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Technical and economic feasibility study of a solar plant on a commercial surface in Azogues, Ecuador.

Authors: I. Bermeo[1], L. Matute[1], E. Barragán-Escandón[1], X. Serrano-Guerrero[1], E. Zalamea-León[2].

[1]Universidad Politécnica Salesiana, Grupo de Investigación en Energía
[2]Universidad de Cuenca, Facultad de Arquitectura y Urbanismo
Cuenca - Ecuador

Phone: +593 99565681, e-mail: **ibermeot@est.ups.edu.ec, lmatutev@est.ups.edu.ec, ebarragan@ups.edu.ec, jserranog@ups.edu.ec, esteban.zalamea@ucuenca.edu.ec**

Abstract. The submitted paper deals with the shopping mall project that will be supplied with solar power. The selected location was "La Playa Store" shopping center located in the city of Azogues, south of Ecuador. This type of building has at least two characteristics worth studying i) the available surface on the roof, ii) the characteristics of the energy demand curve. This evaluation process establishes the energy requirement of the installation; that is, the energy potential available depending on the surface of its roof, to design a solar plant according to international standards and local ARCONEL 003/18 regulations. The tools used for the involving simulation were the Lumion software, an IFC file created and imported into the Solarius Pv energy simulator, a software specialized in the design of photovoltaic systems. The designed photovoltaic system has a projected annual energy generation of 9,3695.26 kWh; an installed price per watt of $1.1 with viable results at the end of the fifth year of implementation with an IRR of 7.33% and NPV of $390.51. As this is a commercial facility, a constant and flat consumption throughout the day is expected, so implementing solar energy would reduce the actual power requirements by 32.63%

Key words. Grid connected photovoltaic system, large commercial areas, roof surface, solar generation, energy consumption.

1. Introduction

The photovoltaic (PV) solar energy emerges as a main future alternative to establish a sustainable global energy system. A constant evolution has been observed in terms of application scale, cost reduction and technology performance [1]. Under favorable economic and political conditions, urban PV generation is expected to promote energy self-sufficiency. There are high expectations of a distributed generation environment, which provides improvements in energy efficiency, boosts the economy and increases its potential due to architectural integration in urban areas [2]. In Ecuador, there is little experience in the grid connected photovoltaic system (GCPV) implementation. Figure 1 shows the previous PV installations carried out in the country, which serve as a comparative basis for validating the result of these projects.

PARAMETERS	Universidad Politecnica Salesiana	Escuela Politecnica Nacional	Escuela Politecnica Nacional	Universidad Politecnica Salesiana	Universidad de Cuenca	Centrosur	CENACE	Departments
Consumer type	Medium voltage with hourly demand	Medium voltage with hourly demand	Medium voltage with hourly demand	Medium voltage with hourly demand	Medium voltage with hourly demand	Medium voltage on demand	Public	Community
City	Cuenca	Quito-Los Bancos	Quito-Turubamba	Cuenca	Cuenca	Cuenca	Quito	Cuenca
Power installed kWp	62,40	171,60	171,60	12,70	35,00	28,00	44,00	18,00
Capture area (m^2)	313,87	1483,00	1490,00	73,00	226,60	187,20	307,20	116,00
Energy saving (kWh annual)	93695,26	141757,07	212508,93	20759,00	51035,10	28121,00	56940,00	25176,00
Plant Factor (%)	19,03%	12,37%	18,99%	18,00%	18,00%	15,00%	28,00%	16,00%
Irradiation (kWh/m^2 daily)	5,62	4,60	5,10	4,60	3,90	4,10	4,50	4,60
kWh/kWp annual	2051,30	1679,00	1861,50	1641,00	1458,10	1004,30	1294,10	1400,20
Energy Saving/surface (kWh/m^2)	298,52	95,59	142,62	284,37	225,22	150,22	185,35	217,03
Total project cost $	63352,81	165275,59	171833,32	N/A	N/A	N/A	N/A	N/A
Energy demand (kW)	59,66	47,48	49,55	N/A	N/A	N/A	N/A	N/A
Tons CO2 avoided (20 years)	79650,15	100,22	1873,66	N/A	N/A	N/A	N/A	N/A
Payback time (years)	6,00	15,00	20,00	N/A	N/A	N/A	N/A	N/A
TIR % (20 years)	0,23	0,10	0,04	N/A	N/A	N/A	N/A	N/A
VAN $ (20 years)	133530,64	17329,33	-50029,14	N/A	N/A	N/A	N/A	N/A
Feasible	Yes	Yes	No	N/A	N/A	N/A	N/A	N/A

Fig. 1. Previous works resume.

Currently, regulation 003/18 of ARCONEL called "Photovoltaic generation for self-supply of final consumers of electricity", conditions the forms of implementation for consumers that have PV generation systems located on roofs, housing areas or buildings for users in either low or medium voltage [3]. The PV building integration capability promotes a reduction to environmental impact for urban energy supply. The commercial center was chosen as A case study as well as its highest energy demand occurs during the day; which may coincide with the availability of solar radiation. This type of building has at least two characteristics worth studying, the available roof area and the demand curve. This project is located in southern Ecuador, specifically in the province of Cañar, in the city of Azogues (2.7397° S $78.8486°O$), at an altitude of 2 513 meters above sea level and with an annual irradiation of 2 174.49 kWh/m^2 [4]. The building has an area of 4043.87 m^2 and a high energy consumption; therefore, it is considered optimal to use non-conventional electricity generation alternatives.

Although the potential of PV has been extensively studied for years, PV generation remains underdeveloped in the Andean Equatorial zone despite being worth analyzing specially in high potential commercial buildings. In order to promote the introduction of alternatives that allow energy sufficiency from clean sources.

2. Case study

By means of on-site inspection of the low-voltage networks; it was deduced that the power supply in this commercial building to be analyzed is 66.467 kW, distributed in different loads as lighting appliances distributed in 1514 lamps of 2x18W each, for a total of 5 4504 W. There are no cold rooms or 24/7 loads in the facility.

The maximum consumption requirements were defined by taking measurements, using the three-phase power quality recorder Fluke 1735. The recorder was installed in the facility transformer to record energy data of power consumption by the establishment every ten minutes for a week. Likewise, the same three-phase power quality recorder was used as a tool to carry out the electrical load and demand studies within the facilities. The data sampling was carried out between December 4 and 11 of 2019, resulting in the following active power curves.

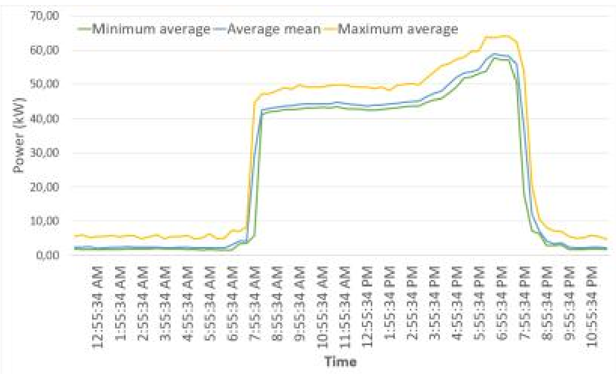

Fig. 2. Power curve.

Figure 2 shows that the power curve of the shopping center has an almost flat behavior throughout the day, to peak in the evening hours. Therefore, the entire solar resource is used to generate the most energy during the day and at sunset the system consumes entirely from the distribution grid.

A. Energy potential

There are no meteorological stations in the sector to access the daily radiation data presented, so three options were studied to obtain the data. The solar atlas for electricity [6] and finally the Meteonorm 7.1 licensed software extension were used [7].

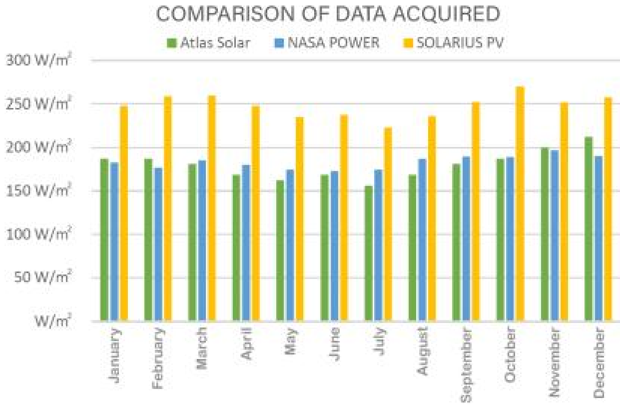

Fig. 3. Data base radiation levels.

When comparing the radiation levels of the mentioned sources, as can be seen in Figure 3, it was decided to analyze the results of Meteonorm 7.1[7] because it showed availability of updated data at the date of completion of the project to the other two sources; besides being a software annexed to Solarius Pv which is the main simulation tool used in this analysis. For this study, the value of the month with the lowest radiation corresponding to July with 223 W/m^2 and was used to simulated on Solarius Pv.

B. Available area

The roof of the building is made of Galvalume aluminum AR-2000 with a thickness of 40 mm. Due to the presence of polycarbonate sheets on the roof, the available area was reduced by 246 m^2 , leaving a remaining total useful area of 1 733.72 m^2.

Lumion software was used to simulate the building because it specializes in building simulation and 3D modeling[4] . Based on the plans provided by the builder and on-site inspections the 3D survey was carried out.

C. Characteristics of the 60kW three-phase solar power plant

Based on the measurement and power supply data, it is proposed to design a solar plant with a nominal power SUPPLY of 60 kWp. The 003/18 ARCONEL regulation limits the power supply capacity in commercial locations to less than 1000 kWp [3]. The main characteristics of the plant are shown in Table I and the monthly energy yield is shown in Table II.

Table I.- Plant Characteristics

Plant Characteristics 62,4 kWp	
Occupied area	313.87 m^2
Panels numbers	156
Investors numbers	3

Power yield by array	20 800 Wp
Installed nominal power	62 400 Wp
Annual energy produced	93 695.26 kWh
Energy per kW	1 501. 53 kWh/kW
Plant factor	19.03%
Cost $/W installed	1.1 $

Table II.- Monthly energy yield

Monthly energy produced (kWh)	Annual system production (kWh)	System performance %
7 968.86	93 695.26	8.51%
7 637.84	93 695.26	8.15%
8 273.9	93 695.26	8.83%
7 515	93 695.26	8.02%
7 490.84	93 695.26	7.99%
7 400.4	93 695.26	7.90%
7 135.58	93 695.26	7.62%
7 394.74	93 695.26	7.89%
7 877.7	93 695.26	8.41%
8 929.24	93 695.26	9.53%
7 863.6	93 695.26	8.39%
8 207.56	93 695.26	8.76%

D. Architectural Integration

To start the integration of the PV plant to the building roof, we proceed to perform the architectural integration with a dimension of roof space capability. Zalamea-León & Quesada [8] mention that in this case the ideal is to make three groups of PV panels, excluding the area of polycarbonate sheets for natural lightning. In addition, it is advisable to have a symmetrical distance between these groups for the future circulation for purposes of maintenance and inspection [9]. Figure 4 shows architectural integration under the described parameters.

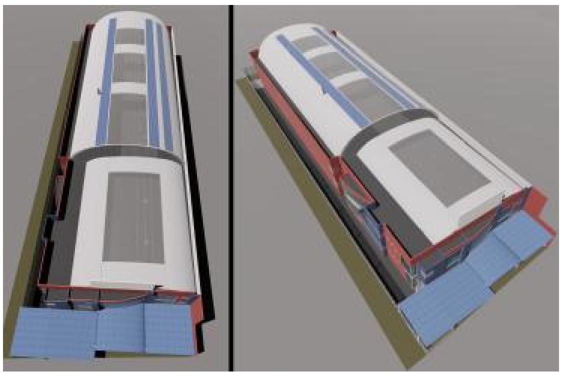

Fig. 4. Side view with the panels installed.

It is not necessary to perform an architectural integration of high level 3 with special building type PV product to replace the cover elements of the roof envelope. But rather superimpose traditional PV plates that could be installed in a coplanar and symmetrical way reaching a good aesthetic level [10]. Although, from the urban-architectural perspective, the visual impact achieved is avoided anyhow.

E. Production and demand analysis

To simulate the PV plant, licensed software from Solarius Pv was used. This software can simulate installations in new or existing buildings, PV parks, availability of geolocation of climatic data and 3D modeling. All these can be based on projects already completed in DXF/DWG or IFC formats. In addition, it allows the design of different PV systems whether connected to the grid or not. Since it has a database for global radiation levels from an external source (Meteonorm 7.1). Solarius PV shows that the highest production month corresponds to October with a value of 8929.24 kWh and the lowest production month corresponds to July with a value of 7 135.58 kWh, the plant will have an annual yield of 93 695.26 kWh. Based on the invoices obtained from the distribution company, it was possible to know that the month of highest energy demand was June with 24 009 kWh, while the month of lowest demand was November with 19 971 kWh. Throughout 2019, the energy demand of the shopping center was 236 926 kWh.

1. Net energy values per month

Net values are the difference between the energy billed and the energy generated by the PV system connected to the grid. The reduction in demand with the presence of the solar plant changes from 236 926 kWh to 143 230.74 kWh. Based on this behavior, the hourly demand will be reduced over a year by 35.54% with the designed rooftop solar plant of 62 400Wp.

2. Cost of the PV plant

Based on invoices from local distributors, the total value of the installation and purchase of materials was estimated at US$ 69 352.81, with an estimated price per installed W of $1.11.

3. Invoicing of the installation

The “La Playa Store" shopping center, is a commercial consumer at medium voltage with hourly demand. Therefore, it is subject to different fees to be charged on its monthly bill. The following items to be considered are detailed in the tariff specifications for the year and are shown in Table III.

Table III. - Cost of components and installation of the PV plant.

Time	Energy USD/kWh	Demand USD/kW-month	Comercialization USD/consumer
8:00 - 22:00	0.095	4.576	1.414
22:00 - 8:00	0.077	4.576	1.414

Based on these items, the total bill by the distribution company for 2019, under the above conditions for medium voltage commercial customers with three-phase hourly rate is $ 29 095.19 US dollars.

The Tables IV and V show the annual energy billed values for the hourly rate of 8:00 - 22:00 and 22:00 - 8:00 with the energy USD/kWh values detailed in Table III.

Table IV. - Monthly value billed at rate 8:00-22:00 year 2019.

Annual cost of electricity tariff: 8:00 - 22:00 year 2019			
Month	**Energy consumption kWh**	**U$D/kWh**	**Subtotal**
January	19 354	0.095	1 838.63
February	17 689	0.095	1 680.455
March	19 782	0.095	1 879.29
April	20 392	0.095	1 937.24
May	20 390	0.095	1 937.05
June	22 677	0.095	2 154.315
July	19 123	0.095	1 816.685
August	17 010	0.095	1 615.95
September	19 354	0.095	1 838.63
October	19 778	0.095	1 878.91
November	12 281	0.095	1 166.695
December	17 301	0.095	1 643.595
Total $ year			**21 387.445**

Table V. - Monthly value billed in rate 22:00- 8:00 year 2019.

Annual cost electric power rate: 22:00 - 8:00 year 2019			
Month	**Energy consumption kWh**	**U$D/kWh**	**Subtotal**
January	1 331	0.077	102.487
February	1 057	0.077	81.389
March	1 189	0.077	91.553
April	1 120	0.077	86.24
May	1 119	0.077	86.163
June	1 332	0.077	102.564
July	960	0.077	73.92
August	661	0.077	50.897
September	1 331	0.077	102.487
October	613	0.077	47.201
November	690	0.077	53.13
December	683	0.077	52.591
Total $ year			**930.622**

Considering the shopping center is opened from Monday to Sunday from 8:00 to 22:00, the energy demand of the establishment is almost the same throughout the whole week.

Based on the results in Table IV, it can be observed that the highest energy consumption occurred during the specified time interval. A total of $ 21,378.45 US dollars has been invoiced coinciding with the hours of operation of the PV system so a significant reduction of this value is expected. In table V it could be seen that consumption during the night and early morning hours is reduced, due to the closing of the premises and the lack of 24/7 considerable loads such as refrigeration or cold rooms.

It is important to note that the annual cost of power requirement in kWh is not considered as a value to be reduced by the operation of the solar plant according to current regulations ARCONEL 003/18 [3]. Table VI shows the cost of $3799.77 dollars for the power service contracted annually which was taken from the billing data of the year 2019.

Table VI. - Annual cost of demand USD/kW-month.

Annual cost of power kW			
Month	**Power kW**	**U$D/kWh**	**Subtotal**
January	72	4.576	329.472
February	73	4.576	334.048
March	73	4.576	334.048
April	75	4.576	343.2
May	74	4.576	338.624
June	72	4.576	329.472
July	71	4.576	324.896
August	60	4.576	274.56
September	72	4.576	329.472
October	58	4.576	265.408
November	62	4.576	283.712
December	64	4.576	292.864
Total $ year			**3 799.776**

On the other hand, the annual cost of electricity with the solar plant in operation during the hours of 8:00 - 22:00 is $12 486.40, distributed monthly as shown in table VII.

Table VII. - Annual cost of electricity between 8:00-22:00 with grid connected PV system (GCPVS).

Annual cost electric power rate 8:00-22:00 with GCPVS			
Month	**Energy consumption kWh**	**USD/kWh**	**Subtotal**
January	11 385.14	0.095	1 081.59
February	10 051.16	0.095	954.86
March	11 508.1	0.095	1 093.27
April	12 877	0.095	1 223.32
May	12 899.16	0.095	1 225.42
June	1 5276.6	0.095	1 451.28
July	11 987.42	0.095	1 138.80
August	9 615.26	0.095	913.45
September	11 476.3	0.095	1 090.25
October	1 0848.76	0.095	1 030.63
November	4 417.4	0.095	419.65
December	9 093.44	0.095	863.88
Total $ year			**12 486.40**

With the projected data of the new monthly demands, the PV solar system in operation and the historical ones based on the 2019 forms, the annual savings are projected, having considered the items the of hourly demand, contracted power, commercialization, and street lighting. The approximate value of 14% of the total sum of the values of the hourly demand and contracted power was deducted from the analysis of each billed form for one year, estimating its total expenditure, as seen in the Figure 5.

Figure 5 shows that the total annual billing cost without GCPV (grid-connected photovoltaic solar plant) paid by the user is $ 29,095.2, while with GCPV the total annual billing is $ 19,602.3, reducing a total of $ 9,492.81. One year represented a reduction in costs of 32.63% with respect to a normal annual billing cycle. The cost of public lighting with GCPV is higher in the months of February, March, and April than without GCPV, because in 2019 ARCONEL 051/18 came into force, which established a cost coverage that varied according to customer consumption ranges, standardizing a differentiated tariff for different types of consumers.

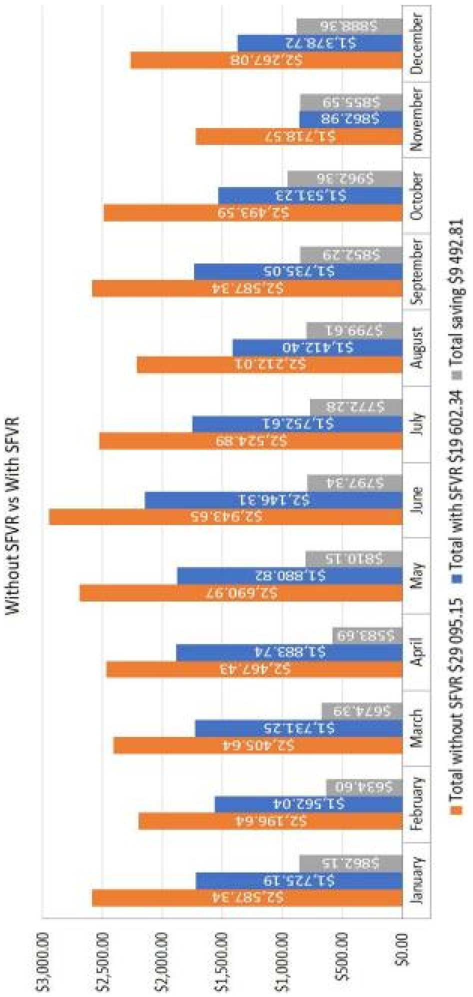

Fig. 5. Annual billing without grid connected PV system vs with grid.

F. *Financial evaluation*

To determine the financial viability of the project, we proceeded to the calculation of IRR (internal rate of return) and NPV (net present value). It is important to note that it is considered a 20-year operating period according to ARCONEL 003/18 regulation. In Figure 6, the accumulated cash flow is observed, noting that starting with the fifth year there is a positive remnant of $2 800.24, until the twentieth year with a positive remnant with $361 663.75.

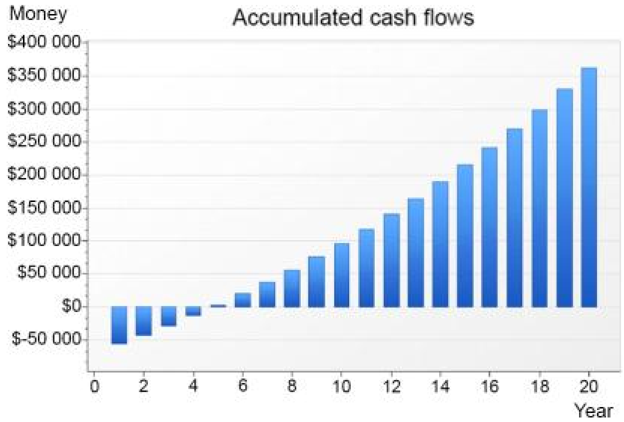

Fig. 6. 20-years accumulated cash flow.

To perform the NPV and IRR analysis, the following economic values from Ecuador's Central Bank website for 2019 (htpps://www.bce.fin.ec) were considered: inflation rate 5%, discount rate 7.15%. The worst inflation rate condition of 5% from the basic data of Ecuador's Central Bank was used.

As seen in Figure 7, the calculated NPV value is positive; therefore, it is feasible to execute the project and start recovering the investment by the 6th year with a value of $390.51 and for the year 20th the NPV will be $133 530.64.

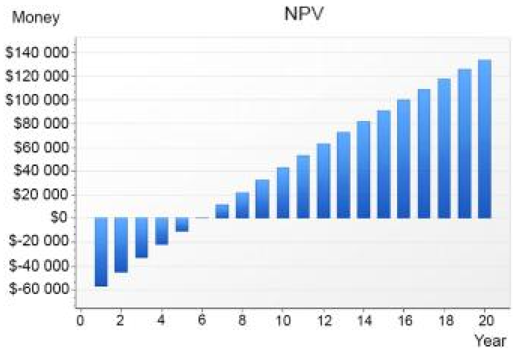

Fig. 7. Net present value.

Figure 8 shows the calculated IRR value, projected to the fifth year with 1.30% and to the twentieth year with 23.21%.

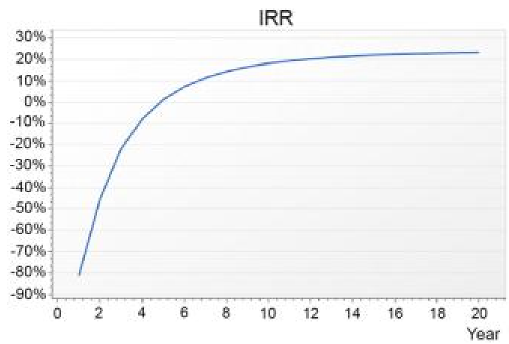

Fig. 8. Internal rate return.

Table VIII shows the facility's financial summary.

Table VIII. – Financial overview.

financial overview			
Total energy	62 400 kWp	payback time	5 years
Total energy per year	93 695.26	NPV 20 years	133 530.64 $
Total annual consumption	236 925.36	IRR 20 years	23.21%

3. Results and discussions

As a consequence of the location, there is regular radiation throughout the year. Hence, there is a very constant monthly energy production, which reaches 93695.26 kWh. In the roof area of 1733.72 m^2 there is an occupation rate of 313.87 m^2 to achieve the proposed power capability. With an entire roof area of PV occupancy, there would be a hypothetical annual generation of 236 209.86 kWh. If compared to the 236926.00 energy requirement, it would be feasible to reach the standard Net-Zero [11] at least for electrical requirements and a potential power of 166.40 kW. However, the ARCONEL 003/18 regulation indicates that the maximum installed capacity for regulated consumers will be 100 kW in roofs, area of housing or buildings. Nevertheless, in ARCONEL 057/18 resolution establishes the limits of installed power to be of 300 kW for residential consumers and up to less than 1 000 kW for commercial or industrial consumers. This means that although the entire roof surface of the facility can be used, it would be necessary to carry out complementary analyses regarding structural reforms and partial or total changes to the roof of the shopping center; interrupting passive solar capture and natural lightning that it is also important. Additionally, a higher power capability could lead to excessive surpluses and grid affection that must be analyzed [12].

The “La Playa Store” facility is categorized as a medium voltage commercial consumer with hourly demand, with energy rates 0.095 USD/kWh from 06:00 am to 22:00 pm and 4.576 USD/kW with the PV system installed in covering; it would manage to reduce 32.63% of its invoicing. This is an important detail since the shopping center attends 12 uninterrupted hours from 08:00 am to 20:00 pm and does not have refrigeration systems or cold rooms that would cause an increase in energy consumption. This can be considered a coupling between demand and PV supply. The PV generator has about 10 hours of sunlight, only no longer providing power to the facility from 18:00 to 20:00, that matches the highest consumption power schedule being in the range of 59664 W which the installation will consume energy entirely from the distribution grid.

ARCONEL 003/18 regulation, states that a PV solar generation system cannot exceed the 20 years of service life. If the system could extend its useful life to 25 years due to the durability of the materials according to its technical specification sheets (except for the inverters), it would generate higher profits. This can be seen from the fact that with 20 years of generation, there will be an accumulated cash flow of $ 361 663.75 and with 25 years of operation the accumulated cash flow will be $ 541 663.64 having a difference of $ 179 999.89 in 5 years. However, for regulatory purposes, the accumulated cash flow from $ 361 663 .75. The inverters will have to be replaced after 15 years, which implies an extra expense of $15 331.18 for inverters alone; in addition, the cost of labor must be considered and added the magnitude of the installation and it will be around $8 000. Additionally, about $800 per year must be invested in maintenance, increasing the cost of the PV solar plant. The annual energy reduction represents about 32.63% which is a quarter of its normal billing. Therefore, according to the estimated economic analysis the investment recovery will be realized at the end of the fifth year. This represents a quarter of the total time that the system could be in operation on the grid. The price per watt installed is around $1.11 due to the total cost of the installation and the power supply are around the same value. This being the lowest value if compared with other similar PV generation systems, as is the case raised by Arévalo Cortes [13] having an approximate cost of $ 1.67 per watt installed, also Loaeza Salcedo, Francisco Adrián; Carmona César Ramiro [14] raises that it will have an approximate cost of $1 346. On the other hand, the cost of electricity is also low in the country, since "La Playa Store" pays around $0.12/kWh, while Cornejo [15] exposes an approximate value of $0.39 per kWh being a high value if we compare with the rate of the case study or also with Whiting [16] that manifests an approximate cost of $0.20 per kWh.

4. Conclusion

The development of a targeted feasibility analysis for a shopping mall will serve as the basis for any future solar generation project in commercial surfaces, because it is a sector where large amounts are invoiced for energy consumption. With the grid systems in commercial areas, it is proposed to reduce the value of the invoices to recover the investment. It should be considered that they should adjust the parameters according to their case study such as: geographic location, radiation, energy demand, power supply and area availability among others. The PV panels should be installed coplanar to the surface so as not to alter the aesthetics and structure of the roof of the installation, the orientation of the panels will vary according to the point where they are in the structure.

Due to the fact the roof surface is circular in shape and because it is a modified installation in its façade during the construction process, it was necessary to rethink the entire installation, especially the roof, since it has polycarbonate sheets in certain sectors that reduce the available area. By means of software and with the data of the stakeout as well as the builder's plans, an architectural rendering of the available surface was obtained, after which, it was imported to Solarius PV to proceed with the development of the PV system. All this to obtain a simulation of the entire envelope to be used in the architectural integration stage through the design software.

This research was done under the guidelines of the ARCONEL 003/18 regulation that currently rules the national grid interconnection. However, soon a new regulation is expected for PV microgrid interconnection [17], [18], [27]–[31], [19]–[26].

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