Estimation of the Photovoltaic Potential on Rooftops in the City of San Pedro Sula, Cortés, Honduras

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Abstract. Honduras is a country that is making a transition away from fossil fuels and towards sustainable energy sources. Currently in San Pedro Sula there is not an accurate data that represent an estimate of photovoltaic potential per district. Calculating an estimate of the photovoltaic potential is important to know how much decentralized energy can be replaced on the energy matrix by photovoltaic energy and thus be able to achieve an energy matrix that has 100% renewable energy in the country. In this study, we calculated an estimate of the rooftop solar power potential over ten out of the twenty districts in the city of San Pedro Sula using globally available solar radiation data from Meteonorm combined with a building polygon, the analysis of the photovoltaic potential was completed using two photovoltaic modules. The annual rooftop solar power potential in San Pedro Sula under Scenario A was of 2.04 GWp and for Scenario B was of 1.88 GWp. This approach of combining Meteonorm data with building polygons can be easily applied in other parts of the country. These findings can provide useful information for policymakers and contribute to local planning for cleaner renewable energy.

1 Introduction

Up to 2022, Honduras has a population of 9,597,739 habitants, and it is expected that for the year 2030 this will reach a population of 10,766,670 [1] habitants which is expected to cause an accelerated urbanization and with this an increase in energy consumption. This means that the urban areas, specifically cities will face enormous challenges regarding energy demands. Renewable energy sources, including solar photovoltaic sources, are a promising solution for satisfying the growing demands for building energy. [2] It is important to note that the photovoltaic energy systems are attractive sources of renewable energy as they can be easily integrated to existing building structures, such as rooftops. Specially, decentralized solar photovoltaic that are one of the most promising energy sources considering the availability of rooftop areas, the ease of installation and the cost of photovoltaic modules.

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The rooftop solar photovoltaic potential has been estimated on many countries, such as Japan, India, Spain, and Switzerland using various methods, geographic information systems. There has been researches that have utilized methods such as LiDAR scanning, to create maps to calculate the photovoltaic potential Quirós et al., [3] used this method to create a map of a solar potential for the rooftops in Cáceres, Spain. Matsumoto et al., used this method to estimate the annual power generation amount of rooftop solar photovoltaic in the city of Nagoya. [4]

This research aimed to estimate the rooftop photovoltaic potential in ten out of the twenty districts of the city of San Pedro Sula using globally available solar radiation data provided by Meteonorm and Solargis. This methodology could be applied on different cities of the country to evaluate the photovoltaic potential on rooftops and aim towards an energy matrix that is completely constituted of renewable energy.

2 Context

Honduras is a country that has a high photovoltaic potential, currently the photovoltaic energy is the second technology with the most renewable generation in the country with 510.80 megawatts installed [5], , only surpassed by Hydropower energy and Fossil Fuel, as shown on figure 1.

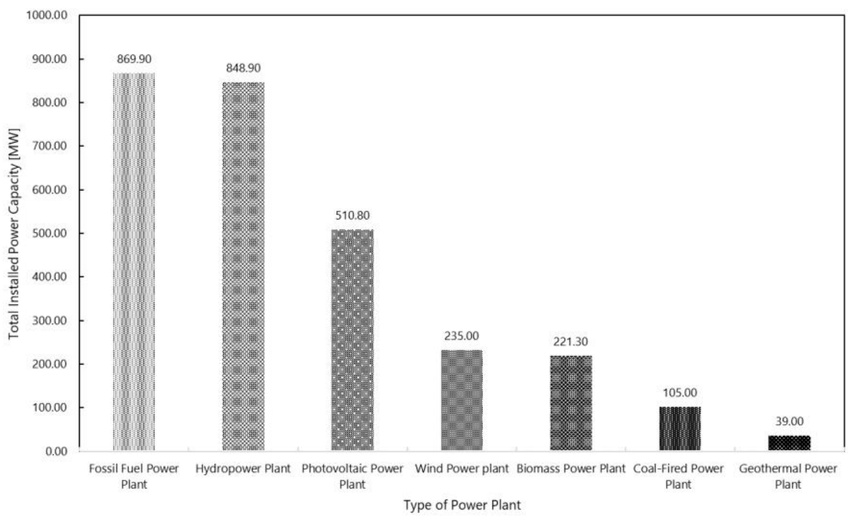

Fig.1. Total Installed Power Capacity through May 2022 [MW]

Source: Own elaboration based on [5].

Currently in San Pedro Sula we do not have an accurate data that represent an estimate of photovoltaic potential per district. Calculating an estimate of the photovoltaic potential is important to know how much decentralized energy can be replaced on our energy matrix by photovoltaic energy and thus be able to achieve an energy matrix that has 100% renewable energy in the country.

Honduras is a country that is making a transition away from fossil fuels and towards sustainable energy sources, however, we must consider that the existing centralized energy system is still fragile and implementing new centralized power plants requires a high cost and may not be as convenient due to deficiency that exists on the power grid of the country.
Which is why we can implement decentralized energy systems, which could be defined as characterized by small-scale energy generation structures that deliver energy to local

customers. To share the energy surplus, these production units could be connected through a network with others nearby or be stand-alone. When this happens, they become local decentralized energy networks, which can be connected with nearby networks. [6]
Photovoltaic generators are already being used in the country, in generation plants, in companies to satisfy their own energy needs and in autonomous systems in households that use transfers to connect to the network.[7]

According to [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.

By knowing the amount of energy that can be installed as a decentralized energy source, the authorities such as the Empresa Nacional de Energía Eléctrica and the National Dispatch Center can plan the consumption and demand strategy on an efficient way.

3 Methodology

This research involves comparing two photovoltaic systems the first scenario using a monocrystalline photovoltaic module, and the second using a polycrystalline photovoltaic module in San Pedro Sula, in ten out of its twenty districts.

The photovoltaic systems involved in this research are a monocrystalline photovoltaic system using the photovoltaic module HiKu CS3N – 420 MS for scenario A and a polycrystalline photovoltaic system using the photovoltaic module HiKu CS3W – 420 PB for scenario B, and the string inverter CSI – 50KTL – GS. AutoCAD, Excel, Meteonorm and Solargis were used as tools to calculate the photovoltaic potential, the number of photovoltaic modules, the nominal capacity in kWp, the nominal capacity kWp per square meter and the annual generation for the first year per district for both scenarios.

To calculate the number of photovoltaic modules on rooftops per district, it is necessary to know the area of the rooftops and the area of the photovoltaic module, as shown in the following equation:

$$Number\ of\ Photovoltaic\ Modules = \frac{Area\ of\ the\ rooftops\ [m^2]}{Area\ of\ the\ photovoltaic\ module\ \ [m^2]} \quad (1)$$

To calculate the photovoltaic potential on rooftops per district, it is necessary to know the number of photovoltaic modules and the nominal capacity in DC of the photovoltaic module that will be used, in this research for both scenarios the same Nominal capacity will be used of 0.420 kW, as shown in the following equation:

$$Nominal\ Capacity = \ Number\ of\ Photovoltaic\ Modules \times Nominal\ Capacity_{DC} \quad (2)$$

To calculate the Nominal Capacity per square meter of the district, it is necessary to know the nominal capacity of the district and the total area of the district, as shown in the following equation:

$$Nominal\ Capacity\ per\ square\ meter = \frac{Nominal\ Capacity_{DC}\ \ [kWp]}{Area\ of\ the\ district\ \ [m^2]} \quad (3)$$

Lastly, to calculate the energy generation for the first year, it is necessary to know the Nominal Capacity of the installation, the capacity factor of the photovoltaic module and the operating hours per year, as shown in the following equation:

$$Energy\ Generation = Nominal\ Capacity\ DC\ \times 4{,}335\ hrs \times FP_{DC} \quad (4)$$

Where:
Nominal Capacity DC: Output Power of the photovoltaic module
4,335 hours: Operating hours of the photovoltaic project in a year
FP_{DC}: Capacity factor of the photovoltaic module

4 Results and analysis

In this section the results are presented from the data that we evaluated on the ten districts. San Pedro Sula is divided in twenty districts, according to the San Pedro Sula Municipality, with the information we obtained from CAD Mapper, we were able to select ten districts that we will use to calculate the photovoltaic potential.

We will use two different Photovoltaic Modules from the brand Canadian Solar, the first is a monocrystalline module HIKU CS3N-420MS that has an area of 2.03 m^2, and the second is a polycrystalline module HiKu CS3W-420PB that an area of 2.21 m^2.

4.1 Monocrystalline Photovoltaic System

Table 1. Summary Monocrystalline Photovoltaic System

	Rooftop Area [m^2]	*Number of Photovoltaic Modules [-]*	*Nominal Capacity [MWp]*	*Nominal Capacity per Square Meter [kWp/m^2]*	*Energy Generation [GWh/year]*
District 2	2,092,907.31	1,029,406	432.35	0.04	601.82
District 3	1,572,007.21	773,199	324.74	0.02	452.03
District 4	1,293,087.23	636,011	267.12	0.03	371.83
District 6	591,342.81	290,854	122.16	0.06	170.04
District 7	1,032,734.81	507,955	213.34	0.06	296.96
District 8	537,615.53	264,428	111.06	0.09	154.59
District 9	679,466.94	334,199	140.36	0.07	195.38
District 10	1,068,890.46	525,738	220.81	0.04	307.36
District 11	409,102.42	201,219	84.51	0.07	117.64
District 12	597,394.59	293,831	123.41	0.09	171.78

Source: Own Elaboration

In table 1, the results of the power system using a monocrystalline photovoltaic module are shown, these were calculated for ten out of the twenty districts of the city of San Pedro Sula. We can see that the nominal capacity per district varies from 84.51 MWp up to 432.35 MWp, this is due to the total area of the district and the number of photovoltaic modules that can be installed by area. However, for the nominal capacity per square meter, we have a range from 0.02 kWp/m^2 up to 0.09 kWp/m^2, the districts with the most photovoltaic potential per square meter are not the ones with the most photovoltaic potential. On figure 2, we can see the city of San Pedro Sula if only Monocrystalline Photovoltaic Modules were installed and the density of these installations throughout the city.

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Fig.2. San Pedro Sula, Cortés with Monocrystalline Photovoltaic Modules

Source: Own Elaboration

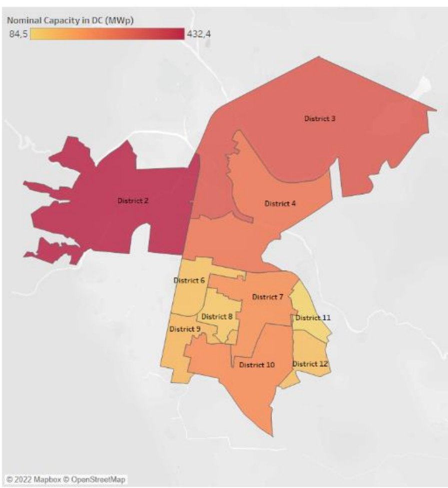

Fig. 3. Nominal Capacity in DC [MWp] using monocrystalline technology.
Source: Own Elaboration

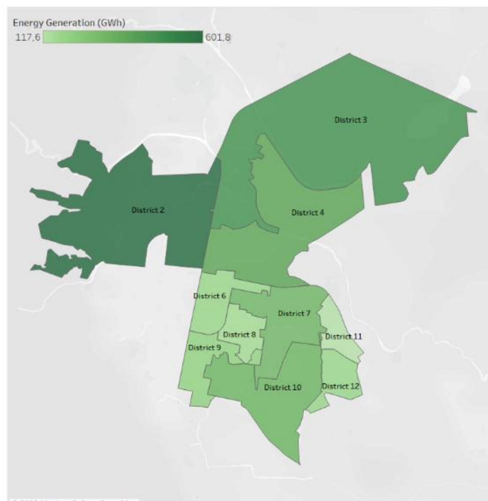

Fig.4. Energy Generation for the first year [GWh/year] using monocrystalline technology.
Source: Own Elaboration

The district with the most photovoltaic potential when considering the area of the rooftops is District 2, as shown in Figure 3, with a photovoltaic potential of 432.35 MWp when using a monocrystalline photovoltaic module (HiKu CS3N-420MS).

The district with the least photovoltaic potential when considering the area of the rooftops is District 11 with a photovoltaic potential of 84.51 MWp when using a monocrystalline photovoltaic module (HiKu CS3N-420MS), and 77.78 MWp when using a polycrystalline photovoltaic module HiKu CS3W-420PB.

Using the photovoltaic module HiKu CS3N-420MS, there is an average photovoltaic potential of 203.99 MWp in the city of San Pedro Sula considering ten of its twenty districts. Additionally, on figure 4, we can observe that the district with the most Energy Generation for the first year is District 2 with 601.8 GWh/year, and the district with the least Energy generation is District 11 with 117.6 GWh/year.

According to [9] the electrical consumption in the city of San Pedro Sula for March 2022 was of 138,122 MWh. Assuming that we have a constant electrical consumption throughout the year, for one year we would have an electrical consumption of 1,657 GWh annually.

With this information we can see that it is not necessary to install photovoltaic modules on every district of the city of San Pedro Sula and based on this brief summary we can see

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that the total energy generation of 2,039.88 GWh for the first year using the monocrystalline photovoltaic module HIKU CS3N-420MS.

Using this particular photovoltaic module, we have a surplus of 382.41 GWh, in case that the installation is completed in ten out of the twenty districts of San Pedro Sula.

Based on the consumption of the city of San Pedro Sula, the installation of these photovoltaic installations could be completed on District 2, District 3, District 4, and District 7. This project will have a surplus of 65.18 GWh but this energy that we could count on in case that there are consumption peaks during the year.

4.2 Polycrystalline Photovoltaic System

Table 2. Summary Polycrystalline Photovoltaic System

	Rooftop Area [m^2]	*Number of Photovoltaic Modules [-]*	*Photovoltaic Potential [MWp]*	*Nominal Capacity per Square Meter [kWp/m^2]*	*Energy Generation [GWh/year]*
District 2	2,092,907.31	947,368	397.89	0.03	540.06
District 3	1,572,007.21	711,579	298.86	0.02	405.64
District 4	1,293,087.23	585,324	245.84	0.03	333.67
District 6	591,342.81	267,675	112.42	0.06	152.59
District 7	1,032,734.81	467,474	196.34	0.05	266.49
District 8	537,615.53	243,355	102.21	0.08	138.73
District 9	679,466.94	307,565	129.18	0.07	175.33
District 10	1,068,890.46	483,840	203.21	0.04	275.82
District 11	409,102.42	185,182	77.78	0.07	105.57
District 12	597,394.59	270,414	113.57	0.08	154.15

Source: Own Elaboration

In table 2, the results of the power system using a polycrystalline photovoltaic module are shown, these were calculated for ten out of the twenty districts of the city of San Pedro Sula. We can see that the nominal capacity per district varies from 77.78 MWp up to 397.89 MWp, this is due to the total area of the district and the number of photovoltaic modules that can be installed by area. However, for the nominal capacity per square meter, we have a range from 0.02 kWp/m^2 up to 0.08 kWp/m^2, the districts with the most photovoltaic potential per square meter are not the ones with the most photovoltaic potential.

The district with the most photovoltaic potential considering the area of the rooftops is District 2, as shown in Figure 5, with a photovoltaic potential of 397.89 MWp when using a polycrystalline photovoltaic module (HiKu CS3W-420PB.)

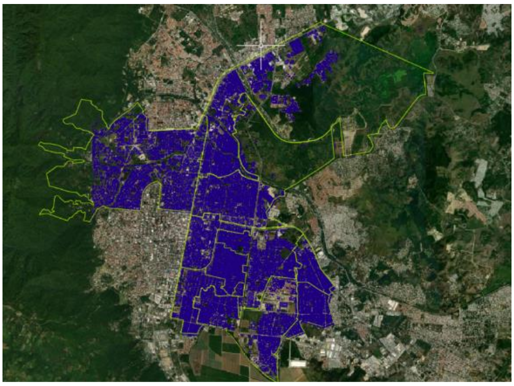

Fig. 5. San Pedro Sula, Cortés with Polycrystalline Photovoltaic Modules

Source: Own Elaboration

The district with the least photovoltaic potential when considering the area of the rooftops is District 11 with a photovoltaic potential of 77.78 MWp when using a polycrystalline photovoltaic module (HiKu CS3W-420PB). These scenarios are showed on figure 6, where we can observe that that the Nominal Capacity goes from 77.8 MWp for District 11 to up to 397.9 MWp for District 2.

Using the polycrystalline photovoltaic module HiKu CS3W-420PB, there is an average photovoltaic potential of 187.73 MWp in the city of San Pedro Sula considering ten of its twenty districts.

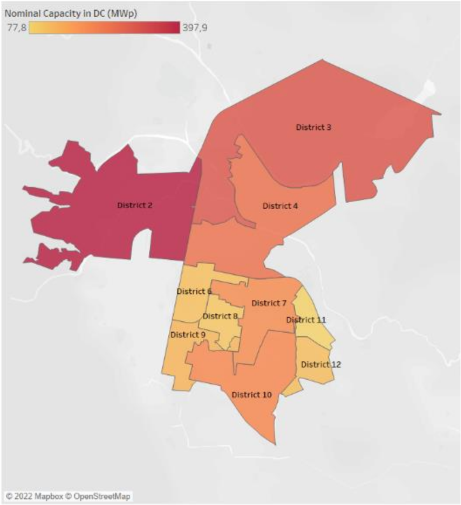

Fig. 6. Nominal Capacity in DC [MWp] using polycrystalline technology.
Source: Own Elaboration

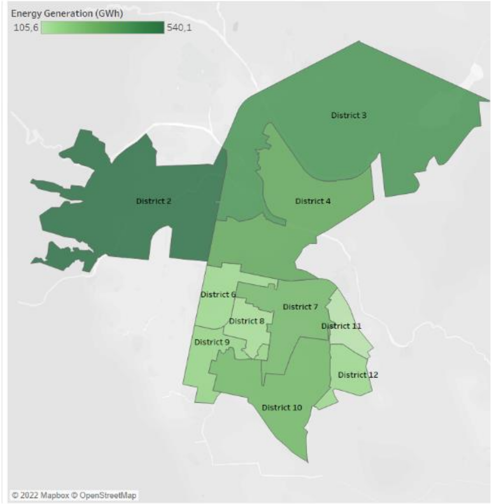

Fig.7. Energy Generation for the first year [GWh/year] using polycrystalline technology.
Source: Own Elaboration

For the installation of the photovoltaic module HiKu CS3W-420PB that we have a constant electrical consumption throughout the year, for one year we would have an electrical consumption of 1,657,464 MWh annually. Additionally, on figure 7, we can observe that the district with the most Energy Generation for the first year is District 2 with 540.1 GWh/year, and the district with the least Energy generation is District 11 with 105.6 GWh/year.

With this information we can see that it is not necessary to install photovoltaic modules on every District of the city of San Pedro Sula and based on this brief summary we can see that the total energy generation of 1,877.31 GWh for the first year using the photovoltaic module HiKu CS3W-420PB.

Using this particular photovoltaic module, we have a surplus of 219.84 GWh, in case that the installation is completed in ten out of the twenty districts of San Pedro Sula.
Based on the consumption of the city of San Pedro Sula, the installation of these photovoltaic installations could be completed on District 2, District 3, District 4, District 7, and District 8. This project will have a surplus of 327.12 GWh but this energy that we could count on in case that there are consumption peaks during the year.

5 Conclusions

This research was based on the design of photovoltaic projects for ten individual districts of San Pedro Sula, in order to calculate its photovoltaic potential using the monocrystalline photovoltaic module, HiKu CS3N-420MS, and the polycrystalline photovoltaic module, HiKu CS3W-420PB. Based on the results compiled, the conclusions of this research are shown below:

1. The districts that were selected for this research were District two, District three, District four, District six, District seven, District eight, District nine, District ten, District eleven, and District twelve.

2. The total photovoltaic potential for the ten districts of San Pedro Sula when using the photovoltaic module HiKu CS3N-420 MS is of 2,039.88 MW. The 87.96% of the energy matrix of Honduras could be replaced with photovoltaic energy from the city of San Pedro Sula.

3. The total photovoltaic potential for the ten districts of San Pedro Sula when using the photovoltaic module HiKu CS3W-420 PB is of 1,877.31 MWp. The 80.95% of the energy matrix of Honduras could be replaced with photovoltaic energy from the city of San Pedro Sula.

4. There is a difference on the photovoltaic potential of 162.57 MW between the photovoltaic modules HiKu CS3N-420 MS and HiKu CS3W-420 PB. The photovoltaic modules that have a higher photovoltaic potential is the HiKu CS3N-420 MS, this photovoltaic module is a monocrystalline module that has a higher efficiency.

A limitation presented through the development of this research is the lack of updated data related to the variables taken into account for the calculation of the areas and the number of buildings such as houses, commercial buildings, and factories as the last census available dates back to 2013.

Words cannot express my gratitude to my professor and advisor, PhD. Héctor Villatoro, for his invaluable patience and feedback. I am also grateful to engineer Alicia Reyes, Gabriela Munguía, and Celeste Parada for their help, and moral support.

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