural Policies in Turkey”. Energy Conversion Management, Vol. 51, pp. 1075–1084.

Leung, D.Y.C. and Yang, Y., 2012. “Wind Energy Development and its Environmental Impact: A Review”. Renewable and Sustainable Energy Reviews, Vol. 16, pp. 1031–1039.

Lund, H., 2006. “The Kyoto Mechanisms and Technological Innovation”. Energy, Vol. 31, pp. 2325–2332.

Nagy, K. and Körmendi, K., 2012. “Use of Renewable Energy Sources in Light of the New Energy Strategy for Europe 2011- 2020”. Applied Energy, Vol. 96, pp. 393–399.

ONS, 2014a. Boletim Mensal de Geração Eólica – Julho/2014. Operador Nacional do Sistema Elétrico – ONS, Brasília-DF. Available in: <http://www.ons.org.br> Access in: 01 aug 2014.

ONS, 2014b. Boletim Mensal de Geração Eólica – October/2014. Operador Nacional do Sistema Elétrico – ONS, Brasilia-DF. Available in: <http://www.ons.org.br> Access in: 01 jun 2015.

ONS, 2015. Boletim Mensal de Geração Eólica – Abril/2015. Operador Nacional do Sistema Elétrico – ONS, Brasilia-DF. Available in: <http://www.ons.org.br> Access in: 28 jun 2015.

Patel, S., 2013. IEA: Wind Power Could Supply 18% of World’s Power by 2050. Power Magazine, Electric Power, 12/01/2013. < http://www.powermag.com/iea-wind-power-could-supply-18-of-worlds-power-by-2050>

Siemens, 2013. Inauguração do Maior Parque Eólico Offshore Equipado com 175 Turbinas Siemens. Press Release, http://www.siemens.pt .

Snyder, B., and Kaiser, M.J., 2009. "A Comparison of Offshore Wind Power Development in Europe and the US: Patterns and Drivers of Development". Applied Energy, Vol. 86, pp. 1845–1856.

World Wind Energy Association (WWEA). World wind energy report 2008. http://www.wwindea.org.

Zhang, H., Li, L., Cao, J., Zhao, M., and Wu, Q., 2011. "Comparison of Renewable Energy Policy Evolution Among the BRICs". Renewable and Sustainable Energy Reviews, Vol. 15, pp. 4904–4909.

Zhixin, W., Chuanwen, J., Oian, A., and Chengmin, W., 2009. "The Key Technology of Offshore Wind Farm and its New Development in China". Renewable and Sustainable Energy Reviews, Vol. 13, 216–222.

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