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Article

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Technical and Financial Assessment of Photovoltaic Solar Systems with Bifacial Technology Comparing Four Scenarios with Different Albedos with Respect to the Base Scenario with Monofacial Technology, in a Tropical Location in Colombia

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ABSTRACT

In photovoltaic system installations worldwide, the use of bifacial technology has begun to be more frequent due to the reduction of the cost gap associated with the manufacture of photovoltaic modules with bifacial technology compared to monofacial, encouraged by the technological maturation of bifacial modules. This research focuses on assessing the technical and financial viability of a photovoltaic solar system with bifacial technology, comparing 4 scenarios with different albedos (0.15, 0.2, 0.3 and 0.4) with respect to a base scenario that uses monofacial technology, the financial viability was evaluated according to three financial goodness criteria (NPV, IRR and Payback Time), where only in the scenario with albedo 0.4 were the costs associated with this land adaptation considered. The results of the research indicate that the most technically and financially viable scenario is the scenario with albedo 0.4, with an investment of $ 37,872 MCOP (3.71% more than the base scenario), an energy generated per year of 21,687 GWh/year (4.83% more than the base scenario), a net present value of $46,425 MCOP (8.42% more than the base scenario), an internal rate of return of 18.31% (1.78% more than the base scenario) and a payback time of 5.21 years (3.52%< the base scenario).

Keywords: Bifacial Technology, Photovoltaic System, Project Evaluation, Albedo, Bifacial Panel
JEL Classifications: Q2, Q4, Q55

1. INTRODUCTION

Photovoltaic (PV) modules have seen a rapid decline in cost over the past decade. As a result, system costs, for example, racking, wiring, ground area, installation, and the others, now account for 63-77% of total system costs, future cost reductions of PV modules will have a decreasing impact on the total cost of the system (Valdivia et al., 2017). Therefore, an alternative to achieving a reduced levelized cost of electricity (LCOE) is to reduce the size of the system by using fewer modules with higher conversion efficiency or by applying strategies that lead to greater energy harvesting (Chung et al., 2015).

Bifacial photovoltaic modules increase energy harvesting compared to conventional monofacial panels by absorbing incident light on their front and rear faces, demonstrating an electrical performance of up to 25% higher than equivalent standard monofacial panels, in addition they can be easily integrated into conventional monofacial panel installation schemes (Guerrero-Lemus et al., 2016). Likewise, bifacial technology provides a next step for PV system expansions with higher yields, lower environmental footprints, and higher rate of return on investment (Yusufoglu et al., 2015; Valdivia et al., 2017).

Comprehensive and perspective reviews of bifacial photovoltaic technology have been carried out in different parts of the world where general descriptions of this technology are shown, including its principle of operation, basic structure, cell categories, energy losses, advantages and disadvantages, however, with the expansive use of bifacial panels, accurately quantifying the bifacial gain in energy performance over standard monofacial panels is crucial for analysis by system designers who choose system types and configurations to implement in the highly variable range of lighting and environmental conditions worldwide (Gu et al., 2020). There are also studies that present comprehensive simulation models with high accuracy to determine the instantaneous and annual energy yields of monofacial and bifacial solar panels under real-field conditions and deployment configurations (Li, 2016).

Several experimental investigations focus on estimating the performance of bifacial panels in a given location, such as in Shanghai, where the bifacial module exceeds the monofacial module and the average daily bifacial gain is 13.08% and 16.54% for sunny days (Gu et al., 2021). In the Asian continent, innovation has been made in automation techniques of transformable and traceable bifacial modules according to the position of the sun (Imran et al., 2018).

Other research (Rodríguez-Gallegos et al., 2018) (Okere and Iqbal, 2021) (Abotaleb and Abdallah, 2018) from the perspective of techno-economic analysis has made it possible to compare the different emerging technologies, including bifacial modules, in relation to monofacial solar modules taking into account their materials; by means of theoretical models and software for different environmental conditions and areas with high possibility of light reflection; where bifacial photovoltaic technology has a good performance and denotes a clear advantage in adapting to various climatic conditions (Yun et al., 2021).

On the other hand, the bibliographic review in different databases focused on this technology denotes the lack of information on energy performance and bifacial technology in Colombia, although a 26.8 MWp solar farm with bifacial technology called La Sierpe has already been implemented, in Sucre which is located in tropical latitude (Urrego, 2022), therefore, this research focuses on evaluating the technical and financial feasibility of a photovoltaic solar system with bifacial technology, comparing 4 scenarios with different albedos with respect to a base scenario that uses monofacial technology, the financial viability was evaluated according to 3 criteria of financial goodness (NPV, IRR and Payback Time) in a tropical location, with high solar potential located in Colombia.

2. DESCRIPTION OF THE SITE AND THE PHOTOVOLTAIC SYSTEM

The potential implementation of a 9.8MWp solar farm located in the municipality of Arauca (site with good solar resource and availability of land for implementation of solar farms), Colombia, is established as a reference, and an available area of 40 hectares is estimated for the installation. Table 1 shows the weather conditions of the site along with some data on its geographical location.

The technical specifications of the bifacial and monofacial photovoltaic modules used are described in Table 2, in the same way, in Table 3 metal structures used are presented, the inverter (the characteristics of the Table 4) and the other elements of the system are the same in each scenario.

3. DESCRIPTION OF THE SCENARIOS

In this study four comparison scenarios are presented, each of these scenarios was compared with a base scenario. Additionally, it is pertinent to mention that this study was developed using software specialized in photovoltaic solar energy (PVsyst®).

3.1. Base Scenario

In this scenario the photovoltaic solar installation is conventional, where monofacial photovoltaic modules are used.

Scenarios 1, 2 and 3 use bifacial photovoltaic modules, therefore, an additional investment associated with the cost of this technology is required.

Scenario 1: Albedo of 0.15.
Scenario 2: Albedo of 0.2.
Scenario 3: Albedo of 0.3.

In scenarios 1, 2 and 3, 3 types of albedos were used in relation to different terrains that were not suitable to improve the performance of bifacial technology, that is, terrain without conditioning.

Scenario 4: This particular case requires two additional investments: (1) associated with the cost of bifacial technology and (2) adaptation of the land to guarantee an albedo of 0.4, which corresponds to the use of fine sand (Stull and Ahrens, 2000).

Table 1: Geographical location and meteorological information of the site

Item	Value
Latitude	7.08°N
Longitude	−70.76°W
Altitude	138 meters above sea level
Average ambient temperature	26.66°C
Daily solar radiation	5,271 kWh/m^2
Annual Solar Radiation	1944.9 kWh/m^2

Source: (IDEAM and UPME, 2017)

Table 2: Technical specifications - monofacial and bifacial photovoltaic module

Module specifications	Monofacial technology	Bifacial technology				Unit
		0%	5%	15%	25%	
Power	545	545	572	623	681	W
Area	2.578	2.583				m^2
Efficiency	21.13	21.10	22.14	24.27	26.36	%
V mppt	40.8	41.32	-	-	-	V
V oc	49.52	49.92	-	-	-	V
I mppt	13.36	13.19	-	-	-	To
I sc	13.94	13.95	-	-	-	To

Source: Taken from the official website of the manufacturer Jinko Solar

The changes in the albedo will be reflected in the software through a variation in the electricity generation of the photovoltaic solar system. The associated costs for each scenario are presented below (Table 5).

4. TECHNICAL AND FINANCIAL CONSIDERATIONS

In this research there were technical and financial considerations, which are described below.

4.1. Technical Considerations

- The optimal angle of inclination obtained in calculations was 9° (Equation 1), however, it will be taken as 10° by arrangement of structures.

$$\beta_{opt}=3.7+0.69\times\theta \quad (1)$$

Where, $\beta_{opt}\theta$ is the optimal elevation angle and latitude of the place.

Table 3: Technical specifications - metal structures

Module type	Monofacial	Bifacial
Tilt angle	10°-12°	10°-12°
Number of frames	13	26
Module layout	Portrait	Portrait
Number of modules per table	81 modules – 3PV×27	81 modules – 3PV×27
Foundation[1]	1.5 m	1.5 m
Minimum ground clearance	1 m	1 m

Source: Information taken from quotes local suppliers

Table 4: Technical specifications-inverter

Technical specifications	DC	AC	Unit
Maximum power	225	150	kW
Yield	99.1		%
Maximum voltage	1500	600/480 to 690	V
Maximum current	180/325	151	A
MPPT number	1		-

Source: Taken from the official website of the manufacturer SMA

- The minimum separation between rows of photovoltaic modules is approximately 1 m (Equation 2), however, it will be taken as 4 m to have adequate space for personnel circulation, cleaning, and maintenance.

$$S_{min}=l\times\frac{sen\beta}{tan(61^{\circ}-\theta)} \quad (2)$$

Where, $S_{min}l$ is the minimum separation between rows of PV modules and is the length of the PV module.

- The degradation of the modules will affect the sale of energy, decreasing its electrical efficiency from 100% to 85.35% in 25 years.

4.2. Financial Considerations

In this study, an average inflation of the project was adjusted by 5% per year and the evaluation of the project was estimated at 25 years, then Table 6 presents the financial considerations.

5. RESULTS

Table 7 presents the performance and energy production of the base scenario and the 4 cases of comparison with the use of bifacial technology, where it is observed that with respect to the base scenario there are increases in energy production 1.88% (1), 2.46% (2), 3.67% (3) and 4.83% (4), due to the amplification in the incidence of irradiance by the back of the photovoltaic modules that varies according to the albedo of the soil 3.41% (1), 4.53% (2), 6.77% (3) and 9.01% (4), all the above has an impact on the increase in the Performance Ratio (PR) 86.22% (base), 87.83% (1), 88.35% (2), 89.36% (3) and 90.36% (4).

The results of the research (Table 8) show that the scenarios obtained internal rates of returns of 17.99% (base), 17.25% (1), 17.60% (2), 18.27% (3) and 18.31% (4); with a payback of 5.4 (base), 5.75 (1), 5.57 (2), 5.24 (3) and 5.21 (4) years; and an NPV of $7,889.16 MCOP (base), $7,555.15 MCOP (1), $7,820.59

Table 5: Costs associated with implementing each scenario[2]

Description	Total Cost (MCOP)		
	Base Scenario	Scenario 1, 2 and 3	Scenario 4
Engineering studies and designs	3,101.05	3,101.05	3,101.05
Land	533	533	533
Financial Structuring	834.68	834.68	834.68
Civil Works	2,206.20	2,206.20	2,206.20
Supply, connection, and assembly of panels	15,835.74	16,176.51	16,176.51
Supply and assembly of structures	4,193.75	4,613.12	4,613.12
Supply of inverters and accessories	2,155.37	2,155.37	2,155.37
Supply of panel connection materials	4,327.45	4,680.60	4,680.60
Supply of transformer units, networks, and accessories	3,108.92	3,108.92	3,108.92
Provision of communications and ICTs	1.90	1.90	1.90
Entry into operation test and RETIE	220.83	220.83	220.83
Land conditioning (fine sand)	0	0	240
Total (investment)	36,518.89	37,632.18	37,872.18

1 This depth varies depending on the Pull-Out Test, however, in this study 1.5 m was taken as a reference.
2 The cost information presented in this table was acquired through quotations from local suppliers.

Table 6: Financial considerations

Income	Expenses	Tax benefits	Investment
1. Sale of energy as a generator to the National Interconnected System (SIN), worth 239.29 COP. 2. Carbon credits worth 17,660 COP.	1. Costs associated with operation and maintenance (OPEX) for an annual value of 2% with respect to the investment. 2. Tax of Financial Movements or 4x1000, that is, for every 1000 COP in financial movements a tax of 4 COP is charged.	1. Deduction of 50% of the investment for 15 years through Law 1715. 2. Accelerated depreciation (5 years) through Law 1715. 3. In years with negative utility, income tax goes from 35% to 0% according to article 188 of the tax statute for the year 2022.	1. The project is financed with 30% of own resources and 70% with bank loan with interest of 5.4% annual cash, has 1 year of grace. 2. The salvage value of the investment will be 10% of the total investment. 3. The Weighted Average Cost of Capital (WACC) is 8.28%.

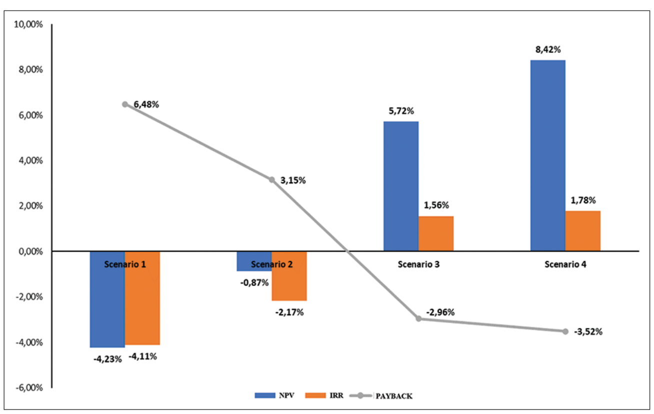
Table 7: Production and energy performance of each scenario

Scenarios	Performance ratio (%)	Global irradiance at the rear		Average annual energy generated (GWh/year)	Energy increase (%)
		(kWh/m^2.year)	(%)		
Base	86.22	0	0	20.69	-
1	87.83	67	3.41	21.08	1.88
2	88.35	89	4.53	21.20	2.46
3	89.36	133	6.77	21.45	3.67
4	90.36	177	9.01	21.69	4.83

Table 8: Comparison of financial goodness criteria

Parameter	Unit	Base scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
NPV	(MCOP)	$7,889.16	$7,555.15	$7,820.59	$8,340.77	$8,553.65
IRR	(%)	17.99%	17.25%	17.60%	18.27%	18.31%
Payback	(years)	5.40	5.75	5.57	5.24	5.21
Additional investment by technology	(%)	-	3.05%	3.05%	3.05%	3.05%
Additional investment for land conditioning	(%)	-	-	-	-	0.66%

Figure 1: Comparison of financial goodness criteria



MCOP (2), $8,340.77 MCOP (3) and $8,553.65 MCOP (4), with a WACC of 8.28%, evidencing that all scenarios are technically and financially viable projects.

Likewise, the analysis of the results (Figure 1) shows that scenarios 1 and 2 require more time to recover the investment (6.48% and 3.15%, respectively) compared to the base scenario; the internal rate of return is also lower (4.11% and 2.17%, respectively) compared to the base scenario; and in the same way, the NPV is lower (4.23% and 0.87%, respectively) for the baseline scenario; however, from the perspective of scenarios 3 and 4, they need less time to recover.

The investment (2.96% and 3.52%, respectively) compared to the base scenario; the internal rate of return is also higher (1.56% and 1.78%, respectively) compared to the baseline scenario; and in the same way, the NPV is higher (5.72% and 8.42%, respectively) with respect to the base scenario.

6. CONCLUSION

In this research, the evaluation of technical and financial feasibility of photovoltaic solar systems with bifacial technology was carried out, where 4 scenarios with different albedos (0.15, 0.2, 0.3 and 0.4) were compared with respect to a base scenario that uses monofacial technology, the financial viability of all scenarios was evaluated according to 3 criteria of financial goodness (NPV, IRR and Payback Time), this for a tropical location with high solar potential located in Colombia.

According to the results of this research, it is concluded that, for large-scale photovoltaic solar energy projects that use bifacial technology, it should be considered to add an investment associated with the conditioning of the land to improve the reflectivity of the soil, that is, its albedo, and in this way, to guarantee the advantages that this technology provides, as observed in the scenario with albedo 0.4, where the best results were achieved from the technical and financial perspective with an investment of $37,872 MCOP (3.71% more than the base scenario), an energy generated per year of 21,687 GWh/year (4.83% more than the base scenario), a net present value of $46,425 MCOP (8.42% more than the base scenario), an internal rate of return of 18.31% (1.78% more than the baseline scenario) and a return on investment time of 5.21 years (3.52% < the baseline scenario).

On the other hand, according to the analysis of the scenarios with albedos 0.15, 0.2 and 0.3 it is concluded that they are also technically and financially viable, however, for large-scale solar energy projects where it is planned to use bifacial technology, it is recommended to guarantee an albedo higher than 0.3, in this way, the additional investment used to acquire this technology will ensure better benefits for investors compared to conventional photovoltaic solar installation.

It is important to mention that in this study the scenario where the land is conditioned to guarantee an albedo of 0.4 using fine sand, led to an additional investment of 0.66%, however, this does not infer that using other elements to increase the reflectivity of the ground will associate an additional investment greater than that mentioned in this work, Because in that case it is necessary to carry out a study of the site to analyze what material would be more viable to use.

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