

Economic and environmental benefits in the production of photovoltaic solar electric energy using a solar tracking system in the municipality of Acacias - Meta (Colombia)

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Abstract—The following article presents the results of the research entitled Design and implementation of a fixed and mobile photovoltaic system to capture the solar power, determining the cost-benefit relation for the Acacias CEAD; research based on determining the solar energy potential that affects the National Open University and Distance - UNAD, located in the municipality of Acacia. In addition, this article will determine the solar radiation in the area, solar power per m² and cost-benefit ratio of the capture of photovoltaic solar electric energy between a fixed panel system and a solar tracking system. This investigation establishes that an additional production of 61.09% of electric energy is captured from solar panels with tracking compared to fixed solar panels.

Keyword - Photovoltaic solar energy, solar tracking system, Renewable energies, solar power, cost benefit.

I. INTRODUCTION

Renewable energies such as solar, wind, hydroelectric and biomass have aroused great interest in the world as a possible solution to the production of non-renewable energies derived from coal, oil and gas [1], which through the history have had a volatile market, with their costs depending on the internal policies of each country. In addition, there is a need to reduce CO₂ emissions in the atmosphere in order to mitigate global warming, as a reference to the European Union which possess close to 40% of the world's patents related to renewable energy and are adopting a transition of energy production through clean energy [2].

Moreover, at the Paris climate conference (COP21), held in December 2015, 195 countries signed the first binding global climate agreement. Their main commitment is directed towards the reduction of greenhouse gas emissions and greenhouse effects, with which it is intended to keep below 2 °C the increase in global average temperature [3]. Colombia is currently one of the countries that has ratified the Paris agreement and has committed to reducing greenhouse gas emissions by 20% by the year 2030. As a first step, it has begun with the tax levy on a gallon of ACPM (\$ 152 pesos), gasoline (\$ 135 pesos) and liquefied petroleum gas (\$ 95 pesos) and soon to kerosene, jet fuel and fuel oil. This tax will have an increase of 1% per year until the year 2050 [4].

The development of new techniques and technologies have reduced the cost of the implementation of photovoltaic solar energy [5]. One of these phenomena is the production of solar panel manufacturing in China. In addition to the decrease in the cost of polysilicon, the main component in the manufacture of solar panels, there is also an important improvement in the implementation of techniques that improve the efficiency of the photovoltaic cells. This has managed to reduce the cost of solar panels, reducing from an average cost of \$ 1.31 dollars per watt in the year 2011 to an average cost of \$ 0.50 dollars per watt for the year 2014. There is to be an estimated reduction by the end of 2017 of the cost of solar panels by 40% [6].

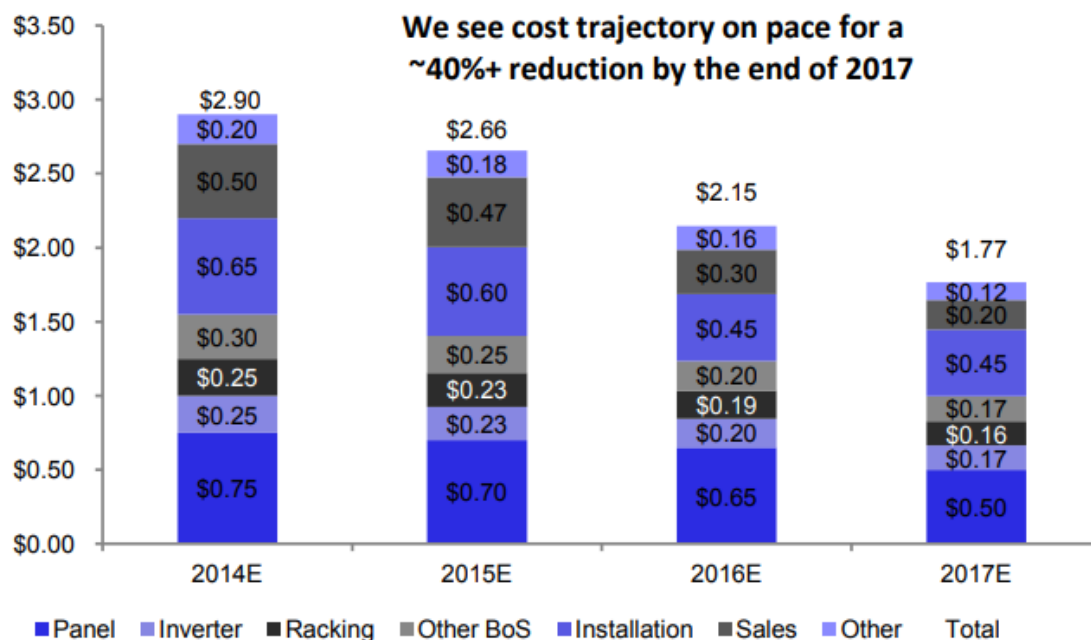


Fig. 1. Cost reduction per watt, Example USA

Another characteristic to take into account in any design aimed at the production of photovoltaic solar energy, is the solar irradiation that exists in the geographical location where the system is intended to be implemented [7] [8]. Depending on the location there can be a greater or lesser strength of sun and therefore can have a greater solar irradiation. In the case of Colombia, it is necessary to take as a reference the information provided by the IDEAM (Institute of Hydrology, Meteorology and Environmental Studies) governmental institution in charge of providing the reference information in the country. For the case study, the Radiation Atlas incorporates solar, ultraviolet and ozone of Colombia [9] and thus have a starting point of the potential energy potential of the area and point of comparison.

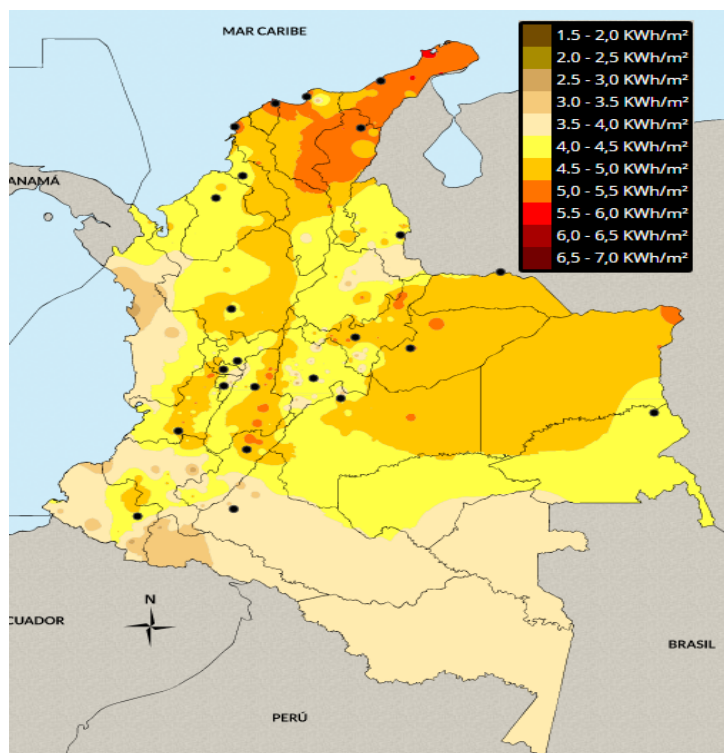


Fig. 2. Atlas of solar radiation, ultraviolet and ozone of Colombia

The solar map in Colombia provided by the IDEAM, shows different measurements in each of its departments which present the global average daily horizontal irradiation measurements of 1.5KWh / m² up to 6.0kWh / m² therefore making some departments and / or municipalities potentially feasible for the implementation of energy production systems based on solar panels. For example, the municipality of Acacias, which has a global average daily irradiation of 4.5 - 5.0KWh / m², making the municipality of Acacias a potential location for production of photovoltaic solar energy [9].

II. DESCRIPTION OF THE SENSORS FOR MEASUREMENT

The sensor implemented for the measurement of solar irradiated power is based on two solar panels of 10W. Each of them has a maximum voltage of 17.4V and a maximum current of 0.58A, which are installed separately. The first in a Fixed position with an inclination of 30 degrees horizontal and pointing directly towards the East. The second is based on a system of active solar tracking of an axis [10] that follows the trajectory of the sun during the day.



Fig. 3. Fixed solar panel



Fig. 4. One axis active solar tracking system

III. SOLAR STORAGE AND TRACKING SYSTEM

The solar tracking system is built by light-sensitive resistances (Photocells) in which the variation of the measurement of its resistive value in Ohms [11] is measured in order to find the position of the sun. The resistive changes are measured by means of a voltage divider and are processed by an Arduino Mega Card. This in turn sends the electrical signals to a H bridge that controls a motor with a linear effector to perform the movement of the solar panel. The system solar tracking has the ability to change the inclination to a range of 140 degrees. On the other hand, the system captures the solar power every 10 minutes and stores the date readings, time and solar power on a micro SD card to later perform the analysis of the data [12]. The system of the fixed solar panel has the same configuration for the measurement and storage of the power, but it lacks a solar tracking system.

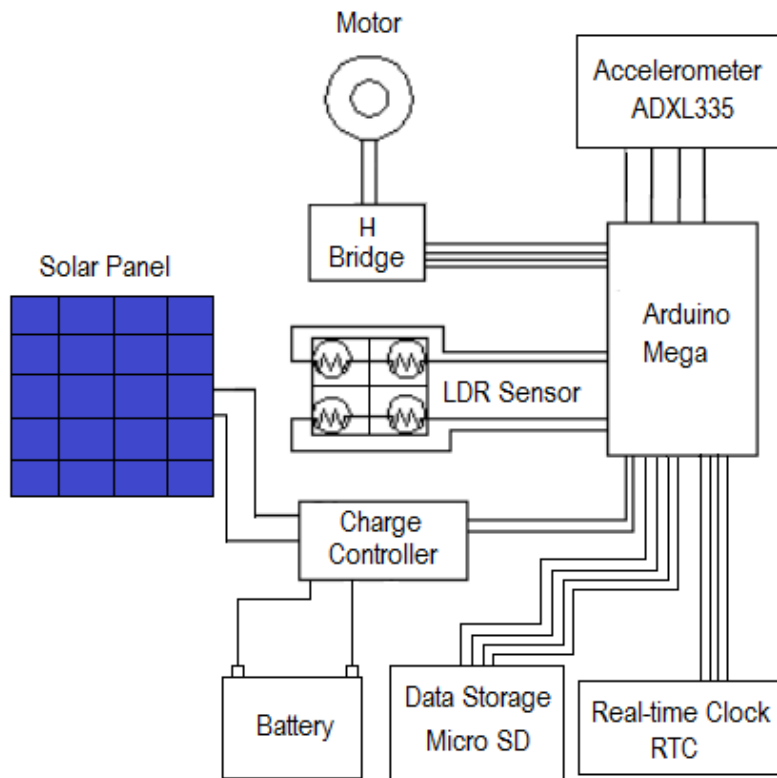


Fig. 5. Solar tracking system and solar power capture

IV. DETERMINING THE LOCATION OF THE SOLAR PANELS

To have a good location for solar panels and obtain good results in the measurement of solar power for both types (fixed-system and solar tracking system), it was necessary to take into account the buildings of the University and the trees near where the panels would be located. This is in order to not have a latent shadow at any time of the day or any time of the year due to the phenomenon that arises from the summer and winter solstice [13] caused by the movement of the earth around the sun. In order to make the ideal location, we worked with the online tool SunEarthTools [14], which shows the sun's rays and shadow rays that are projected over any geographical location at any time of the day. It also shows the exact location of the sun with respect to the east at any time of the year. This tool is supported by Google Maps to establish the location and draw the rays on the map, and can determine the optimal location within the facilities of the University.

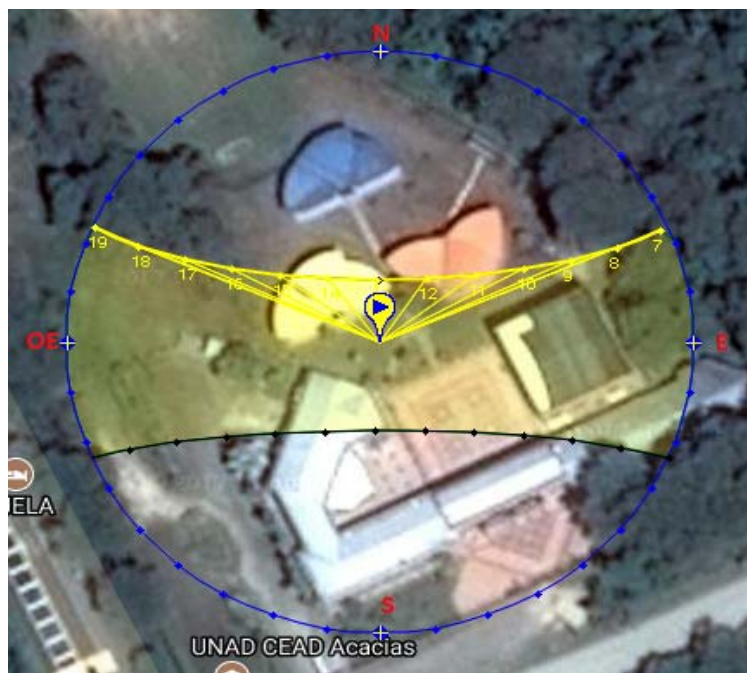


Fig. 6. Location of solar panels

V. ANALYSIS OF RESULTS

Measurement time

The solar power measurement system began in July 2016 and was completed in June 2017. There was a 12-month information window and after making measurements in 10-minute intervals, a total of 10025 records were obtained with information on the power of the fixed solar panel and the solar tracking system. This provided the database for the study of the horizontal solar irradiation of the area.

Average horizontal solar irradiation

The average horizontal solar irradiation [15], allowed us to establish the average solar power per hour from 6am to 5pm for both solar panels. This determines the irradiation values in a panel of 10W and resizes the areas to obtain the average power for each m².

TABLE 1. Horizontal solar irradiation per day

| <i>Hour</i> | <i>Stactic Solar Panel</i> | <i>Mobile Solar panel</i> |
|-------------|--------------------------------|--------------------------------|
| | <i>Power m² (W)</i> | <i>Power m² (W)</i> |
| 6:00 AM | 1.5 | 10.2 |
| 7:00 AM | 8.2 | 42.5 |
| 8:00 AM | 28.1 | 60.6 |
| 9:00 AM | 46.8 | 64.9 |
| 10:00 AM | 59.3 | 60.5 |
| 11:00 AM | 63.4 | 66.0 |
| 12:00 PM | 60.4 | 64.6 |
| 1:00 PM | 45.1 | 59.0 |
| 2:00 PM | 20.0 | 59.4 |
| 3:00 PM | 8.4 | 51.5 |
| 4:00 PM | 1.7 | 10.2 |
| 5:00 PM | 0.6 | 3.6 |
| Total/day | 343.5 | 553.0 |

The data obtained with the fixed solar panel and the solar tracking system showed considerable differences in the production of average electrical power per day. The fixed solar panel system produces a power greater than 70% of the effective power per m² from 10:00 am to 1:00 pm, about 3 hours per day, while the solar panel system with solar tracking produces a power greater than 70% of the effective power per m² from 8:00 a.m. to 2 p.m, about 6 hours per day. This equates to an additional 3 hours of energy production per day, with a power greater than 70% of the effective power of the area.

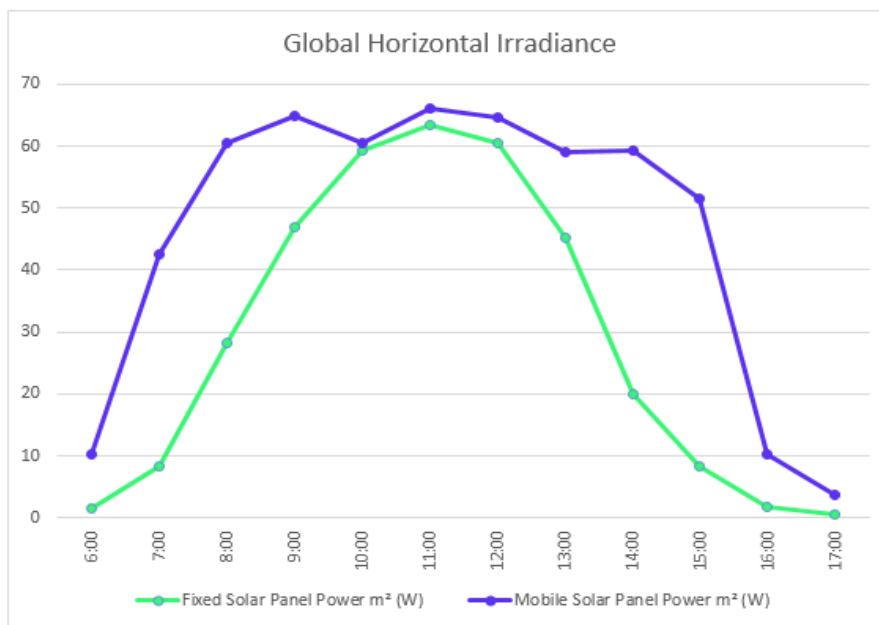


Fig. 7. Global Horizontal irradiance average per day in Acacias

Power generated per month

The capture of solar power by the fixed solar panel type totals 314.9Kw in the period analyzed, while the solar panel system with solar tracking type in the same period was close to 507.2Kw. This reveals a substantial increase in 192.03Kw, equivalent to an additional production of 61.09% between both systems. Next, the monthly data of the measurements are presented:

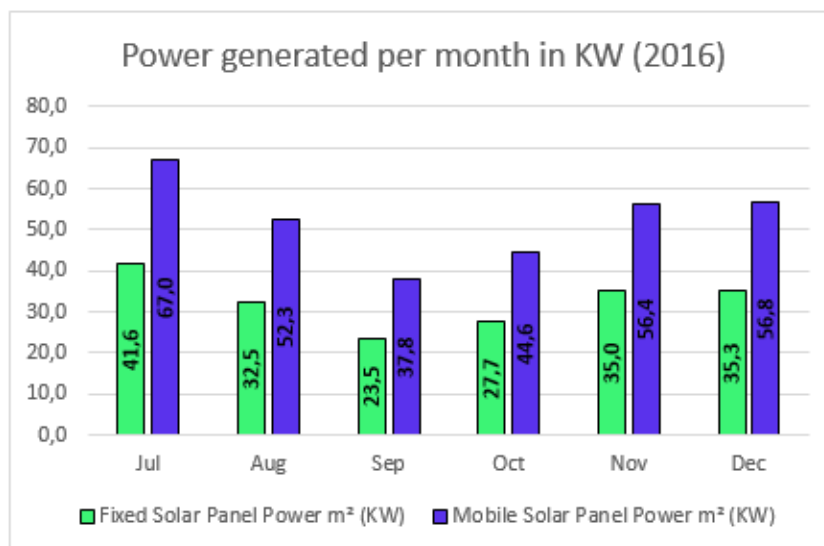


Fig. 8. Power generated per month in KW (2016)

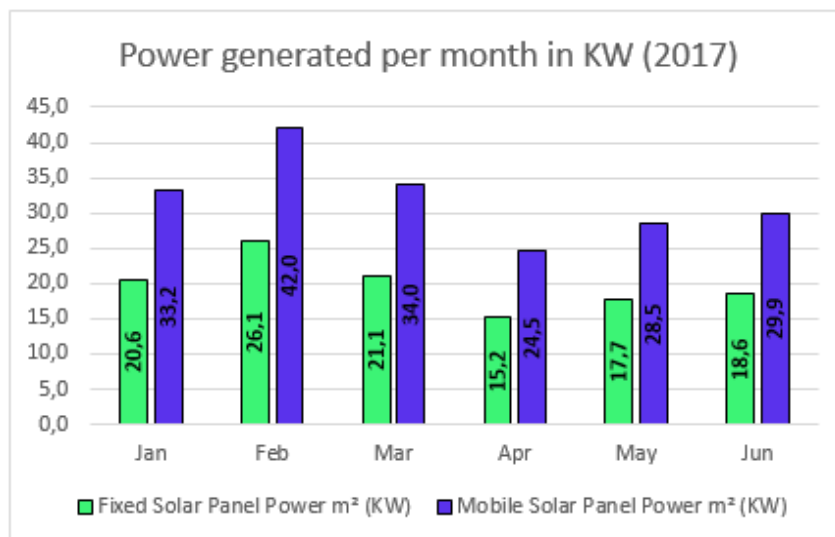


Fig. 9. Power generated per month in KW (2017)

VI. ECONOMIC BENEFITS FOR THE UNIVERSITY

The energy potential of the area is acceptable so that the university can consider generating electricity from solar photovoltaic energy [16], taking into account that the cost of Kw/h is \$ 0.16 USD. In this case, for the period analyzed, the fixed solar panel system generated 314.9Kw per m², equivalent to a cost of \$ 49.67 USD, and the solar panel system with solar tracking 507.2Kw per m², equivalent to a cost of \$ 80.01 USD. This demonstrates a difference between both systems of \$ 30.33 USD, indicating significant savings with the solar panel system with solar tracking. In addition, the cost of implementing a solar system with solar tracking for 500W has an approximate cost of \$ 90 which suggests that the investment can be recovered in 3 years. Taking into account that the useful life of a solar panel is 10 to 20 years [17] [18] there is a margin of at least 10 years to produce additional energy compared to a fixed solar panel.

Environmental benefits of the generation of photovoltaic electric power

The production of electricity in Colombia has an environmental footprint due to the fact that coal is used in some parts of the country. The UPME (Mining and Energy Planning Unit) of Colombia has made available an application called FECOC to determine the emissions of KgCO₂ / KWh [19] in the country. According to this application, each KWh produced in the country emits 0.199KgCO₂ into the atmosphere. The reduction of CO₂ emissions into the atmosphere can be achieved by using the two solar panels presented in this research.

The fixed solar panel generated 314.9Kw in one year per m² which is equivalent to a decrease of 62.66 KgCO₂ into the atmosphere, while the solar panel system with solar tracking generated 507.2Kw in one year per m², equivalent to a decrease of 100.9 KgCO₂ in emissions. Both types of solar panels would therefore contribute to the mitigation of climate change.

VII. CONCLUSIONS

Researching and implementing solar tracking systems and solar panels is a great strategy in helping to fulfill the goals of the Paris Conference by Colombia.

The energy estimates for the tracking system are very high, since it is approximately 61% compared to the site measurements of the static system. However, as there only a year of continuous measurements, it is necessary to carry out a larger number of measurements, to make comparisons between months with the purpose of knowing the possible variations year after year.

The implementation of solar tracking systems and online energy production backed by research, prove to be self-sustaining economically. This is considering the time of use of a solar panel versus the time of investment return made in the system, which is little less than 3 years. It is a fairly high and optimal investment compared with other types of businesses in energy.

In the department of Meta, Colombia, the use of solar energy systems is very limited. The use of solar trackers for the production of electrical energy in similar studies have different possibilities for business development and offer preliminary work in the analysis and energy characterization of the region. It allows bodies such as IDEAM, UPME and others to contrast their resources and verify the changes in solar calculations in the region.

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