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Article

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Technical and Financial Assessment of Photovoltaic Solar Systems for Residential Complexes Considering Three Different Commercial Technologies and Colombia's Energy Policy

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ABSTRACT

The use of solar energy is increasingly prevalent in residential areas around the world due to the decrease in the levelized cost of energy (LCOE) for projects that meet the energy need in homes, in Colombia regulations have begun to facilitate the integration of grid-connected renewable energy projects and in isolated areas. The purpose of this research is to technically and financially assess the feasibility of a solar photovoltaic system connected to the grid in a residential complex in Colombia according to the regulatory framework in force at 2020, comparing three photovoltaic module technologies, as well as three generation scenarios (self-consumption, exchange with the network and sale of surpluses), financial feasibility was assessed taking into account three financial goodness criteria (NPV, IRR and Payback Time). The results of the research indicate that the most feasible generation scenario technically and economically is self-consumption using Si-Poly technology, for the self-consumption scenario the solar photovoltaic system requires an installed capacity of 3.77 kW peak, with an investment cost of $5,748 USD, according to the criteria of kindness the Payback Time is 7 years, with an IRR of 19.67% for the project and $49,920 USD of NPV.

Keywords: PV System ON Grid, Solar Communities, Colombian Renewable Energy Regulations, Technical and Economic Analysis.
JEL Classifications: Q2, Q4, Q55

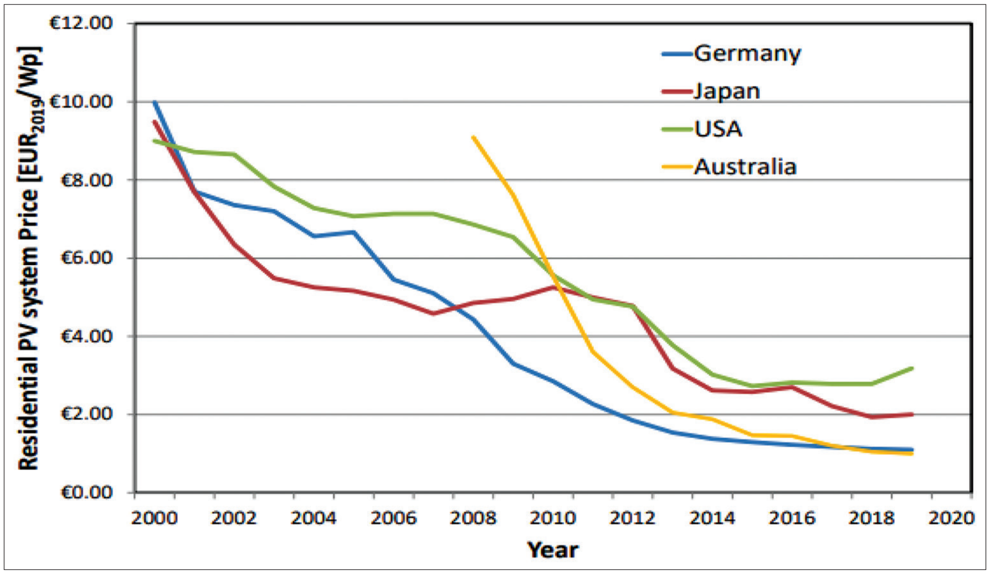
1. INTRODUCTION

The development of unconventional energy sources, mainly those of a renewable nature, is a matter of public utility and social interest, public and of national convenience fundamental to the Colombian state (Paez et al., 2017), since it ensures the diversification of full and timely energy supply, the competitiveness of the economy and the protection of the environment (Congress of Colombia, 2014). Among them, photovoltaic systems have achieved global acceptance and are playing an important role in the supply of clean and sustainable energy (Robles et al., 2018). This has led to the implementation of photovoltaic energy experiencing huge growth in recent years (Das et al., 2018; Ospino-Castro et al., 2017).

Colombia has an average solar energy potential of 4.5 kWh/m^2/day and the area with an optimal solar resource is the La Guajira Peninsula, with 6 kWh/m^2/day of radiation (Muñoz et al., 2014), surpassing the global average of 3.9 kWh/m^2/day (Soonmin et al., 2019; Chamorro et al., 2017). In turn, the multi-year average in the Santander region is between 4.0 and 5.0 kWh/m^2/day in most of its territory, entering the national average (UPME, 2019).

For these reasons, photovoltaic projects registered with the Energy Mining Planning Unit (UPME) have had a dramatic increase as of January 2018, according to Jarger-Waldau in 2019, Figure 1, reaching a total power of more than 400 MWp. However, most are in phase 1 and 2 of development, with installed power being

Figure 1: LCOE of photovoltaic systems connected to the network for residential areas.



just over 100 MWp, still leaving great potential to be exploited (Rueda-Bayona et al., 2019).

Globally, there has been a considerable decrease in the costs of photovoltaic systems (Figure 2) (Padmanathan et al., 2018), reducing the cost of energy by implementing photovoltaic solar systems in residential areas (Jarger-Waldau, 2019), which coupled with the tax incentives offered by the Colombian state for the implementation of renewable sources, Law 1715 of 2014, reduce the financial barrier, offering an auspicious scenario for photovoltaic systems of distributed generation in Colombia (Eras et al., 2018), reflected in a level cost of competitive, and financially attractive energy, even for small and medium-scale projects (Castillo-Ramírez et al., 2017).

In this context, residential complexes offer an opportunity to expand photovoltaic solar generation projects on a small scale and break the financial barrier, as they have the required space and considerable energy demand. This article presents the technical and financial study of the feasibility of a solar photovoltaic system connected to the grid in a residential complex in Colombia according to the regulatory framework in force in 2019, comparing three solar panel technologies, as well as three generation scenarios in order to determine the optimal option for these renewable energy projects.

2. REGULATIONS FOR SOLAR PHOTOVOLTAIC SYSTEMS CONNECTED TO THE GRID

Colombian law establishes Law 1715 of 2014, which allows any natural or legal person, for commercial, personal or industrial purposes, to deliver to the energy grid the electricity produced through Unconventional Renewable Energy Sources (FNCER), that is, promotes the integration of unconventional renewable energies into the national energy system, the tax incentives promoted by this law are (Hernandez et al., 2017):

1. Special deduction in the determination of income tax.
2. Accelerated depreciation.
3. Exclusion of VAT goods and services.
4. Exemption from tariff levies (Moya-Chaves et al., 2019).

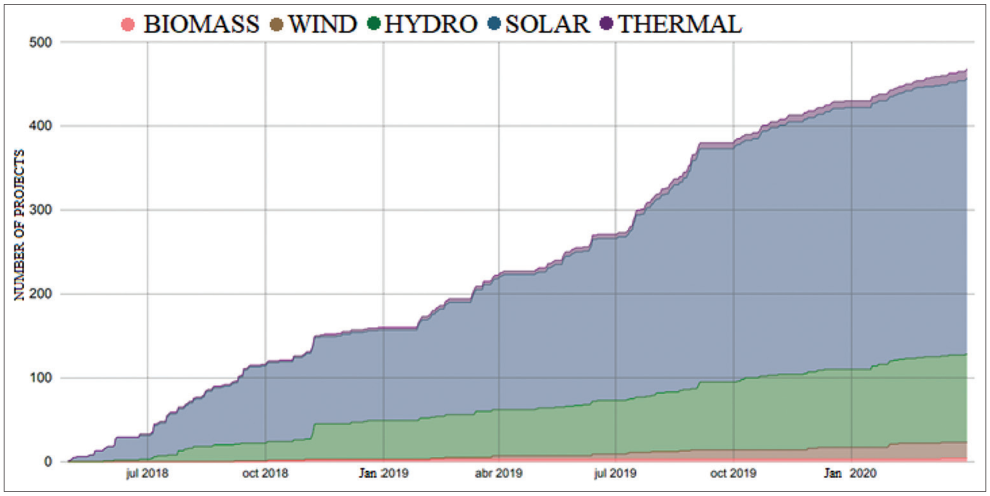
The sale of energy credits is one of the most important incentives established by Law 1715 of 2014, regulated by Energy and Gas Regulation Commission (CREG), resolution 030 of 2018, Because through the sale of energy credits, it is that the delivery of surplus energy to the grid, with the essential use of bidirectional meters as established in resolution CREG 038 of 2014, can show the added value as an economic benefit. for those who are generating and delivering energy to the grid (Hernandez et al., 2017).

The resolution CREG 030 of 2018 regulating the activities of Small Scale Self-Generation (AGPE) and Distributed Generation (GD) in the National Interconnected System has incentivized 368 projects of solar energy at the national level up to January 2020 (Figure 2) (Gutiérrez et al., 2020). This resolution simplifies the connection to the electricity grid to the self-generators in order to take advantage of surplus energy, the resolution also specifies that a solar photovoltaic system connected to the grid can only be connected to a commercial border (counter), i.e. the same photovoltaic solar system cannot meet the electricity demand of two households, even if it has the capacity installed to do so.

The different commercial borders that are located in a residential complex hinder or make it impossible to connect with different users through a centralized system (NTC 2050, 1998), for this reason, it is advised that residential complexes use photovoltaic solar systems to supplement the consumption of common areas that in these cases require to meet a demand for high electricity.

For the sizing of the solar photovoltaic system suitable for the load profile, commercial boundaries for common areas must be taken into account and the availability of the distribution transformer of the network, the availability is regulated by resolution CREG 030 of 2018 indicating that it is only possible to inject into the grid a

Figure 2: Report on the registration of electricity generation projects in Colombia



power less than or equal to 15% of the nominal capacity of the distribution transformer , so, according to the resolution, energy marketers are required to publish on their website the percentage of availability presented by the transformer for each user.

After sizing the solar photovoltaic system, the type of cable, protections and other elements to be used in accordance with the Colombian Technical Standard (NTC) 2050 required by Colombian law (Mermoud and Lejeune, 2010) is established, when sizing these elements must take into account the electrical intensity, distances, weather, among others.

3. TECHNICAL EVALUATION FOR THE INTEGRATION OF THE SOLAR PHOTOVOLTAIC SYSTEM CONNECTED TO THE GRID

When technically evaluating a solar photovoltaic system, it is essential to know the load profile. In the common areas of residential complexes, electricity consumption consists of two power consumption profiles; the first can be considered as constant electricity consumption where continuous operating equipment that is normally associated with safety appliances and their complements are related, the second component presents a variable behavior that depends on the social stratum of the residential complex, this is related to the services provided by the residential complex, among them the most common are usually: night lighting, swimming pool and spa areas, social rooms, recreational spaces, electric action doors, among others (Chandel et al., 2017).

For the case study the load profile was determined from on-site measurements showing total electrical power consumption in common areas. The construction of the load profile was done with weekdays and weekends to compare the behavior of working days and rest days, in order to obtain an average load profile.

PVsyst software was used to size and evaluate the solar photovoltaic system, selecting three more available technologies in the Colombian market (Table 1) (Bahaidarah et al., 2016), three

Table 1: Technologies available in the Colombian market

Technical data	Si-Poly	Si-Mono	HIT
Pot (W)	290	290	290
Area (m^2)	1.94	1.637	1.641
Efic (%)	14.96	17.79	17.69
V mppt (V)	35.8	32.2	35.9
V oc (V)	44.9	38.8	44.04
I mppt (A)	8.11	9.02	8.08
I sc (A)	8.69	9.78	8.727

generation scenarios and a shadow analysis of the installation site. The three selected technologies were: polycrystalline silicon (Si-Poly), monocrystalline silicon (Si-Mono) and HIT (Heterojunction with Intrinsic Thin-layer) (Taguchi et al., 2014).

General information and case restrictions:
- Residential complex located in Piedecuesta, Santander.
- The residential urbanization consists of homes with an average of 3 levels.
- The maximum power that could be injected into the grid by restriction on the distribution transformer is 22.5 kW.
- The space available for the installation of the solar photovoltaic system is 200 m^2.
- Minimum two investors are required, one for each trading border.
- Replace current one-way counters with bidirectional counters.

The proposed generation scenarios are:

A. Self-consumption is the system in which the electrical energy is consumed instantly in which it is generated, avoiding surpluses by not exceeding the peak of electrical energy consumed.
B. Exchange with the grid exists when the energy produced is equivalent to the energy demanded over the billing period.
C. Excess sales occurs when the electrical energy generated by the system exceeds the electricity demanded in the billing period.

Once the residential assembly load profile is established (Figures 3 and 4), the maximum power to be installed is calculated (see equation 1) from the average electrical energy consumed during the year.

Figure 3: Load profile – trade border 1

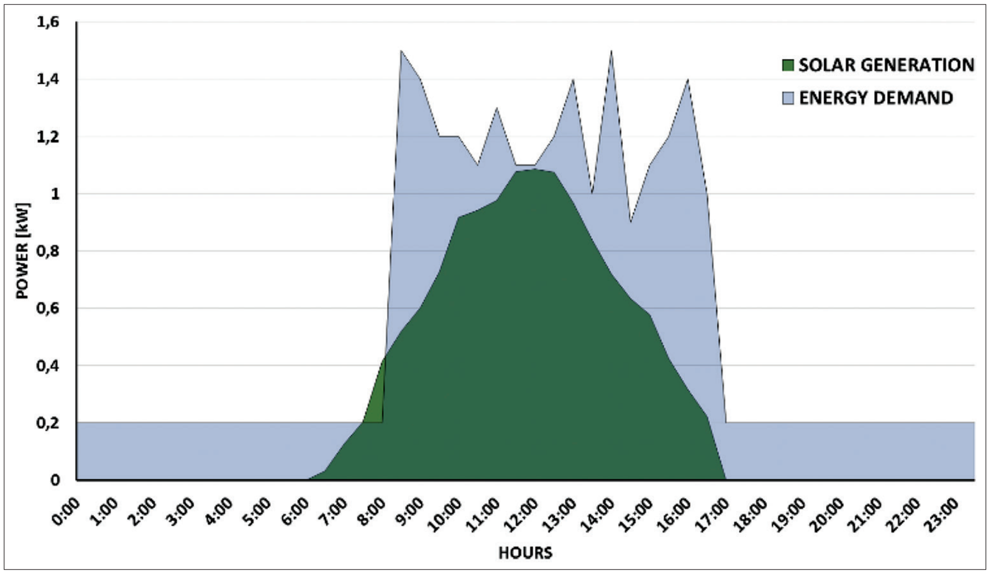
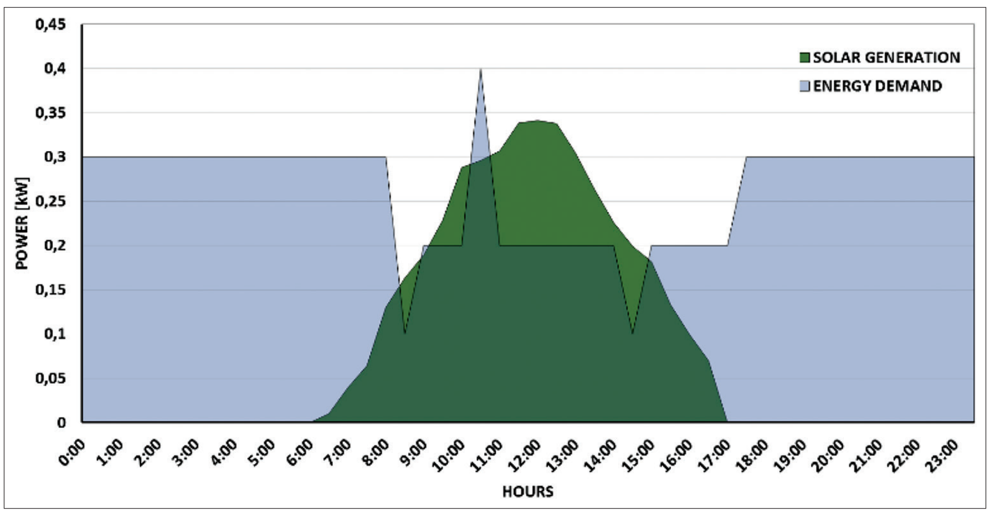


Figure 4: Load profile - trade border 2



$$E_{PA}[\frac{kWh}{año}] = P_{sist_{max}}[kW] \times PR[-] \times HSP[\frac{h}{año}] \quad (1)$$

E_{PA}: Average electrical energy that is demanded annually.
$P_{sist_{max}}$: Maximum power to be installed depending on the scenario to be evaluated.
PR: Performance Rate.
HSP: Peak hours of sun per year.

To determine the optimal configuration of the solar photovoltaic system it is necessary to correctly set the number of photovoltaic modules in series and parallel to achieve maximum performance, to define this parameter optimally it is necessary to know the working voltage range at maximum power of the inverter(s) to be used.

$$Total_{módulos} = \frac{P_{sist_{max}}}{P_{módulo}} \quad (2)$$

$Total_{módulos}$: Maximum number of photovoltaic modules required in the solar photovoltaic system.

$P_{módulo}$: Peak power of the photovoltaic module.

$$Serie_{max_{mppt}} = \frac{Vinversor_{mppt_{max}}}{Vmódulo_{mppt}} \quad (3)$$

$$Serie_{min_{mppt}} = \frac{Vinversor_{mppt_{min}}}{Vmódulo_{mppt}} \quad (4)$$

$Serie_{max_{mppt}}$: Maximum number of photovoltaic modules that can be installed in series on the inverter for optimal performance.
$Vinversor_{mppt_{max}}$: Maximum value of the working voltage range at maximum power of the inverter.
$Vmódulo_{mppt}$: Working voltage at maximum power of the photovoltaic module.
$Serie_{min_{mppt}}$: Minimum number of photovoltaic modules that can be installed in series on the inverter for optimal performance.
$Vinversor_{mppt_{min}}$: Minimum value of the working voltage range at maximum power of the inverter.

$$Paralelo_{max} = \frac{Iinversor_{max}}{Imódulo_{sc}} \quad (5)$$

$$Paralelo_{min} = \frac{Total_{módulos}}{Serie_{max}} \quad (6)$$

$Paralelo_{max}$: Maximum number of photovoltaic modules in parallel.
$Iinversor_{max}$: Maximum operating current of the inverter.
$Imódulo_{sc}$: Short-circuit current of the photovoltaic module.
$Paralelo_{min}$: Minimum number of photovoltaic modules in parallel.

Once the optimal configuration is obtained for the solar photovoltaic system, it is essential to establish the main parameters that affect the performance of the system during its operation.

- Losses by Angle of Incidence Modifier (IAM).

$$F_{IAM} = 1 - b_0 \times \left(\frac{1}{\cos(i-1)}\right) \quad (7)$$

F_{IAM}: Loss factor by IAM.
b_0: Estimated value for photovoltaic modules of 0.05 (Dubey et al., 2013).
i: Angle of incidence in the receiving plane of the photovoltaic module.

- Temperature losses: Temperature strongly affects the electrical performance of photovoltaic modules, commonly temperature affects the performance of photovoltaic systems at a factor of approximately 0.45% of the yield rate per 1°C temperature, varies depending on the type of technology used (Mermoud and Lejeune, 2010; Kant et al., 2016).
- Dust and dirt losses: This type of loss has a value of no more than 2% (Kant et al., 2016).
- Missmatch losses: These are the losses that occur when the photovoltaic cells are not operating identically, they can occur between cells of the same module, between different modules, between strings and between the inverter connections.
- Light Induced Degradation Losses (LID): This type of loss only affects polycrystalline silicon modules and its value is estimated by the manufacturer, by default its value is 3% (Cutillas et al., 2017).

4. FINANCIAL ASSESSMENT OF THE SOLAR PHOTOVOLTAIC SYSTEM CONNECTED TO THE GRID

After technically sizing the solar photovoltaic system is evaluated financially, for this purpose considerations were established to know in advance any financial risks that may affect the system.

It is assumed that:

- Moderate growth in the Colombian economy.
- The price of electricity according to estimated economic growth.
- The volatility of the price of electricity in the exchange according to projections from 3 years of data.
- A projection of the electrical energy generated in the photovoltaic solar system taking into account the natural degradation of the system.
- Evaluate the project to 25 years because that is the lifespan of the photovoltaic modules, after that time optimal production of electrical energy is not guaranteed.

Taking into account the above considerations, financial assessments are performed and cash flows are obtained for each generation scenario. The 2018 Consumer Price Index was established with an annual growth of 0.5%, so the price of electricity for the residential complex is increased by 0.0416% per month (2% per year). The price volatility of electricity in the exchange was estimated from simulations using the Monte Carlo method with data from September 2015 to September 2018. Finally, the Internal Rate of Return (IRR), Net Present Value (NPV), and Payback Time were used as criteria for the project financially.

5. RESULTS

The load profiles characterized for the sizing of the solar photovoltaic system of the common areas are found in Figures 3 and 4. The graphs of the load profiles also present a solar power generation according to the scenario of generation of self-consumption (on the trade border 2 a small part of the energy generated is exchanged with the grid even being the scenario with the lowest possible installed power).

The load profile of the commercial border 1 has constant energy consumption (0.2 kW) during the night and early morning, its behavior during the day shows consumption up to seven times higher (1.5 kW) compared to night. While the load profile of commercial border 2 has a higher constant consumption (0.3 kW) during the night and early morning compared to variable consumption (0.1-0.4 kW) during the day.

Table 2 presents the technical results of the simulations, including the power, area, configuration and number of inverters for each generation scenario (A: Self-consumption, B: Exchange with the grid and C: Excess sales).

The shadow analysis allowed to know the behavior of shading in the photovoltaic solar system through the recreation of the place where it will be implemented where it was estimated to be located 6 meters from the ground to reduce losses by nearby shading and not to modify the architecture of the whole, the perspective of the place is shown in Figure 5.

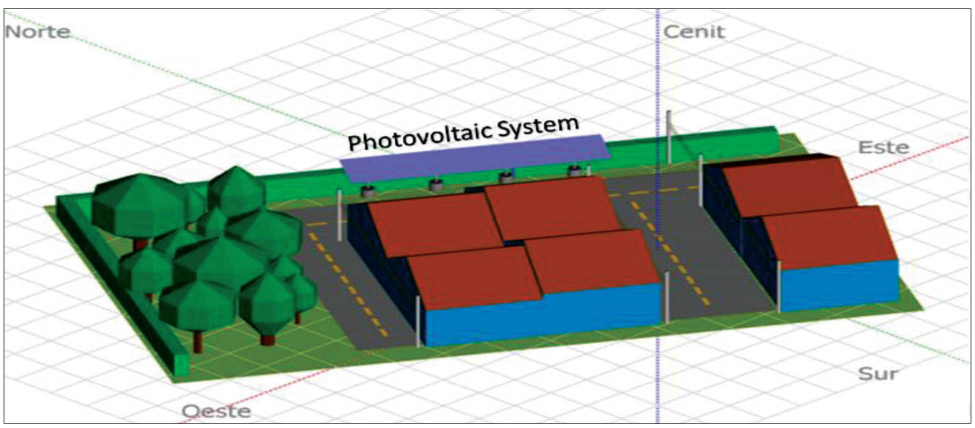
The results obtained clearly show that monocrystalline silicon technology and HIT require a similar area for the same installed power (Si-Mono Self-consumption 21.1 m^2; HIT Self-consumption 21.3 m^2; Si-Mono Exchange with network 54 m^2; HIT Exchange with network 54.2 m^2; Si-Mono Sale of Surpluses 128 m^2; HIT Sale of Surpluses 131 m^2) except in the case of sale of surpluses where the installed power in HIT technology is 0.6 kW lower.

A broader analysis of system performance for each scenario is found in Table 3, where it can be seen that the technology that

Table 2: Technical evaluation of dimensioned photovoltaic solar systems.

Photovoltaic solar subset (Trade border 1)									
Technology	**Si-Monocrystalline**			**Si-Polycrystalline**			**HIT**		
Scenario	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Power (kW)	3.48	6.38	11.31	3.48	6.38	11.6	3.48	6.38	11.6
Area (m^2)	19.463	36	64	23.26	42.66	77.5	19.659	36.149	65.5
N. Panels	12	22	39	12	22	40	12	22	40
N. Chains	2	2	3	2	2	4	2	2	4
N. Series	6	11	13	6	11	10	6	11	10
N. Investors	1	1	1	1	1	1	1	1	1
Photovoltaic solar subset (Trade Border 2)									
Technology	**Si-Monocrystalline**			**Si-Polycrystalline**			**HIT**		
Scenario	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Power (kW)	0.29	3.19	11.31	0.29	3.19	11.6	0.29	3.19	11.6
Area (m^2)	1.637	18	64	1.94	21.34	77.5	1.641	18.051	65.5
N. Panels	1	11	39	1	11	40	1	11	40
N. Chains	1	1	3	1	1	4	1	1	4
N. Series	1	11	13	1	11	10	1	11	10
N. Investors	1	1	1	1	1	1	1	1	1
Global system									
Technology	**Si-Monocrystalline**			**Si-Polycrystalline**			**HIT**		
Scenario	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Power (kW)	3.77	9.57	22.62	3.77	9.57	23.2	3.77	9.57	23.2
Area (m^2)	21.1	54	128	25.2	64	155	21.3	54.2	131
N. Panels	13	33	78	13	33	80	13	33	80
N. Investors	2	2	2	2	2	2	2	2	2

Figure 5: Perspective of the solar photovoltaic system at the installation site (using PVSyst software)



offers the highest performance index in the different generation scenarios is monocrystalline silicon (Self-consumption 80.81%; Exchange with network 81.91%; Sale of Surpluses 81.36%), it can also be inferred that in the annual energy production monocrystalline silicon technology generates more energy in the scenario of Self-consumption (5.3 MWh/year) and Exchange with the grid (13.67 MWh/year), for the case of Sale of Surpluses HIT technology has the maximum annual energy production (32.76 MWh/year).

The highest shading losses were obtained in the Self-Consumption scenario without distinction of technology (Si-Mono 5.48%; Si-Poly 5.44%; Hit 5.48%), these shadow losses are the sum of nearby shading caused by structures (buildings, trees, poles and wiring of the electricity grid, etc.) and distant shading (horizon) that refers to the topographical area of the place.

Other analyses presented in the technical evaluation in the different simulations are:

- Due to the architectural design of the residential complex the modules are at a height of 6 meters from the floor of the place, therefore, the temperature losses are minor when compared to installation that is fixed on a roof or do not have natural ventilation from the back of the modules.
- The most representative losses are by temperature, shadows and inverter, respectively with the exception of HIT technology (Si-Mono: Temperature 6.09%, Shadows 5.05%, Inverter 3.69%; Si-Poly: Temperature 6.74%, Shadows 4.99%, Inverter 3.7%; HIT: Temperature 4.31%, Shadows 5.07%, Inverter 3.56%).
- Polycrystalline silicon is the largest area (Si-Poly: Self-consumption 25.2 m^2; Exchange with network 64 m^2; Sale of Surpluses 155 m^2).
- Monocrystalline silicon and HIT have higher yield rates with slight differences between them (Si-Mono: Self-

consumption 80.81%, Exchange with network 81.91%, Sale of Surpluses 81.36%; HIT: Self-consumption 80.41%, Exchange with network 81.23%, Sale of Surpluses 80.74%).

- Higher power scenarios decrease their shadow losses (Self-consumption 5.46%; Exchange with network 5.09%; Sale of Surpluses 4.56%).
- SCENARIOs with HIT have considerably lower temperature losses than the other two technologies (HIT: Self-consumption 4.3%, Network Exchange 4.31%, Surplus Sales 4.32%).

The annual cash flow by technology for each generation scenario, together with the IRR and the energy saved are presented in Figures 6, 7 and 8. In Table 4, you can see that self-consumption

Table 3: Overall performance of the photovoltaics solar systems

Technology	Si-Monocrystalline			Si-Polycrystalline			HIT		
Scenario	A	B	C	A	B	C	A	B	C
Performance index (%)	80.81	81.91	81.36	78.27	79.39	78.88	80.41	81.23	80.74
Annual energy (MWh)	5.3	13.67	32.19	5.13	13.25	32.01	5.27	13.56	32.76
Shadows* (%)	5.48	4.98	4.7	5.44	5.1	4.44	5.48	5.19	4.54
IAM factor* (%)	2.8	2.81	2.83	2.8	2.81	2.84	2.8	2.81	2.83
Dust and dirt* (%)	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Temperature loss (%)	6.21	6.03	6.03	6.73	6.74	6.75	4.3	4.31	4.32
Light-induced degradation (%)	-	-	-	2	2	2	-	-	-
Missmatch (%)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Inv losses (%)	4.16	3.23	3.68	4.2	3.21	3.69	3.87	3.18	3.64

*Losses that affect the solar resource directly

Figure 6: Financial comparison of generation scenarios (Si-Poly)

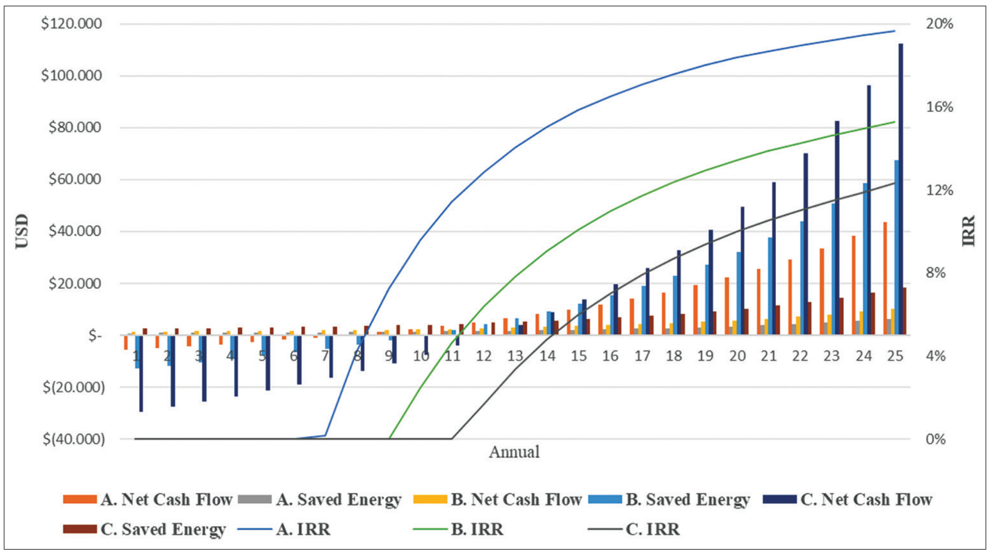


Figure 7: Financial comparison of generation scenarios (Si-Mono)

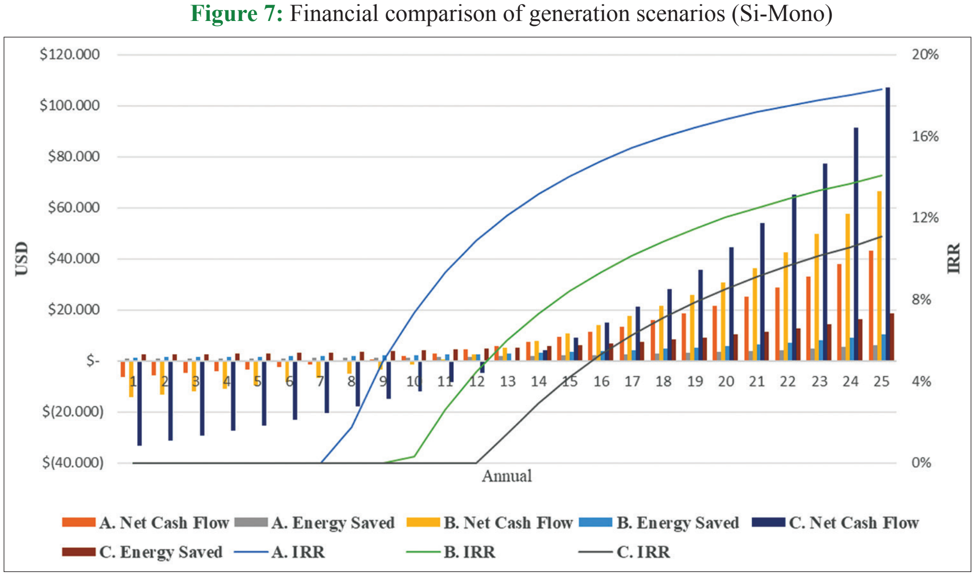


Figure 8: Financial comparison of generation scenarios (HIT)

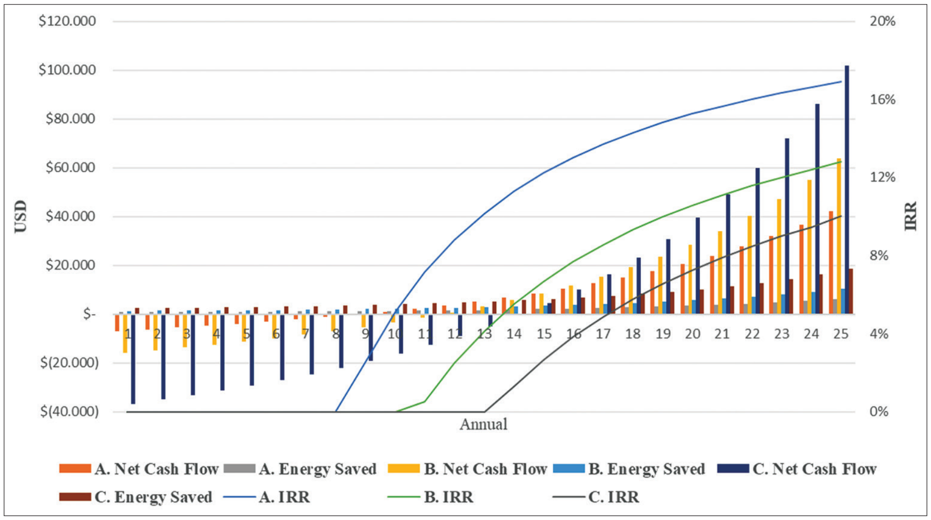


Table 4: Financial assessment.

Technology	Si-Monocrystalline			Si-Polycrystalline			HIT		
Scenario	A	B	C	A	B	C	A	B	C
Investment (USD)	6,328	14,359	33,233	5,748	12,887	29,663	6,908	15,832	36,803
NPV (USD)	49,804	78,035	128,237	49,920	78,623	133,056	48,623	75,324	123,418
IRR (%)	18.292	14.070	11.081	19.678	15.287	12.324	16.901	12.824	10.026
PAYBACK TIME (Years)	7.58	9.91	12.25	7	9.16	11.166	8.25	10.75	13.16

is the generation scenario that requires less investment in the three technologies analyzed (Si-Mono $6,328 USD; Yes-Poly $5,748 USD; HIT $6,908 USD), also presents the highest IRR (Si-Mono 18.292%; Si-Poly 19.678%; HIT 16.901%) and offers a lower Payback time (Si-Mono 7.58 years; Si-Poly 7 years; HIT 8.25 years), this occurs because the kWh saved is priced at the full unit price charged to the user.

Among the three technologies studied, Polycrystalline Silicon obtains the best results according to the criteria of financial kindness: NPV (Si-Mono $6,328 USD; Yes-Poly $5,748 USD; HIT $6,908 USD), IRR (Si-Mono 18.292%; Si-Poly 19.678%; HIT 16.901%) and Payback time (Si-Mono 7.58 years; Si-Poly 7 years; HIT 8.25 years, although it has the lowest performance rate for each scenario: Self-consumption (Si-Mono 80.81%; Si-Poly 78.27%; HIT 80.41%), Network Exchange (Si-Mono 81.91%; Si-Poly 79.39%; HIT 81.23%) and Sale of Surpluses (Si-Mono 81.36%; Si-Poly 78.88%; HIT 80.74%).

HIT technology is the one that generates the most energy (Self-consumption 5.27 MWh/year; Exchange with the network 13.56 MWh/year; 32.76 MWh/year), however, it is the worst results presented in all financial kindness criteria. Still, having a recovery period less than the life of the project (25 years) makes it financially viable.

6. CONCLUSIONS AND RECOMMENDATIONS

In this work the technical and financial study of the feasibility of a solar photovoltaic system connected to the grid was carried out in a residential complex in Colombia according to the regulatory framework in force in 2018, comparing three solar panel technologies (Si-Mono, Si-Poly and HIT) in three generation scenarios (Self-consumption, Exchange with network and Sale of Surpluses).

The Colombian regulatory framework in force in 2018 through Law 1715 of 2014 has allowed the development of electricity generation projects through the FNCER, with tax benefits and under resolution CREG 030 of 2018 has encouraged the activities of Small-Scale Self-Generation and Distributed Generation in the National Interconnected System.

The most influential factors in the performance index of grid-connected solar photovoltaic systems are: temperature (Si-Mono 6.03%; Si-Poly 6.74%; HIT 4.31%), the shading in the system (Si-Mono 4.98%; Si-Poly 5.1%; HIT 5.19%) and investor losses (Si-Mono 3.68%; Si-Poly 3.69%; HIT 3.64%). The influences of these factors are maintained by changing technology.

It was found that using Si-Poly, Self-consumption presents the maximum IRR (19.678%) in the minimum payback time (7 years). However, Network Sale delivers the maximum NPV at the end of the project duration ($133,056 USD), maintaining this behavior for all three technologies.

Based on the results obtained in the financial assessment, the goodness criteria used (NPV, IRR and Payback time) ensure that polycrystalline silicon technology in each of the generation scenarios (Self-Consumption, Network Exchange and Surplus Sales) is the most feasible option.

If you want to replicate this study elsewhere, you must take into account the weather conditions and the solar chart, as these factors can affect the position and configuration of the photovoltaic solar panels of the system or energy production. Therefore, if the site does not have the same conditions as the Bucaramanga metropolitan area, the orientation and position of the panels may be different and the number of panels will vary from this study.

Depending on the region where the study is carried out for the implementation of a solar photovoltaic system, the process and requirements for the network connection of these projects with the energy marketing company in charge should be consulted. This is because each electric service company is responsible for the approval of such projects.

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