Mapping of Solar Power Potential Structures Using Geographic Information System

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***Abstract*— Solar energy has massive potential to address energy shortage problems and elevate living standards. More and more people are starting to invest in solar power systems by installing solar panels on their roofs. It is a way to generate electricity for homes and businesses without increasing the negative impacts on the environment. However, the fact remains that some buildings will not benefit from solar panels as they are not located in the right area or position. For this reason, this study developed a method of generating a map showing structures suitable for solar panel installation. The method was applied in the town center of a third-class component city in the Philippines. Digital Elevation Model (DEM), Geographical Information System (GIS) tools, and digitized structures were used to generate the map along with different criteria which served as a guide in identifying suitable structures. The criteria used were the rooftop's slope, orientation, solar radiation, and surface area. The results show that 24.23% of the structures in the town center are suitable structures for solar panel installation with a potential energy generation of 7681.796135 MWh.**

Keywords*— GIS; DEM; solar power; solar radiation; solar panel

I. INTRODUCTION

Worldwide primary energy demand is expected to continue growing due to economic and population growth. Researchers have projected global energy consumption to grow by 1.2% every year from 2010 to 2050 [1]. Half of this energy usage in the world is related to domestic and non-domestic buildings, most of which are to be found in cities. The troublesome rise of overall rates of energy consumption [2] in many countries has driven the displacing of some of the conventionally generated energy with non-polluting sources of energy. The consensus view is that the cleanest and safest option is renewable energy, of which direct and indirect sources of solar energy are the most abundant [3]. Solar energy solutions or solar photovoltaic (PV) systems have tremendous potential to solve issues of energy scarcity and to improve living standards. It is a renewable energy source that will play a crucial role in diversification in achieving a sustainable and stable energy future [4].

The solar panel is the main part of a solar PV system. It is a large frame consisting of solar or PV cells that are connected electrically and organized neatly. It has no moving parts and requires no maintenance. They are constructed ruggedly and are kept properly for decades to last. The direct conversion of sunlight by solar photovoltaic (PV) technology into electricity has enormous untapped potential and represents a technically feasible and sustainable solution to energy demands [5]. Most solar panels are installed on rooftops because of their potential in urban sustainability initiatives such as solar thermal heating, green roofs, and runoff management. However, the maximum potential of PV when installed on any suitable rooftop does not yet exist in most regions [6] in the world.

The solar activity in tropical countries is said to be higher as compared to polar countries [7]. This high solar activity in the tropics is beneficial for the successful operation of a solar farm with electricity generation capacities ranging from 10 megawatts (MW) to 150 MW [8]. The Philippines which is a tropical country, is fifth worldwide in terms of the use of solar PV systems for electricity generation, according to a Dutch consultancy company [9]. Solar PV systems in the Philippines are not only seen in solar farms but also on rooftops of buildings, houses, and other structures. Although the use of solar PV systems is increasing in the country, there is a dearth of studies as to how much electricity can be generated by a solar PV system that is installed on rooftops.

This study created a map that shows structures that will benefit most in the installation of a solar PV system on its rooftop. It was done by determining the potential solar energy that can be generated from each structure in the study area using the Geographic Information System (GIS) software. GIS has been used in locating potential areas where a solar farm can be built but there is a dearth of studies in pinpointing structures that can benefit from solar PV systems.

II. METHODS

The research process presented in Fig. 1 shows the activities done to map the solar power potential of the different structures in the study area.

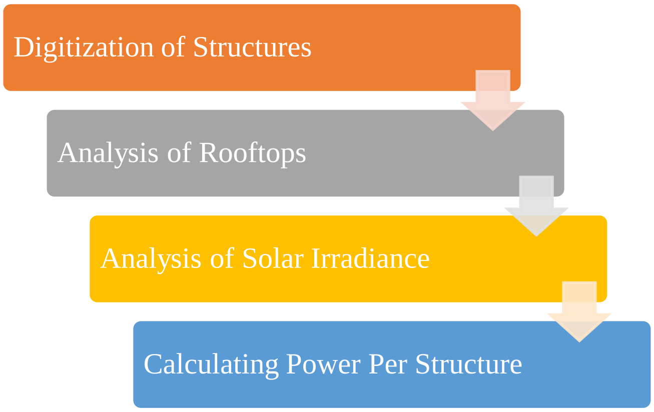

Fig. 1. Research process of the study.

The study area shown in Fig. 2 is in the urban area of Tuguegarao City called Centro Barangays. Tuguegarao City is a third-class component city in the Philippines that is known for its hot weather during summer. Its economy gradually changed from agricultural activities to industrial activities such as businesses, commerce, and services. These changes led to Tuguegarao as one of the primary centers for businesses in Northern Luzon; thus, it must have a sustainable and enough power supply to sustain all the businesses and works it has.

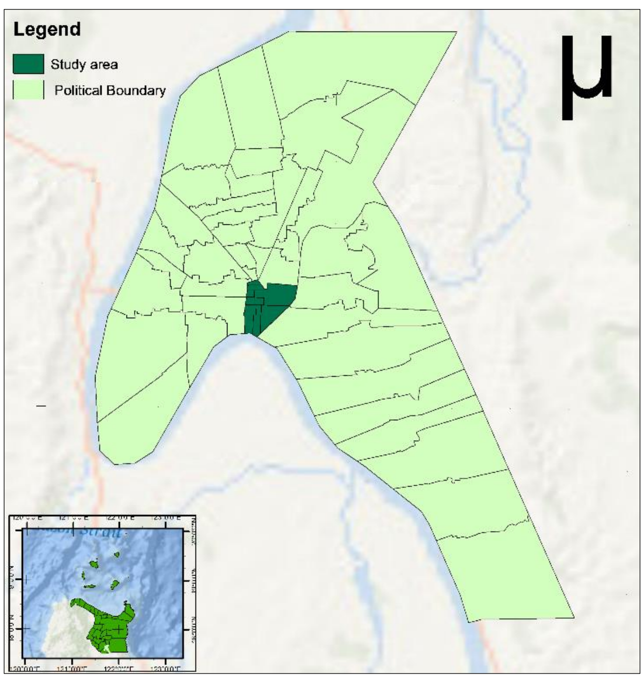

Fig. 2. The political boundary map of Tuguegarao with the study area shaded in green.

The data used in this study were gathered from government agencies and other online free resources. These data sets were subjected to further processing using GIS toolsets to harmonize and use them. All datasets were projected into a common projection, the World Geodetic System 1984 (WGS84). ArcGIS 10.2 was utilized for data processing and data analysis.

The study followed the five criteria presented in Table 1 aside from identifying structures that will benefit most in the installation of a solar PV system on its rooftop. Each of these criteria is explained in the following subsections.

TABLE I. CRITERIA FOR IDENTIFYING SUITABLE ROOFTOPS FOR SOLAR PANELS

Criteria	Description
Shadow Aspect	removed shaded structures
Area	greater than 30 sqm
Slope	40 degrees or less
Orientation	between south-east (-45°) and south-west (+45°)
Solar Radiation	greater than 800 kWh/m^2/year

A. *Digitization of Structures*

Generating a digitized structure map of the study area was the first process of finding suitable rooftops for solar PV system installation. The map shown in Fig. 3 was generated using ArcGIS by entering the information on the heights and floors of structures as well as inputting the base map and political boundary map of the study area.

The heights and floors of the structures in the study area were gathered by ground validation. The base map used was a downloaded image from Google Earth. The Tuguegarao City political boundary map which was used to delineate the extent of the study area was taken from a government agency.

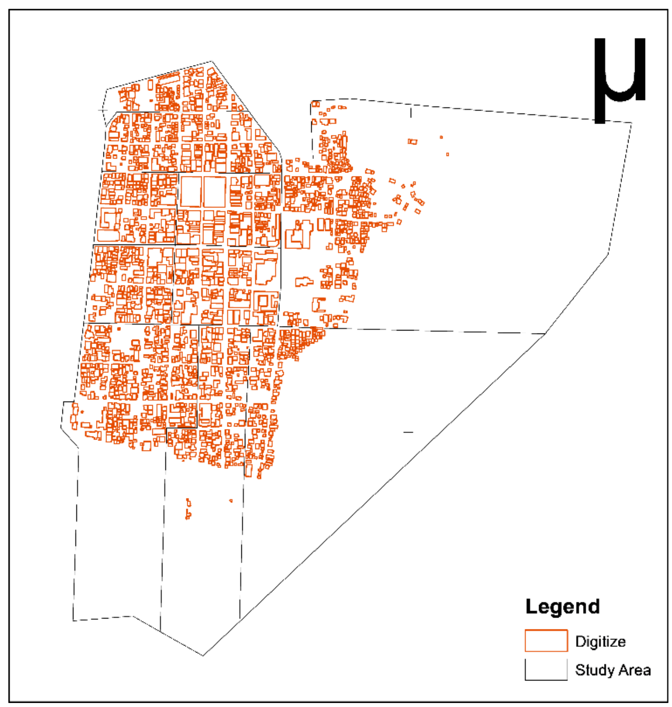

Fig. 3. Digitized map of the study area.

The first criterion in finding suitable rooftops was the shadow aspect of the structure. The heights of structures were used to perceive the shaded structures. Shaded structures were not selected to analyze the rooftop solar energy potential because this condition reduces the overall performance of solar panels [10].

The rooftop surface area is another criterion that was determined through the digitized map. It was considered as a criterion in identifying suitable rooftops because a typical 5-kilowatt peak (kWp) solar PV system installation occupies about 30 square meters [11] of surface area on the roof.

B. Analysis of Rooftops

The rooftop slope is important in finding suitable rooftops for solar PV system installation because roofs that are too steep have lesser solar energy harvest [12]. Structures with pitched roofs characterized by a slope not greater than 40° range have been disregarded while flat roofs have been considered suitable. The rooftop slope of the structures in the study area was determined using the slope map shown in Fig. 4. This map was generated using the Slope Spatial Analysis Tool of ArcGIS with the DEM as the input raster layer.

The last criterion in finding suitable structures for solar PV system installation is the rooftop orientation. Rooftop orientation has been assessed using the Calculated Metric ArcGIS tool. The rooftops that were considered suitable are only buildings oriented South (0°), precisely just the ones between South-East (-45°) and South-West (+45°). These orientations were selected because the north-facing rooftops in the northern hemisphere receive less sunlight [13]. The DEM was also used as the input raster layer for the creation of the rooftop orientation map shown in Fig. 5.

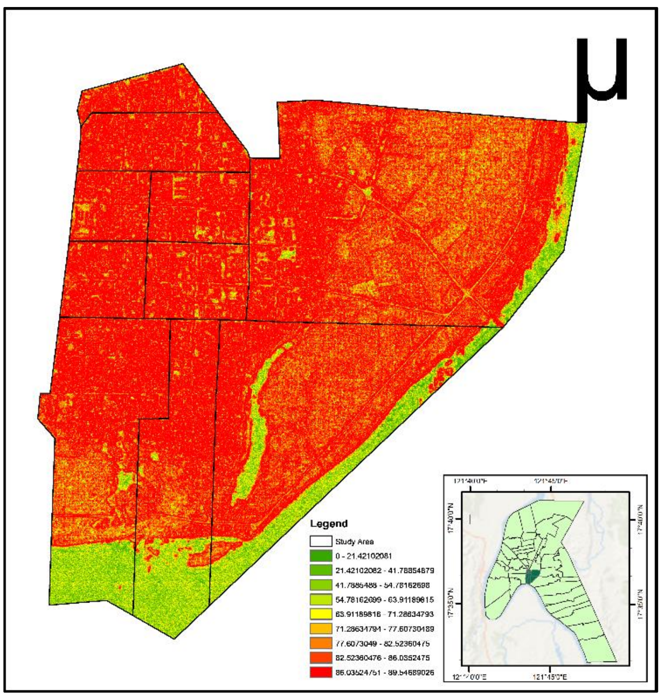

Fig. 4. Rooftop slope map of the study area.

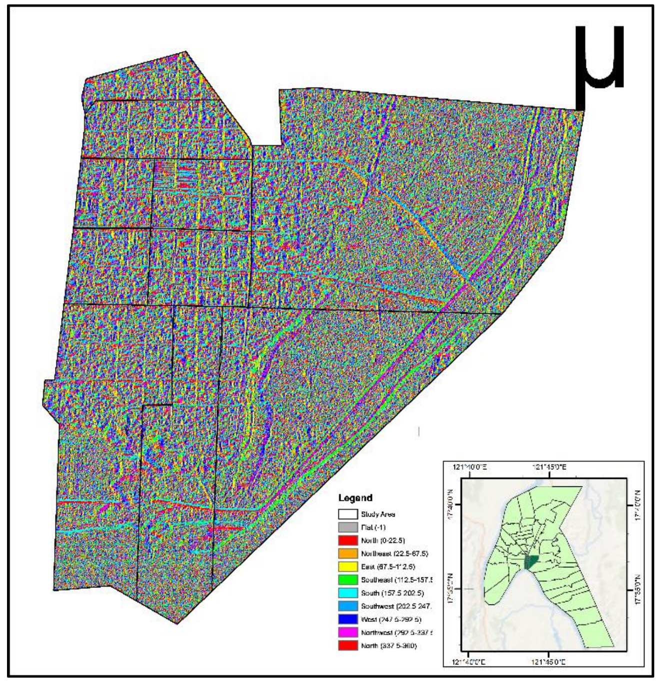

Fig. 5. Rooftop orientation map of the study area.

C. Analysis of Solar Irradiance

The next process in finding suitable rooftops for solar PV system installation is through solar irradiance analysis. From this analysis, a solar irradiance map will be created. The solar irradiance map is a layer that maps the amount of solar energy that reaches the rooftop of the study area. When a roof surface receives more solar energy, more electric power will be produced by solar panels. The solar radiation is a criterion that can be assessed using the solar irradiance map. Surfaces with a mean irradiation of below 800 kWh/m2 per year were not considered suitable [14].

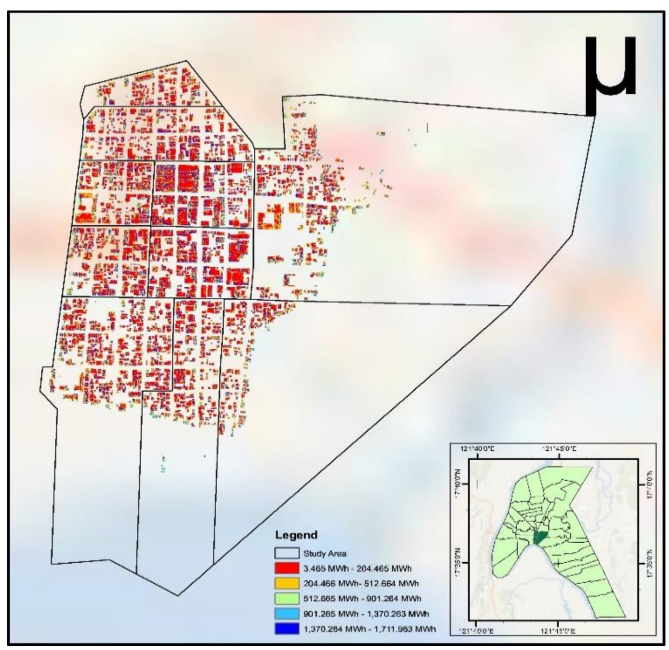

Fig. 6. Solar irradiance map of the study area.

In creating the solar irradiance map, the Area Solar Radiation tool of ArcGIS was utilized. It is a tool that calculates solar radiation based on a model that considers the sun's position at different times of the day all year round, obstacles like trees or buildings that may block sunlight, and the orientation and slope of the surface. The DEM provides information about the slope, orientation, and obstacles. For this study, the DEM was downloaded from PhilGIS, a website where free GIS data for the Philippines can be downloaded. Aside from the DEM, the digitized map was also used in creating the solar irradiance map to get only the solar radiation from the building surfaces. Anything that is outside the surfaces is not displayed. Further adjustments on units of measurement and symbolization of layers were the last step done in this process for better visualization of the solar irradiation map shown in Fig. 6.

D. Calculating Power per Structure

The solar irradiance map shows how much solar radiation each raster cell receives. The cells in the raster layers cover a relatively small area, so this information is not that meaningful when looking at the entire Centro barangays or even a single structure. The solar radiation data were aggregated to determine how much solar radiation each structure receives in a typical year. Then, the solar radiation is converted to electric power production potential. This process is done using the Zonal Statistics Table of the ArcGIS.

To appreciate the outputs from this study, the electric power production potential of the Centro Barangays is computed using the usable solar radiation values. The amount of power that solar PVs can produce depends not only on solar radiation but also on the solar panel efficiency and the installation's performance ratio. For this study, the conservative estimate of 15 percent efficiency and 86 percent performance ratio is recommended by the United States Environmental Protection Agency (EPA). These values mean that the solar panels are capable of converting 15 percent of incoming solar energy into electricity, and 86 percent of that electricity is maintained throughout the installation. To determine electric power production potential, the ArcGIS was used to multiply the usable solar radiation values by the efficiency and performance ratio values.

III. RESULTS AND DISCUSSION

The map of potential solar energy in the City of Tuguegarao was generated through overlaying of all map layers and applying criteria. All the suitable structures shown in Fig. 7 were classified from the maximization of solar energy.

TABLE II. PERCENTAGE OF STRUCTURE SUITABILITY

Classification	Percentage
Not Suitable	75.77%
Less Suitable	21%
Suitable	2.93%
Most Suitable	0.30%

In terms of percentage, the suitability of solar PV system installation in the structures located at Centro Barangays is very low as shown in Table II. This result is due to the shading of neighboring structures which was also a prominent factor in [15]. Most commercial and residential structures located in the Centro barangays are one-story buildings which are located around high structures. Moreover, the rooftops of most structures in the Centro barangays only cover a small area which is not suitable for the installation and racking of solar PV systems.

The potential PV system energy generation per barangay is shown in Table III which indicates that Centro 5, Centro 6, and Centro 7 can double the energy generation of the other Centro barangays. This indicates that the kinds of structures in the Centro barangays are different. Some of the Centro barangays are still used as a residential area where the one-story house is located. These one-story houses receive less sunlight due to the shading of neighboring structures.

TABLE III. POTENTIAL PV SYSTEM POWER GENERATION PER BARANGAY

Barangay	Electric Power Genenration (MWh)
Centro 1	621.890538
Centro 2	719.897307
Centro 3	633.111427
Centro 4	815.492583
Centro 5	1048.663422
Centro 6	1224.138533
Centro 7	1184.349896
Centro 8	321.833785
Centro 9	342.599414
Centro 10	769.81923

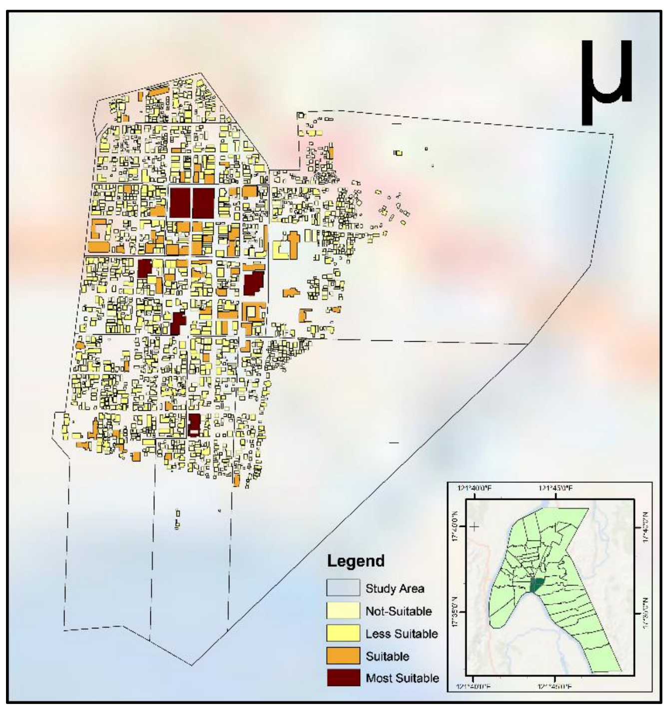

Fig. 7. Solar PV System Installation Suitability Map.

The total potential PV system energy generation in the Centro barangays is 7,681. 796135 MWh. Although this result is hard to compare with [16] and [17] who studied a whole city, the total potential PV system energy generation is relatively lower. This suggests that only those structures that are considered highly suitable for PV system installation on the generated map from the study should consider this renewable energy generation option.

IV. CONCLUSION

This study demonstrated the utility and advantages of GIS techniques in the evaluation of solar radiance and the analysis of structures' rooftop suitability for solar PV system installation. The derived solar irradiance map showed the solar availability in the Centro barangays of Tuguegarao receives an adequate amount of exploiting solar energy capacity, and the performed suitability analysis concludes that the majority of the structures in the area which is suitable for solar panel installations are large structures. The study area may subsequently opt to venture into it to meet growing power source needs. The findings obtained will be of great help in the preparation and decision-making cycle for solar panel installation.

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