Techno-economic comparison between photovoltaic systems with solar trackers and fixed structure in “El Valle de Sula”, Honduras

H Andino García¹, A Reyes Duke² and H Villatoro Flores³

¹ Undergraduate student, Faculty of Engineering, Universidad Tecnológica Centroamericana UNITEC, Honduras
² Assistant Professor and corresponding author, Faculty of Engineering, Universidad Tecnológica Centroamericana UNITEC, Honduras
³ Lecturer, Faculty of Engineering, Universidad Tecnológica Centroamericana UNITEC, Honduras
E-mail: alicia.reyes@unitec.edu.hn

Abstract. Solar energy has the greatest energy potential among all types of renewable energies. In 2018, the annual demand for electricity worldwide was 22,964 TWh. Daily, earth receives about 174 PW in the form of solar irradiance. This means that, if all this radiation could be harnessed, in approximately 8 minutes the electricity needed to meet the global annual electricity demand could be generated. Therefore, the need arises to implement photovoltaic systems that take better advantage of the solar resource, but in turn provide greater economic profitability. This article aims to evaluate the technical and economic feasibility of photovoltaic systems with solar trackers and compare them with fixed structure systems in “El Valle de Sula”, Honduras, Central America. The research was able to determine the levelized cost of electricity (LCOE) of each type of photovoltaic system from the generation of electricity in municipalities comprising the study area and the costs associated with initial investment, and operation and maintenance of each photovoltaic system. This research was carried out by implementing a methodology with a quantitative approach, using data collection to test hypotheses, based on numerical measurement and statistical analysis. Considering the value of the land, the photovoltaic system with a horizontal axis tracker has the lowest LCOE in 14 of the 18 municipalities of “El Valle de Sula”. Without taking into account the value of the land, the system with the lowest LCOE in all municipalities of this region is the system with a horizontal axis tracker, then the system with a dual-axis tracker and finally the system with fixed structure.

1. Introduction
Since man has cared to harness energy from the sun, he has realized that the solar incidence is higher on an object as it follows the path of the sun. Photovoltaic solar systems are designed to obtain the greatest possible use of the solar resource, that is why photovoltaic systems with solar trackers arise to follow the trajectory of the sun and increase electricity production. Solar trackers are classified according to their axis of rotation relative to the ground, and they may include vertical axis, horizontal axis and dual-axis.
Assessing how viable it is to implement this class of photovoltaic systems requires multiple technical and economic considerations because photovoltaic systems with solar trackers allow greater use of solar radiation during the day, and consequently generate more electricity. However, these systems
require a higher cost of initial investment, operation, maintenance, and territorial extension for assembly compared to fixed-structure systems. Such systems are not economically viable anywhere, as favourable environmental conditions must exist for the increase in electricity production to be much greater than fixed-structure photovoltaic systems. This research will evaluate the techno-economic feasibility of photovoltaic systems with solar trackers in "El Valle de Sula", by comparing with fixed-structure photovoltaic systems and will be developed with the main purpose of facilitating decision-making on what type of photovoltaic system is more feasible to implement from the lowest LCOE, as there is currently no study for this region to demonstrate if photovoltaic systems with solar trackers are more viable than fixed-structure systems, or vice versa.

2. Previous studies
Multiple studies have been conducted around the world comparing photovoltaic systems with solar trackers and fixed-structure systems. Petros J. Axaopoulos & Emmanouil D. determined that photovoltaic systems with dual-axis trackers in Greece are more attractive than fixed-structure systems; in contrast, in Germany and Scotland where these kinds of systems are not as economically attractive [1]. In Saudi Arabia, a techno-economic study shows that photovoltaic systems with vertical or dual-axis solar trackers provide a lower LCOE than fixed-structure systems [2]. A study developed in Kuala Lumpur, Malaysia drew a comparison in terms of electricity production between a photovoltaic system with a dual-axis tracker and a fixed-structure system. It was determined that for this location the system with a dual-axis tracker has an increase in electricity production of 82.12% during sunny days and 24.91%, during cloudy days [3]. In Mexico and El Salvador, it has been possible to determine that through photovoltaic systems with a horizontal axis tracker the increase in electricity production compared to fixed structure systems is 36.76% and 38% respectively [4,5]. In the particular case of Honduras, in the southern part of the country it was determined that two photovoltaic plants increased their electricity production by 33%, by implementing solar trackers of a horizontal axis [6].

3. Context
A report by the Economic Commission for Latin America (CEPAL) notes that the kWh average cost in Central America in 2016 was $13.48 cents, meanwhile the kWh average cost in Honduras was higher than the average cost of the region, being $13.77 cents [7]. The high price of electricity, low-quality electricity service and low reliability provided by the state-owned electricity company have practically forced many companies to partially or fully generate the electricity they demand, and in many cases by photovoltaic solar energy. This research takes place in “El Valle de Sula”, which is considered to be the most active economic region nationally, contributing around 124 billion Lempiras annually to GDP, representing more than 60% of the country's GDP. The municipality of San Pedro Sula is located in this region and is classified as the industrial capital of the country as more than 20 industrial branches generate a high percentage of the income of the people living in this city [8]. More than 40 different shops in San Pedro Sula currently have photovoltaic systems to meet a part of their electricity demand. In 2018, the installed power of photovoltaic systems in San Pedro Sula was 8.493 MW, representing an increase in installed capacity of 100% compared to 2017. The development of photovoltaic solar energy in this region and mainly in San Pedro Sula generates very good expectations and it is estimated that by 2030 the installed capacity in this city will be 194.49 MW [9].

4. Methodology
The research involves comparing photovoltaic systems with solar trackers and systems with fixed structure in “El Valle de Sula”, a region that is composed of 18 municipalities.
The photovoltaic systems involved in this research are: photovoltaic system with fixed structure (to be used as a reference), with a horizontal axis tracker and with a dual-axis tracker. PVsyst and Meteonorm were used as tools to develop the simulations and determine the annual electricity generated from each system in all the municipalities that make up the study area. The LCOE will be also calculated for these systems, and in this way, the systems can be compared and determine which is most convenient to implement in this region.

To calculate the LCOE, it is necessary to know the capital cost, cost of O&M, fuel cost (in this case it is zero, as it is a type of energy that does not require some fuel for its operation) and also determine the electricity generated by each system over the lifetime, as shown in the following equation [10]:

\[
Gen_{cost_{(cap)}} = \frac{GC_{(cap)} + O&M + FC_{(cap)}}{AnnGenElec_{(cap)}}
\] (1)

In the case of the fixed-structure system, the inclination was determined from the following equation:

\[
\beta_{opt} = 3.7 + 0.69 \cdot |\varnothing|
\] (2)

Where \(|\varnothing|\) = Latitude of the Place

"El Valle de Sula" is located at a latitude of approximately 15 degrees.

The selected azimuth was to the south, since the study area is located in the northern hemisphere and in this way, a greater use can be achieved with this orientation.

The tilt limits of photovoltaic systems with solar trackers were selected from the technical sheets of the manufacturers. In the case of a horizontal axis tracker system, the inclination limits are from -60 to 60 degrees, meanwhile for the dual-axis tracker system, the tilt limits are from 0 to 60 degrees on the horizontal axis and from -135° to 135° on vertical axis.

37,680 Sun Power solar modules, model X21-345-COM, 345W were used. 100 Fronius AGILO 100.0-3 100 kW brand inverters were also used. Both the module type and the solar inverter were selected from a decision matrix that allows you to evaluate various market options and choose the most convenient one.

Another important aspect to manage to compare all the systems involved equally is through the appropriate Ground Coverage Ratio (GCR) according to the type of installation, this to avoid shadows between the same solar modules. In the case of the fixed-structure system a GCR of 50% was used, for the system with horizontal axis tracker a 33% was used and in the case of the system with dual-axis tracker a GCR of 25%, as shown in Table 1.

To perform a fair comparison, the DC and AC power capabilities are the same for all photovoltaic systems involved in this research, these being the following: 13 MWp and 10 MWac, thus using a DC/AC ratio equal to 1.3, since 10 MWac is a representative value of the power installed in photovoltaic systems on land that currently exist for this region.

| Photovoltaic systems | DC power | AC power | GCR | Tilt Limits                  |
|----------------------|----------|----------|-----|------------------------------|
| Fixed structure      | 13 MW    | 10 MW    | 50% | 14th south-facing           |
| Horizontal axis tracker | 13 MW    | 10 MW    | 33% | -60° a +60° (horizontal)    |
| Dual-axis tracker    | 13 MW    | 10 MW    | 25% | 0° a +60° (horizontal)      |
|                      |          |          |     | -135° a +135° (vertical)    |

Table 1. Technical specifications of photovoltaic systems
After having carried out the simulations by PVsyst in each of the municipalities of “El Valle de Sula” and obtained the necessary information, a techno-economic analysis is carried out, considering the lifetime of the project that was determined for 25 years and in turn taking into account the degradation factor of photovoltaic systems and the rate of inflation. Two different scenarios were developed for the initial investment financing type: With financing and without financing. Both scenarios consider the initial investment costs and costs of O&M according to each photovoltaic system, for the scenario with financing the capital proceeds by 70% through a loan and the remaining 30% of the investor's contribution. Meanwhile, for the unfunded case the entire investment comes from the investor. Table 2 shows the financial specifications of photovoltaic systems involved in this research.

| Parameters                  | Fixed structure system | Horizontal axis tracker system | Dual-axis tracker system |
|-----------------------------|------------------------|-------------------------------|--------------------------|
| Specific Capital Cost       | 1.45$ Wp⁻¹             | 1.72$ Wp⁻¹                    | 2.00$ Wp⁻¹               |
| O&M Cost (annual)           | 13$ kWp⁻¹              | 14$ kWp⁻¹                     | 16.25$ kWp⁻¹             |
| Inflation rate (annual)     | 1.5%                   | 1.5%                          | 1.5%                     |
| Loan interest rate          | 10%                    | 10%                           | 10%                      |
| Loan term                   | 10 years               | 10 years                      | 10 years                 |
| Financing (Loan-Investor)   | 70%-30%                | 70%-30%                       | 70%-30%                  |

5. Results and analysis

5.1. Annual Electricity Generation

The simulations in PVsyst allow to calculate the electricity generation for each municipality of “El Valle de Sula” according to the technical specifications of each of the photovoltaic systems involved in this research.

The average electricity generation for the first year with the fixed structure system is 19,241 MWh, meanwhile for the system with a horizontal axis tracker is 22,766 MWh, representing an increase of 18.32% in relation to the fixed structure system. On the other hand, the dual-axis tracker system has an average annual electricity generation of 24,242 MWh, representing an increase of approximately 26% compared to the fixed-structure system. Figure 1 shows the annual electricity generation for the first year of each photovoltaic system in all the municipalities of “El Valle de Sula”.

5.2. Initial investment, operation and maintenance costs

Initial investment, operation and maintenance costs are critical to determining which type of photovoltaic system has a lower LCOE.

The specific capital cost [$/Wp] for a photovoltaic system with a horizontal axis tracker is greater than 8% relative to a fixed structure system, without considering the value of the land. Meanwhile the O&M costs of systems with a horizontal axis tracker and fixed structure system, considering the replacement of investors between the year 10 and 13 of the project, are $14 and $13 respectively [11]. On the other hand, the specific capital cost for a photovoltaic system with a dual-axis tracker is greater by 18% relative to a fixed structure system, without considering the value of the land [12]. O&M's costs for systems with dual-axis tracker is 25% higher relative to O&M costs for fixed structure systems [13].
The average specific capital cost in “El Valle de Sula” for the fixed structure system is 1.45$/Wp, considering the value of the land, meanwhile in the case of a horizontal axis tracker system is 1.72$/Wp, representing an 18.62% increase relative to the fixed structure system. On the other hand, the dual-axis tracker system averages a specific capital cost of 2$/Wp, representing an increase of 37.93% over the fixed-structure system. Figure 2 shows the specific capital cost of each photovoltaic system in all the municipalities of “El Valle de Sula”.

Photovoltaic systems with solar trackers have a higher cost of O&M to fixed structure systems because the required maintenance includes motors, sensors and moving parts that fixed structure systems do not use. The difference between the system with a horizontal axis tracker and with a fixed structure is 7.69%, meanwhile the difference between the system with dual-axis tracker and the system...
with fixed structure is 25%. Figure 3 shows the costs of operation and annual maintenance of photovoltaic systems in all the municipalities of “El Valle de Sula”.

Figure 3. Costs of operation and annual maintenance of photovoltaic systems.

5.3. Ground coverage
The distribution of photovoltaic modules is extremely important to avoid shadows between themselves, which is why the GCR allows to determine the ratio of Ground coverage between the area covered by the photovoltaic modules and the total area of the assembly.

The area covered by the 37,680 photovoltaic modules is 61,447 m², therefore, the territorial extension of each photovoltaic system, considering the appropriate GCR, is determined according to Figure 4.

Figure 4. Ground coverage of each photovoltaic system

5.4. LCOE without financing and considering the value of the land
For this scenario, the value of the land is considered that the entire initial investment cost comes from the investor.
In 14 of the 18 municipalities of “El Valle de Sula”, the lowest LCOE is presented by the photovoltaic system with a horizontal axis tracker while in the rest of the municipalities (La Lima, Omoa, Puerto Cortés y San Pedro Sula) the lower LCOE is presented by the system with fixed structure. This is because in municipalities where the value of land is higher, the implementation of solar trackers is not economically viable. Otherwise in those municipalities where the value of the land is lower, the implementation of this type of systems is economically viable. Figure 5 shows the LCOE without financing and considering the land value of each photovoltaic system in all the municipalities of “El Valle de Sula”.

![Graph showing LCOE without financing and considering the value of the land.](image)

**Figure 5.** LCOE without financing and considering the value of the land.

5.5. **LCOE with financing and considering the value of the land.**

In this scenario, the value of the land is considered that 70% of the initial investment cost comes from a loan, and the remaining 30% comes from the investor.

The result of the LCOE with financing and considering the value of the land follows the same trend as the results of the previous scenario, only that the value of the LCOE for each photovoltaic system is increased by approximately 30% compared to the previous scenario. Figure 6 shows the LCOE with financing and considering the land value of each photovoltaic system in all the municipalities of “El Valle de Sula”.

5.6. **LCOE without financing and without considering the value of the land.**

This scenario applies to all those projects that already have a land previously for the assembly of the solar modules and which financing is totally covered by the investor.

The behavior of the value of the LCOE for the different photovoltaic systems is the same in all the municipalities of “El Valle de Sula”, this means that, if you already have a land, the best option is the system with a horizontal axis tracker, then the system with a dual-axis tracker and finally the system with fixed structure. Figure 7 shows the LCOE without financing and without considering the land value of each photovoltaic system in all the municipalities of “El Valle de Sula”.

![Graph showing LCOE without financing and without considering the value of the land.](image)
Figure 6. LCOE with financing and considering the value of the land.

Figure 7. LCOE without financing and without considering the value of the land.

5.7. LCOE with financing and without considering the value of the land.
This scenario applies to those projects that already have a land previously for the assembly of the solar modules and which financing comes from 70% by a loan and the remaining 30% comes from the contribution of the investor.

The behavior in this scenario follows the same trend as the results from the previous scenario, only that the LCOE value for each PV system is increased by approximately 28% compared to the previous scenario. Figure 8 shows the LCOE with financing and without considering the land value of each photovoltaic system in all the municipalities of “El Valle de Sula”.


This sensitivity analysis evaluates the variation of LCOE based on changes in the land value [$/m^2$]. This lets anybody know from which land prices the order of photovoltaic systems is modified according to the LCOE, based on the average value of LCOE for “El Valle de Sula”.

In the unfunded scenario when the ground value ranges from 1-14$/m^2$ the system with the lowest LCOE is the system with a horizontal axis tracker, then the dual-axis tracker system and finally the fixed structure system, which at 14$/m^2$ equals the LCOE of the system with a dual-axis tracker. This order is modified when the range increases between 13-45$/m^2$, since the system with a horizontal axis tracker continues to have the lowest LCOE, but then finds the system with fixed structure, which equals the value of the LCOE with a horizontal axis tracker at 45$/m^2$, and ultimately the system with a dual-axis tracker. From 46$/m^2$ onwards, the same order of LCOE is maintained, with the system with fixed structure the one that has the lowest LCOE, then the system with a horizontal axis tracker and finally the system with a dual-axis tracker, as shown in Table 3.

In the scenario with financing when the ranges of the land value varies from 1-13$/m^2$, the system with the lowest LCOE is the system with a horizontal axis tracker, then the system with a dual-axis tracker and finally the system with fixed structure, which equals the LCOE value of the system with a dual-axis tracker at 13$/m^2$. This order is modified when the range increases between 14-43$/m^2$, since the system with horizontal axis tracker system continues to have the lowest LCOE, but then the system with fixed structure, which at 43$/m^2$ has the same value of LCOE as the system with a horizontal...
axis tracker and last the system with dual-axis tracker. From 44$/m^2$ onwards, the same order of LCOE is maintained, with the system with fixed structure the one that owns the lowest LCOE, then the system with a horizontal axis tracker and finally the system with dual-axis tracker, as shown in Table 4.

### Table 4. LCOE variation with financing according to the value of the land

| Land value [$/m^2]$ | LCOE Fixed structure system [$/kWh$] | LCOE Horizontal axis tracker system [$/kWh$] | LCOE Dual-axis tracker system [$/kWh$] |
|--------------------|--------------------------------------|---------------------------------------------|---------------------------------------|
| 1-13                | 0.062 - 0.068                        | 0.057 - 0.064                               | 0.059 - 0.068                        |
| 14-43               | 0.068 - 0.081                        | 0.065 - 0.081                               | 0.069 - 0.089                        |
| 44-forward          | 0.081 -                               | 0.082 -                                     | 0.090 -                               |

#### 6. Conclusions

The research presented has managed to determine the most viable photovoltaic system from the lowest LCOE in all the municipalities that comprise the Sula Valley through a techno-economic comparison between photovoltaic systems with solar trackers and with a fixed structure for a 10 MWac installation above ground. The investigation revealed the following results:

1. The system with a horizontal axis tracker has an increase in electricity generation of 18.32% relative to the fixed-structure system. On the other hand, the system with a dual-axis tracker has an increase of approximately 26% compared to the fixed-structured system.
2. The system with a horizontal axis tracker has a specific capital cost of 18.62% in relation to the fixed structure system, considering the value of the land. In contrast, the system with a dual-axis tracker has an increase of 37.93% in relation to the fixed-structure system.
3. The horizontal axis tracker system has a higher O&M cost of 7.69%, relative to the fixed structure system; meanwhile, the dual-axis tracker system has a higher O&M cost of 25% compared to the fixed-structured system.
4. The area required for the assembly of the photovoltaic system with fixed structure is 122,894 m$^2$; meanwhile, for systems with a horizontal axis tracker the assembly area is 186,203 m$^2$; which represents an increase of 51.5% compared to the Fixed-structure system. On the other hand, the dual-axis system is 245,788 m$^2$, which represents an increase of 100%.
5. The most convenient system for a photovoltaic installation is the one with a horizontal axis tracker, since it has the lowest LCOE in 14 of the 18 municipalities of the Sula Valley, with an average value of 0.059 $/kWh in the scenario without financing and $0.077 /kWh for the scenario with financing, then the fixed structure system has the lowest LCOE in the rest of the municipalities (La Lima, Omoa, Puerto Cortés and San Pedro Sula) with an average value of $0.060 /kWh in the scenario without financing and of 0.078 $ /kWh for the scenario with financing and finally the system with dual-axis follower with an average value of 0.065 $ /kWh in the scenario without financing and of 0.084 $ /kWh for the scenario with financing, considering the value of the land.
6. If the land value is not considered, the best option in the 18 municipalities of the Sula Valley from the lowest LCOE for a photovoltaic installation is the system with a horizontal axis tracker with an average value of 0.044 $/kWh in the scenario without financing and of 0.056 $ /kWh for the scenario with financing, then the system with dual-axis tracker with an average value of 0.046 $ /kWh in the scenario without financing and of 0.059 $ /kWh for the scenario with financing and finally, the system with a fixed structure that has an average value of $0.049 /kWh in the scenario without financing and $0.062 /kWh for the scenario with financing.

The main limitation of this research is that only one region in the north of Honduras was selected as the study area. It is recommended that bifacial modules be used for a future research.
7. References

[1] Petros J. Axaopoulos, P., & Emmanouil D. Fylladitakis, MSc. (2013). ENERGY AND ECONOMIC COMPARATIVE STUDY OF A TRACKING VS. A FIXED PHOTOVOLTAIC SYSTEM. European Scientific Journal.

[2] Hassan Al Garni, A. A. (2017). Techno-Economic Feasibility Analysis of a Solar PV Grid-Connected System with Different Tracking Using HOMER Software.

[3] J. F. Lee, N. A. (2013). Performance Comparison of Dual-Axis Solar Tracker vs Static Solar System in Malaysia. Kuala Lumpur.

[4] Adriana Robles, R. R. (2018). Evaluation of energy production of photovoltaic systems with solar tracking vs fixed structures. It's a great time.

[5] Pedro García, R. P. (2016). Implementation of a horizontal-axis solar tracker controlled with freely distributed hardware and software. San Salvador.

[6] Jackson, M. (May 2020). MECER and Helios. (H. Andino, Interviewer).

[7] ECLAC. (2016). Statistics of the electricity subsector of the countries of the Central American Integration System (SICA).

[8] San Pedro Sula Municipal Management Plan. (2015).

[9] Reyes, F. (2018). Photovoltaic energy demand forecast in San Pedro Sula.

[10] Flores, H. F. (2015). Decentralised electricity generation system based on local renewable energy sources in the Honduran rural residential sector.

[11] Ran Fu, D. F. (2018). U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018.

[12] allearthsolar. (2016). Obtained from https://www.allearthrenewables.com/blog/dealers/dealers/comparing-the-power-production-of-roof-mount-solar-and-dual-axis-trackers

[13] Jose Simon, G. M. (2013). Feasibility Study of Economics and Performance of Solar Photovoltaics at the Kerr McGee Site in Columbus, Mississippi.