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Renewable Sources Potential Analysis in the Electrical Matrix of Paraná State – Brazil

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One of the key issues for sustainable development is the generation of electricity with more use of renewable sources, and less environmental degradation. Historically the Paraná State of Brazil has been one of the largest producers of electricity in the country, almost entirely from hydropower. However the use of this source in Paraná State is declining due to depletion of water potential and also the pressure of society with respect to environmental, social and economic impacts caused by damming of rivers and flooding of cities and areas to form large reservoirs, hindering increasing its expansion in the electrical matrix. To overcome these limitations, other sources have been researched such as wind, biomass and photovoltaic. The improvement and application of new technologies for generating electricity using an integrated and distributed system may result in a gain on a large scale in the environmental, social and financial aspects. In this context, this paper aims to present an analysis of the potential for electricity generation from renewable sources in the State of Parana - Brazil. The results of this analysis may contribute to development of policies for incentives for research and development projects for the dissemination of renewable sources in the State of Paraná.

1. Introduction

The concept of sustainable development is a long process of review of the relationship between society and the environment, and as a continuous process several approaches try to explain this concept, which initially this topic was discussed by the World Conservation Union through the document World's Conservation Strategy. This estudy suggests that for a sustainable development, should be considered the social and ecological dimensions as well as economic aspects of living and nonliving resources. With the development of the Brundtland Report, the concept of sustainable development was formally defined and published, intending to generate among environmental, economic and social dimensions (Van Bellen, 2006).
According to Glenn et al. (2011), there is a forecast to a significant increase in the per capita income by 2030 globally. This increase in income can result in higher consumption by energy sources, due to the improved quality of life and greater population affording possibilities, causing it acquires consumer goods hitherto inaccessible.
Within these aspects, the planning of the energy sector is extremely important to ensure continuity of energy supply to the society at less cost, lowest risk of shortages, and with the lowest socioeconomic and environmental impacts, and a significant portion is aimed at generating electricity, essential for the current stage of society development, that comes from several sources of energy, renewable and nonrenewable (Tiepolo et al., 2012).

Currently, the electrical power generation in a global way is mainly based on fossil fuels. There is an tendency that this will decrease participation in the world electric matrix, mainly due to a greater awareness and pressure from the society to search for renewable energy sources.
The data presented in REN21 (2010, 2011, 2012) show that the share of fossil and nuclear power in the electric global energy are very expressive, showing a slight downward tendency data analyzed from 2008 to 2011. During the same time is also shown a trend of increased participation from other renewable sources for electricity generation.
The main source of energy in Brazil comes from hydropower, mainly because of the potential available in large river basins, followed by other sources such as fossil fuel and nuclear, and non-hydraulic sources like biomass and wind, and negligible participation of solar in the electric matrix (MME, 2012). However, comparing data from 2011 and 2012 (MME, 2013b), it can be noticed in the Brazilian energy matrix an increase in the share of renewable sources non-hydraulic, a decrease in the share of hydropower, and increase in the share of fossil fuel and nuclear. The share of energy sources in the electricity production in the Global and Brazilian energy matrix is shown in Table 1.

Table 1: Energy share of global electricity production by energy source for years 2008, 2010, 2011, and Brazil for years 2011 e 2012. Source: REN21 (2010, 2011, 2012), MME (2012), MME (2013b)

	REN21 - RENEWABLE ENERGY POLICY NETWORK / RENEWABLES GLOBAL STATUS REPORT (GSR)			*BRAZILIAN ENERGY BALANCE 2012 reference 2011 - %*	*BRAZILIAN ENERGY BALANCE 2013 reference 2012 - %*
SOURCE TYPE	*REN21 2010 reference 2008 - %*	*REN21 2011 reference 2010 - %*	*REN21 2012 reference 2011 - %*		
Fossil fuel and Nuclear	82.0	80.6	79.7	11.0	15.5
Hydropower	15.0	16.1	15.3	81.9	76.9
Other Renewables (non-hydro)	3.0	3.3	5.0	7.1	7.7
TOTAL	100.0	100.0	100.0	100.0	100.0

The state of Paraná is one of the largest producers of electricity through hydropower, due to the large basin existing in the state, with a pre-disposition for analysis and application of other sources such as biomass, wind and solar photovoltaic. However, new hydropower are increasingly rare, hindering its expansion in the energy matrix of the state due to depletion of water potential and also the pressure of society about the caused environmental, social and economic impacts to form large reservoirs .
This search was conducted as follows: a brief explanation of renewable sources for electricity generation in Paraná and its potential. Then an analysis of the values found will be held and what it represents in the energy matrix of the state of Paraná, and at the end the conclusions on this study will be presented.

2. Methodology

The State of Paraná is located south of Brazil, with an area of 199,880 km², with a population of 10,440,526 habitants distributed in 399 counties, and presented in 2010 consumption of electricity of approximately 25.17 TWh (IPARDES 2010).
According to the BEN (2013), the State of Paraná an Installed Capacity of Electricity Generation of 17.14 GW, distributed as follows by type of energy source: Hydraulic - 93.15 %, Wind - 0.02 %, Thermal - 6.84 %, Nuclear – 0 %, and other sources such as biomass and solar with negligible values.

2.1 Hydraulic Generation Potential

The State of Paraná has a Hydraulic Potential of 24.12 GW. Adding to the projects in operation with the construction, it is estimated that almost 70 % of this potential has already been exploited, which hamper the implementation of new projects (BEN, 2013).
Assuming an average capacity factor used in hydroelectric power plants of 53 %, it can be said that the hydropower potential estimated could generate about 112 TWh / year. However exploring 100 % of the hydropower potential estimated is socially and economically impossible, it implies large displacement or destruction of highly threatened ecosystems.

2.2 Biomass Generation Potential

According to Gupta and Demirbas (2010), biomass usually refers to wood, wood waste, grass, short rotation woody and herbaceous crops, bagasse, industrial residues, waste paper, waste from food

processing, aquatic plants, among others, and similar materials with energy value and that can be converted into mechanical, thermal or electric energy. The fossil fuels are excluded from the biomass definition, mainly because the use of fossil fuels causes an increase in CO^2 concentration in the atmosphere, and on the other hand, the CO^2 released during combustion of biofuel is removed from the environment by photosynthesis during the production of biomass.
In Brazil, many forms of electricity generation from biomass has been investigated, including the residual biomass. According to Bley et al. (2009), in the residual biomass is formed by plant remains unusable for consumption or plant such as grains, seeds, straw, and the solid and liquid effluents from the production livestock, which are biodegradable, such as manure, manure, among others. In this study, it was estimated a potential of producing electricity from residual biomass of animals from the biogas generated is 12 TWh / year.
In relation to Parana State, according to Souza et al. (2002), the estimated technical potential to produce electricity only vegetable waste is 108,619,490 GJ / year, equivalent to 30.16 TWh / year, and were not considered in this study other types of waste.

2.3 Wind Generation Potential

According CRESESB (2001), the Brazilian Wind Potential is estimated at 143.47 GW, with annual production of electricity estimated 272.20 TWh. The values were designed taking into account the mean performance curves of wind turbines on towers 50 meters high, which is much lower than the current standards. Of this total, northeast region is the one with the most potential, representing approximately 50 % of the total estimated potential in Brazil.
Regarding the Wind Power Potential in the state of Paraná, according to COPEL (2007), to wind turbines on towers 50 meters high, the estimated capacity is 312 MW, and estimated electricity production is 847 GWh / year. To turbines 75 meters high, the estimated capacity is 1,363 MW and estimated electricity production is 3,756 GWh / year, while for turbines 100 meters high, the estimated capacity is 3,375 MW and estimated electricity production is 9,386 GWh / year.

2.4 Solar Photovoltaic Generation Potential

The Grid connected photovoltaic (PV) systems presents a new concept of generation of clean and renewable energy, with a total global capacity installed in 2012 reached close to 100 GW, and of these approximately 33 GW installed in Germany (IEA, 2013).
In Brazil there is not yet a significant number of relevant projects employing PV systems, which complicates the analysis of the impact on the electrical system. Much of the investment in PV systems in the Europe, happened thanks to public policies adopted incentives to promote the development of photovoltaic technology. Following this trend, it is expected that the same will happen in Brazil.
In face these difficulties, in 2012 was published in Brazil the 482 / 2012 regulation of ANEEL (Brazilian Electricity Regulatory Agency), which regulates and allows consumers of electricity generating part or all of the electrical energy they consume through sources of electricity connected to the distribution network, limited up to 1 MW in the energy compensation model (net metering) (ANEEL, 2012). The PV systems deployed in Brazil in 2012 surpassed the 8 MW (MME, 2013a), much higher than the existing 161.3 kW by 2009 (Benedito and Zilles, 2010), but far below the installed capacity in other countries, mainly Europeans with values of the order of tens of GW.
In the state of Paraná until December 2013 had only two PV systems implanted. In a Technological Federal University of Paraná of 2.1 kW (installed in december 2011 before Resolution 482 / 2012), and another of 8.64 kW in ELCO company (approved in october 2013), this being the first link "on-grid" PV system in Parana following the ANEEL regulation. However, these initiatives are still very small. According Tiepolo et al. (2013), considering the annual average and the winter average in the Paraná, the electric energy production through photovoltaic source respectively are 52 % and 40 % higher than the average value shown in Germany, demonstrating the potential of this source in state of Parana.
The Figure 1 shows the PV maps of the state of Paraná - Brazil and Czech Republic, the ideal conditions for generation of electricity: potential solar electricity (kWh / kWp) generated by a 1kWp system per year with photovoltaic modules mounted at an optimum inclination and assuming system performance ratio 0.75.
According to Suri et al. (2007), Huld et al. (2012) and Tiepolo et al. (2014), as also showed in Figure 1, were found the values of estimated yearly sum of solar electricity generated:
- Paraná State (Brazil): between 1,200 and 1,650 kWh / kWp;
- Czech Republic: between 825 and 1,013 kWh / kWp.

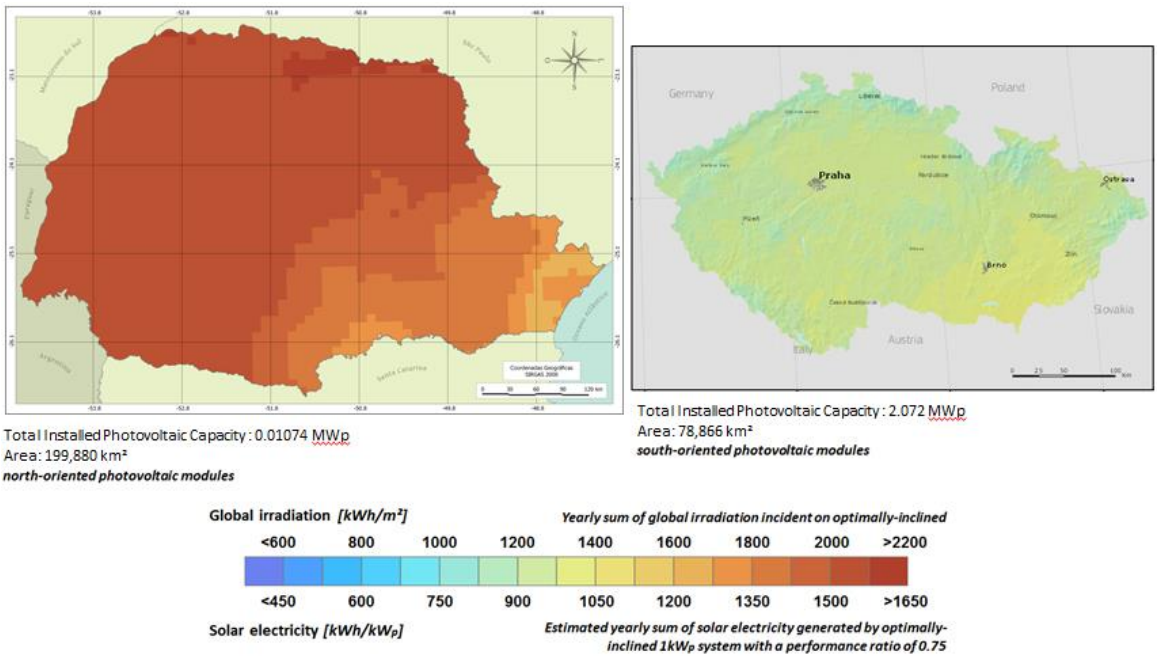

Figure 1. Solar irradiation and estimated photovoltaic electricity generation maps for Paraná State and Czech Republic. Source: European Map adapted from Šúri et al. (2007), Huld et al. (2012), and State of Paraná Map adapted from Tiepolo et al. (2014)

3. Results and Discussion

In the state of Paraná, 93.15 % of capacity installed generation of electricity is hydropower, which represents approximately 15.97 GW. Considering that Total Hydraulic Potential in Paraná is 24.12 GW, close to 70% of this potential is already being exploited. Assuming an average capacity factor of 53 % from hydropower plants, is possible to generate 112 TWh / year.

Analyzing the potential for biomass, the values indicate the possibility of generating 30.16 TWh, value higher than the annual demand of the state. However this estimated potential is partial, since not all wastes were used in this estimate, as is the case of forest wood, municipal solid waste, and waste from the production of pigs and poultry, requiring further studies.

As for wind generation potential, the values found were 3,375 MW of power and 9.39 TWh / year estimated production of electricity, to turbines 100 meters high where the frequency of winds is larger.

Analyzing the potential photovoltaic in Paraná State - Brazil, and the respective estimated electricity generated, one realizes the great potential of the state of Paraná, whose values are found on average 54 % higher than in Czech Republic.

Have been developed three Sceneries of a possible photovoltaic potential that could be installed in the state of Paraná: In the Scenery1, it was considered an Installed capacity 2,000 MW, equal to that found in Czech Republic in the year 2012. In the Scenery2, it was considered an Installed Capacity of 3,375 MW, equal to the estimated wind potential in state of Paraná. In the Scenery3, it was considered an installed capacity of 33,000 MW, equal to that found in photovoltaic systems in the Germany in the year 2012.

To determine the total estimated electricity generated in each Scenery, in case of PV system it was considered a solar electricity potential average of Paraná State of 1,492 kWh / kWp.

With the information collected and scenery elaborate, Table 2 was prepared summarizing the potential by type of renewable source researched.

According to the data presented in Table 2, the renewable generation potential estimated in the Paraná State is 155 TWh / year for Scenery1, 157 TWh / year for Scenery2, and 201 TWh / year for Scenery3.

Table 2: Potential estimated in Paraná State. Source: adapted from BEN (2013), Souza et al. (2002), COPEL (2007), Tiepolo et al. (2014)

STATE OF PARANÁ - ESTIMATED POTENTIAL		
SOURCE	*POWER (MW)*	*ENERGY ESTIMATED (TWh / year)*
Hidraulic	24,120	112
Biomass	not available	30
Wind	3,375	10
Solar Photovoltaic - Scenery1	2,000	3
Solar Photovoltaic - Scenery2	3,375	5
Solar Photovoltaic - Scenery3	33,000	49

4. Conclusion

The objective of this research was to present an initial analysis of the potential for electricity generation from renewable energy sources in the state of Paraná, Brazil. Bucking the global trend, it was observed that in Brazil there was a decrease in the share of hydraulic sources, with a small increase renewable sources (not hydro), and significant increase of non-renewable sources. Although this may be due to lack of rain to fill the reservoirs, shows a certain weakness of the system due to the dependence on this source, accounting for 76.9% of the electricity generated in 2012.

In Paraná state this dependence is larger, with 93.13 % of all current installed capacity. However almost 70 % has been explored, which makes it practically impossible install large hydropower plants, limiting the rest of this potential to be explored with the installation of small hydropower plants.

According to the study, the biomass generation potential is 30.16 TWh / year, while the wind generation potential is 9.39 TWh / year. The sum of the estimated potential of these two sources would be sufficient to meet the demand of the state of Paraná, which in 2010 was 25.17 TWh.

The solar photovoltaic presents lower investment in research and development in Paraná State, despite the great potential in the state, with potential for electric generation 50 % higher than countries like Germany and Czech Republic.

As a final conclusion, it was showed the great potential in Paraná for the generation of electricity through renewable energy sources. However, further studies should be performed, due to the depletion of hidraulic potential in Paraná, and the necessity to meet the growing demand for electricity.

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