INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 7, Issue 2, 2016 pp.123-136
Journal homepage: www.IJEE.IEEFoundation.org

Performance of photovoltaic systems: Green office's case study approach

Juliana D' Angela Mariano[1], Henrique M. Campos[1], Fabianna S. Tonin[2], Jair Urbanetz Junior[1, 2], Eloy F. Casagrande Junior[1]

[1] Post-graduation Program on Civil Engineering, Technological Federal University of Paraná, Curitiba, Brazil.
[2] Post-graduation Program on Electrical Engineering, Technological Federal University of Paraná, Curitiba, Brazil.

Abstract
The aim of this paper is to highlight the parameters that interfere in the performance of grid-connected PV systems. In the three years of analysis, the energy generated and the solar radiation were locally monitored and used to calculate the performance parameters, such as Final Yield, Performance Ratio and Capacity Factor. The results obtained are related to the three years of operation of the Green Office PV system located in UTFPR. The case study compares the monitored PV system in Curitiba, as well as the literature cases in Santa Catarina and Pará states, in order to analyze the photovoltaic systems performance in several conditions. The results were very close in each case, although in Pará PV system case the highest final yield is explained by its location, which is close to the Equator' line, therefore there are the highest solar radiations in Brazil. In the end some suggestions were made to improve the GO's grid-connected PV system, because it has revealed a significant performance decrement, mainly due to partial shading losses.

Keywords: Efficiency; Photovoltaic systems; Renewable energy sources; Solar energy; Solar power generation.

1. Introduction

The Green Office (GO) main objective is to develop innovative green technologies that are exposed in a sustainable building, which is situated in UTFPR (Curitiba, Brazil, latitude: 25°43' S, longitude: 49°25' W), working all together and proving to be technically viable. The project became financially possible when the university signed some cooperation agreements with over 60 companies, which donated sustainable technologies and materials [1]. The photovoltaic system is divided into a grid-connected Photovoltaic (PV) system and a grid-disconnected PV system. The first one is the focus of this paper and consists of a string containing ten modules of 210 W, which was built with polycrystalline silicon cells, connected to a single string inverter input of 2000 W. The modules have about 15º tilt angle and 22º west from due north [2]. It has been operating since December 2011, uninterruptedly, although this paper focuses on 2012 to 2014 operation years.

This paper aims to compare the photovoltaic systems in three years of operation in terms of productivity parameters, while highlighting the factors that interfere in the performance of a grid-connected PV system. The GO's façade is noted in Figure 1.

Figure 1. GO's frontal façade of UTFPR. Source: The authors.

2. Influences on productivity of PV systems

Some of the major performance-limiting factors include: dust deposition on photovoltaic panels, which is called "soiling" effect; environmental factors (temperature effects; relative humidity; wind speed/direction; frequency of dust storms; precipitation); corrosion; delamination of the energy conversion devices; partial shading and, finally, non-optimal tilt and azimuth angles [3].

2.1 Soiling effect

A definitive correlation between accumulated dust concentration density on the module surface and power output losses were found, which resulted in decrement of performance parameters, such as Yield and Performance Ratio [3]. Furthermore, the dust deposition is strongly influenced by the tilt angle, so that large particles decreases with increasing tilt angle, whereas the concentration of fine particles increases [4].

A huge problem regarding dusty modules is the significantly lower operation voltage, because partially-shaded cells act as loads to clear cells connected in series. The result is more output power losses occurring in the formation of the hot spots, which in long-term exposure causes thermal degradation of the PV arrays [5].

In a study in Taiyuan, China, after a two week exposure of six outdoor PV modules in severe air pollution, the output power decreased approximately 1.3% and 2.32% per day, for PV modules tilted at 45° and 0°, respectively [6]. Finally, another study related to models for predicting energy-yield loss, revealed that the average annual loss prediction varies from 1.5% to 6.2% for eight different PV installation sites in California, Nevada, and Arizona [7].

2.2 Partial shading

The problem involving partial shading caused by dust, mentioned above, still occurs when the shadow is caused by an adjacent building or anything that blocks the irradiance reaching the modules surface. In a study related to partial-shading mismatch within a PV system, a methodology was used to estimate the shadow index of a conventional PV system, which does not have a Distributed Maximum Power Point Tracking (DMPPT). This index represents the output power losses caused by partial shading and the overall annual value was 16% [8].

In a wide variety of grid connected PV systems monitored in Europe, an average annual Yield decrement from 5 up to 10 percent due to partial shading was found [9]. Furthermore, a method for estimating energy losses due to partial shading of a grid connected PV system was applied to the PV system of the UNIVER Project and revealed a shading factor of 14.4% [10].

2.3 Non-optimal tilt and azimuth angles

A general statement is that a surface with tilt angle equal to the latitude of the local installation and surface oriented to north (Southern hemisphere) receives maximum irradiance. Although it is truth in most cases, especially in the South of Brazil, the optimum PV inclination and orientation on North of Brazil has a wide variety of possibilities, assuring a 95% of the maximum generation achieved in different azimuth angles since the tilt angle is kept up to 15º [11].

When the solar radiation is approximately symmetric during the morning and afternoon, the maximum available energy may be received by a surface whose azimuth angle is 0º due south (Northern hemisphere) or north (Southern hemisphere). A research in the ECOS PV system, which is a 13 kWp situated in the Northern Ireland (latitude: 54°52'N and longitude: 6°17'W), revealed that annual total incident solar radiation for surface orientation of 30º east or west from due south with 30º tilt angle is approximately 2% lower than the maximum annual total radiation (30º tilt angle and south oriented), while the actual inclination of 45º south oriented represented an PV output 2.9% lower than the maximum value, which permit to conclude that the performance is less affected by surface azimuth angle than tilt angle [12].

2.4 Inverter performance considerations

The inverter considerably impacts in the productivity of the PV system. It is very important to consider that multiple inverter configuration implies more reliability, because a failure does not lead to total system failure. Moreover, the fractional loading, defined as the ratio of the input power to its nominal DC rating influences the inverter's conversion efficiency [13].

Another research revealed that Sizing Factor (SF), which is the ratio of the inverter maximum power to its photovoltaic array power, might be greater than one for PV installations located at low latitude sites [14]. This is important to be considered in the project of the PV system, since a common practice is to undersize the inverter due to the fact that array photovoltaic power will not be equal or above their Standard Test Condition (STC) rated nominal power (STC: 1 kW/m² solar radiation, 25º cell temperature and 1,5 air mass). Such practice leads to a yearly efficiency decrement, because of the losses caused by inverter power limitation. In addition, actual losses due to inverter undersizing increase with increased solar radiation averaging time (using one min averages rather than hourly averages), so it is proved that particularly hourly averages hide important irradiation peaks that need to be considered [15].

3. Material and methods

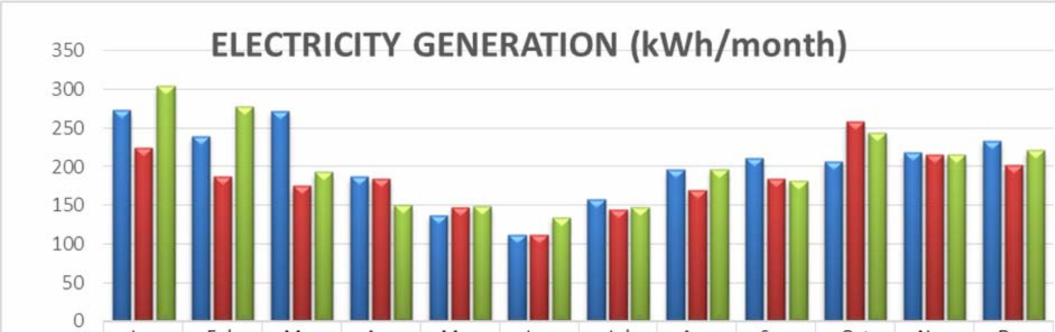
This paper focus on a comparison between an optimum PV system (tilt angle equal to the latitude of the local installation and surface oriented to north) and a real PV system in operation in UTFPR. Moreover, performance parameters previously stated, such as Final Yield, Performance Ratio and Capacity Factor, were analyzed in the period from 2012 to 2014, so it represents three years of operation of the GO's grid-connected PV system in UTFPR. The local solar irradiation in the horizontal plane is obtained from the Brazilian Institute of Meteorology (INMET) [16] as well as Meteorological System of Paraná (SIMEPAR) [17]. This information is the entrance for the software Radiasol [18], which provides the solar irradiation to different inclinations. The energy generation is recorded by the PVP 2000 inverter of the GO's grid-connected PV system, which is online monitored through the internet. The analysis involves the limiting factors for photovoltaic systems, as well as suggests ways to improve its operation performance.

3.1 Performance of PV systems

The performance analysis of GO's grid-connected PV system is based in electricity generated during these three years of operation and also irradiation values that were incident on the surface of the PV panel. Then the electricity generated and the solar radiation were locally monitored, therefore the performance parameters were calculated, such as Final Yield, Performance Ratio and Capacity Factor.

3.2 Generated energy trough the GO's PV system of the UTFPR

Analyzing the PV system working of the GO in the years 2012, 2013 and 2014, was observed a total generation of 7,1 MWh in this time. The electricity generation was proportional at solar radiation reflected into PV panel, whereas in the summer months (higher solar radiation) there is higher generation than the winter months (lower solar radiation). Figure 2 shows the electricity generated in each operation month of GO' PV system of the UTFPR.



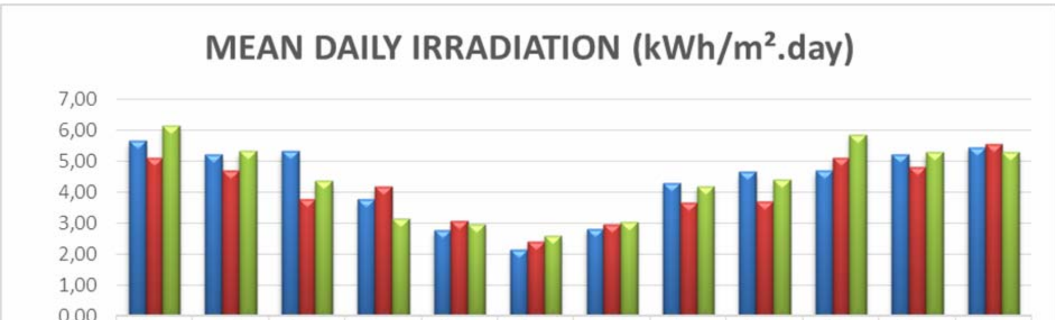
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	273	240	272	187	137	112	158	196	211	206	218	234
2013	225	188	175	185	147	112	144	170	184	258	216	202
2014	304	278	193	151	149	134	148	197	181	244	215	221

Figure 2. Electricity generation (kWh/month) for the years 2012, 2013 and 2014. Source: The authors.

3.3 Irradiation reflected on PV panel of the GO's PV system

The irradiation values reflected on PV panel were used as basis to calculate some of the performance parameters of the PV system. These values were acquired through National Meteorology Institute (INMET) database for the A807 station, located in Curitiba [16]. Besides INMET database, the SIMEPAR Technological Institute, other metrological database, was consulted during to period from 07/19/2014 to 10/08/2014, when the INMET site was unavailable to data collection, caused by technical problems. Although the INMET and SIMEPAR pyranometers are installed in horizontal position, it is necessary to use the RADIASOL program to determine the real irradiation reflected on PV panel of the GO system. The RADIASOL is available for the Federal University of Rio Grande do Sul [18], and it allows to identify the irradiation values to any surface (different azimuth angles and tilt angle related to North) through insertion of the irradiation values on horizontal surface. Figure 3 presents the irradiation values mean diary on horizontal surface to each month of the year for the place cited.

In the software RADIASOL were created the stations "EV_UTFPR_2012", "EV_UTFPR_2013" e "EV_UTFPR_2014", with the irradiation values of Figure 3.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	5,65	5,21	5,31	3,76	2,78	2,15	2,81	4,28	4,65	4,69	5,22	5,45
2013	5,12	4,68	3,78	4,16	3,07	2,39	2,95	3,66	3,70	5,11	4,82	5,55
2014	6,14	5,32	4,35	3,14	2,97	2,59	3,03	4,18	4,39	5,85	5,27	5,28

Figure 3. Mean daily irradiation on horizontal surface provided by INMET A807 station (kWh/m².day). Source: The authors.

Figure 4 shows the initial software interface that allows you to choose parameters according to the specific place where the PV panel is installed.

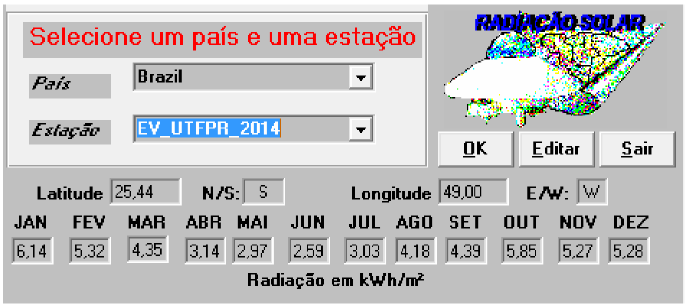


Figure 4. RADIASOL initial software interface. Source: The authors.

Having adjusted the tilt angle to 15° and the azimuth angle to 22° west, the graphic presented at Figure 5 and the irradiation values incident on GO' PV panel surface are presented in the Figure 6.

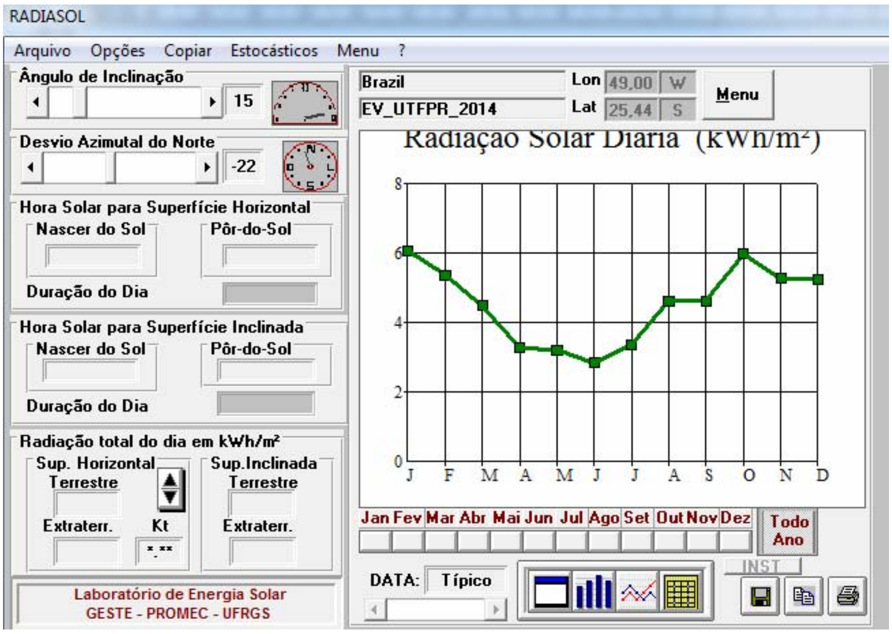
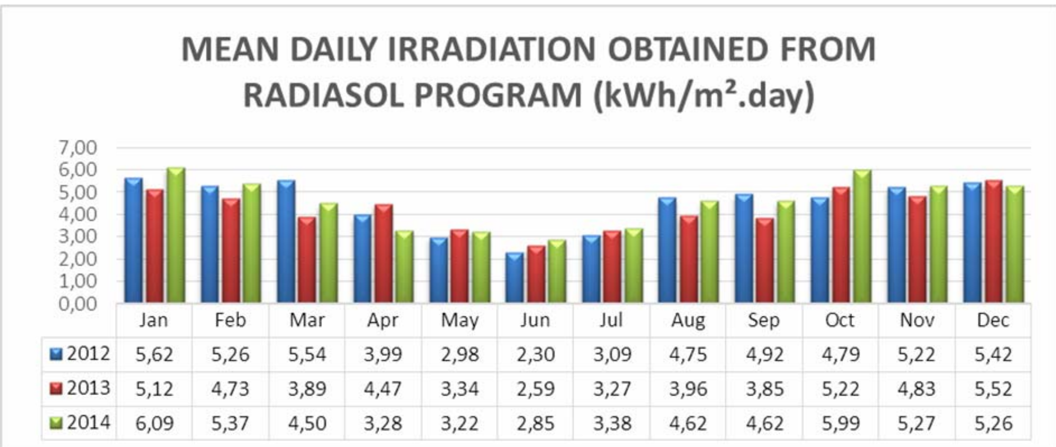


Figure 5. RADIASOL interface showing the mean irradiation graphic during the year at the GO's PV panel. Source: The authors.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	5,62	5,26	5,54	3,99	2,98	2,30	3,09	4,75	4,92	4,79	5,22	5,42
2013	5,12	4,73	3,89	4,47	3,34	2,59	3,27	3,96	3,85	5,22	4,83	5,52
2014	6,09	5,37	4,50	3,28	3,22	2,85	3,38	4,62	4,62	5,99	5,27	5,26

Figure 6. Mean daily irradiation on GO's PV panel surface obtained from RADIASOL software (kWh/m².day). Source: The authors.

3.4 Comparison between an optimum PV system and a real PV

A grid-connected PV system presents the following technical features: the PV panel has tilt angle equal to the local latitude of the installation; the PV surface orientation should be to the northem hemisphere and also any shading effect should be avoided. The comparison of the generation that would be obtained from an optimum system in operation was done with the generation obtained in the real system in operation. In result, it was presented an analysis related to limiting factors of the grid connected PV system performance. Furthermore, the guidelines are provided to optimize the grid connected PV system performance [19].

To calculate the PV generation prediction was applied the Equation 1, where E: electricity generated (kWh); P: PV Peak power (kWp); H_{TOT}: solar monthly irradiation reflected on panel surface (kWh/m².month); G: irradiance in standard test conditions (1 kW/m²); PR: Performance Ratio, considered 0,75 in the optimum system.

$$E = \frac{P.H_{TOT}.PR}{G} \quad (1)$$

Finally, the comparison between the PV generation to an optimum grid connected PV system and the real one (PV system of the GO) is showed, obtaining the relative percentage deviations (D) according the Equation 2, while: E_{OP}: electricity generated by the optimum grid connected PV system; E_{GO}: electricity generated by the GO' grid connected PV system.

$$D = \frac{E_{OP} - E_{GO}}{E_{GO}}.100 \quad (2)$$

3.5 Performance parameters

Final Yield, Reference Yield, Performance Ratio and Capacity Factor are going to be described [20], [21].

Final Yield (YF) is defined by the daily, monthly or annual net AC energy output of the system (E) divided by the rated or nominal power of the PV array at STC (P_{PV}). Equation (3) represents this parameter.

$$Y_F = \frac{E}{P_{PV}}[\frac{kWh}{kWp}] \quad (3)$$

Reference Yield (YR) is calculated with the ratio of the total in-plan solar irradiation H_T (kWh/m²) to the array reference irradiance (1 kW/m²). In summary, Reference Yield represents the duration of time with the highest solar irradiation, according to (4). The H_T has the same meaning as H_{TOT}, which is used in Brazilian literature.

$$Y_R = \frac{H_T}{1}[\frac{kWh/m^2}{kW/m^2}] \quad (4)$$

Performance ratio (PR) quantifies how much of the available solar energy is converted into electricity. It indicates the overall effect of losses, caused mainly by the factors that influences on productivity as mentioned in section II, such as environmental factors (temperature, wind speed, soiling, partial shading). Moreover, performance ratio permits to compare the PV systems independent of location, nominal rated power capacity, orientation and tilt angle. Equation (5) is the calculation process to obtain PR.

$$PR = \frac{Y_F}{Y_R}[\%] \quad (5)$$

To conclude, the capacity factor is defined as the ratio of the actual annual energy output (E) to the amount of the energy that the PV system would generate, if it operated at full rated power for 24 hours per day for a year.

$$CF = \frac{E}{P_{PV}.24.365}[\%] \tag{6}$$

3.6 Other practical cases

The photovoltaic system of the Solar Energy Laboratory (LABSOLAR) is located in the Mechanical Engineering building of Federal University of Santa Catarina (UFSC) in Florianopolis city, at Santa Catarina state. This system was installed in September 1997, and it was the first grid-connected photovoltaic system installed in Brazil [22].

The LABSOLAR PV modules consist of the thin film silicon cells, 54 opaques modules and 14 semitransparent of amorphous silicon. The system composes one photovoltaic panel with 2015 Wp of power and one 2500 W inverter. The modules have about 27º tilt angle and the main influences on productivity are temperature effects and solar radiation spectrum, which present typical seasonal variations of amourphous silicon [22].

An excellent PR of 74% and YF of 1126 kWh/kWp were presented. Some replacements were made since it started to operate due to connector and inverter failures. In despite of this the system presented reliability and great performance, besides being suitable to integrate to urban environment [22].

The UNICRED Building was the first commercial building that had a grid-connected photovoltaic system installed and is located in downtown Belem city, at Pará state. The plant of 12.6 kWp was installed in 2011, however due to great results the system was enlarged to 47.16 kWp in October 2013 [23].

The UNICRED photovoltaic generator was installed for Study Group and Development of Alternative Energy (GEDAE) of the Federal University of Pará (UFPA) team. The system consists of the polycrystalline silicon cells. The 204 modules are installed on the UNICRED roof with 10º tilt angle and 5 inverters (3x3.8 kW and 2x15 kW), as well as other installation accessories [23].

This expansion can supply almost 50% of the building's energy consumption. There are several problems involving shading, lack of maintenance and also limitations regarding on-site measuring devices, which resulted in the decrement of system's performance [23].

The monitored data in 20 months, from 2012 to 2013 demonstrated the YF of 1208 kWh/kWp, the PR of 69.55 % and the CF of 13.8% [23].

4. Results and discussion

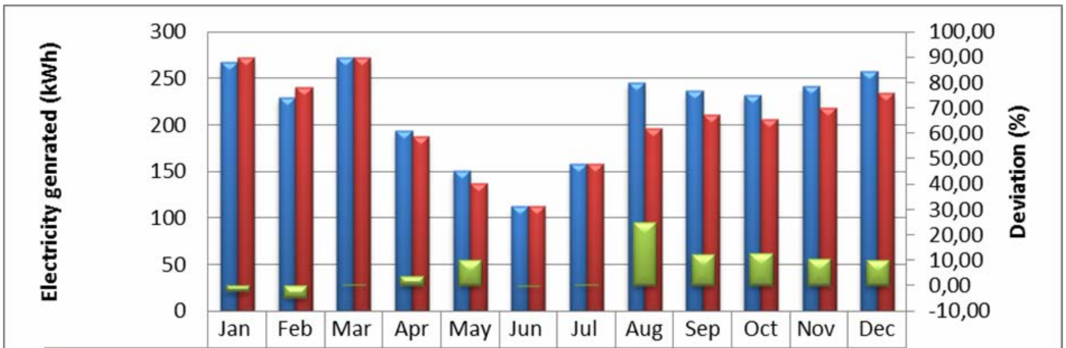
The comparison between the PV generation of an optimum grid-connected PV system and the real GO's grid-connected PV system are presented in Figures 7, 9 and 10 in the three years of operation. The parameter E_{OP} means the electricity generated by an optimum PV system while the E_{GO} means the electricity generated by GO's PV system.

A monthly mean deviation was found equivalent to 6.5%, 11.8% and 9.9%, in 2012, 2013 and 2014, respectively. Considering the PV annual accumulated generation in each year, the deviation was equal to 6,2%, 11% and 8,6% from 2012 to 2014, respectively.

According to Figure 7, from January to July in 2012 the deviation was kept low between the real GO's grid-connected PV and the optimum one. However this deviation had increased significantly on August.

On August 31^{st,} 2013 was done a general cleaning of the PV modules aiming to eliminate the accumulated dust, according to Figure 8. As a result, the dust on PV panel demonstrates its significant interference in the electricity generated by the GO's PV system.

Figure 9 is possible to notice the low relative deviation between the optimum grid-connected PV system and the real GO' grid connected PV in September and October, due to the PV cleaning. On the other hand, a deviation of almost 30% was found in December, probably because of a short period when the monitoring system was not working, and then the electricity generated in this month could not be as accurate as the rest of the year.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EOP (kWh)	267	229	272	194	151	112	158	245	237	232	241	257
EGO (kWh)	273	240	272	187	137	112	158	196	211	206	218	234
Deviation (%)	-2,17	-4,63	0,16	3,60	10,12	-0,02	0,12	25,05	12,19	12,58	10,76	9,96

Figure 7. Comparison between the optimum grid-connected PV system and the real GO's grid-connected PV in 2012. Source: The authors.

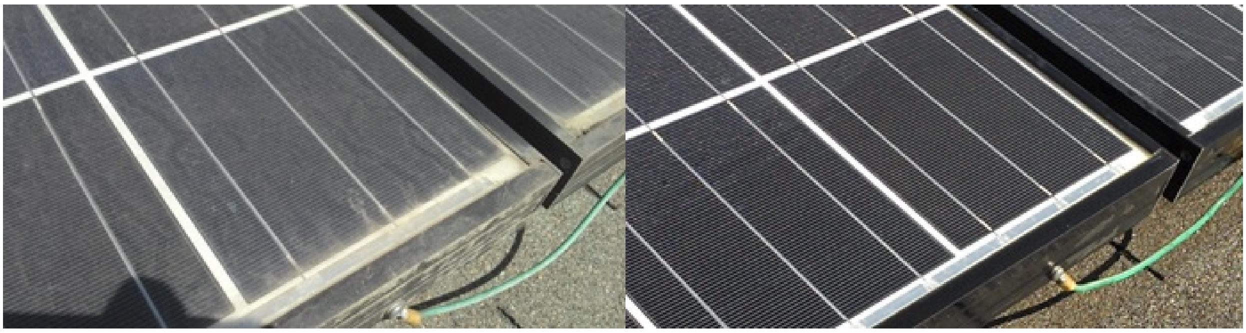
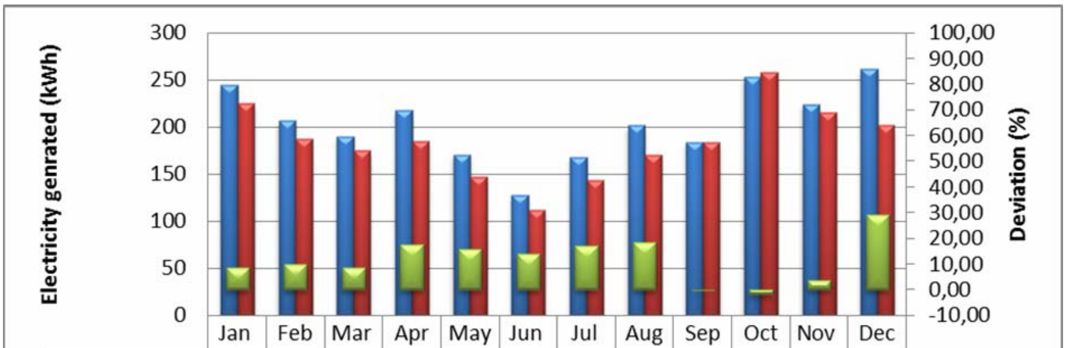


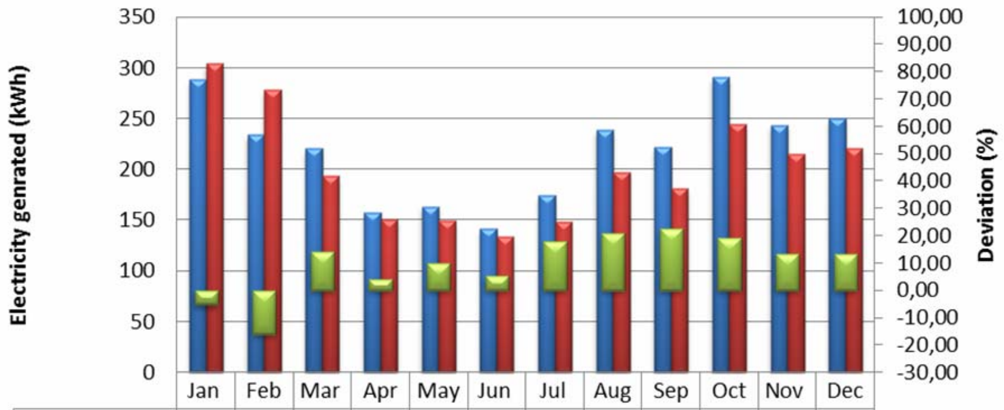
Figure 8. Cleaning of the modules of the GO' grid-connected PV system. Source: The authors.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EOP (kWh)	244	206	190	218	170	128	168	202	184	253	224	261
EGO (kWh)	225	188	175	185	147	112	144	170	184	258	216	202
Deviation (%)	8,50	9,78	8,53	17,74	15,92	13,91	16,98	18,62	-0,11	-1,78	3,69	29,31

Figure 9. Comparison between the optimum grid-connected PV system and the real GO's grid-connected PV in 2013. Source: The authors.

Finally, in 2014 there was higher electricity generation by the GO's grid-connected PV than the optimum one from January to February, which might be justified by the lower tilt angle than the optimum system, so that the generation in Summer is increased.



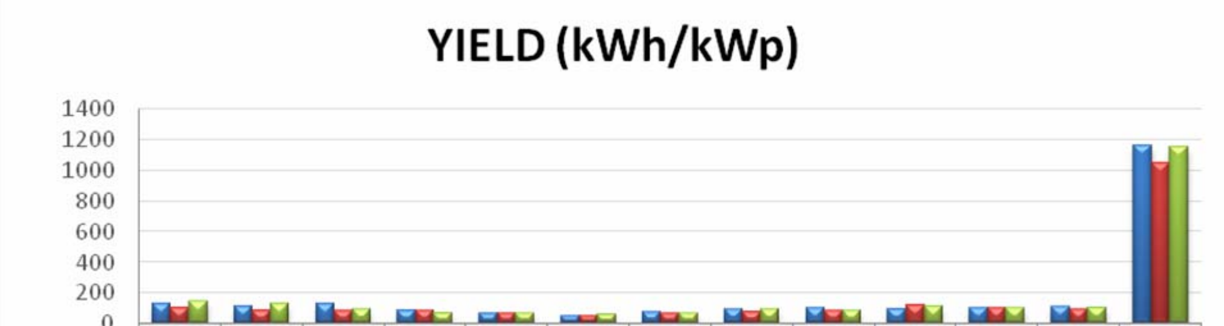
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EOP (kWh)	288	234	220	157	164	141	174	238	222	291	244	250
EGO (kWh)	304	278	193	151	149	134	148	197	181	244	215	221
Deviation (%)	-5,24	-15,9	14,09	4,20	9,77	5,43	17,77	20,95	22,69	19,06	13,40	13,11

Figure 10. Comparison between the optimum grid-connected PV system and the real GO' grid-connected PV in 2014. Source: The authors.

The literature shows that the tilt angle equal to the local and the orientation faced to Equator' line, maximize the annual accumulated PV generation, in other words, results in increment of the PV electricity generated. This aspect is a challenge inside urban environment, where the PV panel architectural integration, which does not always leads to the optimum parameters. Besides, the shading caused by adjacent buildings became other limiting factor to the maximum yield obtained in grid-connected PV system in urban environment [24].

The yield in 2013 was lower than 2012 because of two reasons: less solar incidence in 2013, according to the Figure 11, and the accumulated dust on the PV panel, which was cleaned on August 31st, 2013. After the cleaning was noticed the yield increment. In the first two months in 2014, the yield was higher than two previous years, due to the higher levels of solar irradiation in this period.

PR indicates the amount of losses occurring in the operation of the PV system and in the UTFPR's GO the partial shading has a strong influence on productivity decrement, mainly during the winter when the adjacent building blocks a significant amount of solar radiation after 16:00, according to the Figure 12.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2012	130	114	130	89	65	53	75	93	100	98	104	111	1164
2013	107	90	83	88	70	53	69	81	88	123	103	96	1050
2014	145	132	92	72	71	64	70	94	86	116	102	105	1150

Figure 11. Monthly and annual Yield of the GO's grid-connect PV system of the UTFPR. Source: The authors.

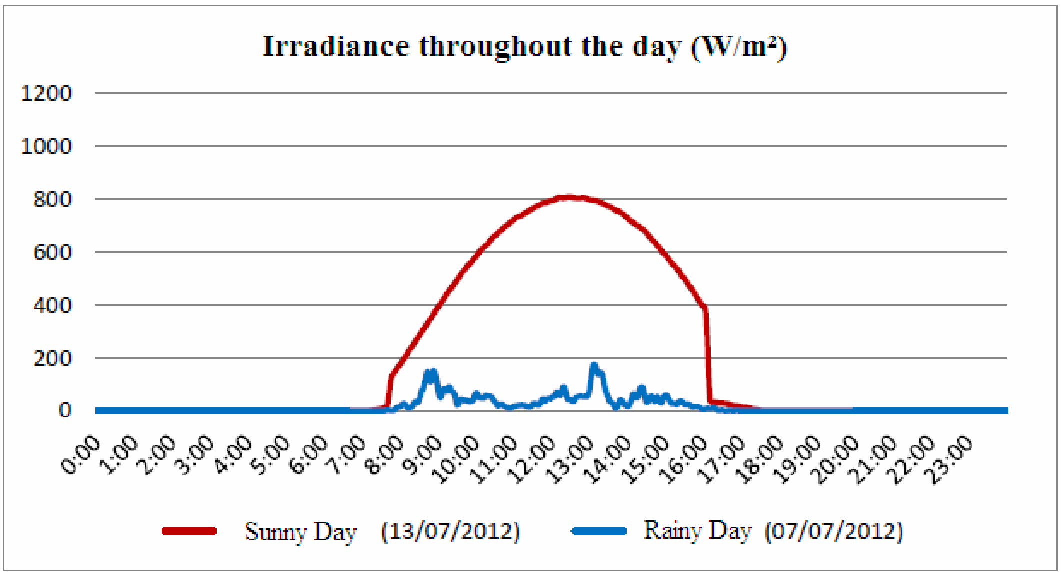


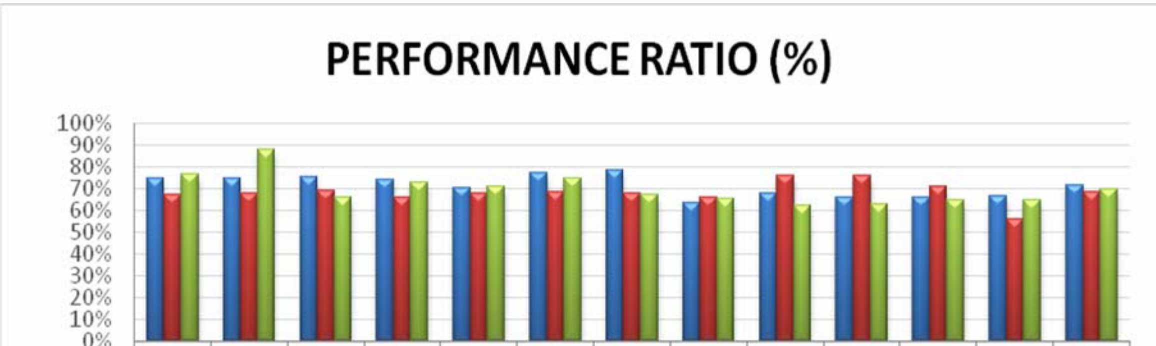
Figure 12. Irradiance curves obtained at panel surface in July [19].

The mean performance ratio in 2013 was higher than 2012 and had significant improvement after the cleaning done on PV in 2013. Analyzing immediately the previous months after the cleaning of the PV panel noticed a gradual reduction in this level, and after the cleaning, the monthly performance ratio returned to level noticed in the first operation months of the grid-connected PV system, remaining higher than 75%. Furthermore, the grid connected PV system performance ratio increased from 66% in august to 76% in September of 2013, according to the Figure 13.

In the beginning of 2014, the performance ratio remained high due to the high irradiation levels in this period.

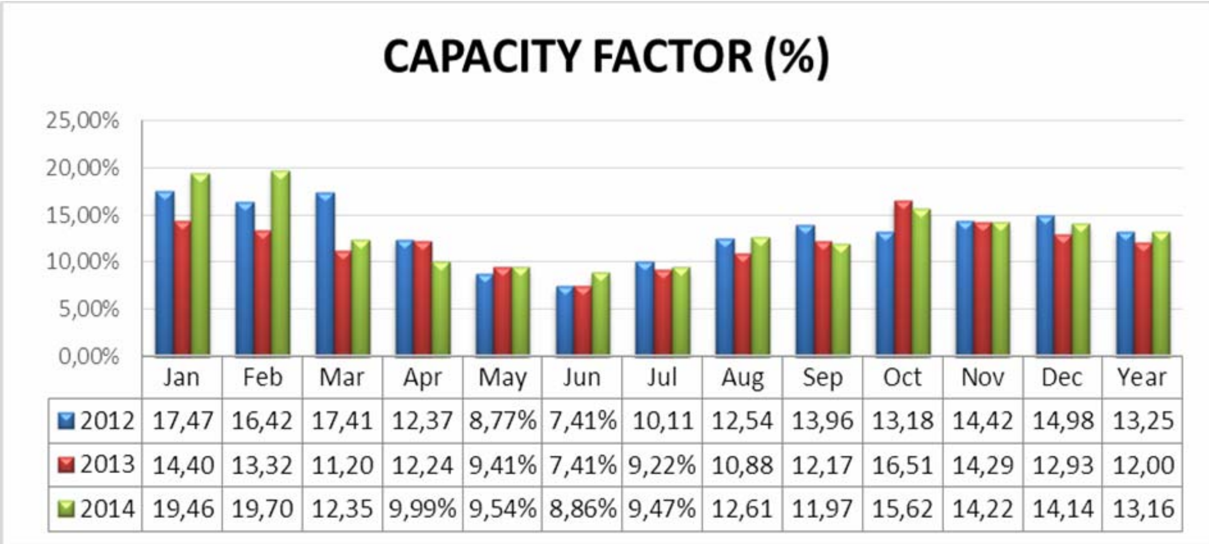
The mean capacity factor in 2013 was lower than 2012, because of the lower solar irradiation in the year 2013 and dust accumulation on PV panel, however there was significant improvement after the cleaning occurred in 2013. In 2014, due to the high irradiation levels observed, there were also higher capacity factors, which are presented in Figure 14.

It is important to mention that the low tilt angle in UTFPR's GO PV system affects the self-cleaning of the modules by the rain, so they tend to accumulate more dust than Santa Catarina's PV system, which not only increases energy losses but in the long-term cause thermal degradation of the PV array.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2012	74,5	74,8	75,4	74,3	70,5	77,2	78,6	63,4	68,1	66,1	66,2	66,3	71,3
2013	67,5	67,5	69,1	65,7	67,5	68,5	67,6	65,8	75,8	75,9	70,9	56,2	68,2
2014	76,7	87,9	65,9	73,0	71,1	74,6	67,3	65,4	62,2	62,5	64,7	64,5	69,7

Figure 13. Monthly and annual Performance Ratio of the GO's grid-connect PV system of the UTFPR. Source: The authors.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2012	17,47	16,42	17,41	12,37	8,77%	7,41%	10,11	12,54	13,96	13,18	14,42	14,98	13,25
2013	14,40	13,32	11,20	12,24	9,41%	7,41%	9,22%	10,88	12,17	16,51	14,29	12,93	12,00
2014	19,46	19,70	12,35	9,99%	9,54%	8,86%	9,47%	12,61	11,97	15,62	14,22	14,14	13,16

Figure 14. Monthly and annual Capacity Factor of the GO's grid-connect PV system of the UTFPR. Source: The authors.

5. Conclusion

The comparative analyses between the optimum grid-connected PV system and the real GO's grid-connected PV system, allowed to observe a performance reduction along of the year due to factors: partial shading of the PV panel through adjacent building; different PV panel angle tilt of the optimum angle; deviation related to the geographical north (to south hemisphere locations) and dust accumulation due to the low panel angle tilt, which harm the self-cleaning due to raining action.

During the winter period was observed a great reduction on electrical generation, caused mainly by stronger partial shading and by the disadvantageous angle tilt of the modules in this period of the year.

By other hand, the low PV panel angle tilt improved the electrical energy generation in the summer period, because made it possible higher irradiation incidence, besides lower shading on PV modules in this season.

Due to less angle tilt chosen for the PV panel, it is recommended to make an annual cleaning on modules aiming to eliminate the dust produced by animals and mainly by car soot.

Observing the years from 2012 to 2014, which comprise the entire annual season, it was revealed an electrical energy reduction in the GO's grid-connected PV system of the 9,4% in comparison to optimum grid connected PV system, which highlights the yield loss in installed grid-connected PV systems under different of the optimum conditions.

The Final Yields obtained in the PV systems of Curitiba and Santa Catarina were very close. The highest Final Yield was obtained in Pará state, due to the fact that it is situated in the highest solar radiation area in Brazil, as well as close to the Equator' line. The two literature PV system cases and the PV systems monitored in this paper revealed very similar values of PR and CF, although the UTFPR's GO case was considerably lower, which is mainly caused by the partial shading losses.

In summary, some suggestions to improve the performance of UTFPR's GO PV system are stated: increment the tilt angle in 10º in order to enhance the annual average solar radiation in the panel surface and also the self-cleaning; implant an inverter with better conversion efficiency; study the possibility to implant a DMPPT to reduce the GO PV panel partial shading losses and, to conclude, as a future research, study about the power generation profile during the highest solar irradiation days in order to identify if the undersized inverter is limiting the output AC power.

Regarding the global performance of the building related to energy efficiency, were obtained excellent results due to the UTFPR' GO design, which within the bioclimatic architecture principles, collecting the natural maximum light, with large and well windows positioned, applying LEDs to light all the environment and the application of the wood framing systems with recycled PET blankets for thermal-acoustic isolation.

These characteristics conjunct, linked to the PV generation, as well as the PV generation, result in a sustainable building, which is a model of construction and the employed strategies are constantly evaluated.

The monitoring in these three years of GO' grid-connected PV system operation in Curitiba confirm to be a system of high reliability, as long as it is operating uninterruptedly since its installation. . Moreover, the electricity generation is in accordance with the expected values, operating quietly and it does not need additional area, and any carbon emissions. Those characteristics make the PV generation the most promising distributed generation for the urban environment.

Acknowledgements

The authors acknowledge the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the financial support to the development of this research.

References

[1] E. F. Casagrande Junior, B. V. Kobiski, J. A. Góis and L. P. P. Agudelo, "Practical Strategy for Sustainable Development in Education: The Green Office's Case of the Federal University of Technology of Paraná, Curitiba, Brazil," presented at 2012 World Symposium on Sustainable Development at Universities (WSSD-U-2012). [Online]. Available: http://www.escritorioverdeonline.com.br/wp-content/uploads/2012/08/Green-Office-Chapter-69-Book-WSSD-2012-Rio+20-Conference.pdf.

[2] H. M. Campos, A. K. R. Manrique, B. V. Kobiski, E. F. Casagrande Junior and J. Urbanetz Junior, "Study of technical feasibility and the payback period of the invested capital for the installation of a grid-connected photovoltaic system at the library of the Technological Federal University of Paraná," International Journal of Energy and Environment, vol. 5, pp. 643-654, Oct. 2014.

[3] A. Sayyah, M. N. Horenstein and M. K. Mazumder, "Energy yield loss caused by dust deposition on photovoltaic panels," Solar Energy, vol. 107, pp. 576-604, July 2014.

[4] A. A. Hegazy, "Effect of dust accumulation on solar transmittance through glass covers of plate-type collectors," Renewable Energy, vol. 22, pp. 525-540, April 2001.

[5] E. Lorenzo, R. Moretón and I. Luque, "Dust effects on PV array performance: in-field observations with non-uniform patterns," Progress in Photovoltaics: Research and Applications, vol. 22, pp. 666-670, Jan. 2013.

[6] L. Liqun, L. Zhiqi and S. Z. L. Chunxia, "Degraded output characteristic at atmospheric air pollution and economy analysis of PV power system: a case study," Przeglad Elektrotechniczny, vol. 88, pp. 281-284, 2012.

[7] A. Kimber, L. Mitchell, S. Nogradi and H. Wenger, "The effect of soiling on large grid-connected photovoltaic systems in California and the south west region of the United States," in Proc. 2006 4th IEEE World Photovoltaic Energy Conversion Conference, pp. 2391-2395.

[8] A. J. Hanson, C. A. Deline, S. M. MacAlpine, J. T. Stauth and C. R. Sullivan, "Partial-shading Assessment of Photovoltaic Installations via Module-Level Monitoring", IEEE Journal of Photovoltaics, vol. 4, pp. 1618-1624, Nov. 2014.

[9] U. Jahn and W. Nasse, "Operational performance of grid connected PV systems on buildings in Germany", Progress in Photovoltaics: Research and Applications, vol. 12, pp. 441–448, 2004.

[10] M. Drif, A. Mellit, J. Aguilera and P. J. Pérez, "A comprehensive method for estimating energy losses due to shading of GC-BIPV systems using monitoring data", Solar Energy, vol. 86, pp. 2397-2404, 2012.

[11] I. P. Santos, R. Rüther, L. Nascimento and L. C. P. Junior, "Ábacos para análise simplificada de orientação e inclinação de sistemas solares fotovoltaicos integrados a edificações", presented at the IV Congresso Brasileiro de Energia Solar e V Conferência Latino-Americana da ISES, São Paulo, Brazil, 2012.

[12] J. D. Mondol, Y. G. Yohanis, B. Norton, "The impact of array inclination and orientation on the performance of a grid-connected photovoltaic system," Renewable Energy, vol. 32, pp. 118-140, 2007.

[13] A. Pregelj, M. Begovic and A. Rohatgi, "Impact of inverter configuration on PV system reliability and energy production", in Proc. 2002 Photovoltaic Specialists Conference, pp. 1388-1391.

[14] G. Velasco, F. Guinjoan, R. Piqué, A. Conesa and J.J. Negroni, "Inverter Power Sizing Considerations in Grid-Connected PV Systems", in Proc. 2007 European Conference on Power Electronics and Applications, pp. 1-10.
[15] B. Burger and R. Rüther, "Inverter sizing of grid-connected photovoltaic systems in the light of local solar resource distribution characteristics and temperature", Solar Energy, vol. 80, pp. 32-45, 2006.
[16] Brazilian Institute of Meteorology (INMET), "Estações automáticas – Estação: CURITIBA-A807". Available in: <http://www.inmet.gov.br/portal/index.php?r=estacoes/estacoesAutomaticas>. Accessed in: Nov. 30 2014.
[17] Technological Institute SIMEPAR, "Tecnologia e informações ambientais". Available in: <http://www.simepar.br/>. Accessed in: Nov. 30 2014.
[18] UFRGS. "Programa RADIASOL". Laboratório de Energia Solar, 2012.
[19] J. Urbanetz Junior, H. M. Campos, A. K. R. Manrique, E.Casagrande Junior and G.M. Tiepolo, "Fatores que Interferem na Produtividade de Sistemas Fotovoltaicos Conectados à Rede Elétrica," in Proc. 2014 Internacional Solar Cities, Buenos Aires.
[20] V. Komoni, I. Krasniqi, A. Lekaj and I. Gashi, "Performance Analysis of 3.9 kW Grid Connected Photovoltaic Systems in Kosova", in Proc. 2014 IEEE International Renewable Energy Congress, pp. 1-6.
[21] R. Fusano, "Análise dos Índices de Mérito do Sistema Fotovoltaico Conectado à Rede Elétrica do Escritório Verde da UTFPR", bachelor degree, Dept. Electrical Engineering, Federal Technological University of Parana, Curitiba, 2013.
[22] L. Nascimento, R. Rüther, "A Avaliação De Longo Prazo De Um Sistema Fotovoltaico Integrado À Edificação Urbana E Conectada À Rede Elétrica Pública," in Proc. 2014 V Congresso Brasileiro de Energia Solar, pp. 1-10.
[23] L. Blasques, S. Vale, R. Cavalcante, "Avaliação De Desempenho Do Primeiro SFCR Instalado Em Edificação Comercial Na Cidade De Belém, Estado Do Pará, Após Os Primeiros 20 Meses De Operação Monitorada," in Proc. 2014 V Congresso Brasileiro de Energia Solar, pp. 1-9.
[24] CEPEL; CRESESB. Grupo de Trabalho de Energia Solar (GTES). Manual de engenharia para sistemas fotovoltaicos. Rio de Janeiro, 2014, 530 p.

Juliana D' Angela Mariano is an electrical technologist and M.Sc graduate student in the Post-graduation program on civil engineering at the Technological Federal University of Parana (UTFPR), situated in Curitiba, Brazil. The main research interests are sustainability, photovoltaic system, renewable energy and environment education.
E-mail address: julianadangela@gmail.com

Henrique Marin Campos is an electrical engineer and M.Sc graduate student in the Post-graduation program on civil engineering at the Technological Federal University of Parana (UTFPR), situated in Curitiba, Brazil. He is a member of the research group TEMA – Technology and Environment and also contributed to the Green Office of the UTFPR as a volunteer and researcher. The main research interests are sustainability, energy efficiency and renewable energy. His dissertation is about large scale grid-connected photovoltaic systems applied to the energy planning of Curitiba, including the environmental impacts related to this energy production and the technical impacts to the electrical grid.
E-mail address: enghenrique@outlook.com

Fabianna Stumpf Tonin is an electrical enginner and M.Sc graduate student in the Post-graduation program on electrical engineering at Technological Federal University of Parana (UTFPR), situated in Curitiba, Brazil. The main research interests are energy efficiency, photovoltaic systems and renewable energy.
E-mail address: fstonin@gmail.com

Jair Urbanetz Junior has obtained his PhD in Photovoltaic Systems at UFSC (2010); his Master degree in Power Electronics and Electrical Drive was obtained at UFSC (2002); he is Specialist in Management of Maintenance Engineering at UTFPR (1999). Graduated in Industrial Electrical Engineering at UTFPR (1995) and in Electronics Technician at UTFPR (1986). He is a professor in the Department of Electrical Engineering, at Federal Technological University of Paraná (UTFPR) in Curitiba, since 1996, where he teaches courses in Electrical Engineering and Engineering of Automation and Control. He is also Coordinator of the Post-Graduation in Renewable Energy, Professor in the Post-Graduation Program on Civil Engineering (PPGEC) and Post-Graduation Program Energy Systems (PPGSE). Have experience in Electrical Engineering with emphasis in Power Electronics and Photovoltaics Systems.
E-mail address: urbanetz@utfpr.edu.br

Eloy Fassi Casagrande Junior has obtained his PhD in Mineral Resources Engineering and Environment, from the University of Nottingham, UK(1996) and his Post-Doctoral in Technological Innovation and Sustainability, at the Technical University of Lisbon (2007). He holds a Bachelor´s degree in Industrial Design from the Catholic University of Paraná, Brazil (1983). He is a teacher of the Post-graduation Program in Technology in the University of Technology of Paraná - UTFPR (master and doctor degrees), in the sustainable development area, in Curitiba, Brazil, since 1997 till present. He is the coordinator of the Green Office of the UTFPR, responsible for the environment management of the Campus Curitiba. He is also the leader of the research group TEMA – Technology and Environment.
E-mail address: eloy.casagrande@gmail.com

