UNIVERSIDAD TECNOLÓGICA CENTROAMERICANA

FACULTY OF ENGINEERING

GRADUATION PROJECT

ESTIMATION OF THE PHOTOVOLTAIC POTENTIAL ON ROOFTOPS IN THE CITY OF SAN PEDRO SULA, CORTÉS, HONDURAS

PRIOR TO OBTAINING THE DEGREE OF

ENERGY ENGINEER

PRESENTED BY:

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DEDICATION

First of all, I thank God for giving me the opportunity to successfully complete this research and my university studies. To my parents, Heiby Cárdenas, and Valente Villanueva, who have supported me throughout my entire life, providing me the resources that I needed to excel and teaching me to endure until the end.

To my sibling, Jimena Villanueva, without you, any of this would have been possible, thank you for being the fuel that I needed and a daily reminder that everything is possible through arduous work.

I would like to express my gratitude to my methodological adviser, PhD. Héctor Villatoro, who guided me throughout this research.

I wish to extend my special thanks to engineer Alicia Reyes, who is not only my mentor but my friend and always had full disposition to listen to me and remind me that I am capable of being excellent.

To Ivan Danilov, who is my person and has been my partner throughout my university years and the countless sleepless nights.

To my friends, “los intensos,” Gabriela Munguía, Celeste Parada, and Omar Enamorado who were definitely an amazing support group and I am thankful that we crossed ways.

To Alejandro Paz, who has been my friend since day one back in 2018. Thanks to your selfless friendship many of my academic achievements were possible. I would not have chosen anyone else with whom to share the achievement of reaching the end of our bachelor’s degree.

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Lastly, I would be remiss in not mentioning my family and my partner. Their belief in me has kept my spirits and motivation high during this process.

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.

Keywords— *rooftop photovoltaic potential, decentralized energy, photovoltaic potential estimation, Solar Energy in Honduras, renewable energy*

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I. INTRODUCTION

Up to 2022, Honduras has a population of 9,597,739 habitants, and according to Diaz Madrid, (2022) it is expected that for the year 2030 this will reach a population of 10,766,670 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.

Jalil-Vega et al., (2020) states that renewable energy sources, including solar photovoltaic sources, are a promising solution for satisfying the growing demands for building energy. 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.

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., (2018) used this method to create a map of a solar potential for the rooftops in Cáceres, Spain. Matsumoto et al., (2021)used this method to estimate the annual power generation amount of rooftop solar photovoltaic in the city of Nagoya.

There have been other approaches using machine learning with LiDAR, Fakhraian et al., (2021) estimated the urban rooftop photovoltaic potential on Riyadh, Saudi Arabia Piedmont, Italy and Honk Kong using different approaches and creating a mathematical approach for each of them.

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. After obtaining the estimated photovoltaic annual power generation using the System Advisor Model as a software to do this, there was a comparison of the electricity demand for the city of San Pedro Sula and the potential of power generation throughout the first year of generation. 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.

This research is divided in five chapters. The first chapter introduces the problem, as well as the objectives expected to accomplish with the actual outlook. The second chapter is the theoretical framework, where all the photovoltaic systems' terms such as: photovoltaic energy generation, the types of generation system structures, the photovoltaic power systems are explained to have a better comprehension of the photovoltaic potential in rooftops. In the third chapter, the research methodology as well as independent and dependent variables are discussed. Chapter four presents the results and their analysis based on the objectives. Finally, in the fifth chapter, conclusions are presented, and recommendations are provided for future research.

II. Problem Approach

This chapter presents the research problem approach, explaining its precedents, its definition, and how this study contributes to its solution. Furthermore, the research questions were identified, and the general and specific objectives were established.

2.1 Precedents of the Problem

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. (Empresa Nacional de Energía Eléctrica, 2022)

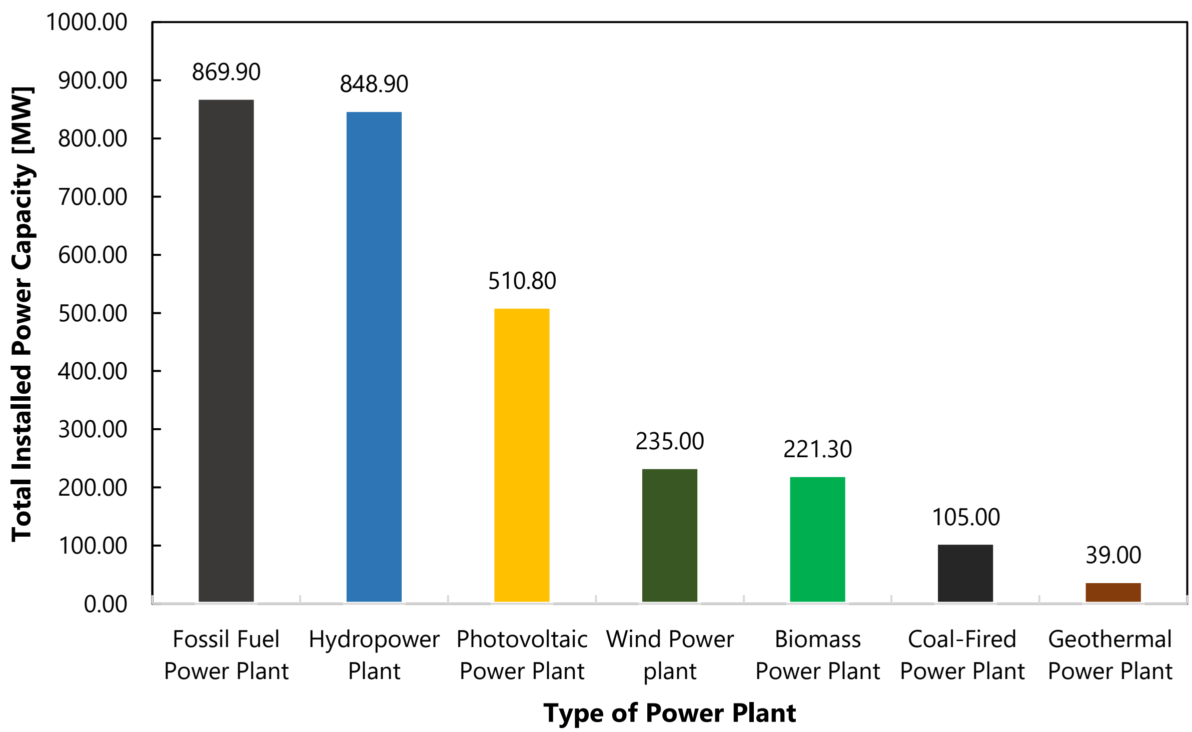

Figure 1. Total Installed Power Capacity through May 2022 [MW]

Source: Own elaboration based on information from (Empresa Nacional de Energía Eléctrica, 2022)

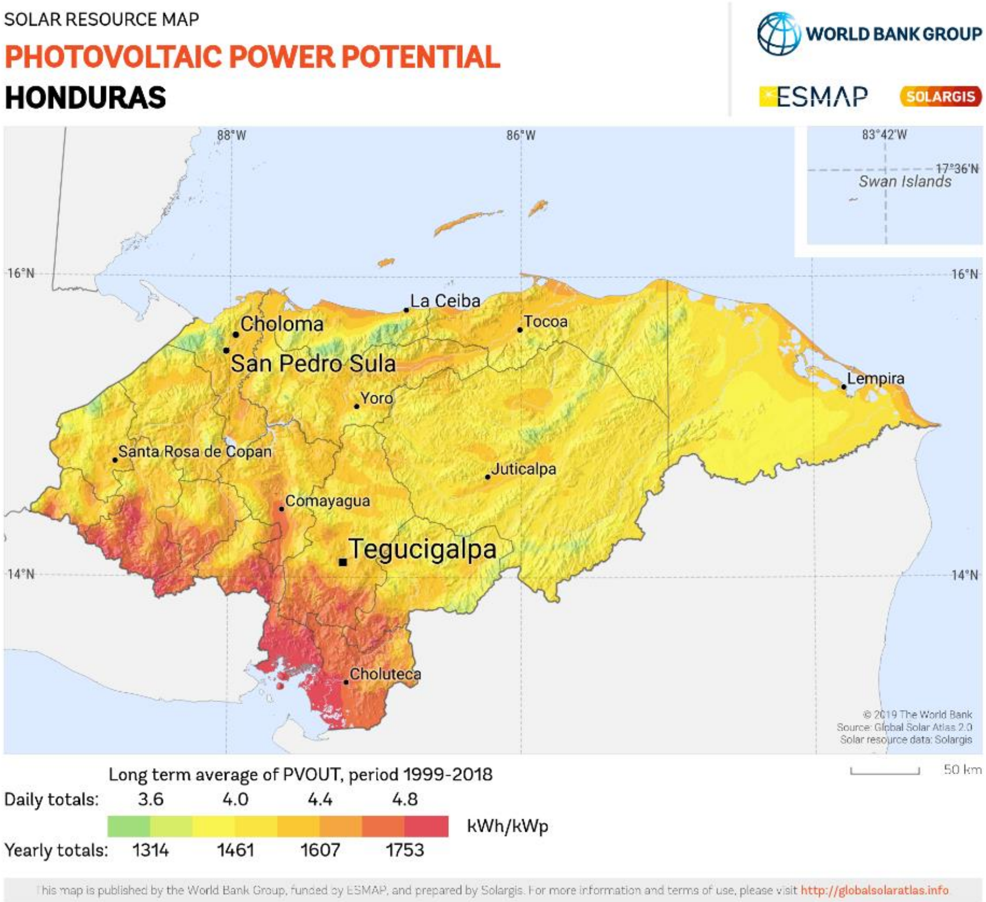

Figure 2. Photovoltaic Power Potential Honduras

Source: 2020 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis. (SOLARGIS, 2020)

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.

2.2 DEFINITION OF THE PROBLEM

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 an excessive 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. (Vezzoli et al., 2018)

There is a need to estimate and quantify the potential for rooftop solar photovoltaic technology in the city of San Pedro Sula with the aim of making a case for its large-scale deployment, and to satisfy the energy demand of consumers whether they are from the residential, industrial, or commercial sector.

2.3 JUSTIFICATION OF THE PROBLEM

The importance of calculating an estimate of the photovoltaic potential is to know how much decentralized energy can be replaced on our energy matrix by photovoltaic energy to reduce fossil fuel use and achieve an energy matrix that is formed exclusively with renewable energy. The present investigation focuses on calculating an estimate of the photovoltaic potential on rooftops. To achieve this, we will focus mainly on ten out of the twenty districts of the city of San Pedro Sula, to manually calculate the photovoltaic potential and evaluate the possibility of training a software that through machine learning using a supervised learning method will calculate an estimate of the photovoltaic potential from a satellite image, and later on this software can be used on different cities throughout the country.

2.4 RESEARCH QUESTIONS

- What is the main data that is necessary to calculate the photovoltaic potential?
- Is it effective having a software that calculates the photovoltaic potential using artificial intelligence?
- What are the advantages of using a decentralized power system instead of a centralized power plant?
- Would it be effective to transition to an energy matrix that is constituted by photovoltaic energy?

2.5 OBJECTIVES OF THE PROJECT

An overview of the research is given in this section, along with the specific objectives that are sought to be achieved.

2.5.1 GENERAL OBJECTIVE

1. Evaluate the photovoltaic potential on rooftops in the city of San Pedro Sula in ten out of its twenty districts.

2.5.2 SPECIFIC OBJECTIVES

1. Select the necessary variables for the calculation of the photovoltaic potential
2. Subdivide the city of San Pedro Sula on different districts.
3. Calculate the potential as a viable alternative to produce photovoltaic energy.
4. Compare the photovoltaic potential on the different districts of San Pedro Sula using the same photovoltaic module.

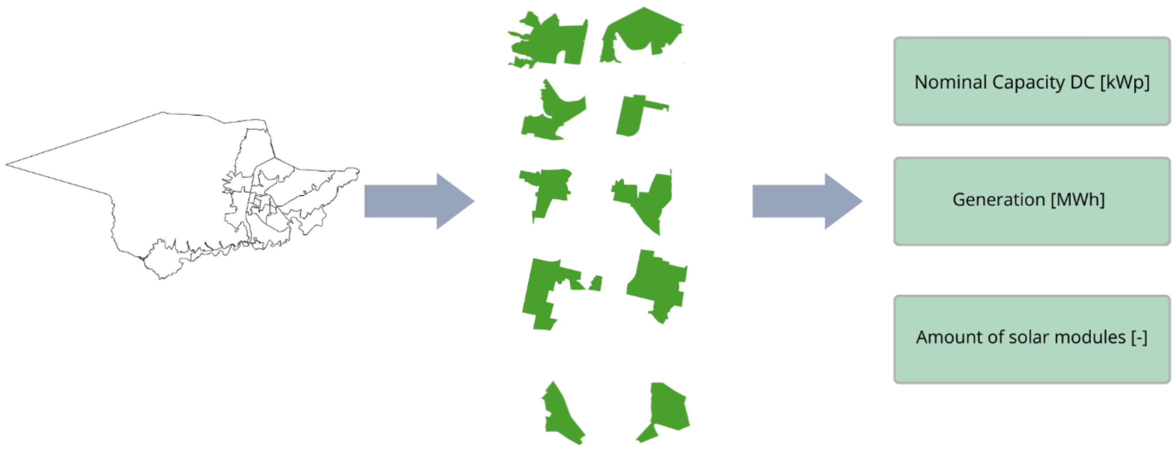

Figure 3. Conceptual Diagram of the Research

III. THEORETICAL FRAMEWORK

The purpose of this chapter is to expose topics related to this research, emphasizing specially on the generation of photovoltaic energy, decentralized energy, and photovoltaic potential with the purpose of nourishing the investigation.

3.1 PHOTOVOLTAIC ENERGY GENERATION

Renewable Energy is known as the energy that is produced from sources that are naturally replenished and do not run out, such as the sun and the wind. This type of energy can be used for electricity generation, space and water heating and cooling, and transportation.

Photovoltaic Energy is a renewable source of energy that with the use of solar radiation produces electricity. It is based on the photoelectric effect, this phenomena occurs when electromagnetic radiation absorbs a material and releases electrically charged particles, electrons. (The Editors of Encyclopedia Britannica, 2021)

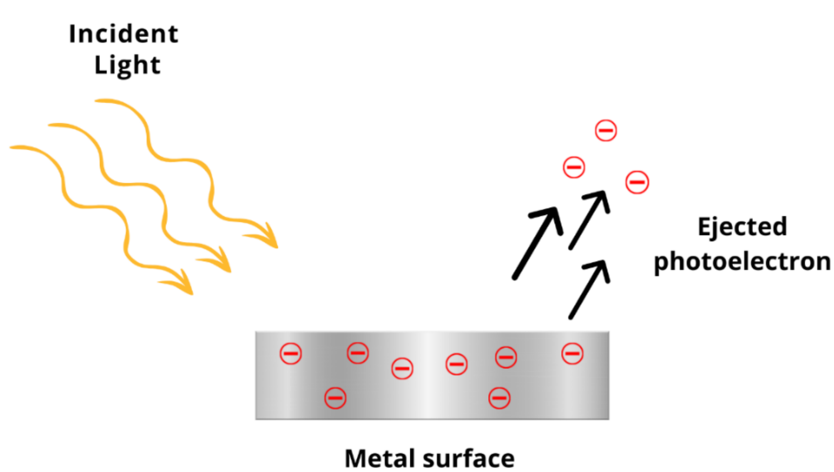

Figure 4. Photoelectric Effect

Source: Own elaboration

Generally, photovoltaic energy is generated by using a semiconductor device called a photovoltaic cell, which can be made of silicon, polycrystalline silicon, or amorphous silicon. (Iberdrola, 2022)

3.2 TYPES OF GENERATION SYSTEM STRUCTURES

According to (Vezzoli et al., 2018) there are three different systems structures that can be distinguished as the following.

3.2.1 CENTRALIZED ENERGY SYSTEM

Sizable energy production units (structures) that deliver energy through a vast distribution system, (typically) farther from the point of use, are referred to as centralized energy systems.

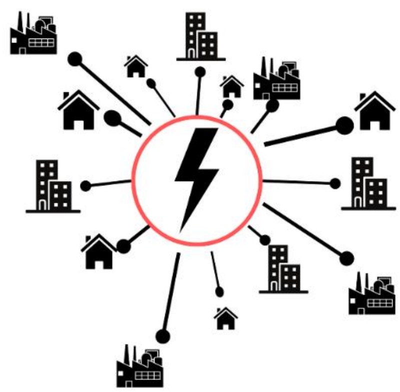

Figure 5. Centralized Energy System

Source: Own Elaboration based on the definition provided by (Vezzoli et al., 2018)

3.2.2 DECENTRALIZED ENERGY SYSTEMS

Decentralized energy systems 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.

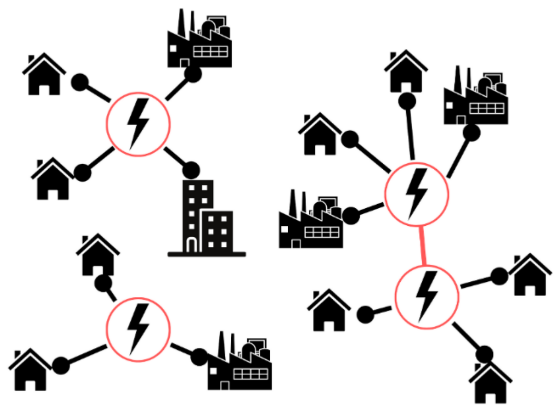

Figure 6. Decentralized Energy System

Source: Own Elaboration based on the definition provided by (Vezzoli et al., 2018)

3.2.3 Distributed Energy Systems

Distributed energy system, users—whether they are people, small enterprises, or local communities—function as both consumers and providers of energy at or close to the point of consumption. Some production units could function independently, or they could be networked together with others nearby in order to distribute, or the energy surplus. During the latter scenario, they transform into regionally distributed energy networks that can be linked to nearby comparable networks.

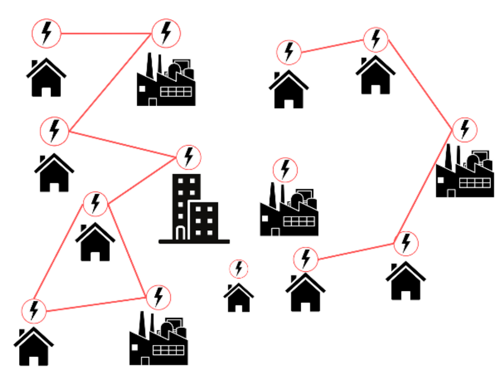

Figure 7. Distributed Energy System

Source: Own Elaboration based on the definition provided by (Vezzoli et al., 2018)

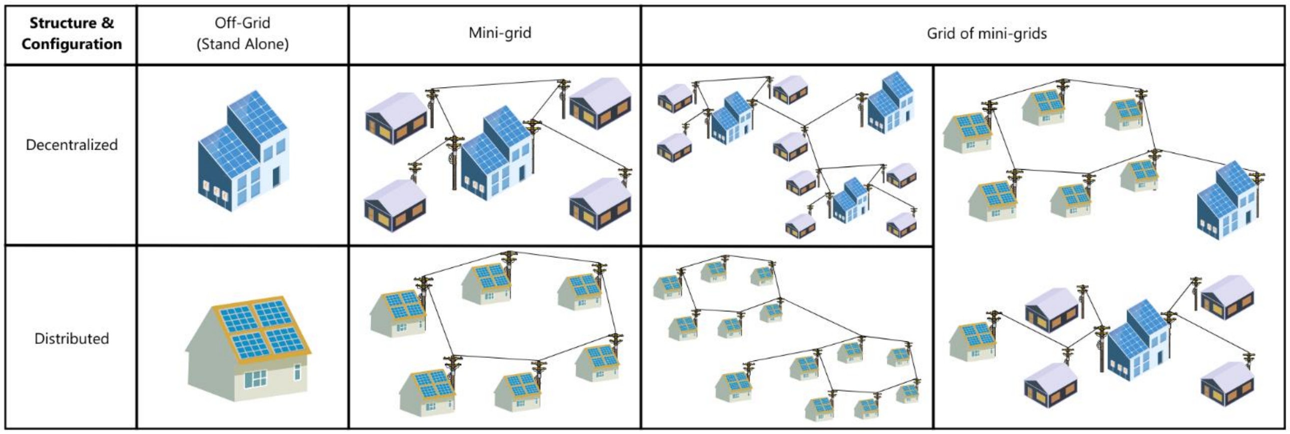

Figure 8. Structure and Configuration of Decentralized and Distributed Energy Systems

Source: Own Elaboration based on the definition provided by (Vezzoli et al., 2018)

Decentralized energy systems, have an additional element which are the batteries to accumulate the excess of energy generated on the photovoltaic system, additionally not all elements of the system have to be generating energy, other elements can be only consumers.

3.3 DECENTRALIZED ENERGY SYSTEMS IN SAN PEDRO SULA

According to (Andino García et al., 2021), 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.

3.4 PHOTOVOLTAIC POWER SYSTEM

To understand a photovoltaic power system, first we must define what is photovoltaic potential. According to (Levesque, 2021): "photovoltaic potential refers to the energy production potential of a photovoltaic solar panel relative to its nominal power and is generally measured in kWh/ kW/year. The higher the potential, the greater the amount of energy that can be produced."

In order to calculate the photovoltaic potential, we take into consideration several factors: the azimuth of the installation, the roof slope angle, the selection of the gable where the installation will be installed; however, the software that we develop will take in consideration that all buildings are two-gabled and will have solar modules installed on both gables, the power capacity of our photovoltaic module and the irradiation of the plane.

3.4.1 AZIMUTH

(Shaher-Soulayman, 2017) defines the azimuth angle as the "compass direction from which the sunlight is coming". On roofs we must take into consideration the azimuth of the gable that we will use. In order to do this, we make an imaginary line on the gable and we calculate the difference on degress between the real north and the imaginary line that we trace to be parrallel with the photovoltaic modules.

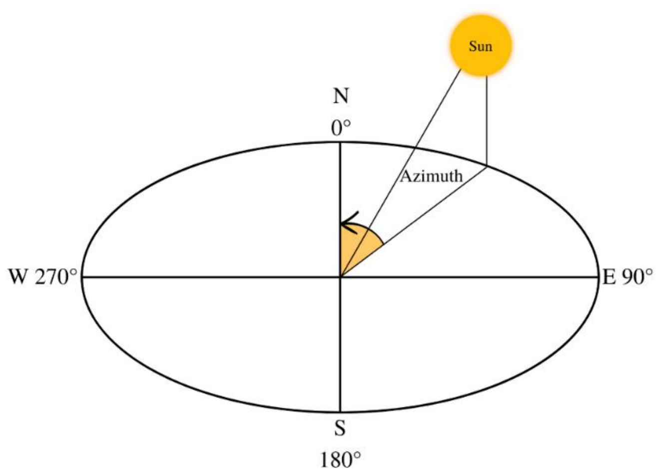

Figure 9. Solar Azimuth

Source: Own Elaboration based on (Jawaid & Junejo, 2016)

3.4.2 ROOF SLOPE

Roof slope is the incline of the roof. It is expressed as a ratio of vertical rise to horizontal run and tells you how many inches the roof rises for every twelve inches in depth. The higher the rise, the steeper the roof is. (Beattie, 2021)

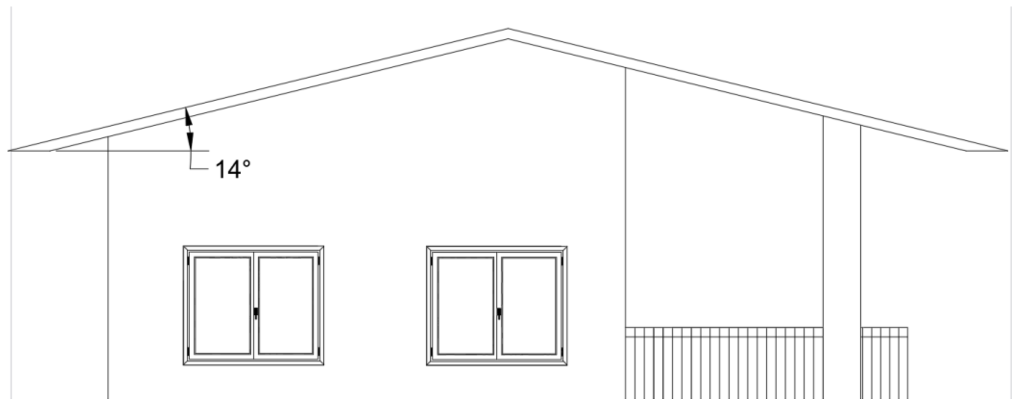

Figure 10. Steep Roof Slope

Source: Own elaboration.

The slope of the roof of the building depends on the climatic conditions to which it will be exposed. In countries like Honduras where the roofs are not affected by strong weather conditions, such as snowfalls or heavy rains, a low roof angle, between 12.5° and 20°, is used.

3.4.3 SOLAR RADIATION

Solar radiation, which is often called the solar resource, is a general term for the electromagnetic radiation emitted by the sun. Photovoltaic energy and thermal energy can be used to capture and convert solar radiation into useful forms of energy, such as heat and electricity. However, it is important to mention that the level of solar resource available at a specific location determines the technical feasibility and cost-effectiveness of these technologies.

3.4.4 PHOTOVOLTAIC MODULE

A photovoltaic module is the main element of a solar photovoltaic installation, this is created by a series of connected solar cells, which transform the energy from the sun, and provide standard output power. There are several types of photovoltaic modules, such as the monocrystalline and polycrystalline.

a) Monocrystalline photovoltaic modules

A monocrystalline photovoltaic module is a solar module that is comprising of monocrystalline solar cells. These cells are made of cylindrical silicon, which are cut from a single silicon source. These solar modules have an efficiency between 15% and 24%.

Figure 11. Monocrystalline Solar Module

b) Polycrystalline photovoltaic modules

A polycrystalline photovoltaic module is a solar module that is comprising of polycrystalline solar cells. These cells are made from different pieces of silicon melted together. These solar modules have an efficiency between 13% and 16%.

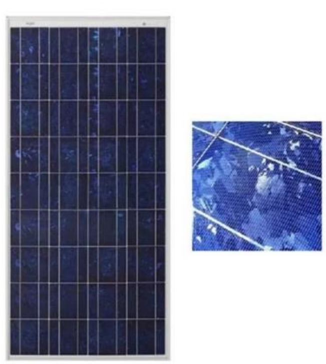

Figure 12. Polycrystalline Solar Module

3.4.5 INVERTER

Solar systems require an inverter to convert direct current (DC) electricity generated by the solar panels into alternating current (AC) electricity that connects to the electrical grid.

Solar inverters come in a variety of types but are typically used as part of large-scale utility plants or mid-scale community projects.

a) String Inverters

There are String inverters which connect a set of modules to one inverter, that inverter converts the power produces by the entire string to AC.

b) Microinverters

A microinverter is a smaller inverter that is placed on every panel. As shading or damage to one module will not affect power drawn from others, there are more efficient than strings inverters; however, it is important to note that they are more expensive. (Office Of Energy Efficiency & Renewable Energy, 2022)

3.4.6 BATTERIES

According to Ponnusamy, (2013) "in photovoltaic power generation system, the generated power and load power requirement are not equal. Hence a necessity for a storage system arises to limit the effect of the variation of the solar power due to the variation in the environmental conditions such as intensity of solar radiation and temperature."

The excess energy that it is generated on a photovoltaic system is accumulated and stored in batteries, which can later be used at night or when there is no other energy input.

There are several types of batteries such as deep cycle lead acid, gel, lithium polymer, lithium ion and NiCad (Nickel Cadmium), and these have a range between 12 and 48V, where the higher the voltage the better the efficiency.

3.5 CALCULATING THE AMOUNT OF PHOTOVOLTAIC MODULES

To calculate how many solar panels are needed on our photovoltaic project, the most crucial information is the climate and amount sunlight in the area, the efficiency of the solar modules that will be considered, the area of the installation, and the physical size of the solar modules that will be considered.

The number of photovoltaic modules will be determined by the following equation.

Equation 1. Number of Photovoltaic Modules

$$Number\ of\ Modules = \frac{A_{installation}}{A_{PV}}$$

Where:

$A_{installation}$: Area of the rooftop where we will install

A_{PV}: Area of the Photovoltaic module

IV. METHODOLOGY

The purpose of this chapter is defining the research variables, this chapter presents the procedures and methods used.

4.1 APPROACH

Research approach assists in identifying the borders of the investigation, the variables that will be considered, dependent or independent; and howe each subject in the theoretical framework relates to the problem that will be addressed.

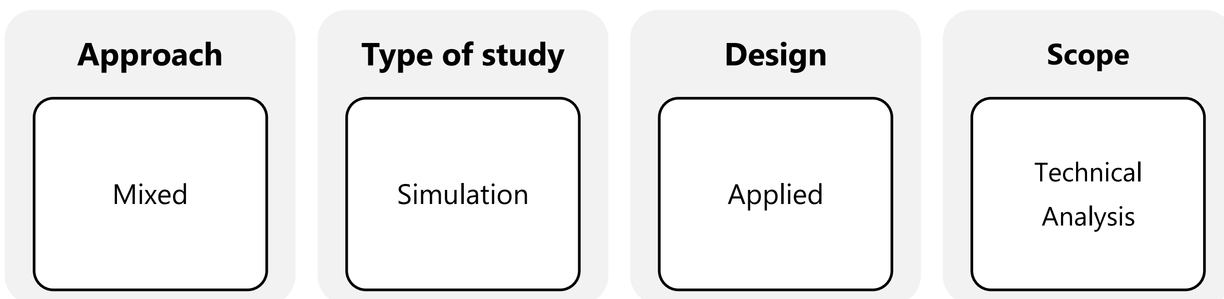

Figure 13. Methodological Scheme of the Research

Source: Own Elaboration based on (Kothari, 2004)

This research will have a mixed approach given that it aims to calculate the photovoltaic potential on rooftops in the city of San Pedro Sula, with the purpose of determining how much photovoltaic energy can be later installed as a decentralized systems to substitute the usage of fossil fuels on the energy matrix of Honduras. Also, we can consider the data from this investigation to later on assist with creating a software that can calculate the photovoltaic potential from a satellite image.

4.2 Research Variables

To demonstrate the influence generated by independent variables on dependent variables, this section classifies the variables considered in this research.

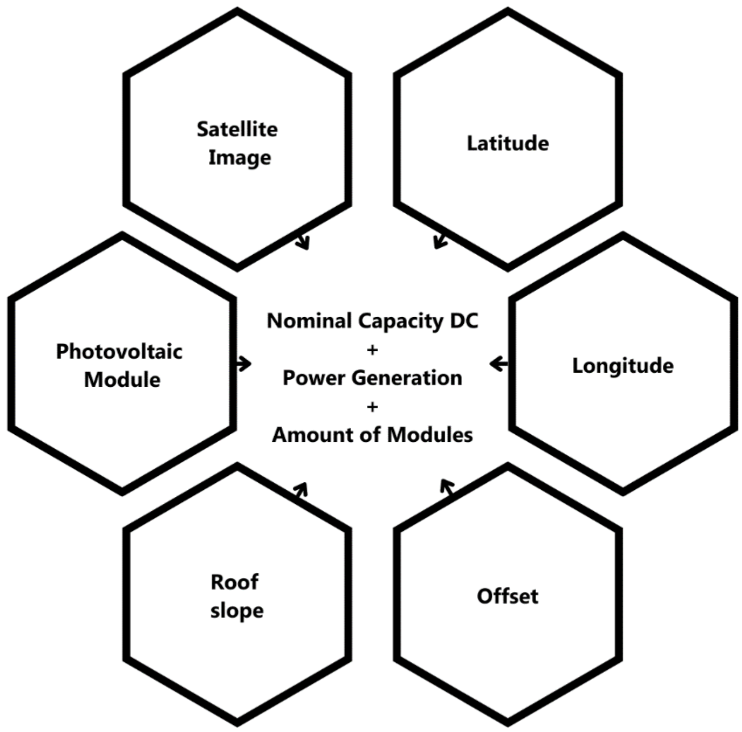

Figure 14. Relationship Between Independent and Dependent Variables

Source: Own Elaboration

4.2.1 Independent variables

Independent variables can be defined as a variable that precedes dependent variables.

a) Satellite Image

A satellite image is a digital image of earth's surface compiled from spectral data collected by sensors that are carried in satellites. These images are available for all parts of the world and can have various sources such as commercial and governmental.

b) Latitude

Merriam-Webster defines latitude as: "angular distance from some specified circle or plane of reference: such as angular distance north or south from the earth's equator measured through 90 degrees."(*Merriam-Webster*, 2022a)

c) Longitude

Merriam-Webster defines longitude as: "angular distance measured on a great circle of reference from the intersection of the adopted zero meridian with this reference circle to the similar intersection of the meridian passing through the object"(*Merriam-Webster*, 2022b)

d) Setback – Offset

Setback is the security distance from the edge of the roof to the photovoltaic installation. The recommended setback of a photovoltaic installation is of one meter; however, this value can be lower, until it reaches 0.5 meters, or higher.

e) Roof slope

Roof slope is the incline of the roof. It is expressed as a ratio of vertical rise to horizontal run and tells you how many inches the roof rises for every twelve inches in depth. The higher the rise, the steeper the roof is.(Beattie, 2021)

f) Nominal Power AC- Photovoltaic Module

By varying the resistance of the circuit under precisely defined conditions, the nominal power is determined, which refers to the nameplate capacity of photovoltaic modules.

4.2.2 DEPENDENT VARIABLES

As a result of manipulating independent variables, dependent variables emerge. This research considers the following dependent variables.

a) Nominal Capacity DC

The Nominal Capacity in DC is referred as the output power of the photovoltaic system this will depend on the intensity of the solar radiation and the number of modules that are installed on a photovoltaic project.

b) Power Generation

Power generation is the term used to describe the electricity that is produced using diverse types of technology, in this case, photovoltaic modules, this value is given in units of kWh or MWh. This can be determined by the following equation

Equation 2. Equation of Power Generation

$$Generation = Nominal\ Capacity\ DC\ \times 4{,}335\ hrs \times FP_{DC}$$

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

c) Number of Modules

There are several techniques to calculate the number of photovoltaic modules. We can determine the number of photovoltaic modules per area, disregarding the inverter that we will use on our project, or we can determine the number of photovoltaic modules depending on the inverter that we will use on our project.

The number of photovoltaic modules will be determined by the following equation.

$$Number\ of\ Modules = \frac{A_{installation}}{A_{PV}}$$

Where:

$A_{installation}$: Area of the rooftop where we will install

A_{PV}: Area of the Photovoltaic module

4.3 TECHNIQUES AND INSTRUMENTS APPLIED

To develop this investigation, we will collect information relevant to the theme of the investigation from several scientific papers, books, and websites for the enrichment of the investigation.

4.3.1 EXCEL

According (Microsoft 365, 2022) to Excel "is a spreadsheet program from Microsoft and a component of its Office product group for business applications. Microsoft Excel enables users to format, organize and calculate data in a spreadsheet."

Excel will play a key role in calculating the photovoltaic potential of the city of San Pedro Sula as it will aid with the calculation of rough data such as the number of photovoltaic modules and the Nominal Capacity in DC of the installations per district.

4.3.2 METEONORM

To obtain the meteorological data, we will use Meteonorm Software, which provides a unique combination of reliable data sources and sophisticated calculation tools with worldwide irradiation data and has a database that provides access to meteorological data, which will be considered for the city of San Pedro Sula.

4.3.3 CAD MAPPER

The data of the rooftops was obtained via CAD Mapper, which is an online software that provides an instant CAD file for any location on earth.

Architects and urban planners typically use this software to save hours of routine drawing. It transforms data from public sources such as OpenStreetMap, NASA, and USGS into meticulously organized CAD files. (CADMAPPER, 2020)

4.3.4 AutoCAD

According to (Autodesk, 2022): "AutoCAD is computer-aided design (CAD) software that is used for precise 2D and 3D drafting, design, and modeling with solids, surfaces, mesh objects, documentation features, and more."

AutoCAD was used to divide the data of the rooftops into ten districts, which were delimited by the Municipality of San Pedro Sula, and then to obtain an estimate of the areas of the rooftops that will be used.

4.4 POPULATION AND SAMPLE

This research will focus on ten out of the twenty districts of the city of San Pedro Sula, Cortes, Honduras to calculate the photovoltaic potential rooftops.

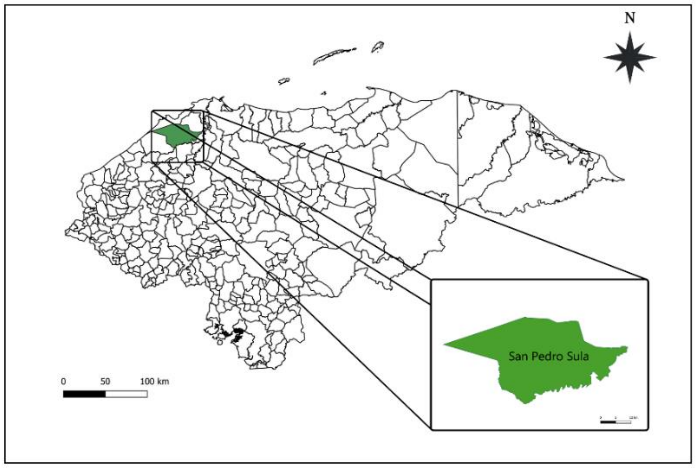

Figure 15. Location of San Pedro Sula

Source: Own Elaboration

The districts that will be excluded from this analysis will be District one, District five, District thirteen, District fourteen, District fifteen, District sixteen, District seventeen, District eighteen, District nineteen, and District twenty.

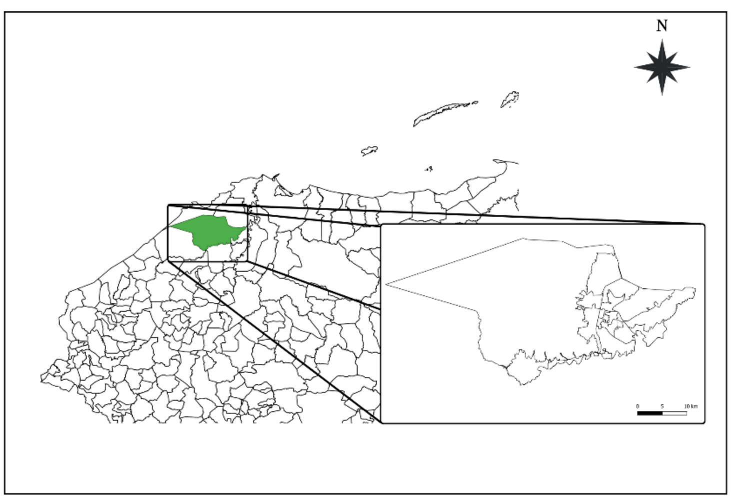

Figure 16. Districts of San Pedro Sula

Source: Own Elaboration

On figure 17, we can see the districts that were selected for this investigation highlighted. Which are District two, District three, District four, District six, District seven, District eight, District nine, District ten, District eleven, and District twelve.

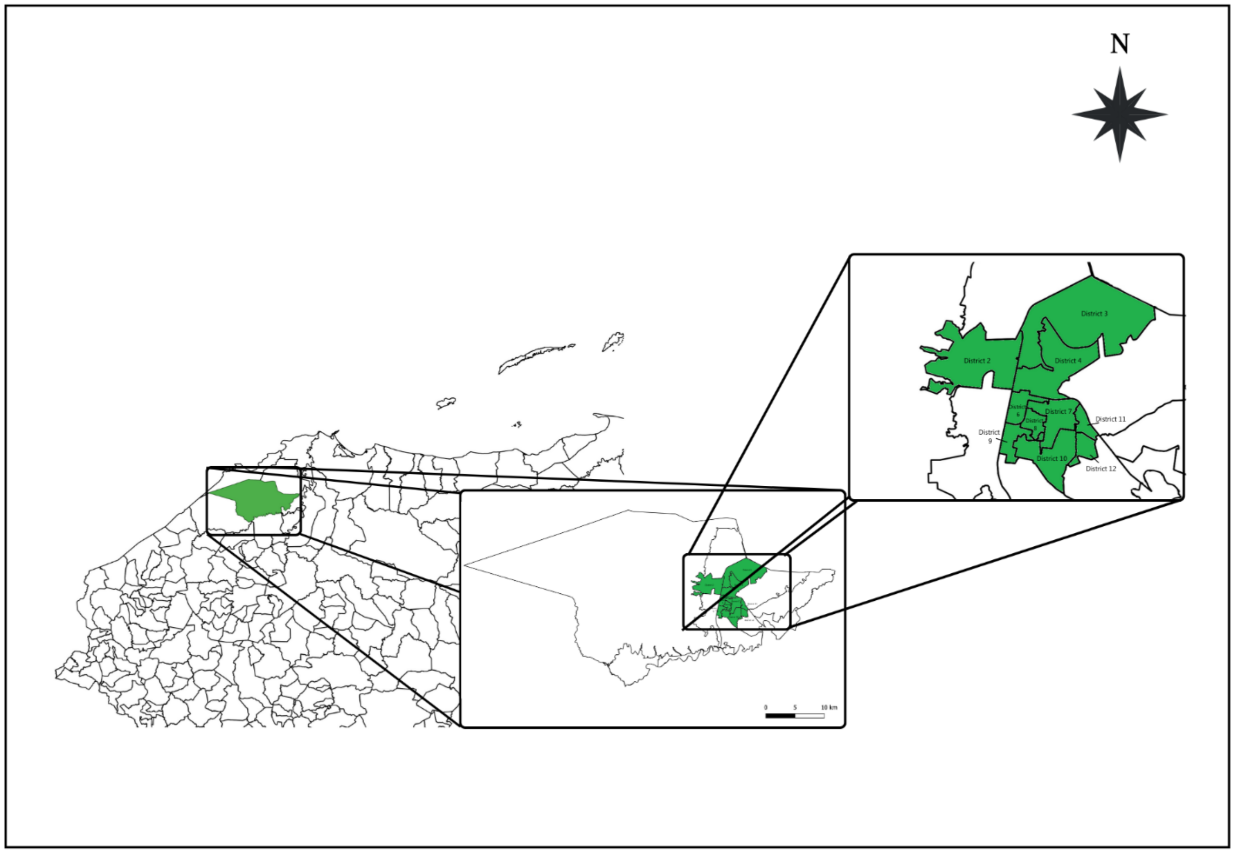

Figure 17. Districts of San Pedro Sula

Source: Own Elaboration

4.5 RESEARCH METHODOLOGY

This section describes all the procedures, techniques, instruments, and activities used and how the data will be analyzed.

4.5.1 AREA CALCULATION

The most crucial part of this research was determining the districts that would be used. For this research ten out of the twenty districts in San Pedro Sula were selected, as the information of the rooftops was available via CAD Mapper. It is important to note that some of the buildings were the photovoltaic potential was calculated have photovoltaic installations already in placed but these were not acknowledged on this research.

Secondly the areas of these ten districts were calculated using AutoCAD, which provided us with an estimate of the total area of the rooftops per district. This value was later used to determine the number of photovoltaic modules that can be installed per district.

4.5.2 CALCULATION OF THE NOMINAL CAPACITY IN DC

Once the areas of the rooftops were determined using the data of the photovoltaic modules, it was important to calculate the nominal capacity in DC of the installations.

Using the nominal capacity of the photovoltaic module and the area of the installations, the nominal capacity of the entire installation was determined. It is important to have this value as this is the photovoltaic potential.

This value was verified using the System Advisor Model (SAM), which was the software that was used in order to calculate the power generation throughout the lifetime of the project and to know the behavior of generation for the first year of production.

4.6 SCHEDULE

Activities for the Development of the Research	Weeks									
	1	2	3	4	5	6	7	8	9	10
Recollection of coordinates to verify the areas of different rooftops in the ten districts of San Pedro Sula.	■									
Develop the Theoretical Framework to Support the Research		■								
Establish the Approach of the Research		■	■							
Support the preliminary results to determine the photovoltaic potential of the ten districts that were selected for this research.				■	■					
Results and Technical Analysis				■	■	■				
Introduction							■			
Conclusions and Recommendations								■		
Final Review									■	
Scientific Article										■
Pre-Defense										■

V. RESULTS

In this chapter will be presented the results 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 $m^{2.}$

Additionally, the calculations presented for this research per District are:

The number of photovoltaic modules, which was calculated by dividing the total area of the rooftops by the area of the photovoltaic module.

The nominal capacity in DC which was calculated by multiplying the number of photovoltaic modules times the Nominal Capacity of the photovoltaic module.

The nominal capacity per square meter, which was calculated by diving the nominal capacity in DC by the total area of the district.

The energy generation for the first year, which was calculated using the equation of energy generation.

5.1 DISTRICT 2

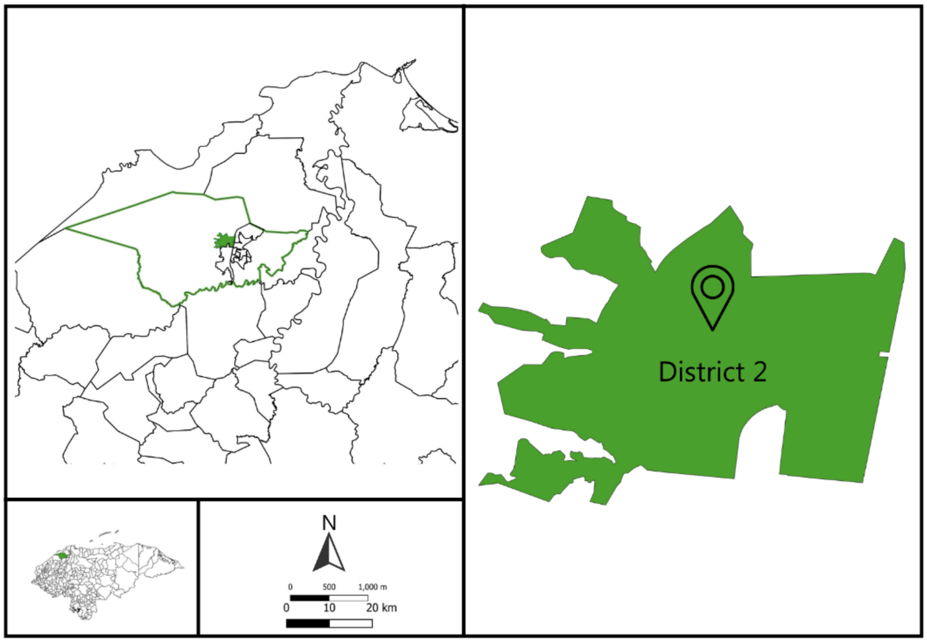

Figure 18. District 2, San Pedro Sula, Cortés

Source: Own Elaboration

Figure 18, shows District 2 which has a total area of 12.2 km^2. Upon calculating the total area of rooftops that we found on District 2, there is an area of 2,092,907.31 m^2.

5.1.1 RESULTS FOR HIKU CS3N-420MS

a) Number of Photovoltaic Modules by area

The number of photovoltaic modules by area was found by dividing the total area of the rooftops by the area of the photovoltaic modules. This calculation gives a result of approximate 1,029,406 monocrystalline HIKU CS3N-420MS modules.

$$Number\ of\ Modules = \frac{2{,}092{,}907.31\ m^2}{2.03\ m^2}$$

$$= 1{,}029{,}406.68$$

$$\approx 1{,}029{,}406$$

b) Nominal Capacity in DC

For District 2 we will have a Nominal Capacity in DC of 468,605.34 kWp.

$$Nominal\ Capacity = \ 1{,}029{,}406 \times 0.420kW$$

$$= 432{,}350.81\ kWp$$

c) Nominal Capacity per square meter by area

For District 2 we will have a Nominal Capacity per square meters of 0.04 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{432{,}350.81\ kWp}{12{,}200{,}000\ m^2}$$

$$Nominal\ Capacity = 0.04\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 432{,}350.81\ kWp\ \times 4{,}335\ hrs \times 32.11\%$$

$$= 601{,}818{,}702.56 \frac{kWh}{year}$$

$$= 601.82\ \frac{GWh}{year}$$

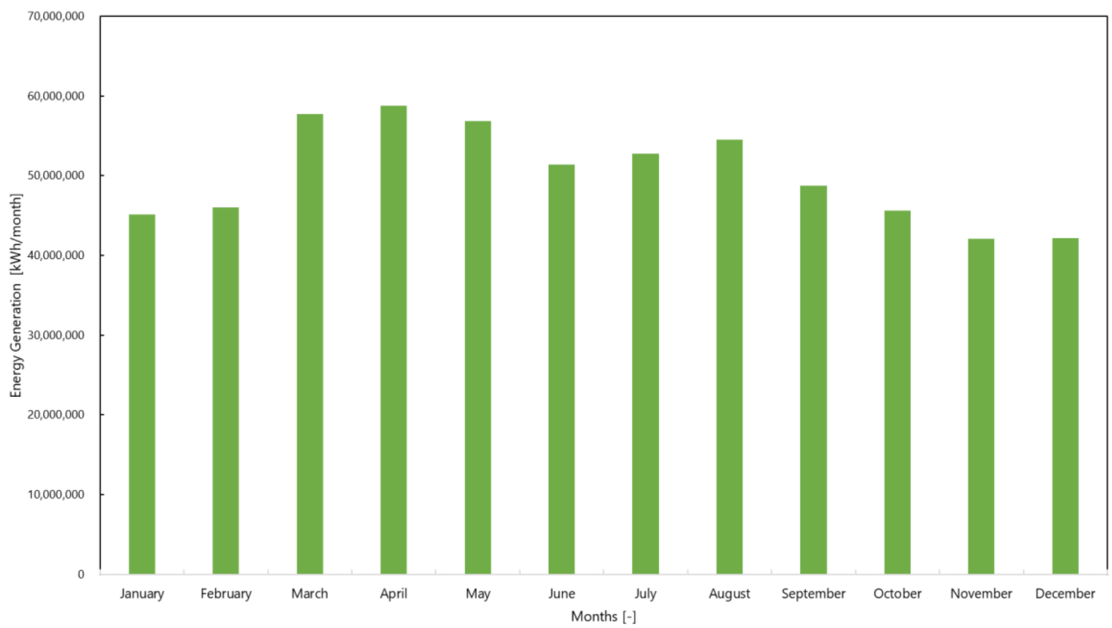

Figure 19. Annual Generation Year 1 HiKu CS3N-420MS

Source: Own Elaboration

The months that might generate more energy for District 2 using the solar module HIKU CS3N-420MS are March and April, with a total generation of 57,737,290.73 kWh/month in March and 58,803,983.11 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 42,205,351.38 kWh/month in November and 42,066,997.39 kWh/month in December, with November being the lowest month.

5.1.2 RESULTS HIKU CS3W-420PB

a) Number of Photovoltaic Modules

The number of photovoltaic modules was calculated by dividing the total area of the rooftops by the area of the photovoltaic module which gives an approximate of 947,368 polycrystalline HiKu CS3W-420PB modules.

$$Number\ of\ Modules = \frac{2{,}092{,}907.31\ m^2}{2.21\ m^2}$$

$$\approx 947{,}368.39$$

$$= 947{,}368$$

b) Nominal Capacity in DC

The nominal Capacity of this photovoltaic module was calculated by multiplying the amount of photovoltaic modules times the nominal capacity of the photovoltaic module. For District 2 we will have a Nominal Capacity in DC of 397,894.73 kWp.

$$Nominal\ Capacity = 947{,}368\ \times 0.420kW$$

$$= 397{,}894.73\ kWp$$

c) Nominal Capacity per square meter

For District 2 we will have a Nominal Capacity per square meters of 0.03 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{397{,}894.73\ kWp}{12{,}200{,}000\ \ m^2}$$

$$Nominal\ Capacity = 0.03\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 397{,}894.73\ kWp\ \times 4{,}335\ hrs \times 31.31\%$$

$$= 540{,}057{,}935.45\ \frac{kWh}{year}$$

$$= 540.06\ \frac{GWh}{year}$$

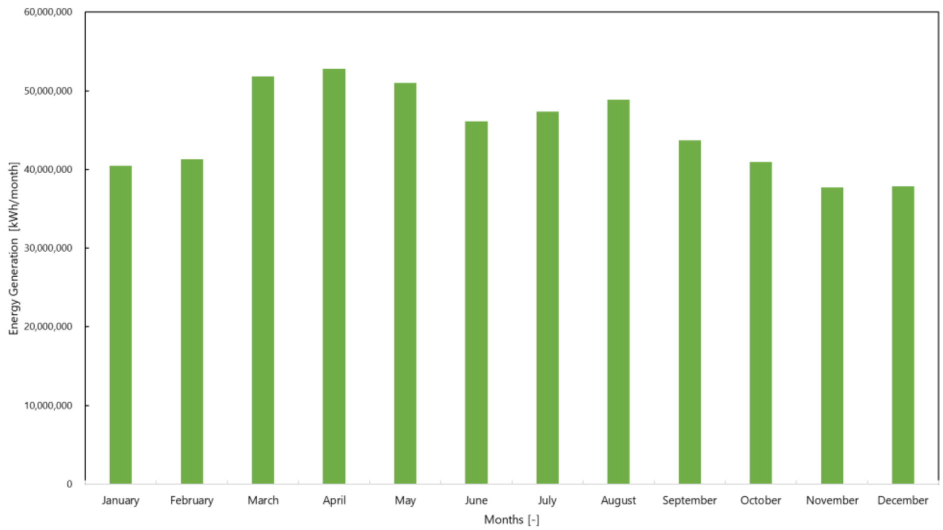

Figure 20. Annual Generation Year 1 HiKu CS3W-420PB

Source: Own Elaboration

For District 2, The months that might generate more energy for District 2 using the solar module HiKu CS3W-420PB are March and April, with a total generation of 57,737,290.73 kWh/month in March and 58,803,983.11 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 42,066,997.39 kWh/month in November and 42,205,351.38 kWh/month in December, with November being the lowest month.

5.2 District 3

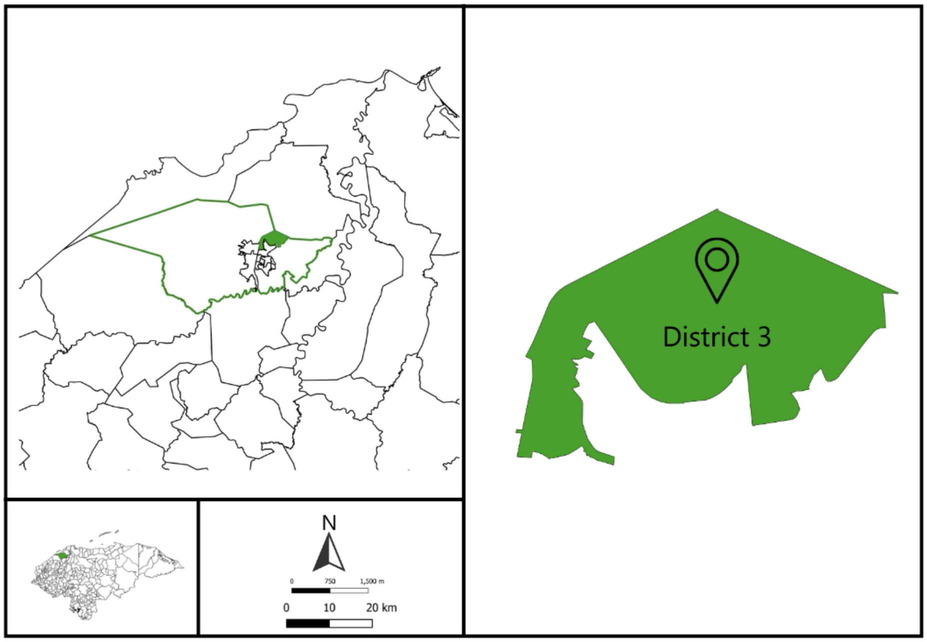

Figure 21. District 3, San Pedro Sula, Cortés

Source: Own Elaboration

Figure 21, shows District 3 which has an area of 19.2 km^2. Upon calculating the total area of rooftops that we found on District 3, there is an area of 1,572,007.21 m^2.

5.2.1 Results for HIKU CS3N-420MS

a) Number of Photovoltaic Modules

The number of photovoltaic modules was calculated by dividing the total area of the rooftops by the area of the photovoltaic module which gives a result of approximate 773,199 monocrystalline HIKU CS3N-420MS modules.

$$Number\ of\ Modules = \frac{1{,}572{,}007.21\ m^2}{2.03\ m^2}$$

$$= 773{,}199.42$$

$$\approx 773{,}199$$

b) Nominal Capacity in DC

The nominal Capacity of this photovoltaic module was calculated by multiplying the amount of photovoltaic modules times the nominal capacity of the photovoltaic module. For District 3 we will have a Nominal Capacity in DC of 324,743.76 kWp.

$$Nominal\ Capacity = 773{,}199\ \times 0.420kW$$

$$= 324{,}743.76\ kWp$$

c) Nominal Capacity per square meter

For District 3 we will have a Nominal Capacity per square meters of 0.02 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{324{,}743.76\ kWp}{19{,}200{,}000\ m^2}$$

$$Nominal\ Capacity = 0.02\ kW/m^2$$

d) *Annual Generation for Year 1*

$$Generation = 324{,}743.76\ kWp\ \times 4{,}335\ hrs \times 32.11\%$$

$$= 452{,}033{,}080.98\ \frac{kWh}{year}$$

$$= 452.03\ \frac{GWh}{year}$$

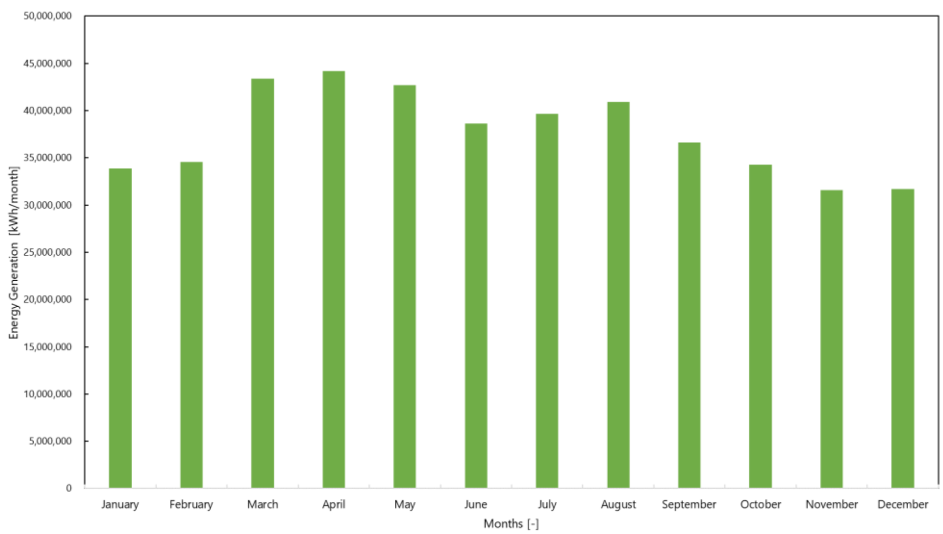

Figure 22. Annual Generation Year 1 HiKu CS3N-420MS

Source: Own Elaboration

For District 3, the months that might generate more energy for District 3 using the solar module HIKU CS3N-420MS are March and April, with a total generation of 43,367,155.76 kWh/month in March and 44,168,360.91 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 31,597,014.78 kWh/month in November and 31,700,934.08 kWh/month in December, with November being the lowest month.

5.2.2 Results HiKu CS3W-420PB

a) Number of Photovoltaic Modules

The number of photovoltaic modules was calculated by dividing the total area of the rooftops by the area of the photovoltaic module which gives an approximate of 711,579 polycrystalline HiKu CS3W-420PB modules.

$$Number\ of\ Modules = \frac{1{,}572{,}007.21\ m^2}{2.21\ m^2}$$

$$= 711{,}579.50$$

$$\approx 711{,}579$$

b) Nominal Capacity in DC

The nominal Capacity of this photovoltaic module was calculated by multiplying the amount of photovoltaic modules times the nominal capacity of the photovoltaic module. For District 3 we will have a Nominal Capacity in DC of 298,863.39 kWp.

$$Nominal\ Capacity = 711{,}579 \times 0.420kW$$

$$= 298{,}863.39\ kWp$$

c) Nominal Capacity per square meter

For District 3 we will have a Nominal Capacity per square meters of 0.02 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{298{,}863.39\ \ kWp}{19{,}200{,}000\ m^2}$$

$$Nominal\ Capacity = 0.02\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 298{,}863.39\ kWp\ \times 4{,}335\ hrs \times 31.31\%$$

$$= 405{,}643{,}844.95\ \frac{kWh}{year}$$

$$= 405.64\ \frac{GWh}{year}$$

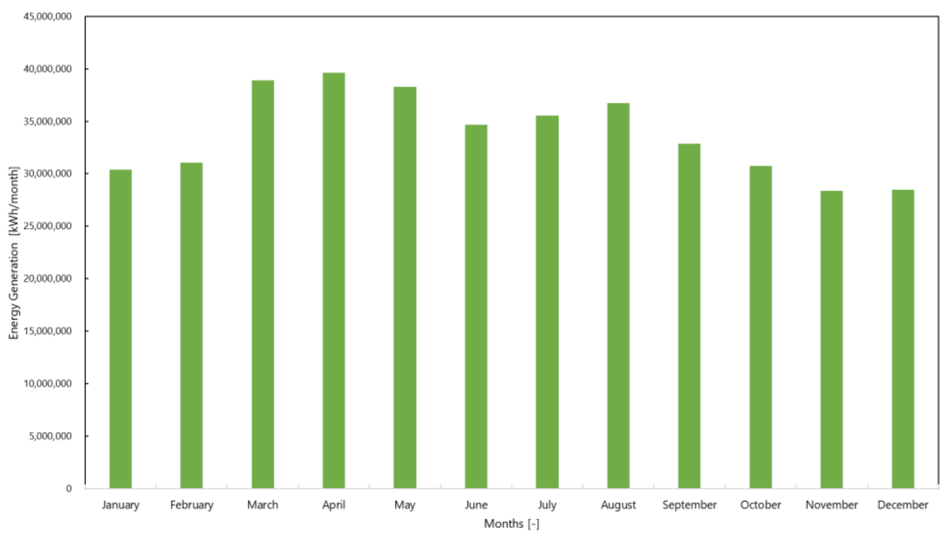

Figure 23. Annual Generation Year 1 HiKu CS3W-420PB

Source: Own Elaboration

For District 3, The months that might generate more energy for District 3 using the solar module HiKu CS3W-420PB are March and April, with a total generation of 38,916,664.62 kWh/month in March and 39,635,647.25 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 28,354,417.19 kWh/month in November and 28,447,671.93 kWh/month in December, with November being the lowest month.

5.3 DISTRICT 4

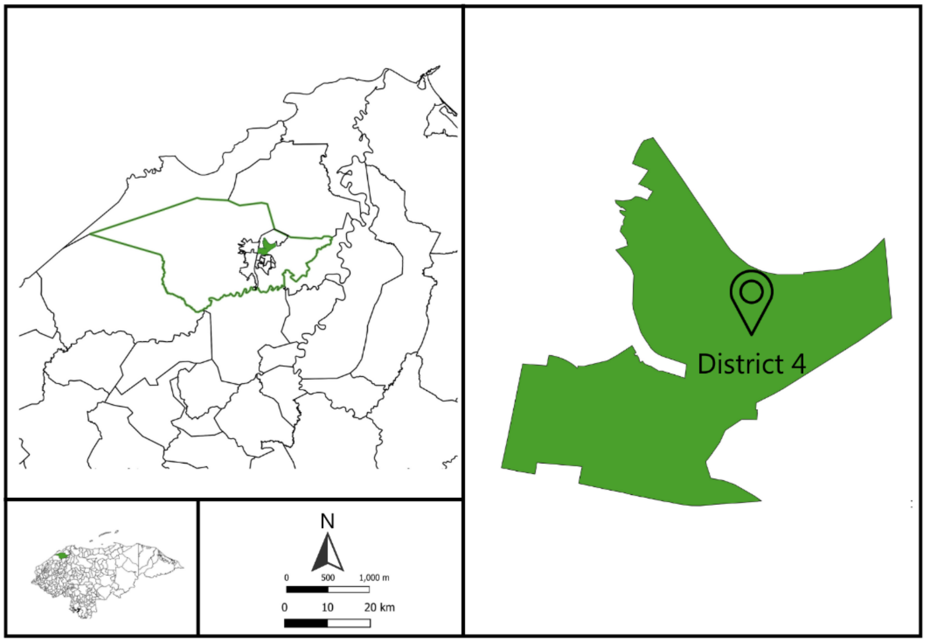

Figure 24. District 4, San Pedro Sula, Cortés

Source: Own Elaboration

Figure 24, shows District 4 which has an area of 8.38 km^2. Upon calculating the total area of rooftops that we found on District 4, there is an area of 1,293,087.23 m^2.

5.3.1 RESULTS FOR HIKU CS3N-420MS

a) Number of Photovoltaic Modules by area

The number of photovoltaic modules by area was found by dividing the total area of the rooftops by the area of the photovoltaic modules. This calculation gives a result of approximate 636,011 monocrystalline HIKU CS3N-420MS modules.

$$Number\ of\ Modules = \frac{1{,}293{,}087.23\ m^2}{2.03\ m^2}$$

$$= 636{,}011.27$$

$$\approx 636{,}011$$

b) *Nominal Capacity in DC by area*

For District 4 we will have a Nominal Capacity in DC of 267,124.62 kWp.

$$Nominal\ Capacity = 636{,}011 \times 0.420kW$$

$$= 267{,}124.62\ kWp$$

c) *Nominal Capacity per square meter by area*

For District 4 we will have a Nominal Capacity per square meters of 31.88 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{267{,}124.62\ \ kWp}{8{,}380{,}000\ m^2}$$

$$Nominal\ Capacity = 0.03\ kW/m^2$$

d) *Annual Generation for Year 1*

$$Generation = 432{,}350.81\ kWp\ \times 4{,}335\ hrs \times 32.11\%$$

$$= 601{,}818{,}702.56 \frac{kWh}{year}$$

$$= 601.82\ \frac{GWh}{year}$$

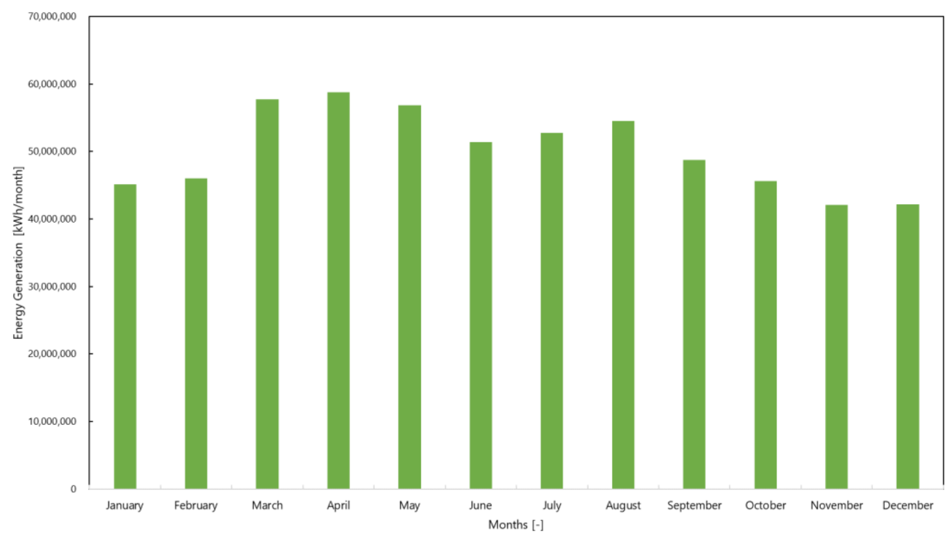

Figure 25. Annual Generation Year 1 HiKu CS3N-420MS

Source: Own Elaboration

For District 4, the months that might generate more energy for District 4 using the solar module HIKU CS3N-420MS are March and April, with a total generation of 35,672,556.06 kWh/month in March and 36,331,604.01 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation 25,990,781.76 kWh/month in November and 26,076,262.74 kWh/month in December, with November being the lowest month.

5.3.2 Results HiKu CS3W-420PB

a) Number of Photovoltaic Modules

The number of photovoltaic modules was calculated by dividing the total area of the rooftops by the area of the photovoltaic module which gives an approximate of 585,324 polycrystalline HiKu CS3W-420PB modules.

$$Number\ of\ Modules = \frac{1{,}293{,}087.23\ m^2}{2.21\ m^2}$$

$$= 585{,}324.52$$

$$\approx\ 585{,}324$$

b) Nominal Capacity in DC

The nominal Capacity of this photovoltaic module was calculated by multiplying the amount of photovoltaic modules times the nominal capacity of the photovoltaic module. For District 4 we will have a Nominal Capacity in DC of 245,836.30 kWp.

$$Nominal\ Capacity = 585{,}324\ \times 0.420kW$$

$$= 245{,}836.30\ kWp$$

c) Nominal Capacity per square meter

For District 4 we will have a Nominal Capacity per square meters of 0.03 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{245{,}836.30\ \ kWp}{8{,}380{,}000\ m^2}$$

$$Nominal\ Capacity = 0.03\ kW/m^2$$

d) *Annual Generation for Year 1*

$$Generation = 245{,}836.30\ kWp\ \times 4{,}335\ hrs \times 31.31\%$$

$$= 333{,}670{,}782.48\ \frac{kWh}{year}$$

$$= 333.67\ \frac{GWh}{year}$$

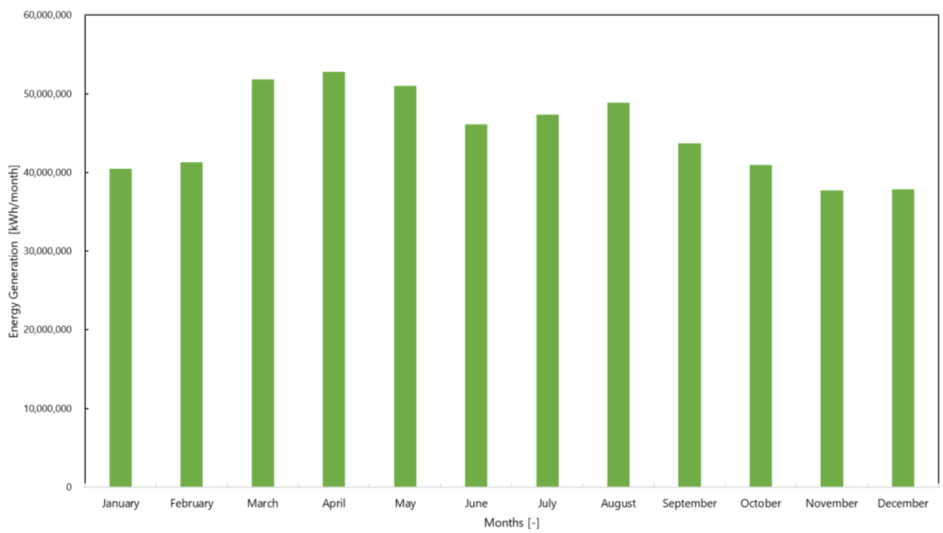

Figure 26. Annual Generation Year 1 HiKu CS3W-420PB

Source: Own Elaboration

For District 4, The months that might generate more energy for District 4 using the solar module HiKu CS3W-420PB are March and April, with a total generation of 32,011,711.99 kWh/month in March and 32,603,126.11 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 23,323,515.66 kWh/month in November and 23,400,224.29 kWh/month in December, with November being the lowest month.

5.4 DISTRICT 6

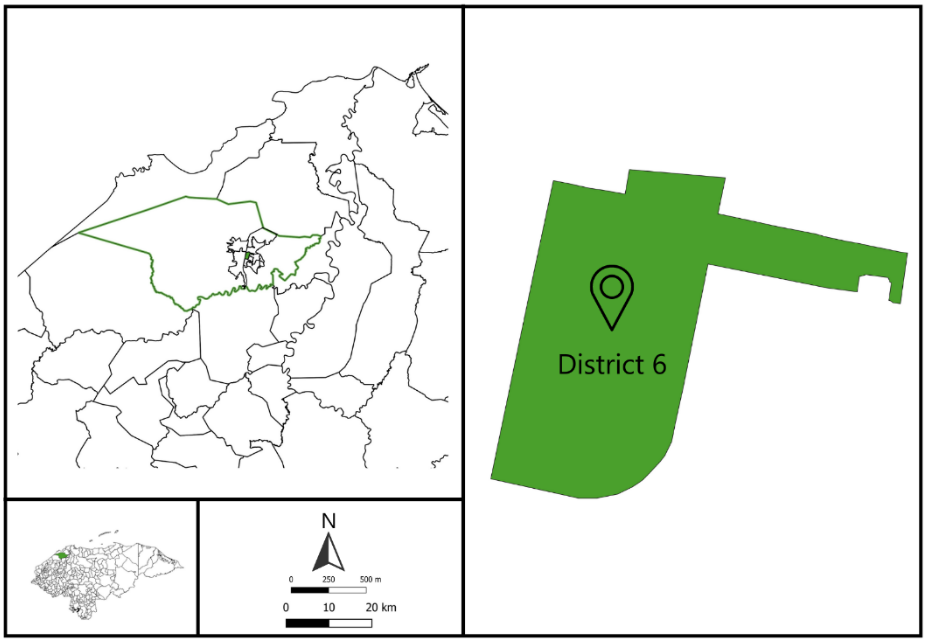

Figure 27. District 6, San Pedro Sula, Cortés

Source: Own Elaboration

Figure 27, shows District 6 which has an area of 1.89 km^2. Upon calculating the total area of rooftops that we found on District 6 there is an area of 591,342.81 m^2.

5.4.1 RESULTS FOR HIKU CS3N-420MS

a) Number of Photovoltaic Modules by area

The number of photovoltaic modules by area was found by dividing the total area of the rooftops by the area of the photovoltaic modules. This calculation gives a result of approximate 290,854 monocrystalline HIKU CS3N-420MS modules.

$$Number\ of\ Modules = \frac{591{,}342.81\ m^2}{2.03\ \ m^2}$$

$$= 290{,}854.85$$

$$\approx 290{,}854$$

b) Nominal Capacity in DC

For District 6 we will have a Nominal Capacity in DC of 468,605.34 kWp.

$$Nominal\ Capacity = \ 290{,}854 \times 0.420kW$$

$$= 122{,}159.04\ kWp$$

c) Nominal Capacity per square meter

For District 6 we will have a Nominal Capacity per square meters of 65.04 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{122{,}159.04\ \ kWp}{1{,}890{,}000\ m^2}$$

$$Nominal\ Capacity = 0.06\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 122{,}159.04\ kWp\ \times 4{,}335\ hrs \times 32.11\%$$

$$= 170{,}041{,}530.74\ \frac{kWh}{year}$$

$$= 170.04\ \frac{GWh}{year}$$

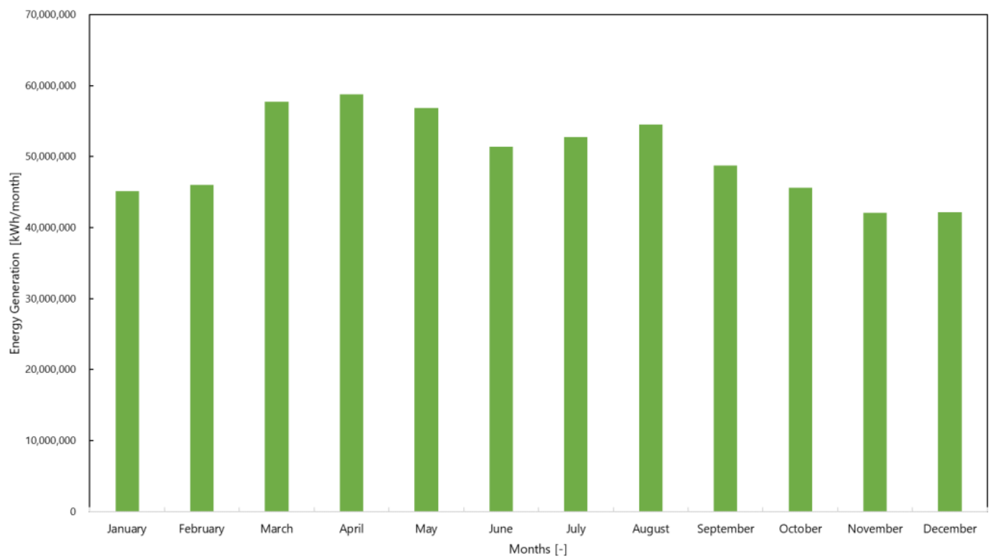

Figure 28. Annual Generation Year 1 HiKu CS3N-420MS

Source: Own Elaboration

For District 6, The months that might generate more energy for District 6 using the solar module HIKU CS3N-420MS are March and April, with a total generation of 16,313,446.65 kWh/month in March and 16,614,836.43 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 11,885,866.29 kWh/month in November and 11,924,957.67 kWh/month in December, with November being the lowest month.

5.4.2 RESULTS HIKU CS3W-420PB

a) Number of Photovoltaic Modules

The number of photovoltaic modules was calculated by dividing the total area of the rooftops by the area of the photovoltaic module which gives an approximate of 267,675 polycrystalline HiKu CS3W-420PB modules.

$$Number\ of\ Modules = \frac{591{,}342.81\ m^2}{2.21\ m^2}$$

$$= 267{,}675.25$$

$$\approx 267{,}675$$

b) Nominal Capacity in DC

The nominal Capacity of this photovoltaic module was calculated by multiplying the amount of photovoltaic modules times the nominal capacity of the photovoltaic module. For District 6 we will have a Nominal Capacity in DC of 112,423.61 kWp.

$$Nominal\ Capacity = 267{,}675 \times 0.420kW$$

$$= 112{,}423.61\ kWp$$

c) Nominal Capacity per square meter

For District 6 we will have a Nominal Capacity per square meters of 0.06 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{112{,}423.61\ \ kWp}{1{,}890{,}000\ m^2}$$

$$Nominal\ Capacity = 0.06\ kW/m^2$$

d) *Annual Generation for Year 1*

$$Generation = 112{,}423.61\ kWp\ \times 4{,}335\ hrs \times 31.31\%$$

$$= 152{,}591{,}266.51\ \frac{kWh}{year}$$

$$= 152.59\ \frac{GWh}{year}$$

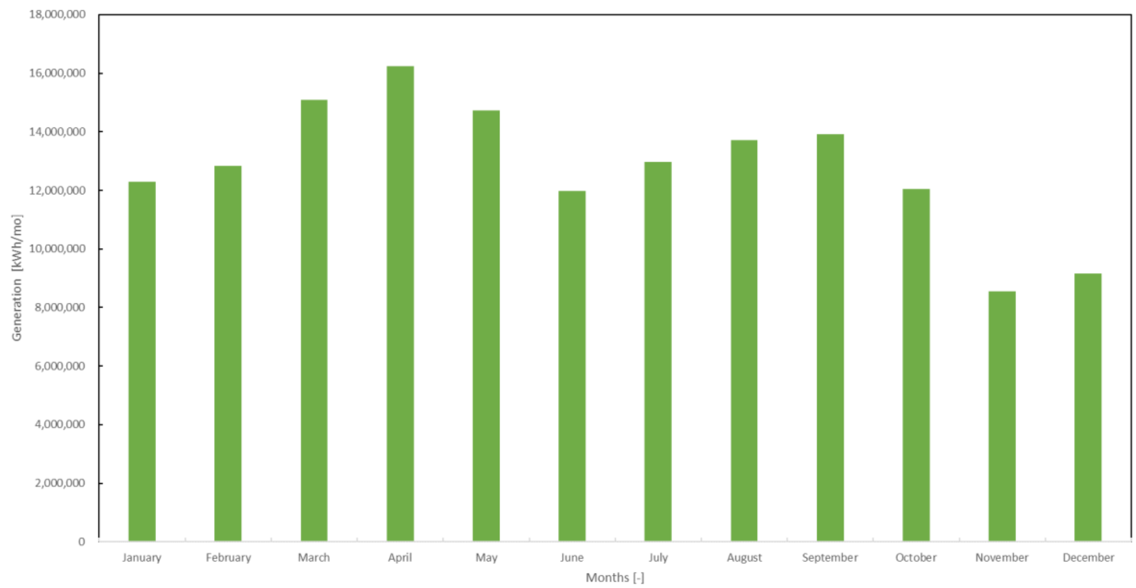

Figure 29. Annual Generation Year 1 HiKu CS3W-420PB

Source: Own Elaboration

For District 6, The months that might generate more energy for District 6 using the solar module HiKu CS3W-420PB are March and April, with a total generation of 28,490,181.90 kWh/month in March and 29,016,536.01 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 20,757,752.79 kWh/month in November and 20,826,022.89 kWh/month in December, with November being the lowest month.

5.5 District 7

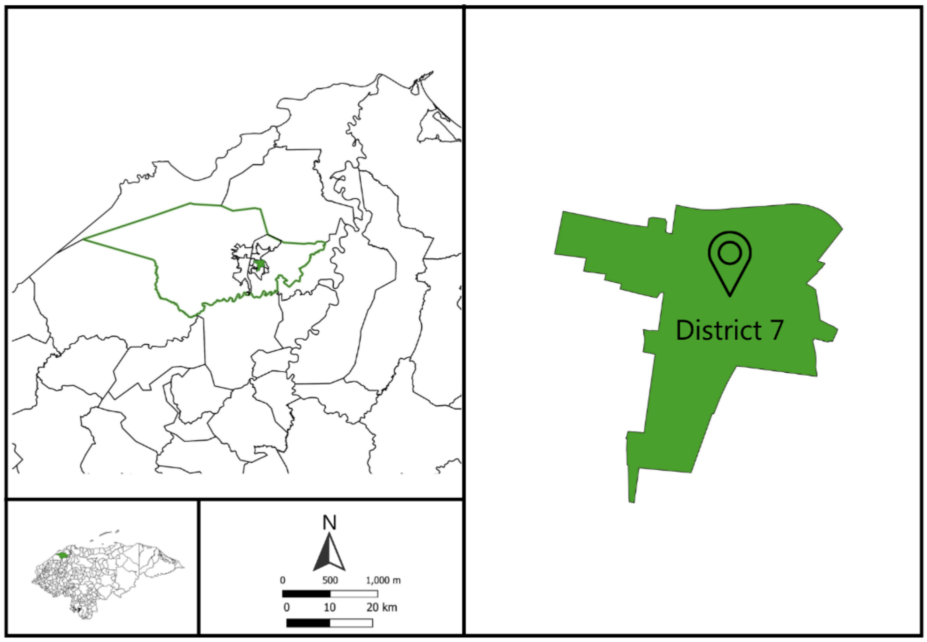

Figure 30. District 7, San Pedro Sula, Cortés

Source: Own Elaboration

Figure 30, shows District 7 which has an area of 3.81 km^2. Upon calculating the total area of rooftops that we found on District 7, there is an area of 1,032,734.81 m^2

5.5.1 Results for HIKU CS3N-420MS

a) Number of Photovoltaic Modules by area

The number of photovoltaic modules by area was found by dividing the total area of the rooftops by the area of the photovoltaic modules. This calculation gives a result of approximate 507,955 monocrystalline HIKU CS3N-420MS modules.

$$Number\ of\ Modules = \frac{1{,}032{,}734.81\ m^2}{2.03\ \ m^2}$$

$$= 507{,}955.66$$

$$\approx 507{,}955$$

b) Nominal Capacity in DC

For District 7 we will have a Nominal Capacity in DC of 468,605.34 kWp.

$$Nominal\ Capacity = \ 507{,}955 \times 0.420 kW$$

$$= 213{,}341.38\ kWp$$

c) Nominal Capacity per square meter by area

For District 7 we will have a Nominal Capacity per square meters of 0.06 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{213{,}341.38\ \ kWp}{3{,}810{,}000\ m^2}$$

$$Nominal\ Capacity = 0.06\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 213{,}341.38\ kWp\ \times 4{,}335\ hrs \times 32.11\%$$

$$= 296{,}964{,}476.39\ \frac{kWh}{year}$$

$$= 296.96\ \frac{GWh}{year}$$

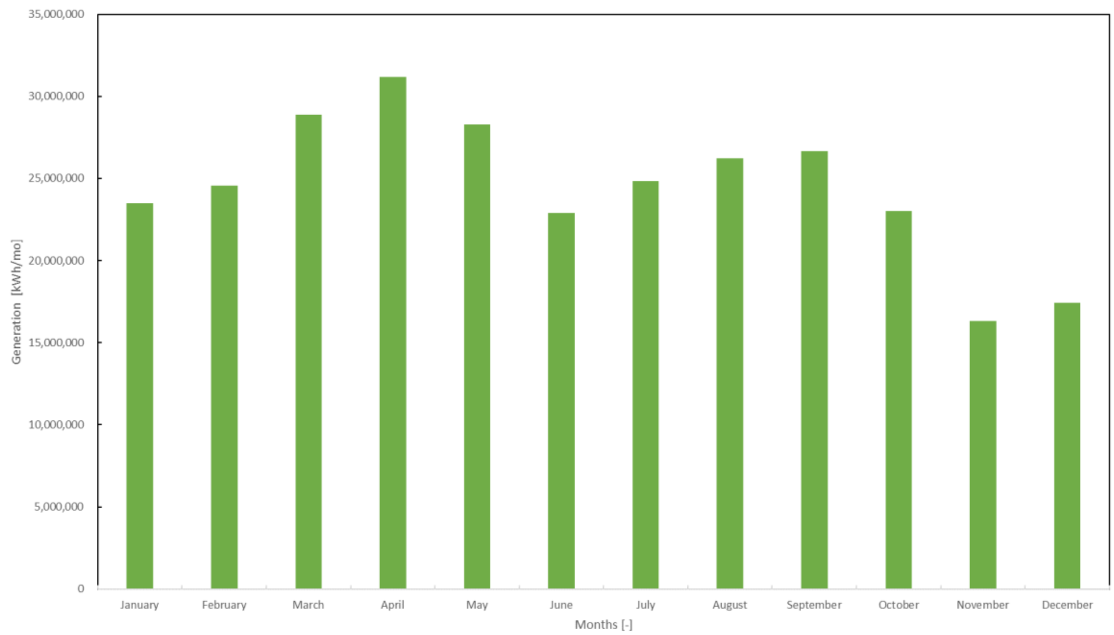

Figure 31. Annual Generation Year 1 HiKu CS3N-420MS

Source: Own Elaboration

For District 7, The months that might generate more energy for District 7 using the solar module HIKU CS3N-420MS are March and April, with a total generation of 28,490,181.90 kWh/month in March and 29,016,536.01 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 20,757,752.79 kWh/month in November and 20,826,022.89 kWh/month in December, with November being the lowest month.

5.5.2 Results HiKu CS3W-420PB

a) Number of Photovoltaic Modules

The number of photovoltaic modules was calculated by dividing the total area of the rooftops by the area of the photovoltaic module which gives an approximate of 477,304 polycrystalline HiKu CS3W-420PB modules.

$$Number\ of\ Modules = \frac{1{,}032{,}734.81\ m^2}{2.21\ m^2}$$

$$= 467{,}474.27$$

$$\approx\ 467{,}474$$

b) Nominal Capacity in DC

The nominal Capacity of this photovoltaic module was calculated by multiplying the amount of photovoltaic modules times the nominal capacity of the photovoltaic module. For District 7 we will have a Nominal Capacity in DC of 196,339.19 kWp.

$$Nominal\ Capacity = \ 467{,}474 \times 0.420kW$$

$$= 196{,}339.19\ kWp$$

c) Nominal Capacity per square meter

For District 7 we will have a Nominal Capacity per square meters of 0.05 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{196{,}339.19\ \ kWp}{3{,}810{,}000\ m^2}$$

$$Nominal\ Capacity = 0.05\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 196{,}339.19\ kWp\ \times 4{,}335\ hrs \times 31.31\%$$

$$= 266{,}488{,}929.87\ \frac{kWh}{year}$$

$$= 266.49\ \frac{GWh}{year}$$

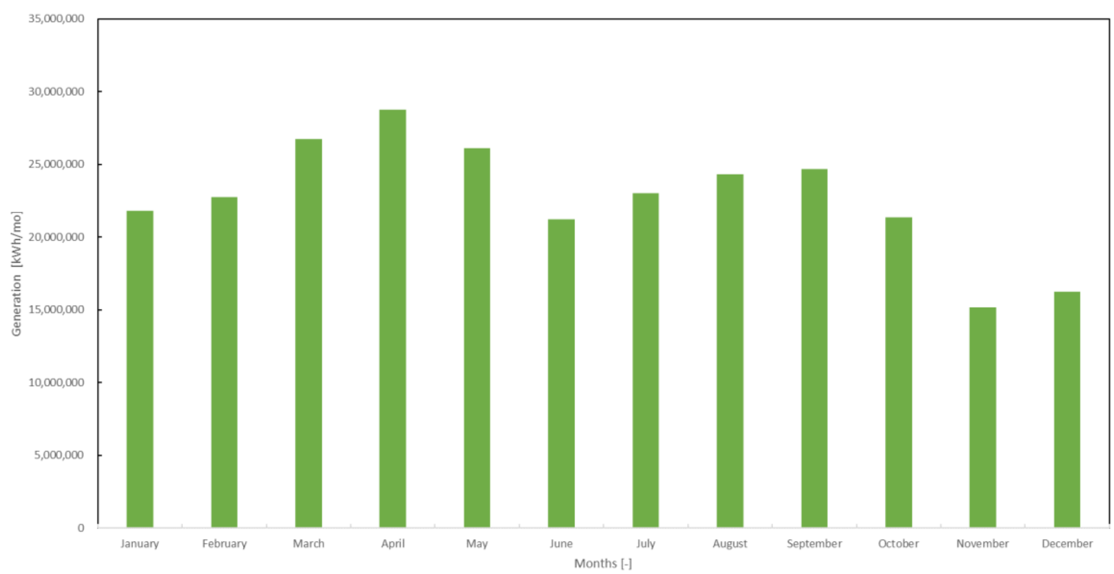

Figure 32. Annual Generation Year 1 HiKu CS3W-420PB

Source: Own Elaboration

For District 7, The months that might generate more energy for District 7 using the solar module HiKu CS3W-420PB are March and April, with a total generation of 25,566,418.51 kWh/month in March and 26,038,756.29 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 18,627,518.67 kWh/month in November and 18,688,782.65 kWh/month in December, with November being the lowest month.

5.6 District 8

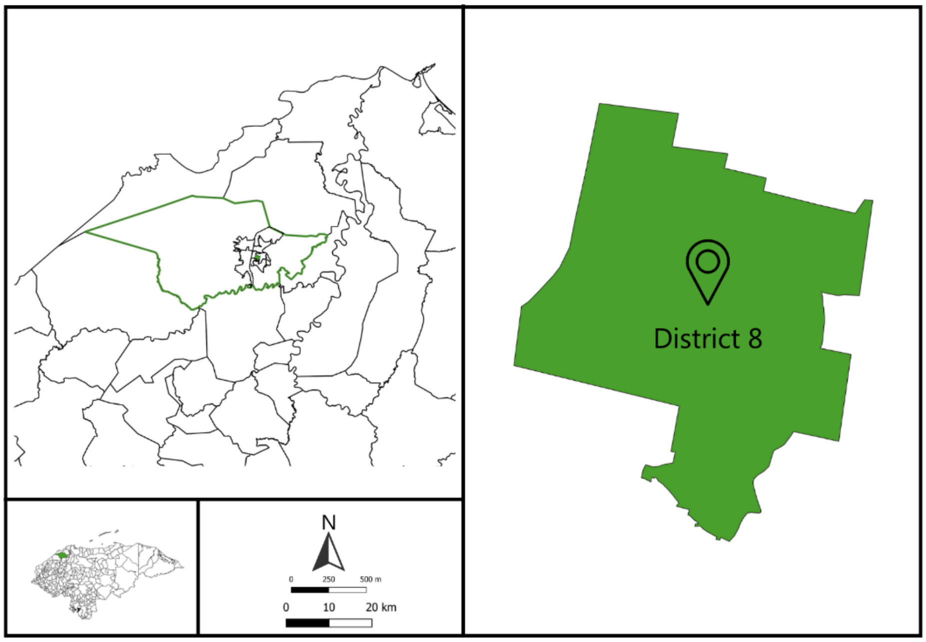

Figure 33. District 8, San Pedro Sula, Cortés

Source: Own Elaboration

Figure 33, shows District 8 which has an area of 1.29 km^2. Upon calculating the total area of rooftops that we found on District 8, there is an area of 537,615.53 m^2

5.6.1 Results for HIKU CS3N-420MS

a) Number of Photovoltaic Modules by area

The number of photovoltaic modules by area was found by dividing the total area of the rooftops by the area of the photovoltaic modules. This calculation gives a result of approximate 276,294 monocrystalline HIKU CS3N-420MS modules.

$$Number\ of\ Modules = \frac{537{,}615.53\ m^2}{2.03\ \ m^2}$$

$$= 264{,}428.82$$

$$\approx 264{,}428$$

b) Nominal Capacity in DC by area

For District 8 we will have a Nominal Capacity in DC of 116,043.48 kWp.

$$Nominal\ Capacity = \ 264{,}428 \times 0.420kW$$

$$= 111{,}060.11\ kWp$$

c) Nominal Capacity per square meter

For District 8 we will have a Nominal Capacity per square meters of 89.96 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{111{,}060.11\ \ kWp}{1{,}290{,}000\ m^2}$$

$$Nominal\ Capacity = 0.09\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 111{,}060.11\ kWp\ \times 4{,}335\ hrs \times 32.11\%$$

$$= 154{,}592{,}169.08\ \frac{kWh}{year}$$

$$= 154.59\ \frac{GWh}{year}$$

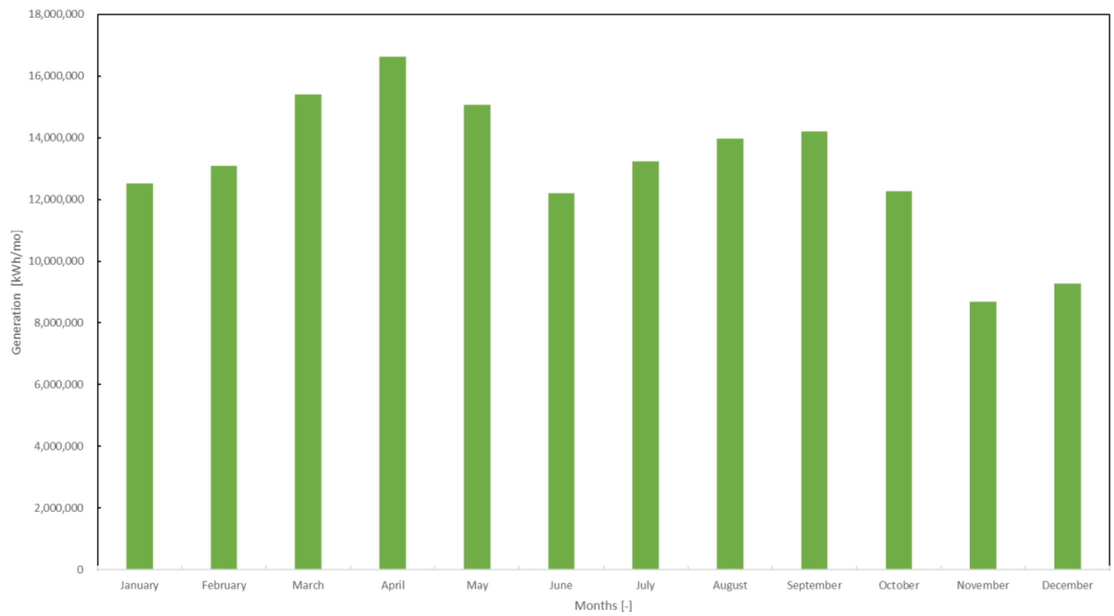

Figure 34. Annual Generation Year 1 HiKu CS3N-420MS

Source: Own Elaboration

For District 8, The months that might generate more energy for District 8 using the solar module HIKU CS3N-420MS are March and April, with a total generation of 14,831,265.58 kWh/month in March and 15,105,272.17 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 10,805,959.25 kWh/month in November and 10,841,498.93 kWh/month in December, with November being the lowest month.

5.6.2 Results HiKu CS3W-420PB

a) Number of Photovoltaic Modules

The number of photovoltaic modules was calculated by dividing the total area of the rooftops by the area of the photovoltaic module which gives an approximate of 243,355 polycrystalline HiKu CS3W-420PB modules.

$$Number\ of\ Modules = \frac{537{,}615.53\ m^2}{2.21\ m^2}$$

$$= 243{,}355.24$$

$$\approx 243{,}355$$

b) Nominal Capacity in DC

The nominal Capacity of this photovoltaic module was calculated by multiplying the amount of photovoltaic modules times the nominal capacity of the photovoltaic module. For District 8 we will have a Nominal Capacity in DC of 102,209.20 kWp.

$$Nominal\ Capacity = 243{,}355 \times 0.420kW$$

$$= 102{,}209.20\ kWp$$

c) Nominal Capacity per square meter

For District 8 we will have a Nominal Capacity per square meters of 0.08 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{102{,}209.20\ \ kWp}{1{,}290{,}000\ m^2}$$

$$Nominal\ Capacity = 0.08\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 102{,}209.20\ kWp\ \times 4{,}335\ hrs \times 31.31\%$$

$$= 138{,}727{,}373.07\ \frac{kWh}{year}$$

$$= 138.73\ \frac{GWh}{year}$$

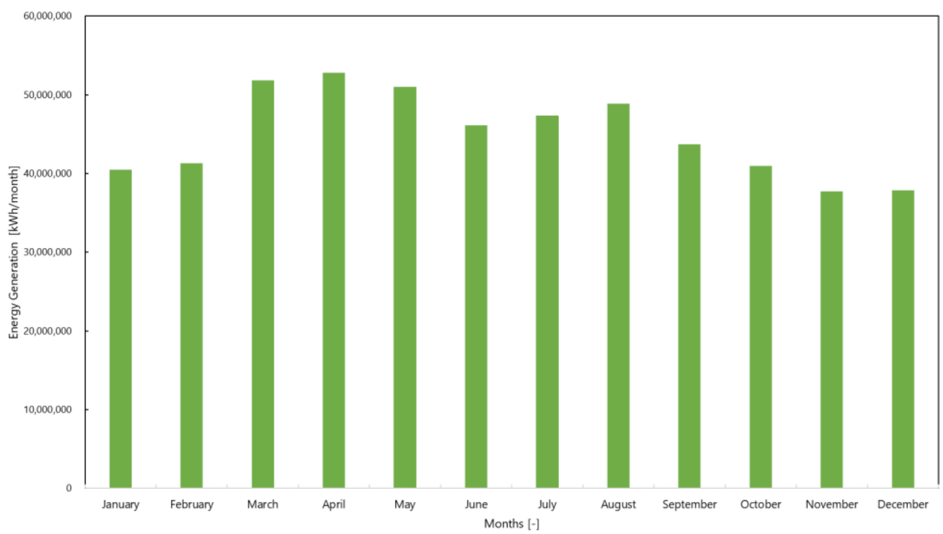

Figure 35. Annual Generation Year 1 HiKu CS3W-420PB

Source: Own Elaboration

For District 8, The months that might generate more energy for District 8 using the solar module HiKu CS3W-420PB are March and April, with a total generation of 13,309,228.57 kWh/month in March and 13,555,115.63 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 9,697,013.43 kWh/month in November and 9,728,905.90 kWh/month in December, with November being the lowest month.

5.7 DISTRICT 9

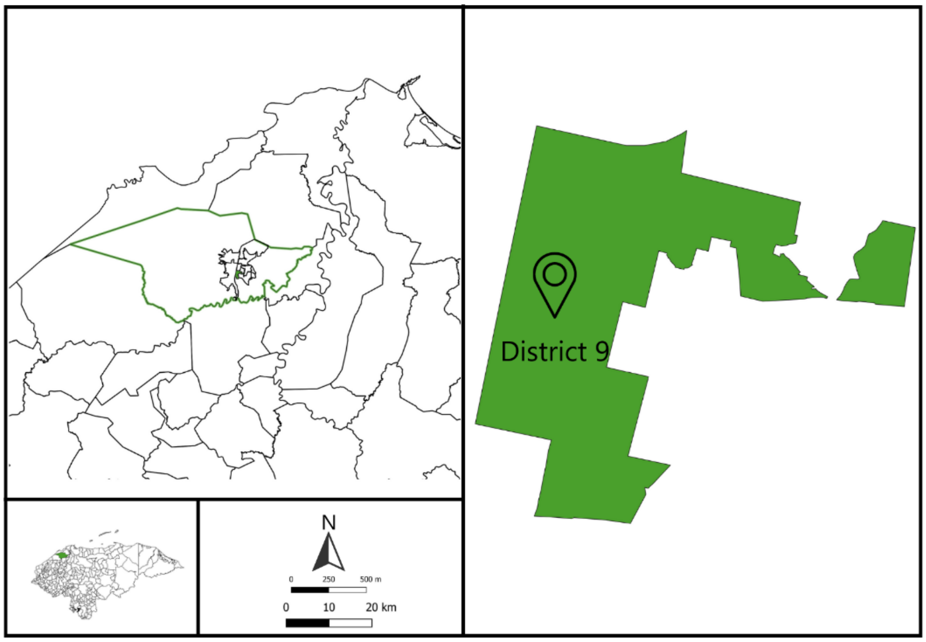

Figure 36. District 9, San Pedro Sula, Cortés

Source: Own Elaboration

Figure 36, shows District 9 which has an area of 1.96 km^2. Upon calculating the total area of rooftops that we found on District 9, there is an area of 679,466.94 m^2.

5.7.1 RESULTS FOR HIKU CS3N-420MS

a) Number of Photovoltaic Modules

The number of photovoltaic modules by area was found by dividing the total area of the rooftops by the area of the photovoltaic modules. This calculation gives a result of approximate 334,199 monocrystalline HIKU CS3N-420MS modules.

$$Number\ of\ Modules = \frac{679{,}466.94\ m^2}{2.03\ \ m^2}$$

$$= 334{,}199.13$$

$$\approx 334{,}199$$

b) Nominal Capacity in DC by area

For District 9 we will have a Nominal Capacity in DC of 468,605.34 kWp.

$$334{,}199 \times 0.420kW$$

$$= 140{,}363.58\ kWp$$

c) Nominal Capacity per square meter

For District 9 we will have a Nominal Capacity per square meters of 0.07 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{140{,}363.58\ \ kWp}{1{,}960{,}000\ m^2}$$

$$Nominal\ Capacity = 0.07\ kW/m^2$$

d) *Annual Generation for Year 1*

$$Generation = 140{,}363.64\ kWp\ \times 4{,}335\ hrs \times 32.11\%$$

$$= 195{,}381{,}759.29\ \frac{kWh}{year}$$

$$= 195.38\ \frac{GWh}{year}$$

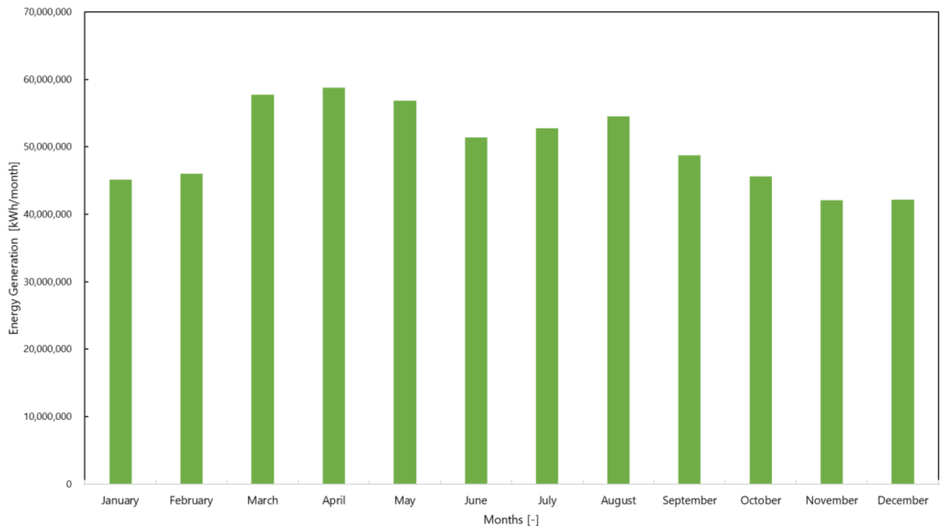

Figure 37. Annual Generation Year 1 HiKu CS3N-420MS

Source: Own Elaboration

For District 9, The months that might generate more energy for District 9 using the solar module HIKU CS3N-420MS are March and April, with a total generation of 18,744,537.83 kWh/month in March and 19,090,841.85 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 13,657,142.80 kWh/month in November and 13,702,059.72 kWh/month in December, with November being the lowest month.

5.7.2 RESULTS HIKU CS3W-420PB

a) Number of Photovoltaic Modules

The number of photovoltaic modules was calculated by dividing the total area of the rooftops by the area of the photovoltaic module which gives an approximate of 307,565 polycrystalline HiKu CS3W-420PB modules.

$$Number\ of\ Modules = \frac{679{,}466.94\ m^2}{2.21\ m^2}$$

$$= 307{,}565.22$$

$$\approx 307{,}565$$

b) Nominal Capacity in DC

The nominal Capacity of this photovoltaic module was calculated by multiplying the amount of photovoltaic modules times the nominal capacity of the photovoltaic module. For District 9 we will have a Nominal Capacity in DC of 129,177.30kWp.

$$Nominal\ Capacity = 307{,}565 \times 0.420kW$$

$$= 129{,}177.30\ kWp$$

c) Nominal Capacity per square meter

For District 9 we will have a Nominal Capacity per square meters of 0.07 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{129{,}177.30\ \ kWp}{1{,}960{,}000\ m^2}$$

$$Nominal\ Capacity = 0.07\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 129{,}177.39\ kWp\ \times 4{,}335\ hrs \times 31.31\%$$

$$= 175{,}330{,}991.04\ \frac{kWh}{year}$$

$$= 175.33\ \frac{GWh}{year}$$

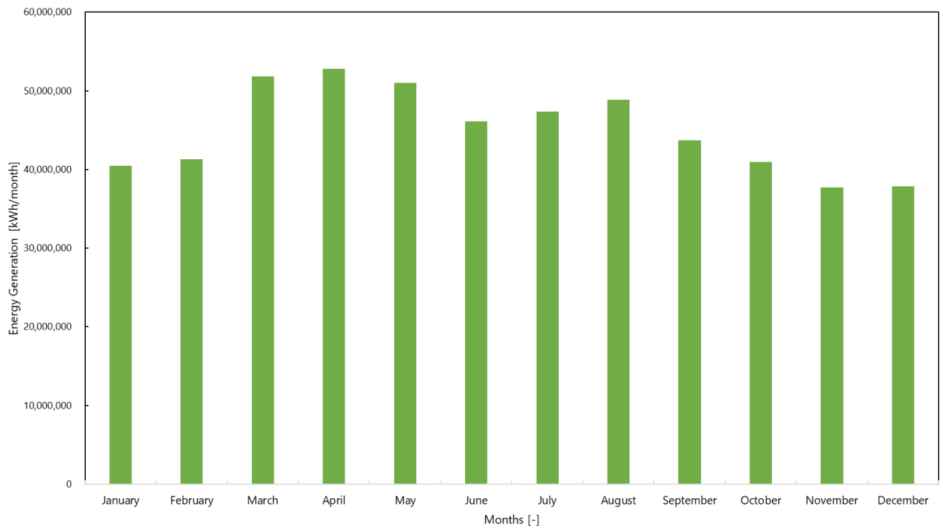

Figure 38. Annual Generation Year 1 HiKu CS3W-420PB

Source: Own Elaboration

For District 9, The months that might generate more energy for District 9 using the solar module HiKu CS3W-420PB are March and April, with a total generation of 16,820,906.96 kWh/month in March and 17,131,672.03 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 12,255,598.42 kWh/month in November and 12,295,905.82 kWh/month in December, with November being the lowest month.

5.8 District 10

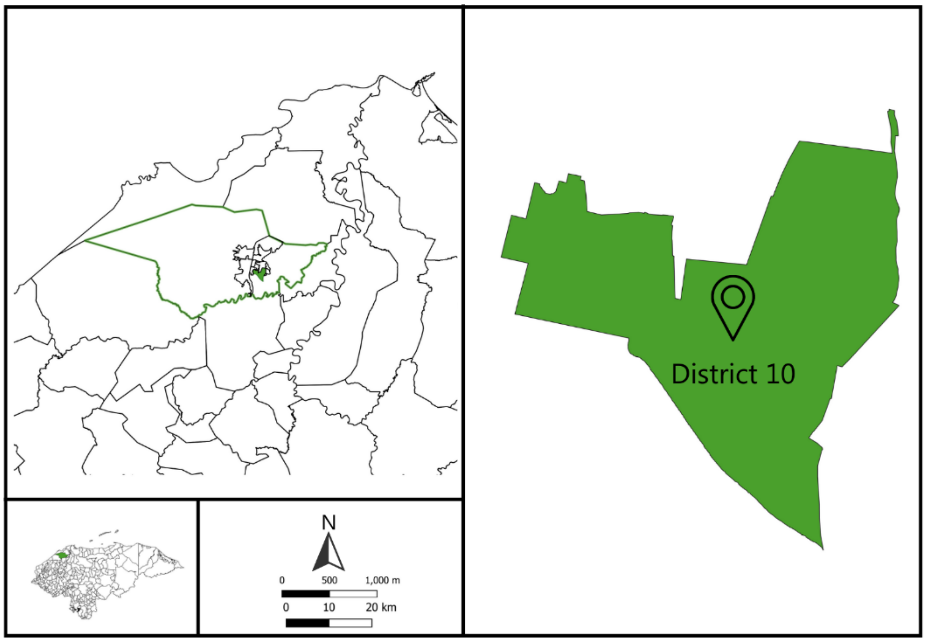

Figure 39. District 10, San Pedro Sula, Cortés

Source: Own Elaboration

Figure 39, shows District 10 which has an area of 5.36 km^2. Upon calculating the total area of rooftops that we found on District 10, there is an area of 1,068,890.46 m^2.

5.8.1 Results for HIKU CS3N-420MS

a) Number of Photovoltaic Modules by area

The number of photovoltaic modules by area was found by dividing the total area of the rooftops by the area of the photovoltaic modules. This calculation gives a result of approximate 525,738 monocrystalline HIKU CS3N-420MS modules.

$$Number\ of\ Modules = \frac{1{,}068{,}890.46\ m^2}{2.03\ m^2}$$

$$= 525{,}738.99$$

$$\approx 525{,}738$$

b) Nominal Capacity in DC by area

For District 10 we will have a Nominal Capacity in DC of 220,810.38 kWp.

$$Nominal\ Capacity = 525{,}738 \times 0.420kW$$

$$= 220{,}810.38\ kWp$$

c) Nominal Capacity per square meter

For District 10 we will have a Nominal Capacity per square meters of 0.04 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{220{,}810.38\ kWp}{5{,}360{,}000\ m^2}$$

$$Nominal\ Capacity = 0.04\ kW/m^2$$

d) *Annual Generation for Year 1*

$$Generation = 220{,}810.38\ kWp\ \times 4{,}335\ hrs \times 32.11\%$$

$$= 307{,}361{,}088.92\ \frac{kWh}{year}$$

$$= 307.36\ \frac{GWh}{year}$$

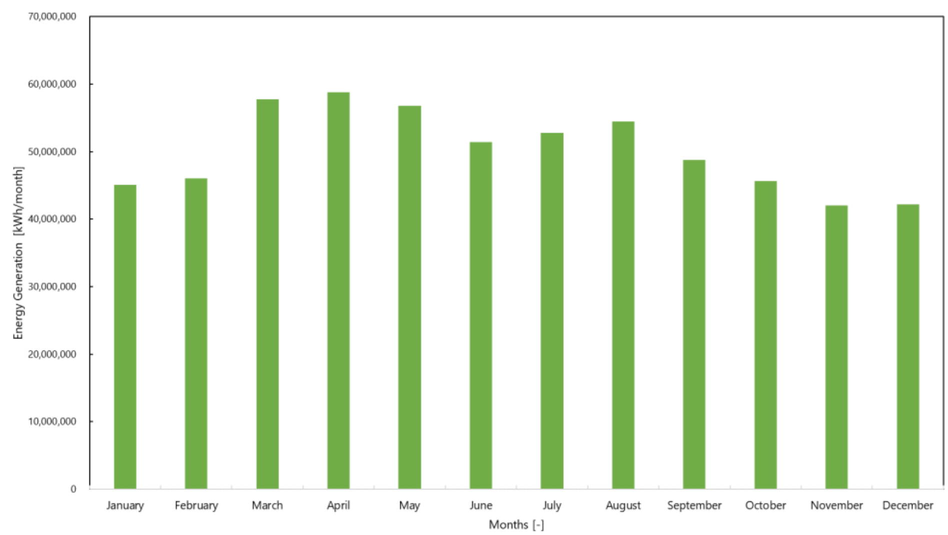

Figure 40. Annual Generation Year 1 HiKu CS3N-420MS

Source: Own Elaboration

For District 10, The months that might generate more energy for District 10 using the solar module HIKU CS3N-420MS are March and April, with a total generation of 29,487,612.26 kWh/month in March and 30,032,393.81 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 21,484,473.76 kWh/month in November and 21,555,133.97 kWh/month in December, with November being the lowest month.

5.8.2 RESULTS HIKU CS3W-420PB

a) Number of Photovoltaic Modules

The number of photovoltaic modules was calculated by dividing the total area of the rooftops by the area of the photovoltaic module which gives an approximate of 483,840 polycrystalline HiKu CS3W-420PB modules.

$$Number\ of\ Modules = \frac{1{,}068{,}890.46\ m^2}{2.21\ m^2}$$

$$= 483{,}840.37$$

$$\approx\ 483{,}840$$

b) Nominal Capacity in DC

The nominal Capacity of this photovoltaic module was calculated by multiplying the amount of photovoltaic modules times the nominal capacity of the photovoltaic module. For District 10 we will have a Nominal Capacity in DC of 203,212.95 kWp.

$$Nominal\ Capacity = 483{,}840\ \times 0.420kW$$

$$= 203{,}212.95\ kWp$$

c) Nominal Capacity per square meter

For District 10 we will have a Nominal Capacity per square meters of 0.04 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{203{,}212.95\ \ kWp}{5{,}360{,}000\ m^2}$$

$$Nominal\ Capacity = 0.04\ kW/m^2$$

d) *Annual Generation for Year 1*

$$Generation = 203{,}212.95\ kWp\ \times 4{,}335\ hrs \times 31.31\%$$

$$= 275{,}818{,}605.20\ \frac{kWh}{year}$$

$$= 275.82\ \frac{GWh}{year}$$

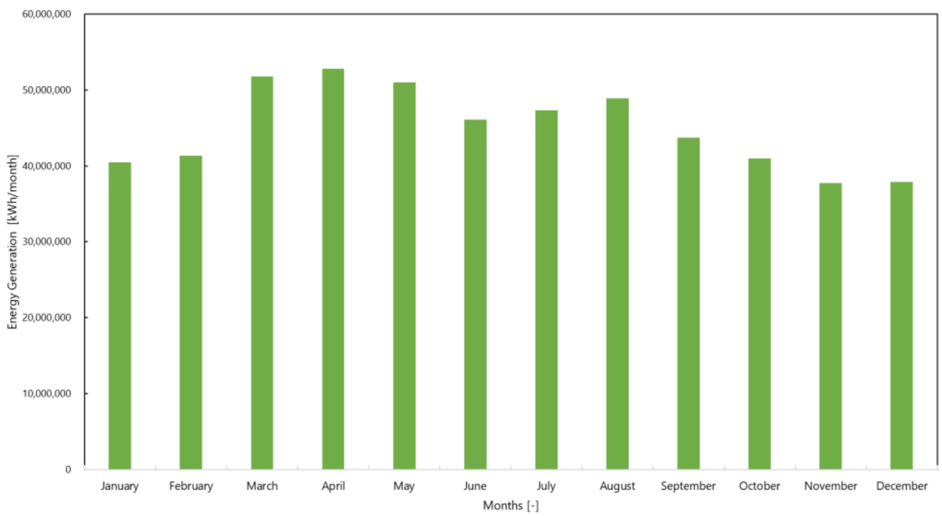

Figure 41. Annual Generation Year 1 HiKu CS3W-420PB

Source: Own Elaboration

For District 10, The months that might generate more energy for District 10 using the solar module HiKu CS3W-420PB are March and April, with a total generation of 26,461,489.03 kWh/month in March and 26,950,363.18 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 19,279,660.96 kWh/month in November and 19,343,069.77 kWh/month in December, with November being the lowest month.

5.9 District 11

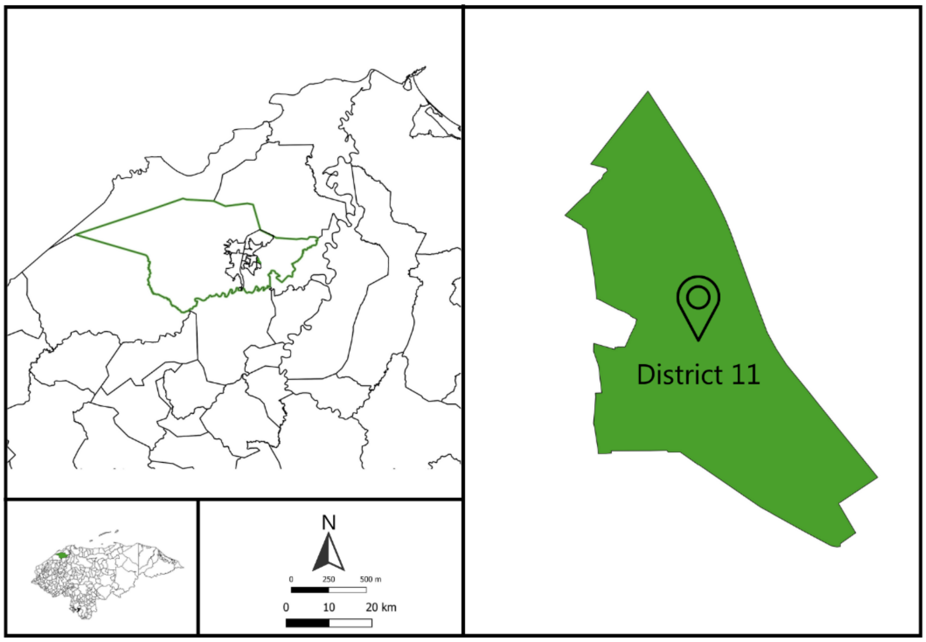

Figure 42. District 11, San Pedro Sula, Cortés

Source: Own Elaboration

Figure 42, shows District 11 which has an area of 1.13 km^2. Upon calculating the total area of rooftops that we found on District 11, there is an area of 409,102.42 m^2.

5.9.1 Results for HIKU CS3N-420MS

a) Number of Photovoltaic Modules by area

The number of photovoltaic modules by area was found by dividing the total area of the rooftops by the area of the photovoltaic modules. This calculation gives a result of approximate 201,219 monocrystalline HIKU CS3N-420MS modules.

$$Number\ of\ Modules = \frac{409{,}102.42\ m^2}{2.03\ m^2}$$

$$= 201{,}219.02$$

$$\approx 201{,}219$$

b) Nominal Capacity in DC by area

For District 11 we will have a Nominal Capacity in DC of 91,547.40 kWp.

$$Nominal\ Capacity = \ 201{,}219\ \times 0.420kW$$

$$= 84{,}511.99\ kWp$$

c) Nominal Capacity per square meter

For District 11 we will have a Nominal Capacity per square meters of 0.07 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{84{,}511.99\ \ kWp}{1{,}130{,}000\ m^2}$$

$$Nominal\ Capacity = 0.07\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 84{,}511.99\ kWp\ \times 4{,}335\ hrs \times 32.11\%$$

$$= 117{,}638{,}027.47\ \frac{kWh}{year}$$

$$= 117.64\ \frac{GWh}{year}$$

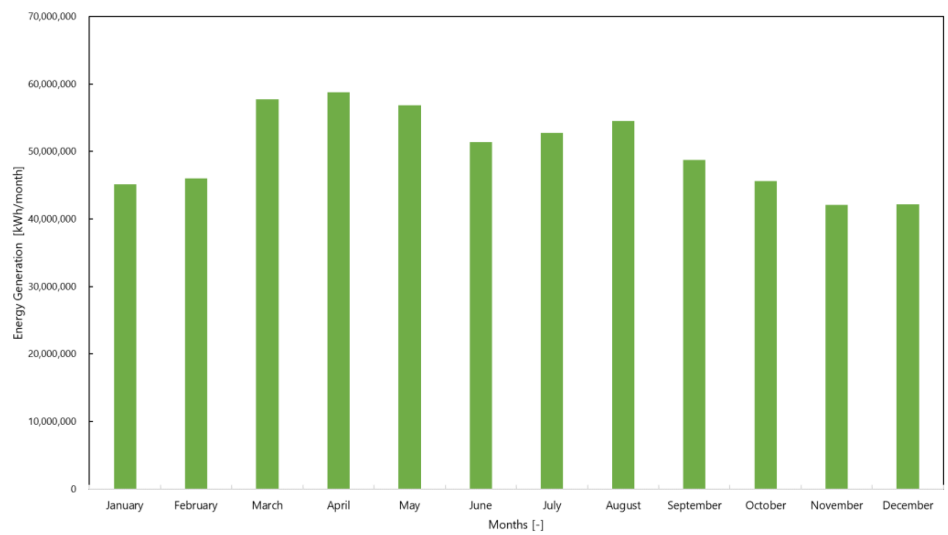

Figure 43. Annual Generation Year 1 HiKu CS3N-420MS

Source: Own Elaboration

For District 11, The months that might generate more energy for District 11 using the solar module HIKU CS3N-420MS are March and April, with a total generation of 11,285,958.65 kWh/month in March and 11,494,465.94 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 8,222,872.72 kWh/month in November and 8,249,916.90 kWh/month in December, with November being the lowest month.

5.9.2 RESULTS HIKU CS3W-420PB

a) Number of Photovoltaic Modules

The number of photovoltaic modules was calculated by dividing the total area of the rooftops by the area of the photovoltaic module which gives an approximate of 185,182 polycrystalline HiKu CS3W-420PB modules.

$$Number\ of\ Modules = \frac{409{,}102.42\ m^2}{2.21\ m^2}$$

$$= 185{,}182.93$$

$$\approx 185{,}182$$

b) Nominal Capacity in DC

The nominal Capacity of this photovoltaic module was calculated by multiplying the amount of photovoltaic modules times the nominal capacity of the photovoltaic module. For District 11 we will have a Nominal Capacity in DC of 77,776.83 kWp.

$$Nominal\ Capacity = 185{,}182 \times 0.420kW$$

$$= 77{,}776.83\ kWp$$

c) Nominal Capacity per square meter by area

For District 11 we will have a Nominal Capacity per square meters of 0.07 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{77{,}776.83\ \ kWp}{1{,}130{,}000\ m^2}$$

$$Nominal\ Capacity = 0.07\ kW/m^2$$

d) *Annual Generation for Year 1*

$$Generation = 77{,}776.83\ kWp\ \times 4{,}335\ hrs \times 31.31\%$$

$$= 105{,}565{,}596.37\ \frac{kWh}{year}$$

$$= 105.57\ \frac{GWh}{year}$$

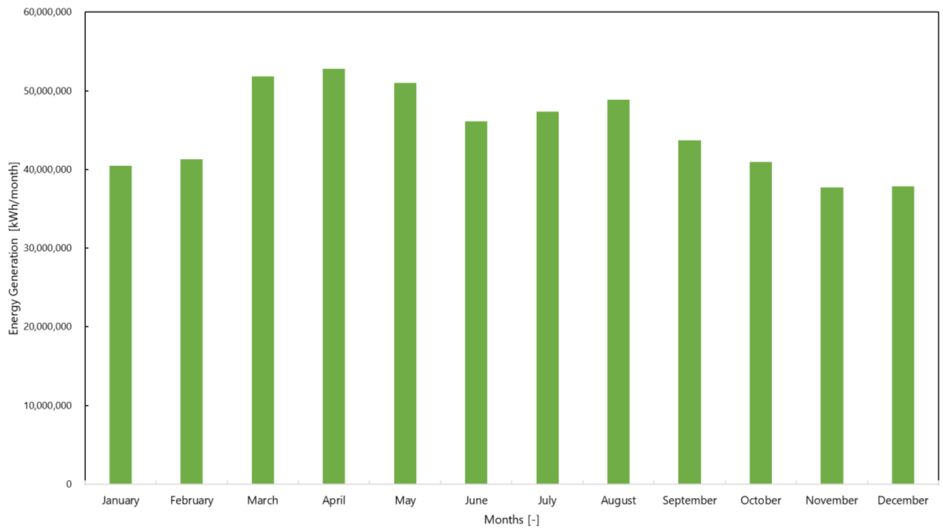

Figure 44. Annual Generation Year 1 HiKu CS3W-420PB

Source: Own Elaboration

For District 11, The months that might generate more energy for District 11 using the solar module HiKu CS3W-420PB are March and April, with a total generation of 10,127,753.60 kWh/month in March and 10,314,863.13 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 7,379,012.40 kWh/month in November and 7,403,281.20 kWh/month in December, with November being the lowest month.

5.10 District 12

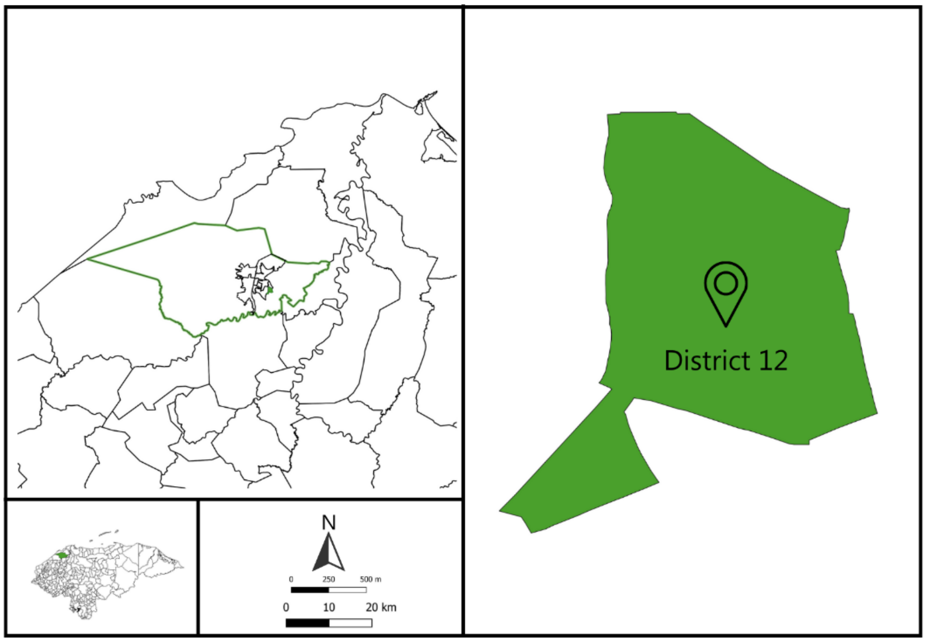

Figure 45. District 12, San Pedro Sula, Cortés

Source: Own Elaboration

Figure , shows District 12 which has an area of 1.40 km^2. Upon calculating the total area of rooftops that we found on District 12, there is an area of 597,394.59 m^2.

5.10.1 Results for HIKU CS3N-420MS

a) Number of Photovoltaic Modules by area

The number of photovoltaic modules by area was found by dividing the total area of the rooftops by the area of the photovoltaic modules. This calculation gives a result of approximate 293,83 monocrystalline HIKU CS3N-420MS modules.

$$Number\ of\ Modules = \frac{597{,}394.59\ m^2}{2.03\ \ m^2}$$

$$= 293{,}831.45 \approx 293{,}831$$

b) Nominal Capacity in DC by area

For District 12 we will have a Nominal Capacity in DC of 123,409.02 kWp.

$$Nominal\ Capacity = 293{,}831 \times 0.420kW$$

$$= 123{,}409.02\ kWp$$

c) Nominal Capacity per square meter by area

For District 12 we will have a Nominal Capacity per square meters of 0.09 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{123{,}409.02\ \ kWp}{1{,}400{,}000\ m^2}$$

$$Nominal\ Capacity = 0.09\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 123{,}409.21\ kWp\ \times 4{,}335\ hrs \times 32.11\%$$

$$= 171{,}781{,}729.35\ \frac{kWh}{year}$$

$$= 171.78\ \frac{GWh}{year}$$

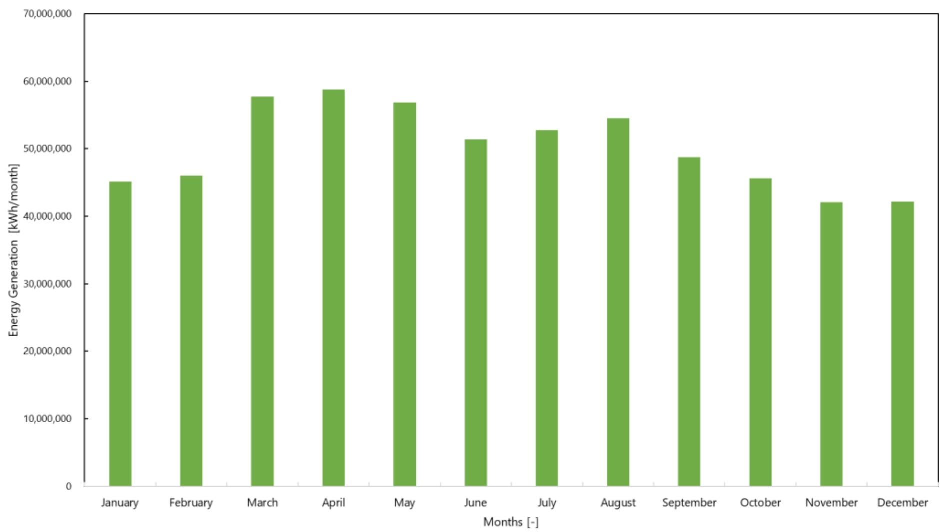

Figure 46. Annual Generation Year 1 HiKu CS3N-420MS

Source: Own Elaboration

For District 12, The months that might generate more energy for District 12 using the solar module HIKU CS3N-420MS are March and April, with a total generation of 16,480,397.85 kWh/month in March and 16,784,872.03 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 12,007,505.80 kWh/month in November and 12,046,997.24 kWh/month in December, with November being the lowest month.

5.10.2 RESULTS HIKU CS3W-420PB

a) Number of Photovoltaic Modules

The number of photovoltaic modules was calculated by dividing the total area of the rooftops by the area of the photovoltaic module which gives an approximate of 270,414 polycrystalline HiKu CS3W-420PB modules.

$$Number\ of\ Modules = \frac{597{,}394.59\ m^2}{2.21\ m^2}$$

$$= 270{,}414.63 \approx 270{,}414$$

b) Nominal Capacity in DC

The nominal Capacity of this photovoltaic module was calculated by multiplying the amount of photovoltaic modules times the nominal capacity of the photovoltaic module. For District 12 we will have a Nominal Capacity in DC of 113,573.88 kWp.

$$Nominal\ Capacity = 270{,}414 \times 0.420 kW$$

$$= 113{,}573.88\ kWp$$

c) Nominal Capacity per square meter by area

For District 12 we will have a Nominal Capacity per square meters of 0.08 kW/m^2, when the nominal capacity in DC by area of the rooftops is considered.

$$Nominal\ Capacity = \frac{113{,}573.88\ kWp}{1{,}400{,}000\ m^2}$$

$$Nominal\ Capacity = 0.08\ kW/m^2$$

d) Annual Generation for Year 1

$$Generation = 113{,}574.14\ kWp\ \times 4{,}335\ hrs \times 31.31\%$$

$$= 154{,}152{,}879.77\ \frac{kWh}{year}$$

$$= 154.15\ \frac{GWh}{year}$$

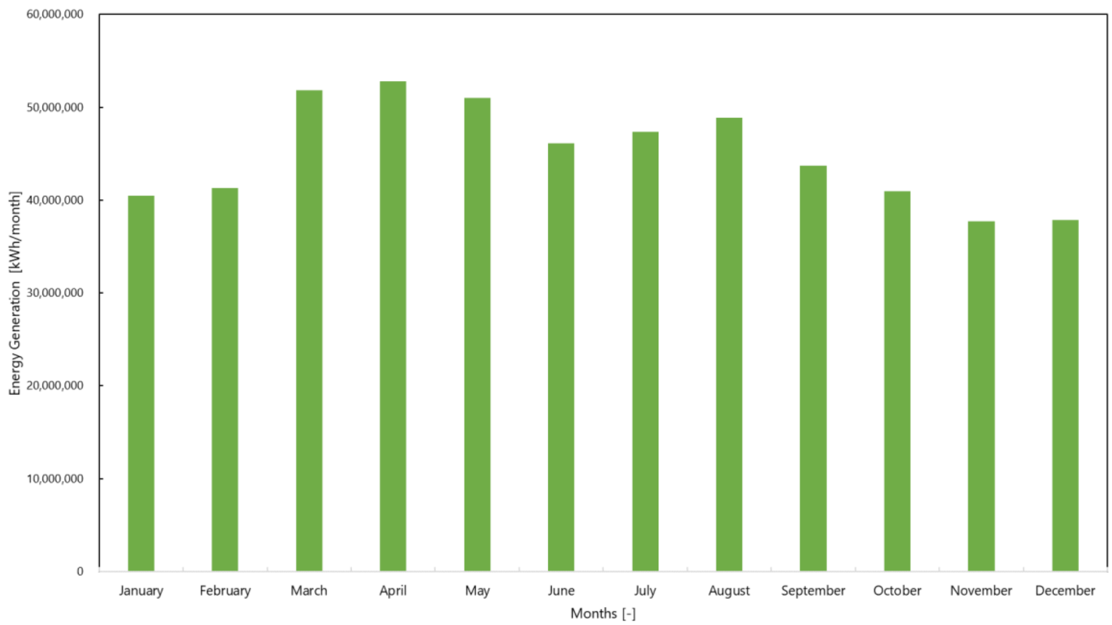

Figure 47. Annual Generation Year 1 HiKu CS3W-420PB

Source: Own Elaboration

For District 12, The months that might generate more energy for District 12 using the solar module HiKu CS3W-420PB are March and April, with a total generation of 14,789,121.04 kWh/month in March and 15,062,349.01 kWh/month in April, the highest month. The months with the lowest overall energy production were November and December, with a collective generation of 10,775,253.02 kWh/month in November and 10,810,691.71 kWh/month in December, with November being the lowest month.

5.11 General Outlook of the Photovoltaic Potential in San Pedro Sula

5.11.1 Photovoltaic Potential per District

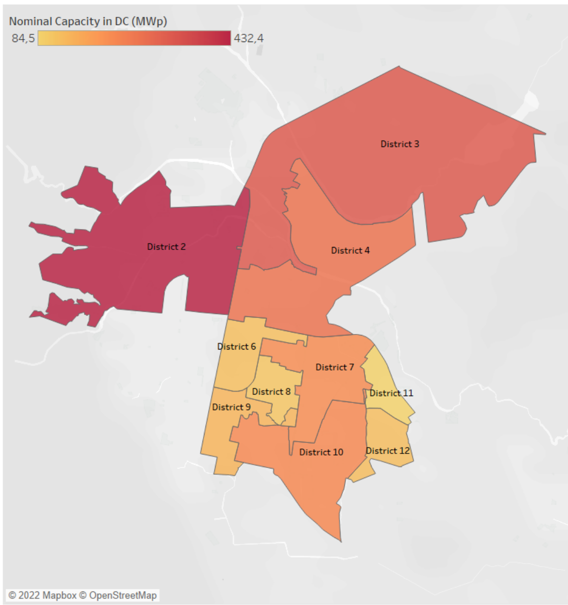

Figure 48. Photovoltaic Potential per district using Monocrystalline technology

Source: Own Elaboration

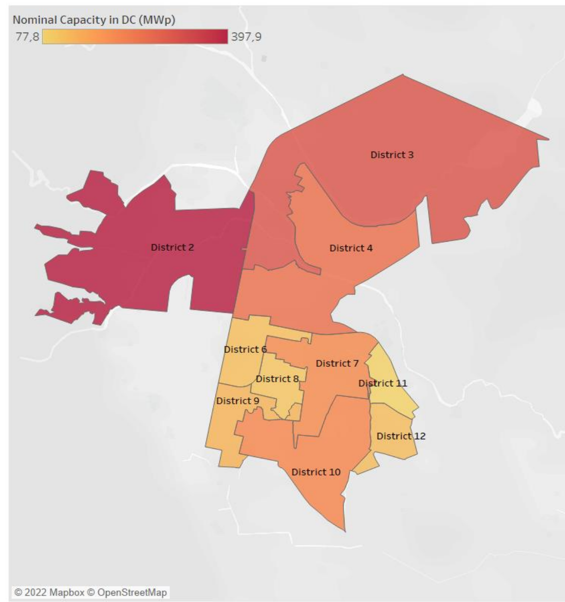

Figure 49. Photovoltaic Potential Per District using Polycrystalline technology

Source: Own Elaboration

The district with the most photovoltaic potential when considering just the area of the rooftops is District 2 with a photovoltaic potential of 432.35 MWp when using a monocrystalline photovoltaic module (HiKu CS3N-420MS), and 397.89 MWp when using a polycrystalline photovoltaic module HiKu CS3W-420PB.

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.

Using the 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.

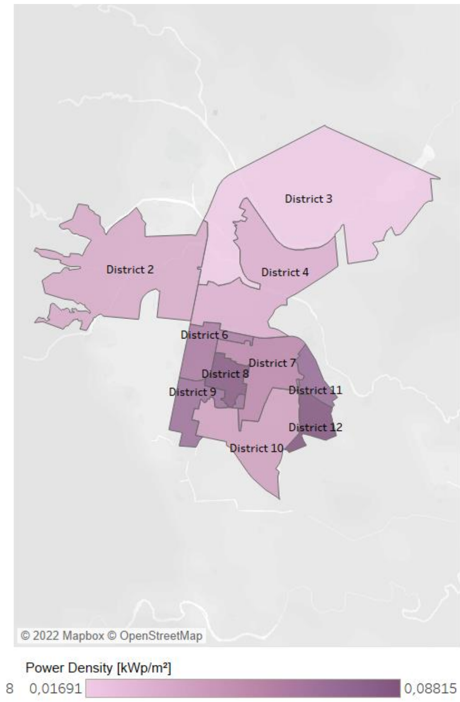

Figure 50. Photovoltaic Potential per square meter using Monocrystalline technology

Source: Own Elaboration

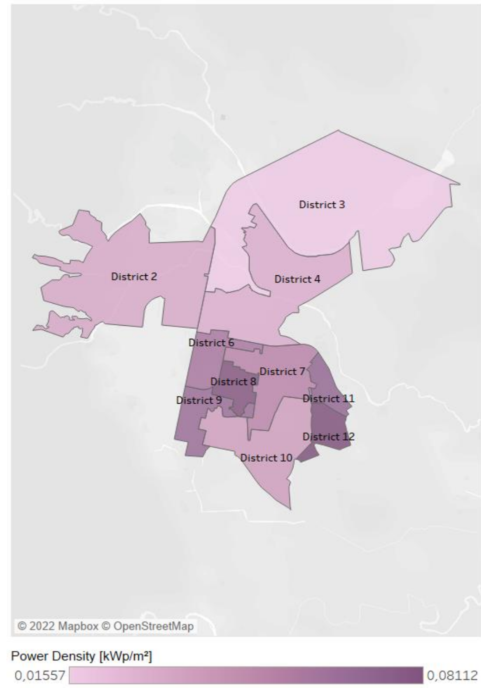

Figure 51. Photovoltaic Potential per square meter using Polycrystalline technology

Source: Own Elaboration

Source: Own Elaboration

The district with the most photovoltaic potential per square meter when considering just the area of the rooftops is District 8, and District 12 with a photovoltaic potential per square meters of 0.09 kW/m^2 when using the monocrystalline photovoltaic module HiKu CS3N-420MS and 0.08 kW/m^2 when using the polycrystalline photovoltaic module HiKu CS3W-420PB.

The district with the least photovoltaic potential per square meter when considering just the area of the rooftops is District 3, with a photovoltaic potential per square meters of 0.02 kW/m^2 when using the monocrystalline photovoltaic module HiKu CS3N-420MS and 0.02 kW/m^2 when using the polycrystalline photovoltaic module HiKu CS3W-420PB.

5.11.2 ENERGY GENERATION

According to Empresa Energía Honduras, (2022) 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 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.

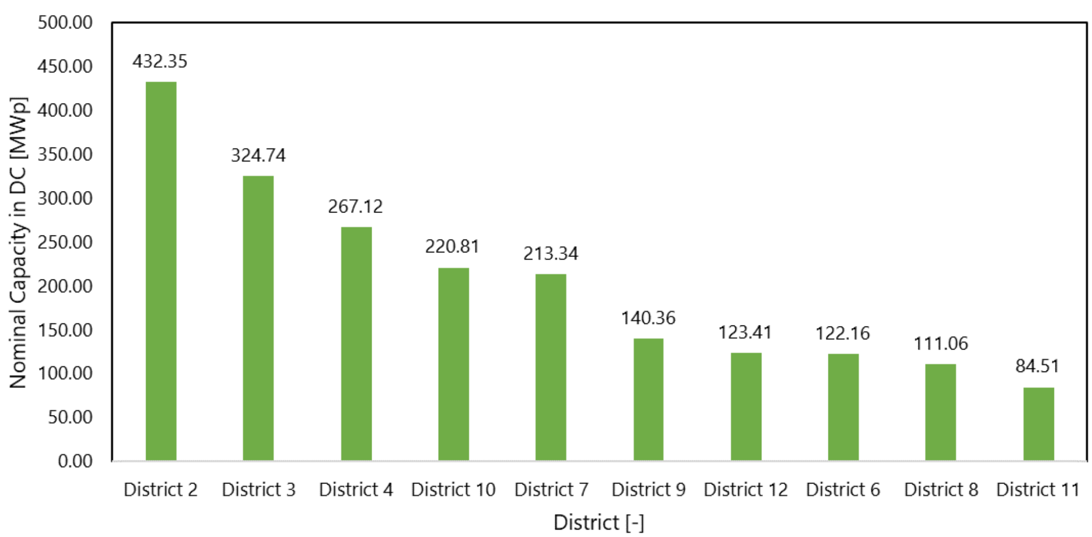

Figure 52. Summary of Energy Generation for Year 1 using monocrystalline technology

Source: Own Elaboration

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.

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.

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.

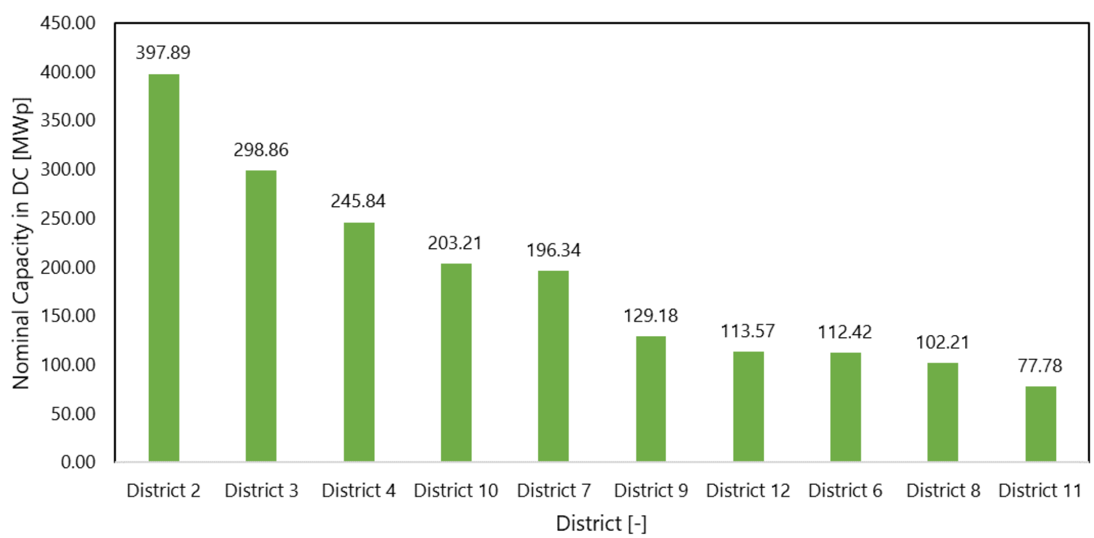

Figure 53. Summary of Energy Generation for Year 1 using polycrystalline technology

Source: Own Elaboration

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.

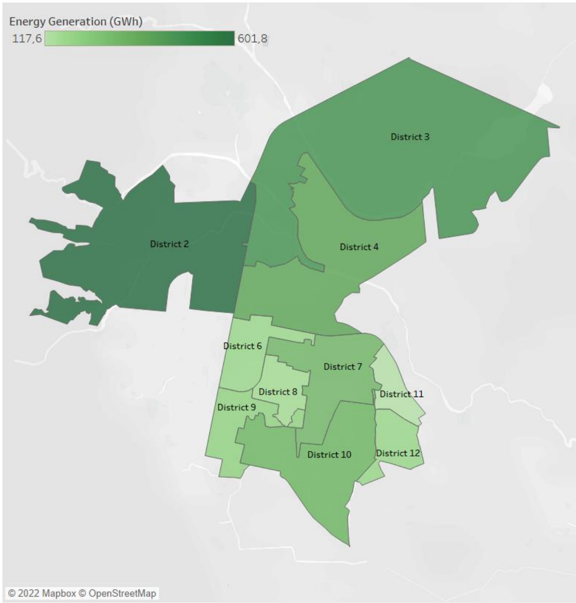

Figure 54. Energy Generation using Monocrystalline technology

Source: Own Elaboration

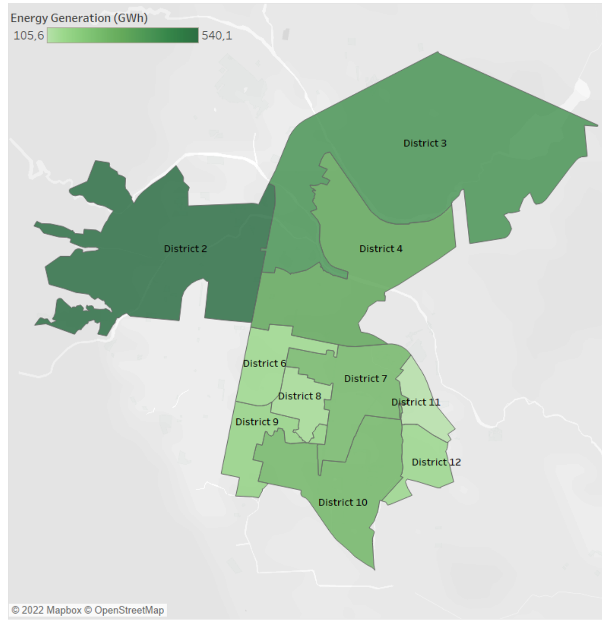

Figure 55. Energy Generation using Polycrystalline technology

Source: Own Elaboration

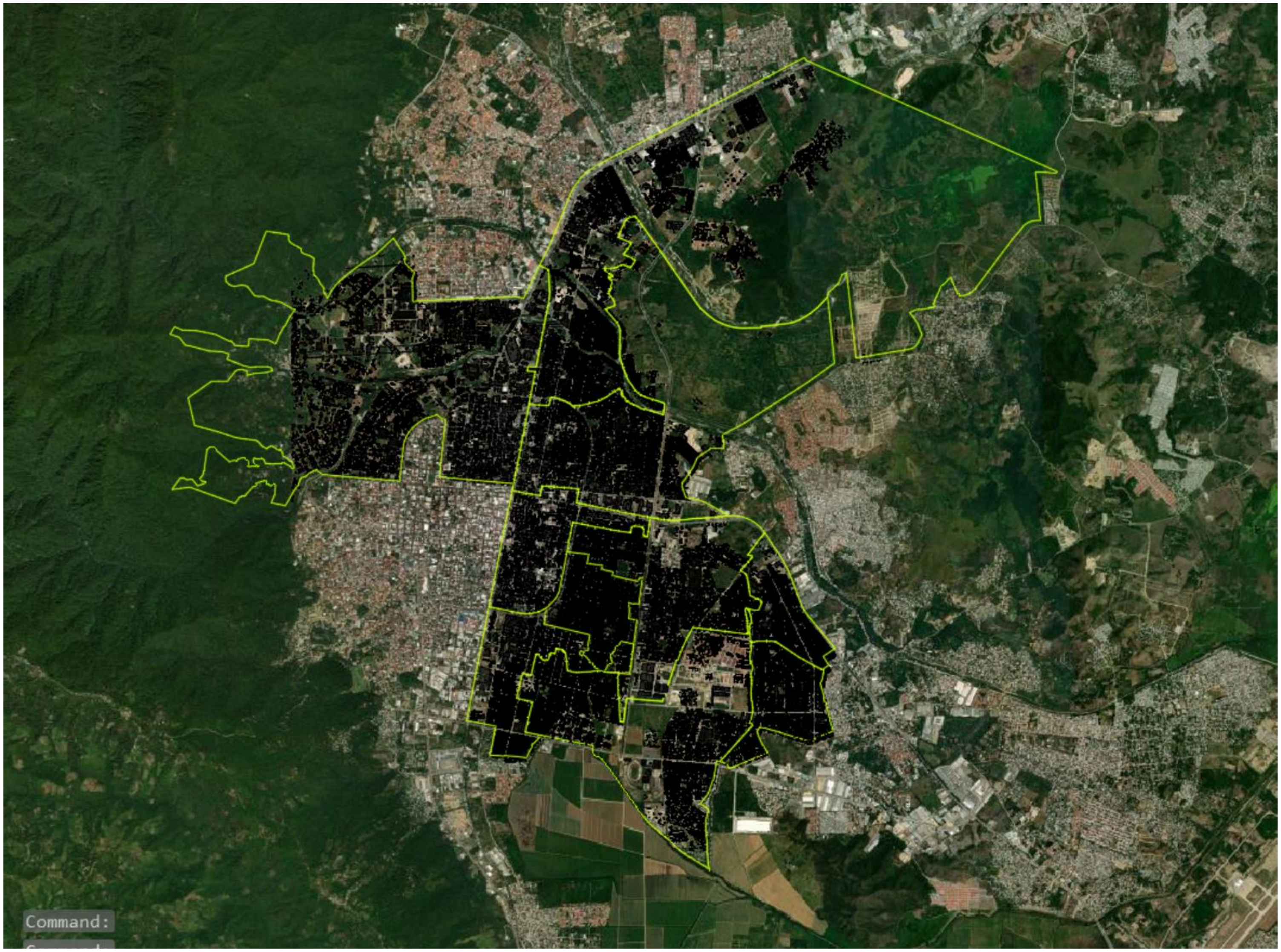

Figure 56. San Pedro Sula, Cortés covered in monocrystalline technology

Source: Own Elaboration

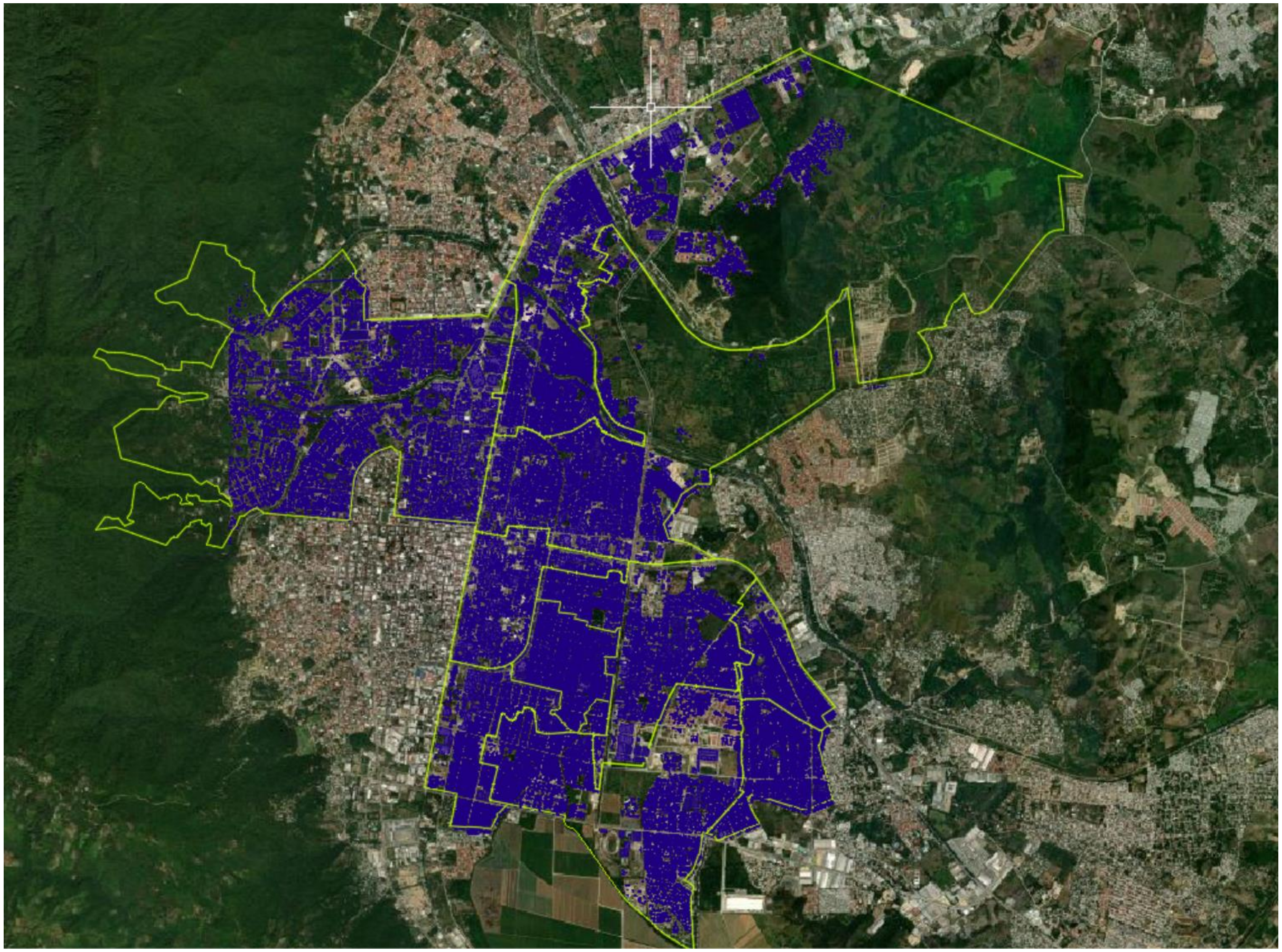

Figure 57. San Pedro Sula, Cortés covered in polycrystalline technology

Source: Own Elaboration

IV. 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 photovoltaic modules HiKu CS3N-420MS and HiKu CS3W-420PB. Based on the results compiled, the conclusions of this research are shown below:

- The variables used on this research for the calculation of the photovoltaic potential were different on the two scenarios considered. In scenario one the areas of the rooftops were considered, we considered two different photovoltaic modules one that was monocrystalline, HiKu CS3N-420 MS, and polycrystalline, HiKu CS3W-420 PB, with the same nominal power in order to calculate the photovoltaic potential.
- In scenario two the areas of the rooftops were considered, the two photovoltaic modules where one was monocrystalline, HiKu CS3N-420 MS, and the second was polycrystalline, HiKu CS3W-420 PB, with the same nominal power, for this scenario there was a calculation of the number of modules per strings as the use of an inverter was introduced.
- Due to the data available on Cad Mapper, we were able to retrieve the information of the areas of the rooftops of the city of San Pedro Sula. For this research ten out of the twenty districts were selected as the available data presented full coverage of those districts, and only partial coverage for the other districts.
- 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.
- 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.
- 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.

- 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.

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. With more accurate data, like detailed information of the height of buildings, azimuth, accurate areas per rooftops, there would be a more precise calculation of the photovoltaic potential on the city of San Pedro Sula. It would be necessary to have an accurate record of the electricity consumption for the city of San Pedro Sula to have an accurate representation of the feasibility of a large-scale photovoltaic project. Additionally, we would have to considered that currently in Honduras there is not a bill that supports the decentralization of energy.

Despite these limitations, this research can be useful for the decision-making process relevant to future projects of photovoltaic installations on rooftops that can help to finish the transition away from fossils fuels usage for energy generation and towards an Energy Matrix composed entirely of renewable energy. The relevant point of this research comes from the calculation of the photovoltaic potential on the city of San Pedro Sula. This type of research can be applied on a smaller scale such as in specific neighborhoods of the city or on a large scale such as different cities of the country, or a full department and not being limited to just one municipality.

V. RECOMMENDATIONS

- The scenario to consider the replacement of non-renewable technology on the energy matrix in Honduras is for photovoltaic monocrystalline technology, using the photovoltaic module HiKu CS3N-420 MS.
- This research can be conducted in the ten districts that were not selected on this current research to compare the photovoltaic potential and have an approximate data for all San Pedro Sula.
- This research can be automated by creating a software that can assist by analyzing an image and identifying the rooftops on it to calculate the photovoltaic potential with more accuracy.

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