Vol.61, no.spe: e18000340, 2018
http://dx.doi.org/10.1590/1678-4324-smart-2018000340
ISSN 1678-4324 Online Edition

Smart Energy

BRAZILIAN ARCHIVES OF
BIOLOGY AND TECHNOLOGY

A N   I N T E R N A T I O N A L   J O U R N A L

Mapping and Characterization of the Grid-connected Photovoltaic Systems in the City of Curitiba: Preliminary Results

Bruno Sabino Scolari [1*], Édwin Augusto Tonolo [1], Roberto Chun Yan Pan [1], Jair Urbanetz Júnior [1,2]

[1] Programa de Pós-Graduação em Engenharia Civil, Universidade Tecnológica Federal do Paraná, Curitiba, Paraná, Brasil. [2] Programa de Pós-Graduação em Sistemas de Energia, Universidade Tecnológica Federal do Paraná, Curitiba, Paraná, Brasil

ABSTRACT

This work presents the mapping of grid-connected photovoltaic systems supported by the Normative Resolution (NR) of the National Agency of Electric Energy (ANEEL) Nº 482/2012 in the city of Curitiba. Firstly, a brief introduction was made justifying the reasons that led to the development of this study, followed by the explanation about the methodology, procedures and criteria adopted in the study. A general mapping of all on-grid photovoltaic systems supported by NR Nº 482/2012 installed in the city of Curitiba, identified by class, is presented, indicating how the urban distribution of these photovoltaic systems occurs, and it is possible to observe in which regions the highest prevalence of installations occurs. From this, the general characterization of these photovoltaic systems is performed, classifying them by class, number of installed systems, power, number of modules, total occupied area, average power of modules and average efficiency of photovoltaic systems. Considerations are also raised regarding the reliability of the Database of Distributed Generation Consumer Units made available by ANEEL.

Key words: Photovoltaic Solar Energy, grid connected photovoltaic systems, Normative Resolution ANEEL Nº 482/2012.

[*] Author of correspondence: brunoengutfpr@gmail.com

INTRODUCTION

The year 2012 was an important milestone for the dissemination of Photovoltaic Solar Energy (PV) in Brazil. The publication of the Normative Resolution (REN) Nº 482, of April 17th, 2012 by the National Electric Energy Agency (ANEEL) and its subsequent update through REN Nº 687, of November 24 th, 2015 of the same agency, established the general conditions for the access of distributed micro and mini generation to the distribution systems of electric power, and the system of compensation of electric energy [1].

In practice, this resolution allowed small residential consumers to large industrial consumers to install grid-connected photovoltaic systems (GCPVS) in their own consuming units (CU) with reduced bureaucracy. In addition, the resolution has implemented the Electric Energy Compensation System, in which the electric energy generated and not consumed by the CU at a given moment can be injected into the distribution system of the local distributor and subsequently compensated at times when the CU is not generating electricity through the photovoltaic system (SFV). These two factors have made the usage of PV solar energy for small and medium-sized consumers in large scale feasible.

Prior to the publication of REN, the grid-connected photovoltaic systems installation was restricted to specific uses of distributors and for research and testing in universities and industries. In just five years of REN's approval, the dissemination of grid-connected photovoltaic systems in residential, commercial and industrial small consumers can be noted. Table 1 shows the increase of grid-connected photovoltaic systems facilities supported by REN Nº 482 in these six years. The amount of PV systems is represented by the letters PV, and Kw represents the total power in the installations.

Table 1 - GCPVS supported by REN No. 482/2012 added per year

Year	2012		2013		2014		2015		2016		2017*		TOTAL*	
Locus	PV	Kw	PV	kW	PV	kW	PV	kW	PV	kW	PV	kW	PV	kW
Brazil	1	403	51	1.340	277	2.362	1.390	9.111	5.981	47.716	3.040	22.987	10.740	83.919
Paraná	0	0	2	4	15	87	108	559	538	3.315	221	1.400	884	5.365
Curitiba	0	0	1	2	5	49	30	170	97	377	37	157	170	754

Source: Compilation of authors' data, based on reference [2].
* Until June 5, 2017.

The Ten-Year Energy Expansion Plan (PDE) 2024 estimates that the installed capacity for photovoltaic generation reaches 8.300 MW by 2024, with 7.000 MW of centralized generation and 1.300 MW of distributed generation. The proportion of PV generation will reach 1% of the total [3].

Studies of the National Energy Plan (NEP) 2050, prepared by the Energy Research Company (EPE), estimate that 18% of homes in 2050 will have photovoltaic generation, which will supply 13% of residential consumption [3].

These projections are corroborated by studies [4] that have already technically confirmed the applicability of distributed PV generation in urban environments.

From the point of view of photovoltaic generation potential, Brazil and, more specifically the state of Paraná, have Annual Irradiation and Total Productivity values significantly higher than those obtained in European countries such as Germany, Italy and Spain, which together represent 54% of the installed power of photovoltaic energy in the world [5] [6].

Even the city of Curitiba, known for its cold and rainy weather, has an average irradiance of only 8.6% lower than the average in Brazil [7].
Researches with an approach to economic viability [8] have also confirmed the feasibility of grid-connected photovoltaic systems for small consumers. However, the high cost of the installation and lack of government incentives end up restricting its access to the higher classes, which in turn, causes the expansion of installed PV systems to occur at a slower speed than it could in more favorable circumstances.
In order for this expansion to take place in an orderly manner and to be improved in its technical, urban and social aspects, it is necessary to understand it from the spatial point of view, determining how an urban distribution of the PV systems occurs in a given city assessed in its different peculiarities.
The set of analyzes in a given place carried out on different aspects, will expand the understanding of how it is expanded, giving the possibility to direct more efficiently urban policies, energy planning, incentive programs for installation of PV systems, etc.
In this context, the objective of this work is to present a general mapping of all grid-connected photovoltaic systems supported by REN Nº 482/2012 installed in the city of Curitiba, identified by class, indicating how the urban distribution of these PV systems occurs, being possible to observe in which regions the highest prevalence of these installations happens. The general characterization of these PV systems is made by class, quantity of installed systems, power, quantity of modules, total occupied area, average power of modules and average efficiency of GCPVS.
This work presents the partial results of a study under development that will provide an overview of the geographic distribution of the grid-connected photovoltaic systems installed in the city of Curitiba and Paraná evaluated by different aspects, such as socioeconomic indicators, levels of solar irradiation, urban aspects, among others.

MATERIAL AND METHODS

Data Collection and Mapping of PV systems in the City of Curitiba

In order to achieve the objective of this work, the database[2] made available by ANEEL with the registration of all CUs that have distributed generation supported by REN Nº 482/2012 was used.
As this database is constantly updated, we used the date of June 5, 2017 to obtain the data, we did not consider the updates in the database after this date. It is also important to highlight that during this work, when numbers of consumers with PV generation are mentioned, these refer only to the PV systems with distributed generation supported by REN Nº 482/2012 and that appeared in the data base mentioned above at the date of consultation.
This database has several relevant information about the installed PV systems, such as: state, city and zip code of the installation, date of connection to the grid, power, consumer class, subgroup of billing, name of the holder of the CU, quantity of modules, quantity of inverters and area occupied by the panel.

The database also considers other types of distributed generation (hydropower, wind, solar photovoltaic and thermoelectric). It was filtered by "Generation Type" and only those units that have "solar photovoltaic generation" were selected. This search resulted in 10,740 PV systems installed in Brazil as shown in Table 1. This result was transferred to a spreadsheet so that the data could be treated with greater flexibility.

Next, only the PV systems installed in the City of Curitiba were selected, which initially resulted in 178 systems.

After that, the mapping process started. Firstly, the approximate address of each system was searched through its zip code using the Google Earth mapping software [9], the point of each CU was marked on the map by registering a new marker. Next, the location and neighborhood of each CU were checked and adjusted through the zip code online search application of the Brazilian Postal and Telegraph Company (ECT), which uses a mailing database (DNE) of more than 900 thousand zip codes of the whole country, being this, the official and exclusive base of the mailing company, therefore, its information is reliable and updated [10].

As the zip code does not indicate the exact location address (but a numeric range of a given street), the mapped points were positioned in the middle positions on their corresponding street. A new column was also created in the electronic table indicating the neighborhood name of each CU.

Identifying the approximate address of the 178 PV systems, it was verified that, in eight CUs, the indicated zip code did not correspond to the city of Curitiba, but to cities in the metropolitan region. For this reason, these eight systems were excluded from this analysis, resulting in 170 PV systems installed in the city of Curitiba, as indicated in Table 1.

The mapping of the points was done so that filters could be added to visually differentiate PV systems by power, class, connection date, and subgroup of billing.

Characterization of the grid-connected photovoltaic systems

The characterization of the grid-connected photovoltaic systems was based on the information available of these systems in the CU database with distributed generation [2]. The characterization was performed according to the class (residential, commercial, industrial or Public Sector) to which the system belongs. The data extracted from the database were: Quantity of grid-connected photovoltaic systems, Total Power, Number of Modules and Total Occupied Area. In order to complement the analysis, the following parameters were calculated: Average Power of the PV system, Equation 1, Average Power of the Modules, Equation 2 and Average Efficiency of the PV system, equation 3.

$$\text{Average Power (kW)} = \frac{\text{Total Power (kW)}}{\text{Quantity of PV systems}} \tag{1}$$

$$\text{Average Power of the Modules (W)} = \frac{\text{Total Power (W)}}{\text{Quantity of modules}} \tag{2}$$

$$\text{Average Efficiency(\%)} = \frac{\text{Total Power (W)}}{\text{Total ocupied area (m}^2\text{) x } G_{TOT}} \text{x100\%} \tag{3}$$

Where: G_{TOT} is the total solar radiant power with the direct, diffuse and albedo components, received in a unit of area on a surface. The G_{TOT} set at standard test conditions is 1000W/m².

Distribution of GCPVS in Curitiba Regionals

The city of Curitiba has 75 neighborhoods, which are grouped in 10 regionals. The Curitiba regional are administrative divisions of the city's territory, aimed at the operationalization, integration and control of decentralized activities.

Although there may be socioeconomic and urban differences within a single regional, each regional tends to have uniform characteristics, since they are formed by neighborhoods geographically close to each other. Thus, it is possible to determine socioeconomic and urban aspects characteristic of each region.

In order to be able to distribute the PV systems geographically through the map of Curitiba and draw a comparison with the socioeconomic and urban aspects of the respective region, the regional division of Curitiba as a spatial limit of analysis was chosen, thus, the PV systems were distributed according to the regional in which they are installed.

Using the division of the neighborhoods of Curitiba for this analysis would bring the inconvenience of a very small number of PV systems samples in each neighborhood, which would result in an unreliable result. The trend is that in the future, with the expansion of the number of PV systems installed, a distribution analysis by neighborhoods will be possible.

The cartographic data of the Curitiba regional divisions were obtained through the Institute research and Urban Planning of Curitiba (IPPUC) [11].

RESULT AND DISCUSSION

Mapping and Characterization of grid-connected photovoltaic systems

Once the data mapping and compilation phase is completed, the results can be presented and analyzed. Figure 1 presents the results of general mapping of PV systems in the city of Curitiba, including residential, commercial, industrial and Public Sector systems, distributed by the regional cities of Curitiba. This figure gives a general overview of the grid-connected photovoltaic systems, allowing to observe the regions of higher incidence.

Table 2 shows the results of the characterization of the grid-connected photovoltaic systems divided by the CU class.

Table 2 - General Characterization of the grid-connected photovoltaic systems divided by UC Class.

CU's class	Quantity of PV systems	Total Power (kW)	Quantity of Modules	Total Area (m²)	Average Power (kW)	Modules Average Power (W)	Average Efficiency (%)
Residential	132	392.40	1.594	2.710	2.97	246	14.48%
Commercial	31	293.82	1.141	1.950	9.48	258	15.07%
Industrial	6	58.12	200	395	9.69	291	14.72%
Public Sector	1	10.00	34	68	10.00	294	14.71%
Total	170	754.34	2.969	5.123	4.44	254	14.73%
Largest System	--------	50.00	168	336.0	--------	298	14.9%
Smallest System	--------	0.05	2	1.9	--------	25	2.6%

Source: Compilation of authors' data, based on reference [2].

It is observed that the residential systems represent 78% of the systems installed in absolute quantity and 52% of the total installed power.

The average power of the home systems is significantly lower than the average power in the other categories, which is explained by the lower energy demand of a home compared to commercial, industrial and public buildings. A greater availability of investment resources for commercial and industrial consumers also justifies the higher power on PV systems installed in these industries.

A deeper study of the technical characterization of the grid-connected photovoltaic systems in the city of Curitiba [4] points out the predominance of PV systems with Polycrystalline Silicon modules, which have an efficiency of 13% to 16.5% [12]. These values are in agreement with the calculated Average Efficiency of the PV systems, which is 14.73%. The calculated Average Power of Modules, which is 254W, also matches with the average commercial values of the Polycrystalline Silicon modules available in the market.

The low power of the smallest PV system registered draws attention. It is observed that the indicated system has two modules of only 25W each, that occupy an area of approximately 1 m² each. These values do not match the common characteristics of PV systems commercially available. One hypothesis is that the information was incorrectly entered in the distributed generation CU’s database.

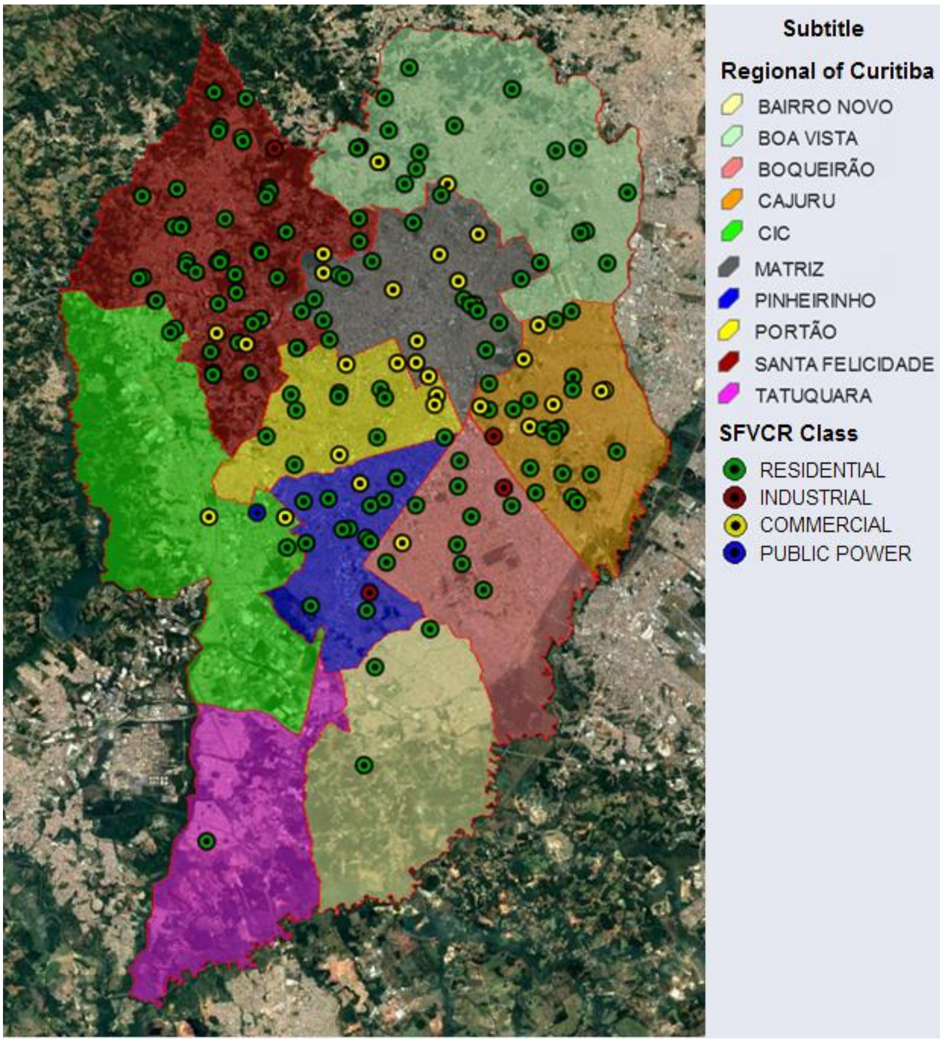

Figure 1 - Distribution of grid-connected photovoltaic systems installed in Curitiba.
Fonte: Author’s mapping. Satellite image [9].

Considerations on CU's Reliability of Distributed Generation Database Information

The Distributed Generation CU's database [2] is a recent and promising database that provides and will increasingly provide a wealth of information for studies and research with a focus on distributed generation and related issues.

However, in order for this database to be used safely, it is necessary that the information registered be reliable. The request for the registry of the CUs with distributed generation is made in a decentralized way, being the responsibility of each distributor. Thus, we do not have control of which sector and what the qualification of the official responsible for the registration of this information in each distributor.is. Therefore, this information is subject to registration errors by those responsible, whether through negligence, recklessness or malpractice.

From those 178 grid-connected photovoltaic systems initially selected in the city of Curitiba, eight of them (4.5%) had the wrong information of the city.

When the efficiency of each system was calculated, two systems showed efficiency of less than 5% and eight systems showed an efficiency greater than 25%, clearly indicating a registration error or information supply, either of the installed power or the occupied area by arrangement. One of the systems had a calculated efficiency of 234%; the simple critical analysis of the information by the person responsible would show inconsistency of the data reported, where theoretically a PV system of 2.5kW would occupy an area of 1m ^{2} only.

For the city of Curitiba, in a sampling of 178 PV systems, 18 systems presented a registration error, which indicates that approximately 10% of the analyzed data are not reliable. Without taking into account other registered information that are not possible to be conferred.

The tendency would be that the more systems that were registered the greater the sample size for analysis and consequently the smaller the sample errors. However, the evidence is that, if the appropriate action, is not taken, these registration errors can cause academic research to present incorrect results, energy planning not based on correct information, public policies not to have the desired efficiency, among several other negative impacts.

Therefore, it is important that those responsible for these registrations be informed of the importance of this database, so that all information is recorded with critical sense and with appropriate caution.

CONCLUSION

Through the mapping and general characterization of the grid-connected photovoltaic systems installed in the city of Curitiba, it was possible to observe its urban distribution and the usual characteristics of these systems. It was observed that the largest number of existing PV systems are installed in residences, these PV systems represents 78% of the total PV systems installed and 52% of the total installed power. While residential systems have an average power of 2.97kW, the commercial and industrial systems have an average power of 9.48kW and 9.69kW respectively. The average power of the PV systems installed in the City of Curitiba is 4.44 kW.

Finally, considerations were made regarding the reliability of the information registered in the CUs database with distributed generation [2]. It was verified that, from the analyzed sample, about 10% of the registered CUs presented some registration error. Thus, the importance of guiding those people responsible for accurate registration of the database is emphasized.

This work presents the partial results of a study under development that will provide a complete view of the geographic distribution of grid-connected photovoltaic systems installed in the city of Curitiba and Paraná, evaluated by different aspects such as socioeconomic indicators, solar radiation levels, urban aspects of the city, among others; expanding the understanding as how the expansion of the PV systems work.

REFERENCES

1- National Electrical Energy Agency: Normative Resolution nº 482, of April 17, 2012 - [cited 2017 Jun 10]. Available from: http://www2.aneel.gov.br/cedoc/ren2012482.pdf
2- National Electrical Energy Agency: Grants and Generation Registers: Distributed Generation Consumer Units - [cited 2017 Jun 05]. Available from: http://www2.aneel.gov.br/scg/gd/gd.asp
3- Ministry of Mines And Energy: Solar Energy in Brazil and the World - Year of Reference 2015 - [cited 2017 Jun 10]. Available from: http://www.mme.gov.br/documents/10584/3580498/17+-+Energia+Solar+-+Brasil+e+Mundo+-+ano+ref.+2015+%28PDF%29
4- Tonin FS, Urbanetz Jr J. [Characterization of Photovoltaic Systems Connected to the Grid]. INDUSCON. 2016. Portuguese.
5- Connectedpolo GM, Canciglieri Jr O, Urbanetz Jr J, Viana T, Pereira EB. [Comparison of the Photovoltaic Generation Potential in the State of Paraná with Germany, Italy and Spain.] CBENS. 2014. Portuguese.
6- Connectedpolo GM, Urbanetz Jr J, Pereira EB, Pereira SV, Alves AR. [Grid-connected Photovoltaic Systems Potential of Generation of Electric in the State of Paraná - Partial Results.] CBENS. 2016. Portuguese.
7- Connectedpolo GM. [Study of Grid-connected Photovoltaic Systems Potential of Generation of Electric in the State of Paraná.] [Thesis]. 2015. Portuguese.
8- Tem-Pass EH, Souza MB, Iatskiu T. [Economic Study for the Implementation of Grid-connected Photovoltaic Systems in the State of Paraná.] [Final course assignment] 2016. Portuguese.
9- Google Earth Pro, version 7.1.8.3036.
10- Brazilian Post and Telegraph Company: Search zip code - [cited 2017 Jun 12]. Available from: http://www.buscacep.correios.com.br
11- Institute of Urban Research and Planning Of Curitiba. Cartographic Files of Curitiba - Regionals Division. 2017 - [cited 2017 Jun 13]. Available from: http://ippuc.org.br/geodownloads/ geo.htm
12- Almeida et al. [Photovoltaic Solar Energy: Bibliographic Review] – [cited 2017 Jun 15]. Available from: http://www.fumec.br/revistas/eol/article/ download /3574/1911

Received: December 21, 2017;
Accepted: August 01, 2018