Techno-Financial comparison between photovoltaic systems with bifacial and monofacial technology in the location of Naco and Marcovia, Honduras

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Abstract. Technology is constantly growing, however, in the same way energy demand; over the years, different ways have been sought to better use of renewable resources in order to achieve better results in energy generation and supply that energy demand, but in turn to be feasible methods, an example of this is bifacial photovoltaic systems. This research carried out a Techno-Financial comparison between bifacial and monofacial systems for the locations of Naco, Cortés and Marcovia, Choluteca. In which the design of a bifacial photovoltaic installation was carried out assuming three types of land, being grass, soil and white gravel, with the purpose of analyzing the increase in albedo, and consequently the increase in energy production. Similarly, a monofacial system was designed for the same locations with the same capacity. The research made use of a quantitative methodology with a correlational focus, in which LCOE was established as the main research variable. In this way it was determined which photovoltaic system of those analyzed presents the lowest LCOE for both locations, of which it was made based on two assumptions, considering the value of the terrain and without considering it. Finally it was possible to determine that the lowest LCOE in a scenario where the value of the terrain is considered is obtained by the monofacial system for both localities, otherwise the scenario without considering the value of the terrain, the lowest LCOE presented by the bifacial system.

1. Introduction

At the end of 2018 there was a global energy consumption of 22,948 (TWh) [1]. Being one of the years with the highest percentage growth in carbon emissions, with 2% respectively [2]. However, this situation changed in 2019, as coal consumption decreased by 0.6%, leading to a reduction in carbon emissions [3]. The reason is due to the growth that renewable energy has been experiencing in recent years. One of the renewable technologies that experienced remarkable development during 2019 was solar energy, which recorded a globally installed capacity of 630 (GW) at the end of 2019 [4]. This is why, with the growth of technology and increased energy demand, different ways to take advantage of solar energy have been sought, such as bifacial photovoltaic technology, which allows the capture of solar irradiation from the front of a photovoltaic module and from the back of it, leading to greater energy production compared to monofacial photovoltaic systems. However, this type of technology involves a higher cost of investment, operation and maintenance compared to monofacial systems.
Therefore, this research will carry out a techno-financial comparison of photovoltaic systems with bifacial and monofacial technology, this for the locations of Naco, Cortés and Marcovia, Choluteca. In order to determine which photovoltaic system is most feasible based on the lowest LCOE.

2. Methodology

The research aims to compare bifacial and monofacial photovoltaic systems, which are composed of the same characteristics as location, installed capacity and orientation. The bifacial design consists of 3 albedo scenarios, being green grass, soil and white gravel, these scenarios were called Case 1, 2 and 3 respectively. NSRDB Data Viewer tool was used to obtain weather data such as terrain albedo and PVsyst for the design and simulation of photovoltaic systems.

2.1. Geometric parameters

The height of a bifacial module differs from the one of a monofacial, a bifacial module with a low height results in losses by shading, because the same shadows generated by the module causes the distribution of irradiance at the rear to not be uniform. It has been shown that close to a height of 0.95 (m) the bifacial gain becomes constant [5], however, this does not guarantee that there will be no loss by structure shading or wiring, since, if there is a terrain with high albedo value, the modules become more susceptible to self-shading losses due to the large fraction of the irradiance reflected in the back. To calculate the optimal elevation of a bifacial module the following equation is shown [6]:

\[ E_0 = H \cdot [ -\text{Lat} \cdot [0.028 \cdot R_a + 0.009] + 3.3 \cdot R_a + 0.4] \]  

(1)

Where \( H \) is the length of the module in meter, \( \text{Lat} \) is the latitude in degrees, \( R_a \) is the albedo of the terrain. Similarly, the optimal angle of a bifacial module should be determined, this in order to improve the uptake of albedo light at the back of the module. Like monofacial modules the inclination depends on the site latitude, however, it depends on more parameters such as albedo, module elevation and the length of the module, calculated with the following equation [6]:

\[ \beta_0 = \alpha \cdot \text{Lat} + b \]  

(2)

\[ a = 0.86 - 0.57 \cdot R_a \cdot \exp(E / H) \]  

(3)

\[ b = 4.5 + 62 \cdot R_a \cdot \exp(-E / H) \]  

(4)

Following the previous variable typology and where \( E \) is the elevation of the module. Also, another parameter to consider is the Ground Coverage Ratio (GCR), in the case of bifacial systems a GCR of 35% is used [7], this in order to avoid shading between module rows. For monofacial systems a GCR of 50% was used.

Finally, the parameters mentioned above were determined for each location and scenario, which are shown in Table 1.

| Location/Scenario | Albedo (%) | GCR (%) | Elevation (m) | Tilt Angle (°) |
|-------------------|------------|---------|---------------|---------------|
| Naco Monofacial   | -          | 50      | 0.5           | 15            |
| Naco/Bifacial Case 1 | 17       | 35      | 1.54          | 22            |

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2.2. Bifacial gain.
The increase in energy production of a bifacial module compared to a monofacial system is given by the bifacial gain, whose parameter depends directly on the albedo of the ground, bifacial factor of the module, height of the modules and separation of rows between modules. Therefore, the calculation of bifacial gain is given by the following equation [8]:

\[
BGE(\%) = \text{Albedo} \times \text{Bifacial factor} \times 0.95 \times (1.037 \times [1 - \frac{1}{r}] [1 - \exp((-8.691 \times h) / r)] + 0.125[1 - \frac{1}{r^2}])
\]  

Where \( r \) is the pitch of the modules in meters, \( h \) the height respect to the ground of the modules in meters and the bifacial factor in percentage, which this parameter is provided by the technical sheet of the modules. Table 2 shows the bifacial gain that each bifacial system would assume for both locations, for this, Table 1 was used to obtain these results.

| Location/Scenario | Albedo (%) | GCR (%) | Elevation (m) | Tilt Angle (°) |
|-------------------|------------|---------|---------------|----------------|
| Naco/Bifacial Case 2 | 18 | 35 | 1.6 | 22.1 |
| Naco/Bifacial Case 3 | 36 | 35 | 2.66 | 23.1 |
| Marcovia/Bifacial Case 1 | - | 50 | 0.5 | 15 |
| Marcovia/Bifacial Case 1 | 19 | 35 | 1.72 | 20.4 |
| Marcovia/Bifacial Case 2 | 18 | 35 | 1.66 | 20.3 |
| Marcovia/Bifacial Case 3 | 36 | 35 | 2.74 | 21.1 |

2.3. Final specifications
Finally, a nominal capacity of 10 (MW) was established, as previous studies in the location of Naco are within this range [9]. A DC/AC ratio of 1.3 was also established for the monofacial system. In the case of the bifacial system, different DC/AC ratios were established in order to keep clipping losses equal to
the monofacial system, as there is an increase in energy production, therefore, clipping losses increase if a ratio equal to the monofacial system is maintained. Results of the ratio DC/AC for each case is shown in Table 3.

| Scenario      | DC Capacity (MW) | Ratio DC/AC (%) |
|---------------|------------------|-----------------|
| Monofacial    | 10               | 1.29            |
| Bifacial Case 1 | 10              | 1.15            |
| Bifacial Case 2 | 10              | 1.15            |
| Bifacial Case 3 | 10              | 1.08            |

2.4. LCOE calculation
After setting the geometric parameters of each solar array and being made the simulation of each scenario in PVsyst, the calculation of the LCOE is performed, for the calculation of this parameter the following equation [10]:

$$
LCOE = \frac{\sum \text{Total cost over lifetime}}{\sum \text{Electricity generated over lifetime}}
$$

(6)

Two financial scenarios were carried out for financial analysis, with financing and without financing, in the same way two assumptions, considering the value of the land and without considering it. In the scenario with financing it is considered that 70% of the investment comes from a loan at an interest rate of 10% with a term of 10 years, and the remaining 30% comes from the investor, while without financing the entire investment is made by the investor.

3. Results

3.1. Simulation of the PV systems in Naco
The simulation in PVsyst showed that on average the monofacial system has an annual generation of 15,034 (MWh), the bifacial system Case 1 with 16,402 (MWh), 16,439 (MWh) for Case 2 and finally Case 3 with 17,621 (MWh), as shown in Figure 1. The bifacial system for Case 1 represents an increase of 9.04% compared to the monofacial. Case 2 with an increase of 9.31% and finally Case 3 with an increase of 17.15% respectively.

![Figure 1. Monthly generation of FV systems in Naco](image-url)
3.2. Simulation of the PV system in Marcovia

Figure 2 shows the simulation for the location of Marcovia, the monofacial system has an annual generation of 15,640 (MWh). While bifacial systems in their three cases have an annual generation of 17,306 (MWh), 16,908 (MWh) and 18,433 (MWh) respectively. Where this represents an increase of 10.62%, 8.11% and 17.84% according to each scenario in comparison to the monofacial.

![Figure 2. Monthly generation of FV systems in Marcovia](image)

3.3. Specific Capital Cost

For the analysis of the Specific Capital Cost, the value of the land for both locations was considered, as shown in Table 4. Where the monofacial system has a territorial extension of 109,726 (m²) and 159,453 (m²) for the bifacial system.

| Location/Scenario       | Specific Capital Cost ($ kWp⁻¹) |
|-------------------------|---------------------------------|
| Naco/Monofacial         | 1.68                            |
| Naco/Bifacial           | 2.14                            |
| Marcovia/Monofacial     | 1.10                            |
| Marcovia/Bifacial       | 1.30                            |

3.4. LCOE without financing considering the value of the land

Figure 3 shows the results of the proposed scenario, the lowest LCOE for both locations is of the monofacial system, secondly followed by the bifacial system in Case 3. On average the LCOE of the bifacial system Case 1 and 2 has an increase of 13.3% compared to the monofacial and Case 3 6.6%. And for the location of Marcovia Cases 1 and 2 have an increase of 7.31% and Case 3 with 2.43% compared to the monofacial.
3.5. LCOE without financing without considering the value of the land
In this scenario, unlike the previous scenario, the lowest LCOE for both locations is that of the bifacial system in Case 3, with a 2.19% decrease from the monofacial system in Naco and a 3.17% decrease in bifacial compared to Marcovia's monofacial system. LCOE for this scenario is shown in Figure 4.

3.6. LCOE with financing considering the value of the land
In this scenario, the same pattern is presented as the without financing scenario, only that in the financed scenario there is an increase in LCOE for all systems, where on average there is an increase of 31%. LCOE for this scenario is shown in Figure 5.
Figure 5. LCOE with financing considering the value of the land

3.7. LCOE with financing without considering the value of the land
Figure 6 shows the results of the scenario with financing without considering land value. Just as in the scenario without financing and without considering the terrain, the same pattern is presented, with the difference that the LCOE for both systems in both locations has on average an increase of 27% compared to the not financing scenario.

Figure 6. LCOE with financing without considering the value of the land

4. Conclusions
This research was able to determine the feasibility of monofacial and bifacial photovoltaic systems from the lowest LCOE by means of a techno-financial comparison for the location of Naco and Marcovia. In which the following results were obtained:

1. The scenario where the value of the land in investment is considered, the lowest LCOE presented is from the monofacial system for both locations, with a value of 0.0602 [$/kWh] in an scenario
without financing and 0.0799 [$/kWh] with financing for the location of Naco, and for the location of Marcovia 0.0417 [$/kWh] without financing and 0.0541 [$/kWh] with financing. In the scenario without considering the value of the land, the lowest LCOE is presented by the bifacial system in Case 3, with a value of 0.0364 [$/kWh] without financing and 0.0462 [$/kWh] with financing for Naco. For the location of Marcovia, an LCOE of 0.0347 [$/kWh] was presented without financing and 0.0441 [$/kWh] with financing.

2. For the location of Naco, the bifacial system in all three cases had an increase in energy production of 9.04%, 9.31% and 17.15% respectively compared to the monofacial system. Similarly, in the location of Marcovia, the three bifacial system scenarios had an increase of 10.60%, 8.11%, 17.84% respectively compared to the monofacial system.

3. Likewise, Case 2 bifacial presented an increase of 0.26% compared to Case 1, and Case 3 an increase of 7.85% compared to Case 2, this for the location of Naco. In the location of Marcovia, Case 2 showed a 2.52% decrease from Case 1 and Case 3 had an increase of 9.74% compared to Case 2.

4. The GCR for a bifacial photovoltaic installation is 35%, meaning that bifacial installations represent a larger territorial area than monofacial ones. Similarly, the optimal elevation and angle of inclination was determined based on the albedo and the location of the solar array.

5. The scenario with financing considering the terrain showed a 31% increase over the scenario without financing considering the terrain, in the same way, the scenario with financing without considering the value of the land showed a 27% increase from the scenario without financing regardless of the value of the land.

5. References
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