CHEMICAL ENGINEERING TRANSACTIONS
VOL. 35, 2013

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editors: Petar Varbanov, Jiří Klemeš, Panos Seferlis, Athanasios I. Papadopoulos, Spyros Voutetakis

ISBN 978-88-95608-26-6; **ISSN** 1974-9791
DOI: 10.3303/CET1335100

Analysis of the Electricity Generation Potential by Solar Photovoltaic Source in the State of Paraná – Brazil

Gerson Maximo Tiepolo[a,b], Osiris Canciglieri Junior[b,]*, Jair Urbanetz Junior[a]

[a]Department of Electrical Engineering, Technological Federal University of Paraná – UTFPR, Avenida Sete de Setembro 3165, Rebouças, CEP 80230-901, Curitiba, Paraná, Brazil
[b]Graduate Program in Production Engineering and Systems – PPGEPS, Pontifical Catholic University of Parana-PUCPR, Rua Imaculada Conceição 115, CEP 80215-901, Curitiba, Paraná, Brazil
osiris.canciglieri@pucpr.br

The theme of Sustainable Development has gained more and repercussion in the society spheres contributing to a greater awareness of the need for natural resources conservation and in the challenge of keeping promoting the socio - economic development of all the regions. One of the key issues for the development in a modern society is the electric power generation and in the current time, the increasing use of renewable energy with less harm to the environment. In this scenario, the state of Paraná historically has been one of the largest producers of electricity from renewable sources in Brazil, almost entirely through hydroelectric plants due to the large watershed in the state. However, this source is in decline due to the hydric potential exhaustion, and also due to the pressure from society related to the environmental, social and economic impact. To overcome these limitations, other sources have been researched and among them, the photovoltaic. Recently, the ANEEL (Brazilian Electricity Regulatory Agency) regulated the electricity generation through Grid-connected Photovoltaic Power Systems. These systems have been widely employed in the urban environment as electricity generators near to the distributed point of consumption as they usually require no additional area, since they can be installed on the roof of the building or be integrated in it. They are intensely applied in many countries, especially in Europe, where the hydric resources are limited. This paper aims to present the Photovoltaic Map of the Paraná State (Brazil) which represents the potential for generating electricity through Grid-connected Photovoltaic Power System with values concerning to the annual daily averages and the seasonal daily averages. For comparison, it was used data from Germany Photovoltaic Map that is one of the largest country with potential installed capacity with the objective to demonstrate the potential obtained in Paraná.
This information may enable the creation of specific programs to improve research and development of this important renewable energy source in the State of Paraná.

1. Introduction

In Brazil the main generation source of electricity comes from hydropower as it is considered a source of low cost since there is large number of river basins. However, the environmental impacts generated by these plants implantation has been increasingly under discussion as it is necessary to flood vast areas to create the reservoir which supplies the water that moves the turbines of the generators (Urbanetz, 2010). There are others impacts that normally occur during the plant implantation, such as the social, since the residents of the flooded areas must be transferred to other places that not always have the same infrastructure, as well as the financial impact of the affected region. However, the use of this source is declining due to the hydric potential exhaustion, and also due to the pressure from society related to the environmental, social and economic impact occasioned by its installation. To overcome these limitations, other sources have been studied and applied such as the biomass, the wind and photovoltaic. Recently, as a function of the Call No. 13/2011 and the Resolution 482/2012, both from ANEEL (Brazilian Electricity Regulatory Agency) there was the regulation of the electricity generation through Grid-connected Photovoltaic Power Systems.

Please cite this article as: Tiepolo G.M., Canciglieri Junior O., Urbanetz Junior J., 2013, Analysis of the electricity generation potential by solar photovoltaic source in the state of paraná – brazil, Chemical Engineering Transactions, 35, 601-606 DOI:10.3303/CET1335100

The solar PV in Brazil still requires more investments. Several studies about this energy source are being developed in universities over the country. However, the financial support for projects of electricity generation, through public and private initiatives, is still incipient. In Europe, most of the investments occurred because of the public policies adopted and consequently the subsidies provided to incremented the investments in this technology. For this purpose the sustainable development and the reduction of greenhouse gas emissions are matters of great concern in current scenario (Sha et al., 2013).

Following this tendency, the same is expected to happen in Brazil, although the country's situation concerning to the water reserves still influences on the aspect of temporarily postponing the more pronounced public policy investments in other sources.

In 2011, the Brazilian Electricity Regulatory Agency - ANEEL released the Call No. 13/2011 - Strategic Project: "Technical and commercial arrangements for solar photovoltaic generation insertion in the Brazilian energy matrix", which foresees the addition of 24.58 MWp of installed power, with four approved projects related to the Solar Stadiums for the 2014 World Cup program (ANEEL, 2011). In the following year, it was enacted the 482/2012 regulation, also from ANEEL, and so that it begins the era of the distributed micro and mini generation in Brazil, that has allowed the electricity consumers generate part or all of their potential of electrical consumption using photovoltaic generators that work alongside the distribution network, under the energy exchange scheme. In this regulation was stipulated the type and maximum power of the generators and their respective generation category, where: for micro generation the generators have power up to 100 kWp (kilowatt peak); for mini generation, it is systems with an output exceeding 100 kWp up to 1 MWp (ANEEL, 2012). Therewith, some initiatives have already begun to be implemented in 2011 and 2012, making the total implanted in Brazil exceeded the 3 MWp, which is a value well below of those existing in other countries, especially the Europeans ones.

In terms of Brazil, the State of Paraná is one of the largest producers of electricity through hydropower due to the large number of rivers basins, but has a pre-disposition for analysis and application of other sources such as biomass, wind and photovoltaic power. In relation to the photovoltaic source applications and studies are in the embryonic phase, requiring from the State of Parana more investment in this sector.

Based on that, this study was developed comparing the solar radiation values found in Brazil, more specifically in the State of Parana, with the values from Germany. Then it is presented the way that the Photovoltaic Map of State of Paraná, Brazil was drawn and the respective radiation values concerning to the annual daily averages and the seasonal daily averages with the analysis of these results. Finally, it is presented the final conclusions.

2. Solar Radiation

Brazil is privileged in terms of incidence of solar radiation when compared with European countries that lead the installed capacity of the Grid-connected Photovoltaic Power Systems. An advantage that using grid connected photovoltaic (PV) systems can greatly enhance the performance of conventional utility grid system (Ghoneim, 2012). The values of solar radiation found in the Brazilian Atlas of Solar Energy - 2006, as noted in Figure 1, indicate the country's vocation for electricity generation through solar photovoltaic source.

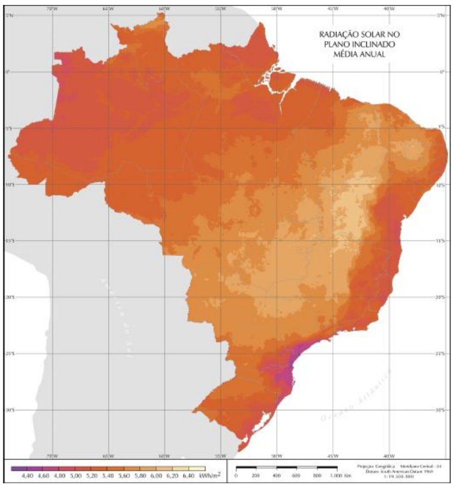

Figure 1: Global Solar Radiation Map on Inclined Plane - Annual Average (Pereira et al., 2006).

The Brazilian Atlas of Solar Energy - 2006 presented in Figure 1 shows the annual average of the daily total of solar radiation on the inclined plane incident in the Brazilian territory, with values ranging between 1,500 kWh/m².year and 2,500 kWh/m².year (Pereira et al., 2006).

Comparatively, using Germany as example, where until 2011 the installed capacity reached nearly 25 GWp. Rüther (2004) shows that the solar radiation levels found there are approximately 40 % lower than those obtained in Brazil and this value was confirmed by Tiepolo et al. (2013) specifically in the State of Paraná. The German solar radiation map in kWh/m².y and the electric energy productivity in kWh/kWp of can observed in Figure 2, which shows radiation values ranging approximately between 1,050 kWh/m².y and 1450 kWh/m².y.

Through this information, it can be observed more clearly the potential of the Brazilian territory to generate electricity through photovoltaic panels. This research presents the productive potential of the State of Paraná, located in southern region of Brazil. Figure 3 shows the location of the State of Paraná, Brazil.

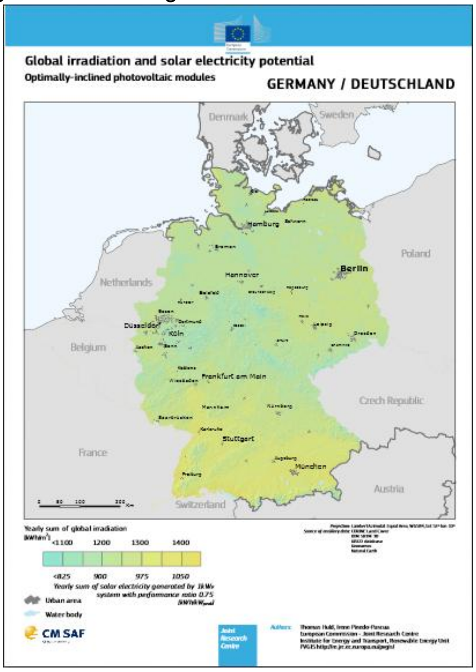

Figure 2: Solar Map of Germany (European Commission, 2013).

Figure 3: The location of the State of Paraná, Brazil. Google Earth.

3. Determination of the electricity generation potential in the State of Paraná through solar photovoltaic power

In this research were selected 48 cities in the State of Paraná in a sample form, distributed as evenly as possible, to cover all regions of the state. Figure 4 shows the State of Paraná Map with the identification of the cities used as basis of the research.

For each of the selected location it was identified its latitude and longitude according to the register of the Google Earth application. Based on these coordinates it were identified the radiation values using the database of the Brazilian Atlas of Solar Energy - 2006 for the inclined plane as to obtain a better performance of the Grid-connected Photovoltaic Power System, they have to be inclined as the local latitude where it will be implanted.

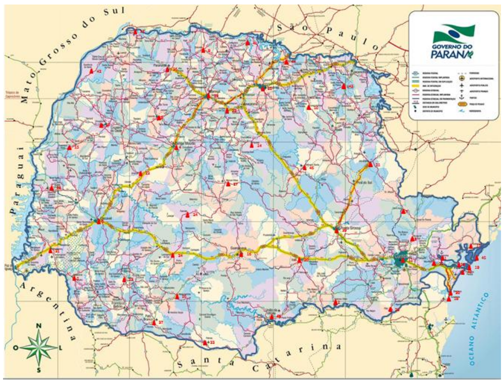

Figure 4: State of Paraná Map with the researched 48 locations (State of Paraná map – Brazil, 2013).

To obtain the predicted values of electricity generation in each of the locations, it was considered the following requirements:

- System Potency: 1 kWp;
- Performance Ratio: 75 %;
- G_{STC}: 1 kW/m²;
- Inclination of the PV system: accompanies the latitude of the studied area (greater production of electricity for Grid-connected Photovoltaic Power Systems);
- The PV system orientation: oriented to True North (geographical), for countries located in the Southern hemisphere.

From the information generated by the map to 1 kWp systems, it is possible to determine the predicted values of power generation for any potency of photovoltaic system to be installed in any of the regions of the state. The PV map of the State of Paraná, Brazil with the values concerning to the annual daily averages is presented in Figure 5 while in Figure 6 it is presented the maps with seasonal daily averages.

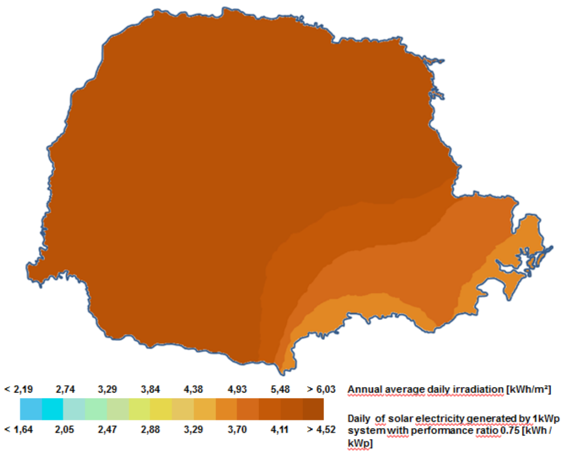

Figure 5: Photovoltaic Map of the State of Paraná, Brazil

The Performance Ratio is the relationship between the Yield (kWh / kWp) and the number of sunshine hours to 1,000 W/m² incidents in PV panel, usually linked to a year of operation, this magnitude is expressed in percentage (Urbanetz et al., 2012). Otherwise, it is possible also to say that this value represents the performance discounting losses in the system such as: losses in the inverters, in the connections, and particularly losses due to the temperature elevation in the modules because of the ambient temperature.

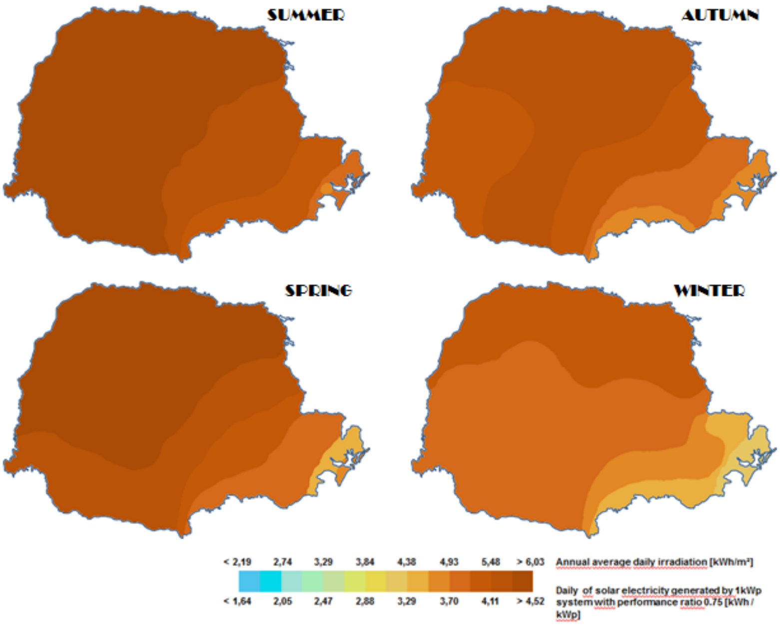

Figure 6: Photovoltaic Map of the State of Paraná, Brazil. Seasonal Daily Averages (complied by the author)

The values of daily power generation planned for each of the localities were calculated through the established criteria.

It is important to point out that these criteria are the same used for the elaboration of the photovoltaic maps by the European Commission: 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 (European Commission, 2013).

Based on these calculations, it is possible to verify the distribution of the values of electric energy annual daily averages in kWh, for every 1 kWp implanted, where the following values were found:

- Lower electricity value: 3.50 kWh/d;
- Higher electricity value: 4.32 kWh/d.

4. Analysis of the results

Through the Photovoltaic Map of the State of Paraná, Brazil it was found productivity values between 3.50 and 4.32 kWh/kWp for an average day of the year. Considering the seasonal photovoltaic maps for the State of Paraná, Brazil, it was found, also the follow productivity values for an average day of the evaluated period:

- Spring: between 3.29 and 4.52 kWh/kWp;
- Summer: between 3.50 and 4.52 kWh/kWp;
- Autumn : between 3.50 and 4.32 kWh/kWp;
- Winter: between 3.09 and 4.11 kWh/kWp.

Analysing the German photovoltaic map, the productivity values found were 2.16 and 2.98 kWh/kWp for an average day of the year. It is observed in the data presented in Paraná, Brazil that even during the winter where the values of radiation are much smaller in comparison to other periods of the year, the productivity values for an average day (between 3.09 and 4.11 kWh/kWp) still outweigh the productivity values for an average day of the year in Germany (between 2.16 and 2.98 kWh/kWp).

If the daily average of the presented values is considered, the values are:

- Annual average in Germany: 2.57 kWh/kWp;
- Annual average in Paraná, Brazil: 3.91 kWh/kWp;
- Average during the winter in Paraná, Brazil: 3.6 kWh/kWp.

Considering the values of the installed power of Grid-connected Photovoltaic Power Systems in Germany by 2011 approximately 25 GW, and the average productivity calculated previously, it results in an estimated daily generation average of electricity for this potency:

- Germany: 64.3 GWh/d;
- Paraná, Brazil: 97.8 GWh/d;
- Paraná, Brazil – winter's time: 90 GWh/d.

Therefore, considering the annual average of Paraná and the average during the winter, the electric energy production through photovoltaic source are respectively 52 % and 40 % higher than the average value shown in Germany, demonstrating the potential of this source in State of Paraná, Brazil.

5. Conclusion

The research objective was to present an initial analysis of the productive potential through Grid-connected Photovoltaic Power Systems for the State of Paraná, Brazil.

The selection of 48 cities allowed that, valuable information could be obtained, in a sample form, regarding to the potential for the generation of electricity in each identified region.

The elaboration of the Photovoltaic Map of the State of Paraná, Brazil enables the perception of the regions and their different potential of electricity generation, identifying the different values of generated electricity for each region, predicted annually for each 1 kWp installed, according to the assumptions defined and with performance ratio of 0.75 both annually and seasonally.

The development of the Photovoltaic Map of the State of Paraná, Brazil, within the criteria established by the European Commission, enables the comparison of the results with other photovoltaic maps of the European countries, as Germany in this research case.

The photovoltaic maps with the radiation and productivity seasonal daily averages show that even in periods with less solar incidence (winter) the values presented were higher than the values found in Germany.

The objective of the comparison with Germany values (the country with the largest installed PV power) is not coincidental, but to promote the awareness for the necessity of creating specific programs to encourage research and development of this important renewable energy source in the State of Paraná, Brazil.

References

ANEEL, 2011, Strategic Project- Call No. 13/2011: technical and commercial arrangements for insertion of solar photovoltaic generation in Brazilian energy matrix (in Portuguese). <www.aneel.gov.br/arquivos/PDF/PeD_2011-ChamadaPE13-2011.pdf>, accessed 10/04/2013.

ANEEL, 2012, Regulations for solar photovoltaic energy (in Portuguese). <www.aneel.gov.br/ aplicacoes/noticias/Output_Noticias.cfm?Identidade=5457&id_area=90>, accessed 10/04/2013.

European Commission, Photovoltaic Geographical Information System (PVGIS), Solar radiation and photovoltaic electricity potential country and regional maps for Europe (in English). <re.jrc.ec.europa.eu/pvgis/cmaps/eur.htm>, accessed 14/02/2013.

Ghoneim A. A., 2012, Environmental impacts of grid connected photovoltaic system adapted for peak load reduction in Kuwait, Chemical Engineering Transactions, 29, 1213-1218, DOI: 10.3303/CET1229203.

Map of the State of Paraná, 2013, Brazil (in Portuguese) <www.guiageo-parana.com/mapa-parana.htm>, accessed 03/2013.

Pereira, E. B., Martins, F. R., S. Abreu L., R. Ruther, 2006. Brazilian Solar Energy Atlas, São José dos Campos, Issue 1, p. 34, (in Portuguese), <www.ccst.inpe.br/wp-content/themes/ccst-2.0/pdf/atlas_solar-reduced.pdf>, accessed 13/12/2013.

Rüther, R., 2004, Photovoltaic Solar Buildings: The Potential of Solar Photovoltaic Generation integrated to the Urban Buildings and Interconnected to the Public Power System (in Portuguese). UFSC Publishing House, Florianópolis, Brazil.

Tiepolo, G. M., Urbanetz JR, J., Canciglieri JR, O., 2013, "Insertion of Photovoltaic Energy in Parana State Electric Matrix: Analysis of the Productive Potential". (in Portuguese), SODEBRAS Magazine, 8, 30-37.

Urbanetz J., 2010. Photovoltaic Systems Connected to the Urban Distribution Networks: Their Influence on Electrical Energy Quality and Analysis of the Parameters That May Affect Connectivity, Doctoral Thesis (in Portuguese), UFSC, Florianópolis, Brazil.

Urbanetz J.E., Casagrande F., 2012, Photovoltaic System Connected to the Grid of the UTFPR Green Office, (in Portuguese), UTFPR CBPE VIII - Brazilian Conference on Energy Planning, Curitiba, Brazil.

Sha S., Melin K., Hurme M., 2013, Computer aided solar energy based sustainability evaluations in process design, Chemical Engineering Transactions, 32, 1225-1230, DOI: 10.3303/CET1332205.