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Cost-Benefit Evaluation of the Implementation of a Photovoltaic Solar Generation System in the Archipelago of San Andrés, Providencia, and Santa Catalina

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ABSTRACT- The study highlights the importance of photovoltaic solar energy as a viable alternative for the Archipelago of San Andrés, Providencia, and Santa Catalina in response to the current 99% dependence on fossil sources, especially diesel. There is a need to diversify the energy matrix and reduce associated costs, including significant subsidies. The implementation of renewable sources is considered crucial to achieve sustainable development goals and improve energy autonomy, in addition to mitigating environmental impacts. The study proposes a detailed cost-benefit analysis of implementing a solar photovoltaic system, considering the return on investment and the savings in monthly energy payments for different user segments, classified into four clusters: strata 1 and 2, strata 6, commercial, and official. This financial evaluation is considered essential to ensure the economic viability of the project and maximize its positive impact on the region.

Keywords: photovoltaic solar energy; cost-benefit analysis; sustainable development; environmental impact assessment; Smart grids.

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1. INTRODUCTION

The increase in global electricity consumption, driven by economic development and population growth, poses challenges in terms of energy security and environmental sustainability. In the specific case of Colombia, the energy matrix is largely dominated by fossil fuels, which represent approximately 74% of total energy generation. In this context, the implementation of photovoltaic systems emerges as an alternative to strengthen the existing energy system and mitigate the environmental impacts associated with energy generation. However, the economic viability of these systems requires a detailed cost-benefit analysis. It is necessary to carefully evaluate the installation and operating costs of photovoltaic systems, as well as the benefits in terms of long-term energy cost reduction and the environmental benefits derived from the reduction of greenhouse gas emissions [1].

The Archipelago of San Andrés, Providencia, and Santa Catalina has a high solar potential and could benefit from the diversification of its energy matrix. Despite incentives and favourable regulatory framework, challenges include high initial costs, lack of technical expertise, and regulatory barriers. However, the implementation of solar photovoltaic systems offers reduced dependence on diesel, better air quality, and long-term economic benefits. Colombia has made progress in promoting Unconventional Renewable Energy Sources (URES), and San Andrés Islands and Providencia are ideal for solar generation. In summary, the implementation of photovoltaic systems in the region is technically, economically, and socially viable, with long-term environmental, social, and economic benefits.

The implementation of photovoltaic systems in electricity generation offers the opportunity to strengthen the existing system and reduce the environmental impact of conventional energy sources. However, their economic viability depends on a detailed analysis of the installation, operation, and maintenance costs throughout their useful life; compared to diesel generators, solar photovoltaic systems have a higher initial investment, but lower annual costs. This raises the need to evaluate the comprehensive cost-benefit of their implementation in the department of San Andrés [2].

Likewise, the archipelago has a potential annual average daily solar radiation of 4.5-5.0 kWh/m2, which makes it an optimal place to take advantage of solar energy. The use of photovoltaic solar panels would make it possible to take advantage of this radiation and generate electricity in a sustainable way. As radiation maps show, the archipelago is located in one of the optimal bands for energy production from solar radiation [3].

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The cost-benefit evaluation of the implementation of a photovoltaic solar generation system in the Archipelago of San Andrés, Providencia, and Santa Catalina is a critical step to evaluate the economic viability and the social and environmental impact of this initiative. This analysis considers the uniqueness of the island environment and the prevailing need to move towards cleaner and more sustainable energy sources [4].

The viability of this project is supported by the abundant solar resource available in the region, which offers significant potential for renewable energy generation. Furthermore, the strategic geographical location of the archipelago and its current energy dependence make the adoption of solar photovoltaic energy an attractive and viable option from an economic and technical point of view [5].

The social benefits derived from the implementation of this system are diverse and far-reaching. First, reducing dependence on fossil fuels will help improve the quality of life for local residents by ensuring a more stable and reliable energy supply. Additionally, creating local jobs in the installation, maintenance, and operation of solar panels could stimulate the local economy and increase employment opportunities in the region [6].

From an environmental perspective, the adoption of solar photovoltaics will contribute significantly to the reduction of greenhouse gas emissions and other atmospheric pollutants. This will help mitigate climate change and preserve the archipelago's valuable marine and terrestrial ecosystems, which are essential for biodiversity and sustainable tourism [7].

For a more precise and detailed evaluation, four clusters of users are identified based on their consumption profile: Cluster 1, composed of users from strata 1 and 2; Cluster 2, users from stratum 6; Cluster 3, commercial users; and Cluster 4, official or government users. With this segmentation, it is possible to analyze the benefits and costs associated with the implementation of solar systems in each group, taking into account their specific needs and characteristics.

The cost-benefit evaluation of the implementation of a photovoltaic solar generation system in the Archipelago of San Andrés, Providencia, and Santa Catalina represents a unique opportunity to move towards a more sustainable energy future, with positive economic, environmental, and social impacts.

2. THEORETICAL FRAMEWORK

In order to understand the applicability of a cost-benefit analysis in the island territory, it is necessary to know in more detail what the analysis involves and what methodology will be used to achieve the objective. Cost-benefit analysis is fundamental to evaluating the economic viability of a project, technology, or system, as it provides a quantitative evaluation of the monetary costs and benefits associated with the development, maintenance, and operation of a project during its useful life. Various economic indicators, such as net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR), are used to measure the economic viability of a project [9].

The methodology for this analysis aims to identify the benefits of the project, which can be classified into categories such as economic benefits, energy reliability and quality of, safety and security, and environment. In addition, three groups of beneficiaries are defined: public service companies, end users, and society in general.

Values are assigned to each benefit, and the initial, operating, and maintenance costs of the project are calculated. Tools such as net present value (NPV), internal rate of return (IRR), and benefit-cost ratio (BCR) are used to evaluate the economic viability of the project.

However, there are barriers to the implementation of solar photovoltaic projects, such as the lack of clear policies, technical requirements, financing, and underdeveloped smart grids.

Different methodologies have been proposed to evaluate environmental impacts, such as the Leopold Methodology, which uses a double-entry matrix to evaluate environmental attributes and project actions. Another methodology is qualitative, which assigns numerical attributes to environmental impacts for an objective evaluation.

A more complete methodology is the Battelle-Columbus method, which weights environmental and social characteristics and assigns units of measurement to evaluate environmental quality. This methodology reduces subjectivity and improves the precision of environmental assessment.

Table 1. Barriers in the application of solar photovoltaic systems [1]

Issue	Barrier Description
Sale of surplus	The law (prior to Law 1715 of 2014) prohibits self-generators from selling surpluses under permanent conditions, and there is no regulated number of marginal producers [1].
Energetic politics	There is no energy policy on distributed generation with small-scale URES, developed by or for medium and small users connected to distribution networks [1].

Technical requirements	There is no regulation (technical norms and standards) established for the selection of equipment, configuration, installation, and connection to the SIN of small or large generation systems with solar PV energy [1].
Potential information	There is no certainty about the potential objects of possible development to determine and quantify the possible impacts on the distribution networks based on those objects (UPME, 2015).
Financing	There are no financial schemes aimed at investing in this type of systems, especially aimed at markets or sub-sectors that are conducive to the development of distributed generation systems using solar PV [1].
Smart grids	As of 2014, there have not been proposals or regulatory developments aimed at the development of smart grids [1]

Having clarified about the definitions, benefits, and beneficiaries of the application of these technologies in a cost-benefit analysis, the estimate or assign magnitudes to each benefit are then specified, with the sole intention of achieving precise levels. It is important to note that this methodology aims to evaluate the benefits at qualitative levels, i. e., there is not necessarily a direct relationship between the estimate and the magnitude of the benefit and that it is generally intended to achieve a cost reduction per year by identifying each impact [10].

To carry out a cost-benefit analysis and evaluate the environmental impact of solar photovoltaic energy projects, it is necessary to use systematic methodologies that consider both economic and environmental aspects and reduce subjectivity of the evaluation.

In addition to these methodologies, there is another methodology, analyzed by the Environmental Management Office, that is qualitative, i. e., its evaluation is objective and begins with the identification of eleven attributes that help describe in detail the impact due to the activity within the project to which taxes are assigned and then numerically valued. In the same order, a measurement scale is used to interpret the results represented by the interpretation for the qualitative methodology:

Table 2. Interpretation scale for qualitative methodology [11]

Category	Classification
Irrelevant	<25
Moderate	25-50
Severe	50-70
Critical	>75

This table provides an interpretation scale for the qualitative methodology used to evaluate the environmental impact of a project or activity. The scale is based on the weighting of five attributes: intensity, extension, moment, persistence, and reversibility.

Each attribute is rated on a scale of 1 to 4, with 1 referring to the least impact and 4 referring to the greatest impact. The final impact score is obtained by adding the scores of the five attributes and multiplying the result by 0.25.

The interpretation scale for qualitative methodology is a useful tool to evaluate the environmental impact of a project or activity. However, the scale has some limitations, such as subjectivity and lack of consideration of synergy and accumulation of impacts.

The interpretation scale for qualitative methodology is a useful tool to evaluate the environmental impacts of a project or activity. However, the scale has some limitations that must be considered when using it.

3. METHODOLOGY FOR COST-BENEFIT ANALYSIS

For the application of a methodology valid for the archipelago, various methodologies are analyzed. With the information collected, the aspects considered applicable in the Archipelago are taken to create one adapted to the realities of the department. After analyzing different methodologies, practical adaptations can be made where information from each of these is taken into account to assemble one that best fits the needs and realities of the Department. Following this guideline, the following methodology is proposed:

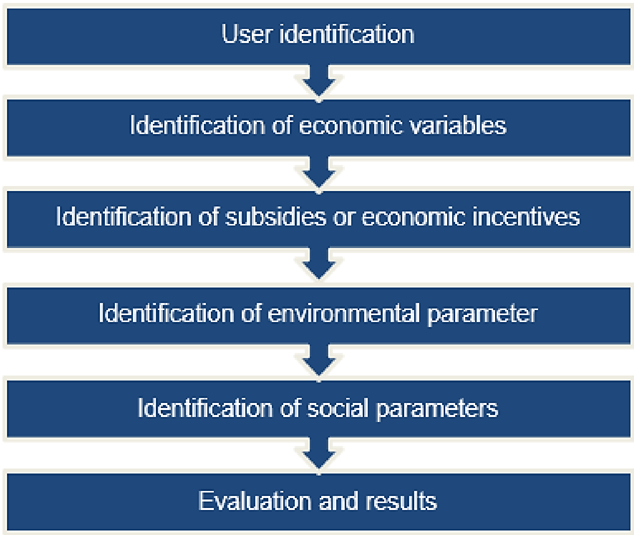

Figure 1. Cost-Benefit Methodology

1. *Identification of users:* for this research, users are classified as follows:

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Table 3. Classification of users of the four clusters

Economic Stratum or Condition	Monthly consumption (Kwh)
Stratum 1 and 2	100 to 800
Stratum 6	1001 to 2000
Commercial	More than 2000
Official	More than 2000

Users were classified according to their consumption and not according to their social stratification. This is because in the development of this research it was found that there were users who lived in areas of social strata 1 and 2, but their consumption was high, *i.e.*, it was similar to the consumption of a stratum 6 user. For this reason, they were classified according to their consumption and not according to their location in the territory or housing conditions.

2. Identification of economic variables: All costs associated with the application of a photovoltaic solar system are quantified to meet the demand of each user and to calculate CAPEX and OPEX based on the costs. This aims to determine the cash flow of each project applied to each specific user as well as the return on investment and capital recovery.

3. Identification of subsidies or economic incentives: The respective calculations are made on the basis of how much money the nation would stop paying in subsidies after the solvency of the demand of each user with a solar PV system.

4. Identification of environmental factors: environmental factors raised in the Battelle-Columbus methodology are taken, which may be affected by the application of a solar system depending on each user.

Table 4. Weighting for environmental parameters

Criterion	Category	Value
It has no effect	Very low	2
Has mild effect	Low	4
May have mild effect	Half	6
May have harmful effect	High	8
It has harmful effect	Very high	10

5. Identification of social parameters: The social impact must be considered and economically determined how the project impacts. This includes quantifying job creation in the renewable energy sector and measuring the impact on local communities and the benefits of reducing dependence on fossil fuels. The social benefits generated by stopping spending money on subsidies and investing them in other areas or activities that positively benefit society are quantified. The money saved in bills and the money recirculating in the local economy benefiting other people are also quantified.

6. Evaluation and results: it is necessary to determine the initial cost for each user and the operation and maintenance costs. It is then necessary to compare all the possible benefits with the aim of determining the impact of these benefits on these economic aspects and the feasibility of the application of photovoltaic solar systems for different users and in the archipelago of San Andrés.

4. APPLICATION OF THE METHODOLOGY FOR COST-BENEFIT ANALYSIS

The methodology for the cost-benefit analysis (CBA) of a PV system project helps evaluate the economic viability of the project. This methodology is based on the comparison of the costs and benefits of the project during its useful life. It is necessary to observe the behavior of this methodology with users who have different consumption, design a solar system that provides the energy required by them at times of the day, and then analyze their costs and Benefits with the application of these technologies in the department.

4.1. Strata 1 and 2

Users in strata 1 and 2 are defined as those who have an average monthly consumption of 100 to 800 kwh. Based on this information, a consumption graph is modeled to design a photovoltaic solar system that provides a large part of the energy required during the day. *Figure 2* shows the average monthly consumption curve in strata 1 and 2 in the department.

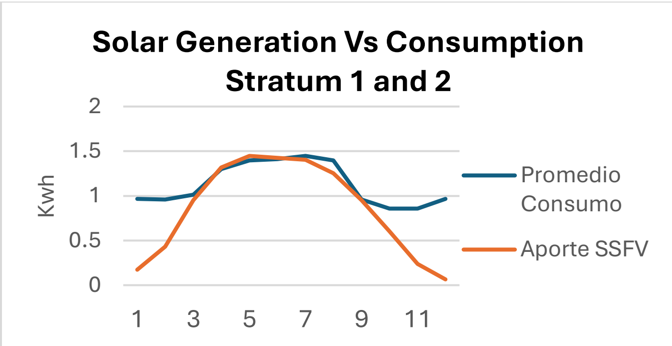

Figure 2. Daily consumption and Solar generation in strata 1 and 2

Figure 2 shows the average behavior of these users with consumption peaks between 1:00 a. m. and 2:00 p. m. This is because most of these users are people who work and have normal working hours, as established by the Colombian labor law. Due to work schedules, they are away from their homes in the morning, return for lunch at noon, resume work in the afternoon, and return home again at the end of their workday.

The analysis of energy consumption behavior shows peaks in the morning (between 8 and 9 am) and in the afternoon (between 4 and 5 pm). The average consumption is 0.8 kWh, with a maximum of 1.6 kWh. The difference between consumption and the average is greater during peak hours and smaller during off-peak hours.

With this information, a solar system was designed. This system has the capacity to provide the maximum amount of energy during the day This results in a solar system composed of four

(4) monocrystalline split-cell solar panels with a generation capacity of 600 Wp, with an installed capacity of 2,400 Wp, supported by its investment system, protections, wiring, and all the related activities that are necessary for its installation. The generation curve is graphed and overlapped with the average consumption curve of strata 1 and 2 to analyze and determine the suitability of the generation plant.

The initial price or CAPEX for the installation of a solar system that meets the needs of a user with this type of consumption is approximately $ 6,055.08 USD, and the amount of the application of this system includes labor and the supply of equipment placed at the installation site.

The average cost of operation, maintenance, and OPEX operation for a system of this size is $215.74 USD: Maintenance is recommended every six months, which is the prudent time for review, inspection, and preventive maintenance of these systems in the archipelago due to the high degree of salinity of the area.

The components with the highest costs are the photovoltaic solar modules ($1,472.09 USD), the DC/AC conversion system ($1,649.75 USD), and the support and fixing elements ($525.13 USD). The cost per user is $736.04 USD. The installation of a Photovoltaic Solar System (PVSS) is a good option for users 1 and 2 to obtain energy bill savings and reduce their carbon footprint. However, it is important to conduct a feasibility study and compare different options before making a decision.

The total cost of the PVSS for users 1 and 2 with subsidy is $238.99 USD. The subsidy for users 1 and 2 is 68.28%. The net cost of the PVSS for users 1 and 2 after the subsidy is $75.81 USD. The annual energy bill savings after installing the PVSS is $33.35 USD. The user must pay $42,45 USD for the PVSS, which is 44% of the total cost. The economic balance shows that the installation of an PVSS can be profitable for users 1 and 2 with a subsidy, since the annual energy bill savings exceed the cost of the PVSS within a reasonable period of time.

Upon analyzing how much this consumption translates into the amount payable on the bill, considering that energy in San Andrés is subsidized (Resolution - MME 180069 of 2008 and 180196 of 2011), it is understood that the actual cost of energy is higher than what the user pays. At the time of the research, the Unit Cost (UC) of energy was ($0.33 USD) (Resolution - GREG 160/2008 GREG 073/2009), of which a subsistence consumption of 187 kWh/month is subsidized. This implies that for a user consuming 800 kWh/month, as defined in this study, the energy bill should amount to approximately $238.83 USD. However, the nation subsidizes 68.28% of this cost, leaving the user with only a balance of approximately $75.81 USD to pay. This is without the implementation of a photovoltaic solar system. With the proposed design, the user would have an 86% daytime energy savings and a 44% monthly savings. This means that out of the $75. USD81, the user would only pay an average of $42,45 USD resulting in savings of $33.35 USD for the user, and a subsidy payment of $163.18 USD from the nation.

The photovoltaic solar system is a profitable and environmentally sustainable investment for households in strata 1 and 2 in Colombia. The system has a positive NPV, a high IRR and a short Payback Period. Additionally, the system reduces greenhouse gas emissions and air pollution.

The IRR of 18% is high. The Payback Period of 6 years indicates that the investment will be recouped relatively quickly, and the positive NPV and IRR indicate that the project will generate economic benefits throughout its useful life. Additionally, the low volatility suggests that annual cash flows are stable and predictable.

Table 5. Balance of benefits of cluster 1 (strata 1 and 2)

Half	Component	Annual Direct Benefits (USD)	Annual Indirect Benefits (USD)
Physical	floor	$243.66	$ -
	water	$ -	$634.52
	atmosphere	$50.76	$ -
Biotic	flora	$ -	$ -
	fauna	$ -	$ -
Energy	ENS	$228.43	$ -
Social		$ -	$1,081.22
CO2 Bonds		$32.61	$ -
Total		$555.46	$1,715.74
Total Benefits		$2,271.2	

Table 6. Step-by-step calculations of economic indicators for strata 1 and 2

Indicator	Calculation
CAPEX (USD)	$6,013.99
VPN (USD)	$3,138.46
GO (USD)	$2,722.52
IRR	18%
PI	1.5
Breakeven	5 years
Payback Period	6 years
Volatility	Low

Table 7. Impact of the physical components of strata 1 and 2

Physical Component	Impact	Numerical value
Geoforms	Very low	2
Landscape	Half	6
Floor	Very low	2
Water	Half	6
Atmosphere	Very low	2

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These results show that, in general, most of the components have an environmental impact classified as very low or medium. The components "landscape" and "water" have the highest impact, classified as medium, while the other components have a very low environmental impact. This suggests that the project may have certain effects on the landscape and water, but not significant, while the impact on other aspects such as soil, atmosphere, flora, and fauna is minimal.

Table 8. Impact of the biotic components of strata 1 and 2

Biotic Component	Impact	Numerical value
Flora	Very low	2
Fauna	Very low	2

4.2. Stratum 6

The stratum 6 user is defined as that with an average monthly consumption of 1001 to 2000 kWh. Based on this information, a consumption graph is modeled to design a photovoltaic solar system that provides a large part of the energy necessary during the day. *Figure 3* shows the average daily consumption curve of stratum 6 in the department.

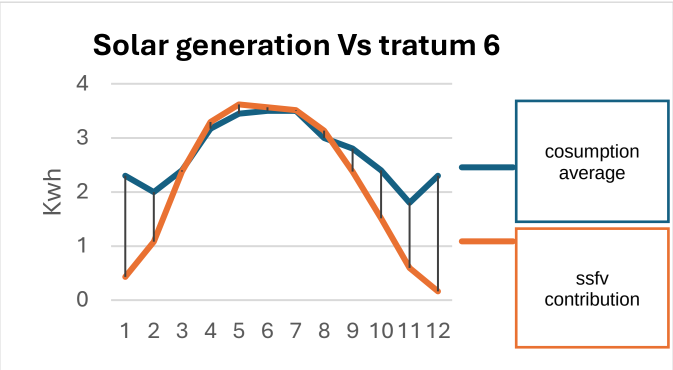

Figure 3. Solar generation vs energy load of stratum 6

With this information, a solar system was designed that has the capacity to provide as much energy as possible during the day. This results in a solar system composed of ten (10) monocrystalline split-cell solar panels with a generation capacity of 600 Wp and an installed capacity of 6000 Wp, supported by its investment system, protections, wiring, and all the related activities necessary for its installation. The generation curve is graphed and overlapped with the average consumption curve of strata 6 with the aim of analyzing and determining the suitability of the generation plant.

The initial price for the installation of a solar system that meets the needs of a user with this type of consumption is approximately $10,664.46 USD. It is important to mention that the amount of the application of this system includes labor and the supply of equipment placed at the installation site.

The average costs of operation, maintenance, and OPEX operation are $239.48 USD every six months, which is the prudent time for review, inspection, and preventive maintenance of these systems in the archipelago due to the high degree of salinity of the area.

The consumption's value in the bill is analyzed considering that energy in San Andrés is subsidized, meaning the real cost is higher than what the user pays. For the research date, the Unit Cost of energy was $0.33 USD, of which up to 800 kWh/month is subsidized, and beyond that, full tariff applies. This implies that for a user consuming between 1001 and 2000 kWh monthly, as outlined in this study, the net energy cost on their bill would be approximately $593.41 USD. However, the nation subsidizes 49.79% of the full tariff, leaving the user with a balance of approximately $297.95 USD to pay.

This calculation doesn't consider the implementation of a solar photovoltaic system. With the proposed design, the user would have a 92% daytime energy saving and a 58% monthly saving. This means that out of the $297.95 USD, they would only pay an average of ($125.14 USD), resulting in a saving of $172.81 USD for the user.

Direct soil benefits are estimated at $242.00 USD annually, which are associated with improved soil quality and reduced erosion. No indirect soil benefits were identified. No direct water benefits were identified. However, an annual indirect benefit of $630.21 USD is estimated, associated with the improved water quality and resource availability. The direct benefit to the atmosphere is estimated at $50.42 USD annually, which is associated with the reduced air pollution. No indirect atmospheric benefits were identified.

The photovoltaic solar system is a profitable and environmentally sustainable investment for stratum 6 homes in Colombia. The system has a positive NPV, a high IRR, and a short Payback Period. Additionally, the system reduces greenhouse gas emissions and air pollution.

Table 9. Balance of environmental benefits for cluster 2 (stratum 6)

Half	Component	Annual Direct Benefits (USD)	Annual Indirect Benefits (USD)
Physical	floor	$242.00	$ -
	water	$ -	$630.21
	atmosphere	$50.42	$ -
Biotic	flora	$ -	$ -
	fauna	$ -	$ -
Energy	ENS	$252.09	$ -
Social		$ -	$1,073.88
CO2 Bonds		$106.83	$ -
Total		$651.34	$1,704.10
Total Benefits		$2,355.43	

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Table 10. Step-by-step calculations of economic indicators for stratum 6

Indicator	Calculation
CAPEX (USD)	$10,664.46
VPN (USD)	$5,747.54
GO (USD)	$5,041.71
IRR	20%
PI	2.2
Breakeven	4 years
Payback Period	5 years
Volatility	Low

The analysis shows that the installation of a solar photovoltaic system is a viable and beneficial option for households in stratum 6. Profitability indicators, such as NPV, IRR, and Payback Period, indicate that the investment is profitable and will be recouped in a relatively short period.

The impact on the geoforms is very small. Solar panels do not significantly alter the shape of the land. The impact on the landscape is medium. Solar panels can have a negative visual impact on the landscape, especially in areas of high aesthetic value.

The impact on the soil is very low. Solar panel mounting systems typically have no significant impact on the ground. The impact on the water is low. Solar panels do not consume water during operation. However, the manufacturing process of solar panels can consume water.

Table 11. Impact of the physical and biotic components of stratum 6

Criterion	Component	Average	Category
Physical	Geoforms	2	Very Low
	Landscape	6	Half
	Floor	2	Very Low
	Water	3	Low
	Atmosphere	2	Very Low
Biotic	Flora	2	Very Low
	Fauna	2	Very Low

The impact on the atmosphere is very low. Solar panels do not produce greenhouse gas emissions or air pollutants. The impact on the flora is very low. Solar panels do not usually affect flora as they are installed in areas with little vegetation. The impact on fauna is very low. Solar panels do not usually affect wildlife as they are installed in areas with little animal activity.

4.3 Commercial

Commercial users are defined as users who carry out a commercial activity within the property. For this reason, the local network operator SOPESA classifies them as commercial. In this study, the category of "commercial" is assigned to users who develop commercial activities but who additionally have an average monthly consumption of 2000 kWh. Based on this information, a consumption graph is modeled to design a photovoltaic solar system that provides a large part of the energy necessary during the day.

Commercial users have the particularity that their consumption significantly increases when the warehouse or commercial premises are open and drops in the hours from 11:00 a. m. to 2:00 p. m., which is the time when the workers close the premises and go home.

With this information, a solar system was designed that has the capacity to provide as much energy as possible during the day. This results in a solar system composed of fourteen (14) monocrystalline split-cell solar panels with a generation capacity of 600 Wp and an installed capacity of 8,400 Wp.

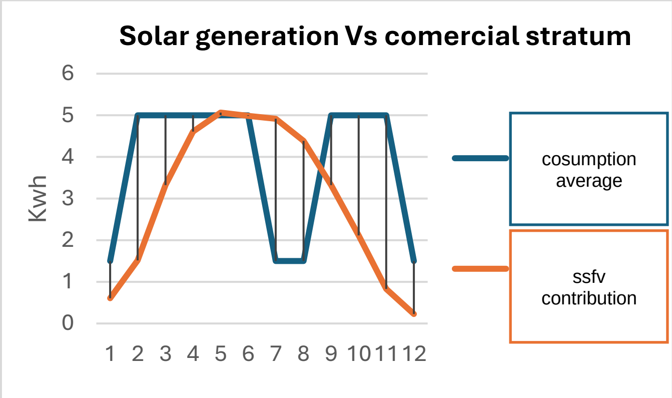

Figure 4. Consumption vs solar generation of cluster 2 (stratum 6).

The initial price for the installation of a solar system that meets the needs of a user with this type of consumption is approximately $16551.95 USD. It is important to mention that the amount of the application of this system includes the labor and the supply of equipment placed at the installation site.

The average costs of operation, maintenance and OPEX operation are ($264.69 USD) every six months, which is the prudent time for review, inspection, and preventive maintenance of these systems in the archipelago due to the high degree of salinity in which we are located.

The real cost of energy is higher than the cost paid by the user. Up to the date of the research, the Unit Cost of energy was $0.33 USD, with consumption being subsidized in 49.79% for commercial users, i. e., 20% less on average than is the amount subsidized for normal users in strata 1 and 2. This means that a commercial user who consumes a monthly average of more than 2000 kwh, as proposed in this research, should pay an approximate amount of $593.41 USD for an energy bill at the net price of energy, but the nation subsidizes 49.79%. This leaves a balance to be paid by the user of approximately $297.95 USD without the implementation of a photovoltaic solar system. The proposed design, the user would have a daytime energy saving of 92% and a monthly saving of 74%.

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This means that the user would only pay an average of $77.47 USD of those $297.95 USD.

So, if the subsidy were removed from the Archipelago, a significant increase in the amount to be paid by the user would be observed. This would result in a monthly payment with a 74% contribution, amounting to ($154.29 USD), representing a 25% increase in the monthly invoice amount.

Table 12. Balance of environmental benefit for cluster 3 (commercial)

Half	Component	Annual Direct Benefits (USD)	Annual Indirect Benefits (USD)
Physical	floor	$242.00	$ -
	water	$ -	$ -
	atmosphere	$50.42	$ -
Biotic	flora	$ -	$ -
	fauna	$ -	$ -
Energy	ENS	$504.17	$ -
Social		$ -	$1,073.88
CO2 Bonds		$136.29	$ -
Total		$932.88	$1,073.88
Total Benefits		$2006.76	

Table 13. Step-by-step calculations of economic indicators for commercial users

Indicator	Calculation
CAPEX (USD)	$16,551.95
VPN (USD)	$8,167.56
GO (USD)	$7,058.39
IRR	22%
PI	2.6
Breakeven	4 years
Payback Period	5 years
Volatility	Low

This study analyzes the economic and environmental viability of a solar photovoltaic system for commercial homes. The system consists of fourteen (14) monocrystalline split cell solar panels with a total generation capacity of 8,400 Wp.

This analysis shows that the project has solid and profitable financial indicators. The NPV and IRR are positive, indicating that the project will generate additional value and that future cash flows will be greater than the initial investment cost. The IRR of 22% is also significantly high, which demonstrates that the project is profitable. The PI of 2.6 is greater than 1, so the project will generate a return of 2.6 monetary units per monetary unit invested. The payback period is 5 years, which suggests that the project will be profitable in the short term.

Table 14. Impact of the physical and biotic components of commercial users

Criterion	Component	Average	Category
Physical	Geoforms	2	Very Low
	Landscape	6	Half
	Floor	2	Very Low
	Water	4	Low
	Atmosphere	2	Very Low
Biotic	Flora	2	Very Low
	Fauna	2	Very Low

Physical Components:
Geoforms: With a category of "Very Low" (value of 2), it indicates that geoforms have a minimal impact on the environment.

Landscape: With a category of "Medium" (value of 6), it indicates that the landscape may experience some noticeable effects due to the project.

Biotic Component:
Flora: With a category of "Very Low" (value of 2), it indicates that the impact on the flora is minimal.
Fauna: With a category of "Very Low" (value of 2), it indicates that the impact on fauna is minimal.

4.4. Officials

Official users as defined as those who have an average monthly consumption of 2000 kwh. With this information, a consumption graph is modeled to design a photovoltaic solar system that provides a large part of the energy necessary during the day.

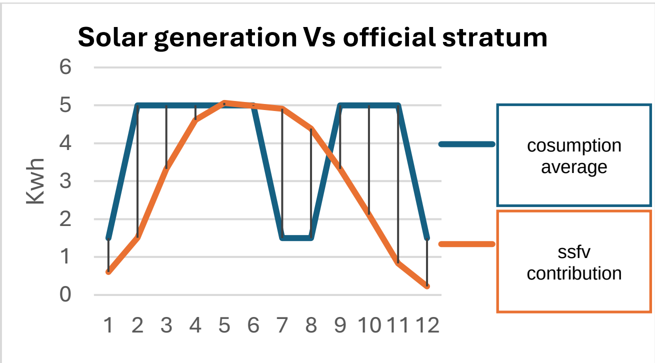

Figure 5. Consumption vs solar generation of the cluster 4 (official)

The analysis of energy consumption versus generation is a useful tool to evaluate the energy efficiency of a system or group of buildings. This analysis helps identify the periods of greatest energy consumption and generation as well as possible imbalances between the two.

The image shows a line graph representing the consumption and generation of PV solar energy for the cluster of official institutions in San Andrés. The graph covers a period of 10 days, from March 3, 2024 to March 12, 2024.

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It is observed that the energy consumption of the cluster is relatively constant during the period analyzed, with an average of 300 kWh per day. A slight consumption peak is observed on March 5, with a consumption of 350 kWh.

PV energy generation varies significantly during the analyzed period, due to climatic conditions. There is greater power generation on sunny days, such as March 3, 4, 6, and 7, with an average generation of 400 kWh per day. On cloudy days, such as March 8, 9, and 10, PV power generation is significantly reduced, reaching a minimum of 100 kWh per day.

An imbalance between the consumption and PV energy generation is observed during the analyzed period. On sunny days, PV power generation exceeds consumption, generating surplus energy that can be injected into the electrical grid. On cloudy days, PV energy generation is lower than consumption, which forces demand to be met with energy from the electrical grid.

The initial price for the installation of a solar system that meets the needs of a user with this type of consumption is approximately $21,124.75 USD It is important to mention that the amount of the application of this system includes the labor and the supply of equipment placed at the installation site. The average costs of operation, maintenance, and OPEX operation is $264.69 USD every six months, which is the prudent time for the review, inspection, and preventive maintenance of these systems in the archipelago due to the high degree of salinity of the area.

Table 1. Balance of environmental benefits for cluster 4 (official)

Half	Component	Annual Direct Benefits (USD)	Annual Indirect Benefits (USD)
Physical	floor	$242.00	$ -
	water	$ -	$ -
	atmosphere	$50.42	$ -
Biotic	flora	$ -	$ -
	fauna	$ -	$ -
Energy	ENS	$ -	$ -
Social		$ -	$1,073.88
CO2 Bonds		$163.92	$ -
Total		$456.34	$1,073.88
Total Benefits		$1530.22	

This study analyzes the economic and environmental viability of a photovoltaic solar system for official users in Colombia. The system consists of eighteen (18) monocrystalline split cell solar panels with a total generation capacity of 10,800 Wp.

The NPV and PI are positive, indicating that the project will generate additional value and that future cash flows will be greater than the initial investment cost. The IRR of 24% is high, suggesting an attractive profitability of the project. The IR of 2.8 is greater than 1, which indicates that the project will generate a return of 2.8 monetary units per monetary unit invested.

The break-even point is reached in four years. This means that the project will become profitable at that time. The payback period is five years, so the project will be profitable in a relatively short period. Low volatility indicates low risk associated with the project. The project appears to be financially viable and profitable, with a low level of risk and a positive impact on profitability for investors.

Table 2. Step-by-step calculations of economic indicators for the official sector

Indicator	Calculation
CAPEX (USD)	$21,124.77
NPV (USD)	$10,587.58
PI (USD)	$9,579.24
IRR	24%
PI	2.8
Breakeven	4 years
Payback Period	5 years
Volatility	Low

Table 17. Impact of the physical and biotic components of the officer

Criterion	Component	Average	Category
Physical	Geoforms	2	Very Low
	Landscape	6	Half
	Floor	2	Very Low
	Water	3	Low
Biotic	Flora	2	Very Low
	Fauna	2	Very Low

This analysis provides an evaluation of the various environmental components in relation to the parameters provided. It indicates that the landscape may be significantly affected, while the other physical and biotic components have minimal impact on the environment.

The direct soil benefit is estimated at $242.00 USD annually, associated with improved soil quality and reduced erosion. No indirect soil benefits were identified. No direct water benefits were identified. However, an annual indirect benefit of $630.21 USD is estimated, associated with improved water quality and resource availability. The direct atmosphere benefit is estimated at $50.42 USD per year, associated with reduced air pollution. No indirect atmosphere benefits were identified.

5. CONCLUSION

The analysis of electricity consumption for strata 1 and 2 reveals significant variability throughout the day, with notable peaks both in the morning and at night. Although the average daily consumption is approximately 1.2 kWh, there are increases on certain days, such as days 17, 18, and 19. Based on this consumption analysis, a solar photovoltaic system was designed consisting of four monocrystalline split-cell solar panels, with an installed capacity of 2400 Wp. The economic analysis shows that the initial cost of the PV solar system for these strata is approximately $6,013.99 USD, including all components and installation. The average costs of maintenance and operation is $214.27 USD, with recommended maintenance every six months.

Based on this consumption analysis, a solar photovoltaic system was designed consisting of four monocrystalline split-cell solar panels, with an installed capacity of 2400 Wp. The economic analysis shows that the initial cost of the PV solar system for these strata is approximately $6,013.99 USD, including all components and installation. The average costs of operation and maintenance is $214.27 USD, with recommended maintenance every six months.

The analysis of electrical consumption for stratum 6 reveals a characteristic behavior, with peaks of consumption between 1:00 a. m. and 2:00 pm, due to the prolonged use of electronic comfort equipment. With this information, a PV solar system was designed consisting of ten monocrystalline split-cell solar panels, with an installed capacity of 6000 Wp. The initial cost for the installation of this solar system is approximately $10,664.46 USD, including labor and equipment supply, with an average cost of maintenance, and operation of $239.48 USD every six months. Considering the energy subsidy in San Andrés, the stratum 6 user could reduce their energy bill from $297.95 USD to approximately $125.14 USD per month with the proposed solar system, with savings of $172.81 USD.

The analysis of electricity consumption for commercial users reveals a pattern with peaks of consumption mainly between 11:00 a. m. and 2:00 p. m. A photovoltaic solar system consisting of fourteen monocrystalline split-cell solar panels, with an installed capacity of 8,400 Wp, was designed to meet a large part of the daytime energy demand. The initial cost of this system is $16,551.95 USD, with an average operation cost of $264.69 USD every six months. Considering the energy subsidy, the commercial user could reduce his energy bill from $297.95 USD to $77.47 USD per month with the proposed solar system. However, in the event of a power outage, the user could face significant economic losses, estimated at approximately $504.17 USD.

As for official users, there are a pattern of consumption with peaks during operation hours and a decrease when the facility closes, with increases on certain days. The installation of an PVSS system generates average annual savings of 70% on the energy bill, which is greater in the months of highest consumption and affected by the energy subsidy. The estimated initial cost for the installation of the PVSS system is $21,124.77 COP, with a payback period of 5 to 7 years.

The implementation of a PV solar generation system in the archipelago of San Andrés, Providencia, and Santa Catalina brings important social and environmental benefits. First, this system will contribute significantly to the reduction of atmospheric pollution by reducing dependence on fossil fuels, the main source of greenhouse gas emissions and local pollutants. This reduction in pollution will improve air quality and reduce negative impacts on the health of residents and the biodiversity of the region.

Additionally, the transition to a cleaner and more sustainable energy source will have a positive impact on the community's quality of life. A more reliable and affordable electricity supply provided by the solar system will allow the communities to have better access to basic services such as lighting, cooling, and communications, improving their overall well-being. These social and environmental benefits highlight the importance and feasibility of implementing this type of systems in the archipelago.

The implementation of solar photovoltaic energy projects will create local economic opportunities by stimulating job creation in sectors such as the installation, maintenance, and operation of solar systems. Additionally, by reducing dependence on imported fuels, the costs associated with the transportation and storage of these resources will be minimized, which could translate into additional economic savings for the community.

The adoption of solar photovoltaic energy will contribute to the conservation of the archipelago's natural environment by reducing the pressure on local natural resources, such as water and land, associated with the extraction and burning of fossil fuels. It also helps mitigate climate change by reducing greenhouse gas emissions, thereby protecting the region's fragile ecosystems and unique.

Solar photovoltaic systems have a positive environmental impact compared to conventional (diesel) generation. Environmental benefits can be monetized through carbon credits, reduced health costs, and reduced investment in environmental restoration. The implementation of PVSS in all strata is feasible and beneficial for the environment and the economy.

The implementation of solar photovoltaic systems creates jobs and improves the quality of life at all levels. Savings in energy payments can be reinvested in the community.
The installation of solar systems highlights the generation of employment for transporters, bricklayers, and certified electricians, which contributes significantly to local economic development. The adoption of solar photovoltaic systems not only has environmental and economic benefits, but also contributes to the social and cultural development of the community, generating employment and optimizing the use of public resources for the common good.

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