Evaluation of Technical Feasibility and Financial Attractiveness of a 1MWp Solar Photovoltaic Generator on Ground and Building Rooftops at the Federal University of Santa Catarina – Brazil

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Abstract

This work aims to evaluate and to compare the technical and financial feasibility of two separate 1 MWp photovoltaic (PV) systems that would be installed in different locations on the Universidade Federal de Santa Catarina (UFSC) campus, located in Florianópolis, Brazil. The PV systems would be connected to the consumer unit (CU) Fazenda da Ressacada (fully ground mounted) and CU Cidade Universitária (fully rooftop mounted) with compensation of surplus energy in medium and low voltage CU's. It is observed that the PV system connected to the CU Cidade Universitária would produce around 1.312 MWh/year, and the PV system connected on the ground of the CU Fazenda da Ressacada would produce 1.460 MWh/year. Considering all the aspects of legal restrictions and financial aspects of the installation, even with a lower energy production, the rooftop PV generator presents itself as a very attractive option due to the potential of self-consumption.

Keywords: Solar energy, photovoltaic solar generation, technical and financial feasibility of photovoltaic systems

1. Introduction

Electricity consumption has become indispensable. Its supply must be safe and sustainable. The obvious choice for a clean energy source, which is abundant and inexhaustible, is energy from the sun. With regard to energy consumption, it is known that buildings represent a very high percentage of electricity consumption compared to other economic sectors (GUL and PATIDAR, 2014). Buildings and the construction industry combined account for more than a third of the world's total energy consumption, with buildings contributing with approximately 28% of all energy-related CO_2 emissions in the world in 2018 (IEA, 2019). Commercial buildings, mainly offices and universities, are among those with the highest consumption of electricity. In addition, in the case of photovoltaic energy generation, electricity produced by means of photovoltaic modules can be made both in large utility-scale power plants and by decentralized, urban rooftop PV systems (SMETS et al., 2015).

University campuses are the ideal places for the deployment of photovoltaic solar generation, because of the nature of the activities taking place; there is a great coincidence between solar availability and the demand for electricity, since the air conditioner is the equipment that presents the highest consumption in these buildings. The adoption of solar PV energy in university campuses, due to the concomitance between generation and consumption, presents itself as a very interesting strategy to reduce electricity consumption.

The concept of sustainable university can be defined as a higher education institution that involves and promotes the minimization of environmental, economic and social effects generated by the use of its resources (VELAZQUEZ et al., 2006). Sedlacek (2013) emphasizes that universities play a fundamental role in sustainable development at the regional level. A greater concern with energy sustainability on university campuses has emerged since the publication of the European Directive on Energy Performance in Buildings (EPBD) (JANSSEN, 2004).

Kolokotsa et al. (2016) state that, with regard to physical space, population and the various types of activities carried out on campuses, universities can be considered as mini-cities. Alshuwaikhat and Abubakar (2008) show that the energy and environmental impacts caused by universities through their teaching and research activities and operations can be considerably reduced by using efficient choices of organizational and

doi:10.18086/swc.2021.17.03 Available at http://proceedings.ises.org

managerial measures.

In Brazil, a net-meetering system is adopted, in the form of credits to be used by the consumer unit in subsequent billing periods. According to Normative Resolution No. 482 (ANEEL, 2012), for CUs participating in the energy credit compensation system, compensation must occur firstly at the same time-of-use period where the generation took place. Any remaining credits can then be used at different time-of-use periods.

According to the publication of the *Conselho Nacional de Política Fazendária* (CONFAZ, 2015), the Goods and Services Circulation Tax (ICMS) Agreement 16, of 4/22/2015, authorized the federated units to grant exemption in internal operations related to the circulation of electricity. Thus, the states that adhered to the ICMS Agreement 16/2015 are allowed to grant exemption from the ICMS levied on electricity injected into the utility's grid by the consumer. In the state of Santa Catarina, Decree No. 233 of August 30, 2019 was issued, which introduced attributions relating to the circulation of electricity subject to billing under the credit compensation system, applying to consumer units with installed generation capacity of less than or equal to 1 MW.

Therefore, for the study of credit compensation arising from the energy injected into the utility grid, in the composition of the compensation tariff, the ICMS levy on the generated energy credit will not be accounted for. An important issue addressed in ANEEL Normative Resolution No. 482 (ANEEL, 2012) is the limitation of the installed PV power capacity. Any installed power plant must be limited by the power made available to the consumer unit by the utility, which is the contracted power demand. In the case of an increase in installed capacity, an increase in contracted demand must be requested.

2. Methodology

This work aims to analyze the technical and financial feasibility of installing a 1 MWp PV generator in two CUs owned by UFSC located in Florianópolis, Santa Catarina, Brazil. UFSC has 82 consumer units, of which 23 are connected to medium voltage (MT) and 59 to low voltage (LV). For this study, the CUs Cidade Universitária and Fazenda da Ressacada were chosen. These CUs are powered by 13.8 kV distribution feeders. UFSC contracts its electricity from the local utility grid.

In order to evaluate the solar photovoltaic generation of a ground-mounted system installed at the CU Fazenda da Ressacada II and a roof-mounted PV systems added to the CU Cidade Universitária, the PVSyst software was used (MERMOUD, 2017). The values for standardized losses that were entered in the program are shown in Table 1.

Tab. 1 – Standardized losses adopted in the PVSyst software

Ohmic Losses	Module efficiency Loss	Mismatch Losses	Soiling Loss	Unavailability of the system	LID Losses
1.50%	-0.80%	1.00%	3.00%	0%	1.30%

2.1. CU– Cidade Universitária

CU Cidade Universitária covers several buildings in the UFSC's main campus. These buildings allow the installation of PV modules on their rooftops. For the installation of the 1 MWp PV system in this CU, the rooftops of buildings that present better positioning and higher solar incidence were selected.

Figure 1 shows the three-dimensional model used in the simulations of the buildings that are part of the UC Cidade Universitária. Figure 1 shows the Environmental Engineering building as an example.

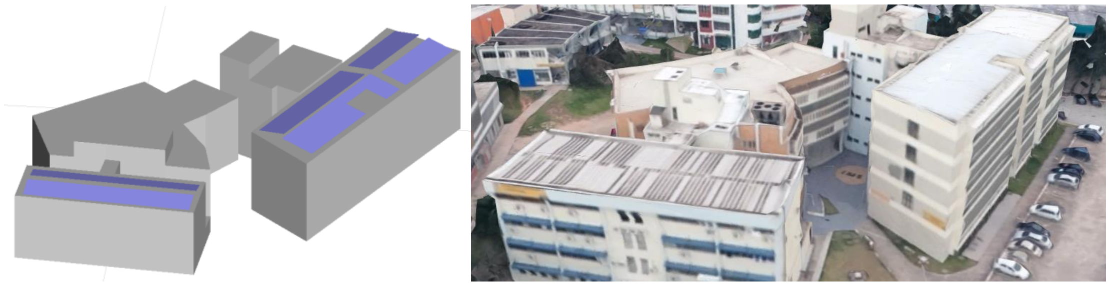


Fig. 1 – Adapted three-dimensional model of the Environmental Engineering building

2.2. CU – Fazenda da Ressacada

Figure 2 shows the three-dimensional model used in the simulation of the CU Fazenda da Ressacada. All aerial images are facing north and are not to scale.

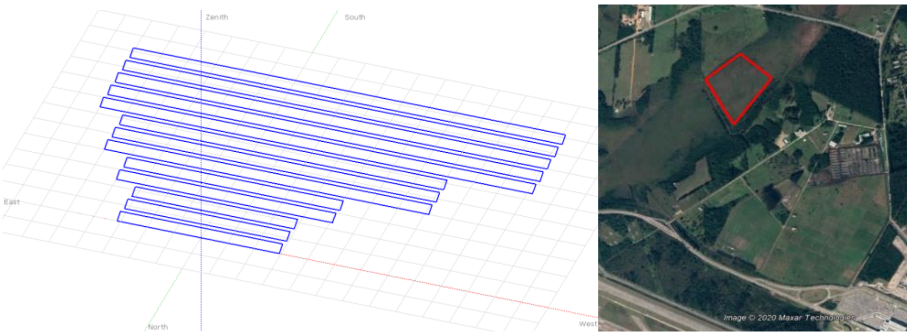


Fig.2 - Simulated system and its location on the ground

In the coverage area of CU Fazenda da Ressacada, in addition to some buildings, there are several areas for different academic activities and areas still without occupation, suitable to install the 1 MWp PV ground-mounted system. For the installation of the 1 MWp PV generator in this CU, only areas that are currently not occupied were selected.

For both CUs, the installed power of the photovoltaic system is equivalent to the sum of the output power of all inverters (990 kVA).

2.3. Technical indicators

To assess the effective production of the PV system for each set of buildings, on a monthly and annual basis, the global performance (Performance Ratio), the productivity and the capacity factor were calculated.

Equation 1 presents the global performance (PR) of the system, where i is the specified time interval, P is the installed power, $E_i^{generated}$ is the energy generated by the PV system in the specified time interval (obtained via PVSyst software), expressed in kWh, I^{ref} is the reference irradiance (1,000 W/m²) and $Irr_i$is the solar irradiation in the specified time interval (obtained via BRSN data), expressed in kWh/m.

$$PR_i = (E_i^{generated}.I^{ref})/(P.Irr_i) \quad \text{(eq. 1)}$$

Equation 2 presents the productivity (Yield) of the system, where Y_i is the yield in the specified time interval i, P is the installed power, expressed in kW; $E_i^{generated}$ is the energy generated by the PV system in the specified time interval, expressed in kWh (obtained via PVSyst software).

$$Y_i = E_i^{gerada} \,/\, P \qquad \text{(eq. 2)}$$

Equation 3 presents the system capacity factor, where FC_i is the capacity factor in the specified time interval i, P is the installed power of the plant, expressed in kW; $E_i^{generated}$ is the energy generated by the PV system in the specified time interval, expressed in kWh (obtained via PVSyst software).

$$FC_i = \frac{E_i^{generated}}{P*i} \qquad \text{(eq. 3)}$$

2.4. Economic indicators

For both PV installations, the financial analysis takes into account the equipment costs including delivery fees to the end customer. A service life span of 25 and 15 years for the photovoltaic modules andfor the inverters, respectively, were adopted. Replacement of these equipments was counted for at the end of their service life. The exchange rate for the transformation of Brazilian real to US dollar used was 5.56.

The energy consumption of the CUs was calculated based on their respective energy bills from January to December 2019. The cost of the rooftop PV system considered was 3.56 R$/Wp (GREENER, 2020) and 3.97 R$/Wp for ground-mounted systems (GREENER, 2020). A drop in the annual efficiency of the PV modules of 0.5% and an annual operating and maintenance rate of 1% were considered.

For both CUs, the analysis of the financial attractiveness of the return on investment was carried out, for various interest rates, by obtaining financial indicators, such as Net Present Value - NPV, discounted payback, Internal Rate of Return - IRR and Levelized Cost of Energy - LCOE. In these studies, inflation was not considered.

The LCOE was calculated, according to equation 4, where *I* is the initial investment, *N* is the equipment's lifetime, *i* is the minimum attractive rate of return, *A* is the maintenance cost and *M* the generated energy.

$$LCOE = \frac{I + \sum_{t=1}^{n} \frac{At}{(1+i)^t}}{\sum_{t=1}^{n} \frac{Mt}{(1+i)^t}} \qquad \text{(eq. 4)}$$

Net present value was calculated from equation 5, where NPV = Net Present Value, I = Initial investment, FCj = Revenue from year j, i = Annual interest rate used and n = Equipment useful life.

$$VPL = \sum_{j=n}^{n} \frac{FCj}{(1+i)^n} - I \qquad \text{(eq. 5)}$$

In both cases, the internal rate of return was calculated from equation 6, where IRR = Internal Rate of Return, i = Annual interest rate used and n = Equipment useful life.

$$-I + \sum_{j=n}^{n} \frac{FCj}{(1+TIR)^n} = 0 \qquad \text{(eq. 6)}$$

3. Results

3.1. Energy generation and consumption

3.1.1. – CU Cidade Universitária

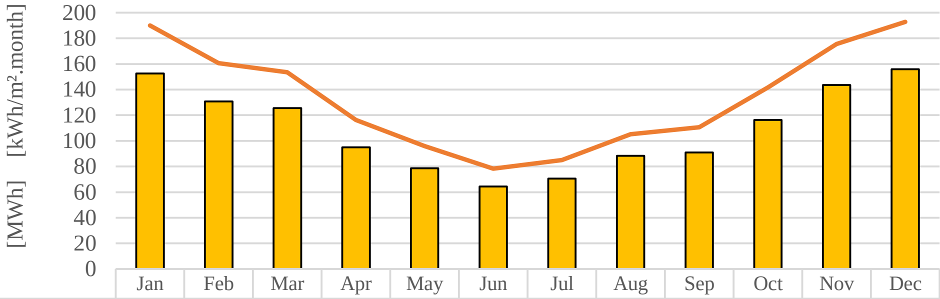
Table 2 shows the inclination, azimuth deviation, performance indicators and the PV generated energy for the buildings that are part of CU Cidade Universitária.

Tab. 2 - Simulated systems characteristics - CU Cidade Universitária

Building	Inclination / Azimuth deviation	System Power (kWp)	Nº Modules	PR (%)	Yf (MWh/ kWp/ year)	Capacity Factor	Energy (MWh/ Year)
University library	10/85 e 10/-95	549	1.526	0.765	1.22	13.92%	669.80
Health Sciences Center	10/-45 e 10/135 e 10/45 e 10/-135	105	292	0.77	1.23	14.04%	129.1
Control and Automation Engineering	10/17 e 10/-163 e 10/-73 e 10/107	101	280	0.765	1.21	13.82%	122.34
Mechanical Engineering	10/175 e 10/-5	101	280	0.727	1.16	13.18%	116.62
Production engineering	10/-4 e 10/175	120	332	0.769	1.23	13.98%	150.07
Environmental Engineering	10/176 e 10/-5 e 10/-118 e 10/62	102	282	0.767	1.23	13.94%	124.63
TOTAL	-	1.081	3.000	0.762	1.22	13.81%	1,312.59

It is observed that the PV systems have very similar PR, yield and capacity factor (respectively 0.77, 1.23 MWh/kWp/year and 14%), except for those installed in the Mechanical Engineering building (0.73, 1 .16 MWh/kWp/year, 13%). This difference is due to the greater losses due to shading verified in the latter.

Figure 3 shows the monthly evolution of the solar irradiation and the generated PV energy of the system to be connected at CU Cidade Universitária.

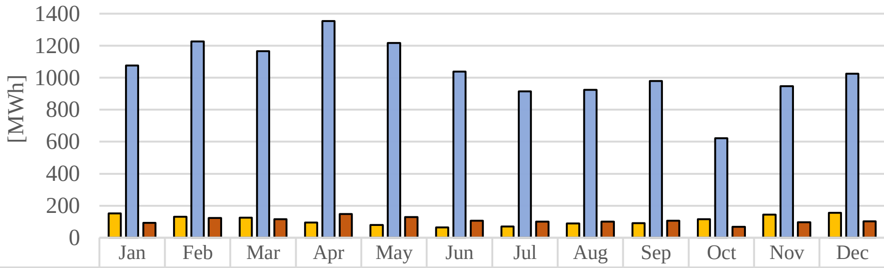


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Generated Energy	152.6	130.8	125.5	95.0	78.7	64.4	70.5	88.3	91.0	116.4	143.6	155.9
Solar Irradiation	190.0	160.7	153.5	116.4	95.8	78.3	84.9	105.1	110.7	141.7	175.5	192.8

Fig. 3 – Monthly evolution of the PV generation and solar irradiation - CU Cidade Universitária

From Figure 3, it can be observed the seasonality of the PV generation. Less energy was generated during the winter months, as oppose to the summer months, given the higher incidence of solar irradiation.

Figure 4 shows the energy consumption during at peak and off-peak hours and solar PV generation at CU Cidade Universitária.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Off-Peak Generated Energy	152.6	130.8	125.5	95.0	78.7	64.4	70.5	88.3	91.0	116.4	143.6	155.9
Off-Peak Consumption	1075.9	1227.2	1166.3	1354.6	1216.8	1039.1	914.7	924.1	979.6	621.6	947.5	1025.1
Peak Consumption	93.6	123.9	114.9	149	128.6	105.4	101.3	100	107.1	67.6	96.3	102.7

Fig. 4 – Energy consumption and solar PV generation at CU Cidade Universitária

Energy consumption at CU Cidade Universitária was higher during off-peak hours. It is during this timeframe that most classes are held, as they take place during business hours. In addition, during daylight hours, consumption in order to meet air conditioning demands is higher, characterizing a seasonality in energy consumption, consuming more in the months with higher temperature.

This work admits that all photovoltaic generation will be generated and consumed/compensated at off peak timeframe at CU Cidade Universitária. Therefore, the savings obtained by the insertion of PV generation will come from the energy itself, which will no longer be purchased from the grid, multiplied by the consumption tariff.

3.1.2. - CU Fazenda da Ressacada

For the buildings that are part of CU Fazenda da Ressacada II, Table 3 shows the inclination, azimuth deviation, performance indicators and the PV generated energy.

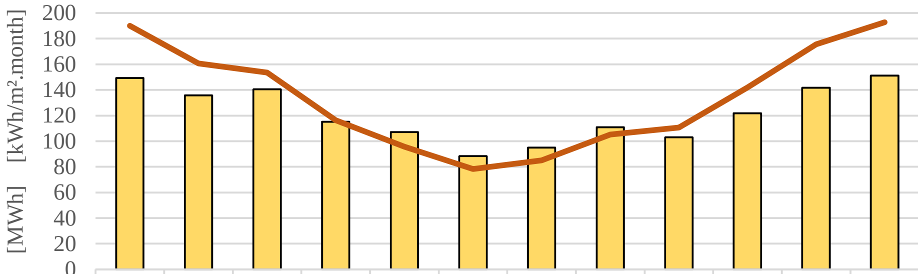
Tab. 3- Simulated systems characteristics - CU Fazenda da Ressacada II

Consumer Unit	Inclination / Azimuth deviation	System Power (kWp)	Nº Module s	PR (%)	Yf (MWh/ kWp/ year)	Capacity Factor	Energy (MWh/ Year)
Fazenda Ressacada	22/0	1,081	3,000	0.789	1,352	15.41%	1,460

In this case, the results show a PR of 0.79, yield of 1.35 MWh/kWp/year and capacity factor of approximately

15%.

Figure 5 shows the monthly evolution of the solar irradiation and the generated PV energy of the system to be connected at CU Fazenda da Ressacada II.

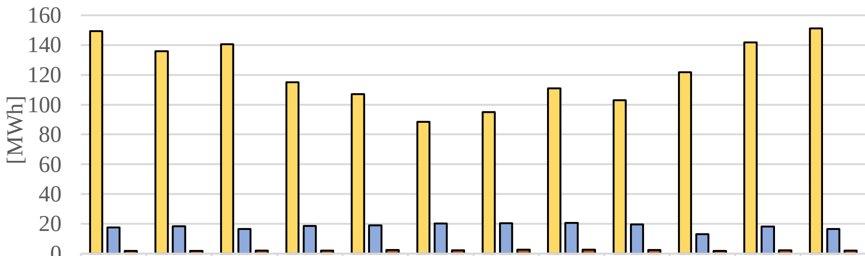


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Generated Energy	149.3	135.8	140.6	115.1	107.1	88.4	95.1	110.9	103.0	121.8	141.8	151.2
Solar Irradiation	190.1	160.7	153.5	116.4	95.8	78.3	85.0	105.2	110.7	142.0	175.6	192.8

Fig. 5 - Monthly evolution of the PV generation and solar irradiation - CU Fazenda da Ressacada II

It is observed that the photovoltaic generation at the UC Fazenda da Ressacada II followed the solar irradiation curve for its location. The seasonality of the generation is observed, producing less during winter months when compared to the summer months, given the higher incidence of solar irradiation.

Figure 6 shows the energy consumption during at peak and off-peak hours and solar PV generation at CU Fazenda da Ressacada II.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Off-Peak Generated Energy	149.3	135.8	140.6	115.1	107.1	88.4	95.1	110.9	103.0	121.8	141.8	151.2
Off-Peak Consumption	17.6	18.5	16.5	18.6	19	20.3	20.4	20.7	19.7	13.1	18.2	16.5
Peak Consumption	1.8	1.8	2.0	2.1	2.4	2.3	2.6	2.6	2.5	1.8	2.3	2.0

Fig. 6 – Energy consumption and solar PV generation at CU Fazenda da Ressacada II

Energy consumption at the UC Fazenda da Ressacada II was higher during off-peak hours. During this time, most classes are held, as they take place during business hours.

Taking into account the low consumption of the CU Fazenda da Ressacada II, the active energy generated in this location, in addition to reducing the off-peak consumption, will have its surplus injected into the utility grid. As a result, energy credits will be generated, which can be used to discount the consumption of CU owned by UFSC through remote self-consumption.

3.1.3. – Energy comparison

Figure 7 shows, for CU Cidade Universitária and CU Fazenda da Ressacada, the monthly evolution of energy that would be generated by the PV-generation of 1 MWp.

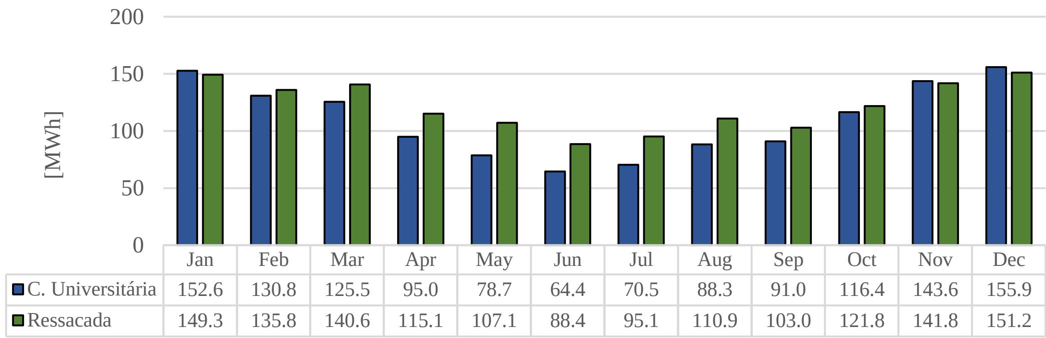


Fig. 7 – Monthly evolution of photovoltaic generation

The results show that the PV generation installed on the roofs of the buildings located at the CU Cidade Universitária, with different tilts and orientations, would produce about 1,312 MWh/year, while the PV generation of 1 MWp, installed on the ground of the CU Fazenda da Ressacada with orientation to the north, tilted at the local latitude angle (27.685º South; 48.544º West), would produce approximately 1,460 MWh/year. In addition, the system of the CU Fazenda da Ressacada II presents less shading, as there are no trees and buildings in the vicinity of the simulated system.

3.2. Financial attractiveness

3.2.1. – CU Cidade Universitária

Table 4 presents the systems installed power, cost per W of rooftop mounted systems (GREENER, 2020) and total cost.

Tab. 4- Installed power and cost of PV installation at CU Cidade Universitária

Installed Power (kWp)	Cost (US$/Wp)	Total (US$)
1,081	0.64	692,151.08

The contracted power demand at the CU is 4,500 kW, so there will not be an increase in contracted values. Due to the uncertainty of the demand reduction value provided by the aggregation of solar PV energy to the CU, the expenses avoided by the reduction in demand (contracted and measured) were not considered in the calculations of the financial attractiveness.

Table 5 shows the PV generation and the expenses that would be avoided by inserting the photovoltaic system at CU Cidade Universitária.

Tab. 5 - Summary table of PV generation and avoided expenses - CU Cidade Universitária

Month	PV Generation (kWh)	Off-peak tariff (US$/kWh)	Cost avoided with energy consumption (US$)	Operation and Maintenance Costs (US$)	Total benefits generated (US$)
Jan/19	152,640	0.0989	15,073.06	576.79	14,529.11
Feb/19	130,780	0.0953	12,355.09	576.79	11,808.00
Mar/19	125,480	0.0881	11,197.06	576.79	10,639.05
Apr/19	94,980	0.0863	8,314.97	576.79	7,746.59
May/19	78,690	0.0881	6,950.96	576.79	6,369.17
Jun/19	64,370	0.0917	6,014.54	576.79	5,430.04
Jul/19	70,480	0.0971	6,970.32	576.79	6,390.77
Aug/19	88,270	0.0971	8,632.04	576.79	8,054.77
Sep/19	91,020	0.0791	7,223.29	576.79	6,661.31
Oct/19	116,440	0.0755	8,948.14	576.79	8,391.13
Nov/19	143,550	0.0737	10,639.82	576.79	10,096.36
Dec/19	155,890	0.0755	11,664.27	576.79	11,128.37
Total	**1,312,590**	-	**113,983.57**	**6,921.50**	**107,244.67**

For CU Cidade Universitária and for the analyzed period, the monetary benefits (avoided expenses) due to the installation of the PV system would be US$ 107,244.67.

3.2.2. – CU Fazenda da Ressacada

Table 6 presents the systems installed power, cost per W of ground mounted systems (GREENER, 2020) and total cost.

Tab. 6- Installed power and cost of PV installation at CU Fazenda da Ressacada

Installed Power (kWp)	Cost (US$/Wp)	Total (US$)
1,081	0.71	771,865.11

As the contracted demand of CU Fazenda da Ressacada is less than 1 MWp, after the installation of the 1 MWp PV generator, it would be necessary to increase the contracted demand of this CU to 1 MW. Table 7 shows the monthly evolution of electricity expenses due to the increase in contracted power demand.

Tab. 7- Monthly evolution of expenses due to the increase in contracted demand - CU Fazenda da Ressacada

Month	Contracted demand (kW)	Charged demand (kW)	New Power Demand (kW)	Increase in contracted demand (kW)	Power demand tariff (US$/kW)	Additional expenses due to Contr. Demand (US$)
Jan/19	100	100	990	890	3.33	2,961.17
Feb/19	50	60.92	990	940	3.18	2,957.32
Mar/19	50	50	990	940	3.01	2,826.17
Apr/19	50	50	990	940	2.95	2,772.66
May/19	50	50	990	940	2.97	2,797.65
Jun/19	50	50	990	940	3.15	2,959.29
Jul/19	50	50	990	940	3.33	3,132.24
Aug/19	50	50	990	940	3.39	3,186.62
Sep/19	50	50	990	940	3.37	3,169.51
Oct/19	50	50	990	940	3.26	3,069.19
Nov/19	50	50	990	940	3.15	2,960.22
Dec/19	50	50	990	940	3.18	2,988.36
Total	-	-	-	-	-	**35,780.42**

For the period analyzed, it is observed that the expenses related to the increase in contracted power demand would be US$ 35,780.42.

Table 8 shows the monthly evolution of the avoided expense due to the PV generation that would be inserted in the CU Fazenda da Ressacada II.

Tab. 8- Total benefits generated - CU Fazenda da Ressacada II

Month	Off Peak Consumption (kWh)	Off peak tariff (US$/kWh)	Peak Consumption (kWh)	Peak energy credits compensation tariff (US$/kWh)	Total benefits generated from avoided expenses (US$)
Jan/19	17,592.40	0.0989	1,847.77	0.28	2,252.49
Feb/19	18,479.38	0.0953	1,807.06	0.27	2,243.87
Mar/19	16,532.32	0.0881	1,979.20	0.25	1,960.01
Apr/19	18,591.27	0.0863	2,147.16	0.25	2,141.80
May/19	18,950.34	0.0881	2,398.87	0.25	2,274.47
Jun/19	20,284.48	0.0917	2,308.37	0.26	2,471.00
Jul/19	20,420.45	0.0971	2,569.00	0.28	2,696.37
Aug/19	20,738.25	0.0971	2,612.06	0.27	2,720.17
Sep/19	19,656.33	0.0791	2,542.84	0.26	2,211.98
Oct/19	13,144.00	0.0755	1,818.00	0.25	1,449.65
Nov/19	18,202.63	0.0737	2,288.60	0.24	1,899.94
Dec/19	16,494.46	0.0755	2,039.18	0.24	1,746.87
Total	**219,086.31**	-	**26,358.11**	-	**26,068.62**

It is observed that, for the analyzed period, the total avoided expenses provided by PV generation would be US$ 26,068.62.

The analysis of the total benefits generated from the injection of PV energy into the utility grid took into account the generation of credits for compensation in medium and low voltage CUs. For the different voltage classes in which the CUs are serviced, energy tariffs have different values.

Table 9 shows the monthly values for the generation of energy credits arising from the energy injected into the grid by the system simulated at the CU Fazenda da Ressacada II. Table 9 also presents the respective tariffs applied to the energy credits for compensation in medium and low voltage.

Tab. 9- Monthly evolution of energy credits that would be generated by CU Fazenda da Ressacada II and respective financial benefits arising from energy credits for compensation in CUs powered by low and medium voltage

Month	PV Generation (kWh)	Energy injected into the grid (kWh)	Compensation tariff for LV CU (US$/kWh)	Benefits arising from energy credits at LV CUs (US$)	Compensation tariff for MV CU (US$/kWh)	Benefits arising from energy credits at MV CUs (US$)
Jan/19	149,300	128,774.63	0.13	16,170.59	0.094	12,087.345
Feb/19	135,800	114,452.27	0.12	13,794.74	0.090	10,289.347
Mar/19	140,600	120,926.09	0.11	13,834.28	0.085	10,304.906
Apr/19	115,100	93,100.53	0.11	10,466.46	0.083	7,782.750
May/19	107,100	84,341.92	0.11	9,572.98	0.084	7,111.354
Jun/19	88,400	64,451.44	0.12	7,698.55	0.089	5,736.176
Jul/19	95,100	70,601.77	0.13	8,878.38	0.094	6,639.709
Aug/19	110,900	85,658.19	0.11	9,623.47	0.078	6,741.079
Sep/19	103,000	78,959.46	0.11	8,458.60	0.074	5,901.014
Oct/19	121,800	105,521.57	0.10	10,957.07	0.072	7,641.365
Nov/19	141,800	119,651.51	0.10	12,038.47	0.070	8,364.254
Dec/19	151,200	131,189.71	0.10	13,287.65	0.070	9,261.092
Total	**1,460,100**	**1,197,629.08**	**-**	**134,781.25**	**-**	**97,860.39**

For the analyzed period, the results show that the annual benefit provided by the energy credits generated in the UC Fazenda da Ressacada II would be US$ 134,781.25, considering that all credits were used in the low voltage CU, and that US$ 97,860.39 were used for compensation in medium voltage CUs.

Table 9 shows the monthly evolution of avoided expenses, the increase in expenses due to the new contracted power demand, expenses with operation and maintenance of the PV system and the benefits due to the usage of energy credits in the CU Fazenda da Ressacada.

Tab. 9- Avoided expenses, increased expenses due to the new contracted demand and benefits from the insertion of PV generation in the UC Fazenda da Ressacada

Month	Total benefits generated from avoided expenses (US$)	Benefits arising from energy credits at MV CUs (US$)	Benefits arising from energy credits at LV CUs (US$)	Additional expenses due to Contr. Demand (US$)	O&M Costs (US$)	Total resulting benefits (compensation MV) (US$)	Total resulting benefits (compensation LV) (US$)
Jan/19	2,252.49	12,087.345	16,170.59	2,961.17	576.79	10,735.442	14,818.691
Feb/19	2,243.87	10,289.347	13,794.74	2,957.32	576.79	8,932.678	12,438.068
Mar/19	1,960.01	10,304.906	13,834.28	2,826.17	576.79	8,795.529	12,324.905
Apr/19	2,141.80	7,782.750	10,466.46	2,772.66	576.79	6,508.664	9,192.371
May/19	2,274.47	7,111.354	9,572.98	2,797.65	576.79	5,944.950	8,406.572
Jun/19	2,471.00	5,736.176	7,698.55	2,959.29	576.79	4,604.656	6,567.032
Jul/19	2,696.37	6,639.709	8,878.38	3,132.24	576.79	5,560.617	7,799.291
Aug/19	2,720.17	6,741.079	9,623.47	3,186.62	576.79	5,631.408	8,513.802
Sep/19	2,211.98	5,901.014	8,458.60	3,169.51	576.79	4,300.268	6,857.853
Oct/19	1,449.65	7,641.365	10,957.07	3,069.19	576.79	5,378.604	8,694.308
Nov/19	1,899.94	8,364.254	12,038.47	2,960.22	576.79	6,660.743	10,334.964
Dec/19	1,746.87	9,261.092	13,287.65	2,988.36	576.79	7,376.381	11,402.942
Total	**26,068.62**	**97,860.39**	**134,781.25**	**35,780.42**	**6,921**	**80,429.94**	**117,350.80**

It is observed that the total benefit generated is the result of the revenues due to the avoided energy expenses during off-peak hours, added to the credits generated resulting from the injection of energy into the grid, subtracted by the system maintenance cost and the additional contracted power demand costs.

The total annual benefits generated by the PV system inserted in the UC Fazenda da Ressacada would be US$ 117,350.80 (for credits written off in LV CUs) and US$ 80,429.94 (for credits written off in MV CUs).

3.2.3. – Comparison of financial attractiveness

Table 10 shows, for the 1 MWp PV generator simulated for both CUs, the evolution of NPV, payback and IRR for different Minimum Attractive Rate of Return (MARR).

Tab. 10: Evolution of NPV, Payback and IRR

	Cidade Universitária			**Fazenda da Ressacada (Energy credit compensation at MV CUs)**			**Fazenda da Ressacada (Energy credit compensation at LV CUs)**		
MARR (%)	NPV (US$)	Payback (years)	IRR (%)	NPV (US$)	Payback (years)	IRR (%)	NPV (US$)	Payback (years)	IRR (%)
2	1,129,340	7.1	12%	585,156	10.5	8%	1,232,719	7.2	13%
3	931,098	7.4		451,053	11.2		1,026,559	7.5	
4	762,557	7.8		336,980	12.1		851,210	7.9	
5	618,479	8.2		239,375	15.6		701,224	8.3	
6	494,649	8.6		155,381	17.2		572,218	8.8	
7	387,655	9.2		82,692	19.4		460,652	9.3	
8	294,726	9.8		19,439	23.1		363,651	9.9	
9	213,602	10.5		-	-		278,872	10.7	
10	142,431	11.4		-	-		204,400	11.7	

It is observed that a PV system of 1 MWp inserted in the CU Fazenda da Ressacada II with compensation of excess PV energy in UFSC’s CUs fed in LV presents a greater financial attractiveness than if compensated in CUs fed in MT. This significant difference is related to its energy credit compensation. As the monomial low voltage energy tariff is higher than the binomial tariff during off-peak hours in medium voltage, it would be more attractive to use these energy credits in units belonging to UFSC powered at low voltage.

For the CU Cidade Universitária, the financial attractiveness would be a close second overall. However, if the CU Fazenda da Ressacada did not present any off-peak energy consumption from its loads, its NPV would be greater, increasing the difference.

4. Conclusion

This study aimed to compare technically and financially, through simulations, two PV installations with a capacity of 1 MWp to be connected in two Consumer Units (Cidade Universitária and Fazenda Ressacada II), both owned by the Universidade Federal de Santa Catarina.

For the insertion of PV generation in the UC Fazenda da Ressacada II, the LCOE was US$ 37.54/MWh (with compensation of the excess PV energy at the CUs fed in low voltage). The results show the feasibility of the project, considering that the LCOE value is lower than the values charged by the utility, both for medium and low voltage rates. Finally, after analyzing the costs involved in the installation of the PV system, together with the costs of contracting a higher power demand and the fact that the compensation tariff for credit generation is different for CU fed in MV and LV, the compensation of excess energy in medium voltage CUs becomes less attractive when compared to compensation in low voltage CUs.

For the insertion of the PV generation in the CU Cidade Universitária, the results showed an LCOE of US$ 30.16 /MWh. In this case, a comparison between LCOE with the average value of the utility's tariff (87.73 US$/MWh), shows that photovoltaic energy is cheaper than energy purchased from the grid.

It is observed that the installation of a 1 MWp PV generator at CU Fazenda da Ressacada with compensation for surplus energy in the low voltage CU's grid presents financial attractiveness very close to the adoption of the same 1 MWp PV generator at the Cidade Universitária CU. However, although there is available land area for the implementation of the PV system, when the cost of availability of the land is considered, which would no longer be used for any other academic purpose, the attractiveness of the project to insert PV generation in the CU Fazenda da Ressacada II would be smaller than the insertion of the PV generation on the roofs of buildings that are part of CU Cidade Universitária.

Furthermore, when applied to the CU Cidade Universitária, a maximization of self-consumption would occur, making the financial attractiveness independent from future Brazilian regulatory changes regarding energy injected into the grid. Therefore, from the point of view of UFSC, the installation of the PV on the roofs of buildings whose electrical systems are connected to the CU Cidade Universitária is very attractive.

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