GIS-BASED ROOFTOP SITE MAPPING FOR SOLAR PHOTOVOLTAIC SYSTEM INSTALLATION USING LIDAR-DERIVED DSM

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ABSTRACT: Photovoltaics (PV) systems have gained attention due to its declining cost and more consumers are now venturing into PV to sustain their energy needs. However, to maximize the energy that can be captured by solar panels on roofs in urban areas, the optimal sites for PV installation must be determined. Using Light Detection and Ranging (LiDAR), this assessment can be performed in larger scopes with higher accuracy in a shorter timeframe. This study utilizes LiDAR data and ArcGIS tools to locate optimal rooftop sites for solar PV installations with the criteria of slope, aspect, surface area and shading. Building footprints were manually extracted from LiDAR-derived Digital Surface Model. Rooftop segments and characteristics were created and measured. The results were presented in a map showing rooftop sites that are optimal for PV installation. The results show that 12.13% of the rooftop segments in the study area are suitable for PV systems installation. Moreover, the total area of the rooftop segments is approximately 497,046 m^2 which can generate an estimated amount of 28,905MWh of energy yield a year. The results of this study are critical for financial and urban planning, deployment of financial schemes and in formulating policies for future energy projects.

1. INTRODUCTION

Global warming and energy crisis are two of the major challenges faced by today’s generation. Since the time of industrial revolution in the 18^{th} and 19^{th} century, there has been a continuous combustion of fossil fuel for energy and transportation which causes the release of various greenhouse gases to the atmosphere. This led to the increase of the average temperature of the earth causing environmental concerns. One major contributor to this issue is in the energy sector, since the global modernization and development are at play coupled with the exponential increase in the world’s population, the demand for energy supply continues to grow. This calls for the immense need of renewable clean energy. In the Philippines, energy shortage is evident mostly during dry season between the months of April and May when the dams dry up which supplies for hydroelectric energy coupled with non-operational transmission sites. This results in power outages and rotational blackouts in the country. This greatly affects mainly the urban areas in every region since these areas consist of commercial establishments which account for higher density of energy usage especially during the day.

Solar energy is regarded as one of the top sources of renewable energy worldwide because of its abundance and sustainability. In fact, over the past years, its share in the global energy mix is steadily increasing (GIZ, 2013). It has long been viewed as a high potential, viable solution against the exceeding demand on electricity. Unlike the commercial sources like fuel and coal, utilizing renewable energies like solar does not lead to contribute to today's ever growing problem in the environment. More countries are now relying to solar power to sustain their energy needs thus making their move in maximizing this high potential energy source through the conversion of sunlight to electricity through photovoltaics.

Over the recent years, photovoltaics has been gaining much attention because of the declining costs of PV systems. Solar industries around the world are rapidly growing with an average annual growth rate of 44% from 2000 to 2014 (Fraunhaufer ISE, 2016) consequently, more individual consumers, companies are becoming interested in having solar PVs installed in their own establishments or houses.

To address the country's increasing demand on electricity as well as to take advantage of the declining cost of solar PV systems, it is essential to understand and assess the potential sites where solar PV systems can be installed specifically in the urban areas. This implies that large scale assessment is imperative. With the use of Light Detection and Ranging (LiDAR) technology, this assessment can be performed in a larger scope with higher accuracy in a shorter timeframe.

2. CONCEPTUAL FRAMEWORK

The LiDAR data, specifically the Digital Surface Model (DSM) of Toril is used in this study along with the extracted building shapefiles to represent the rooftops in the area. With the criteria of slope, orientation, area and shading, rooftop sites that are suitable for for PV systems are determined. After these sites are identified, the potential solar energy production is estimated.

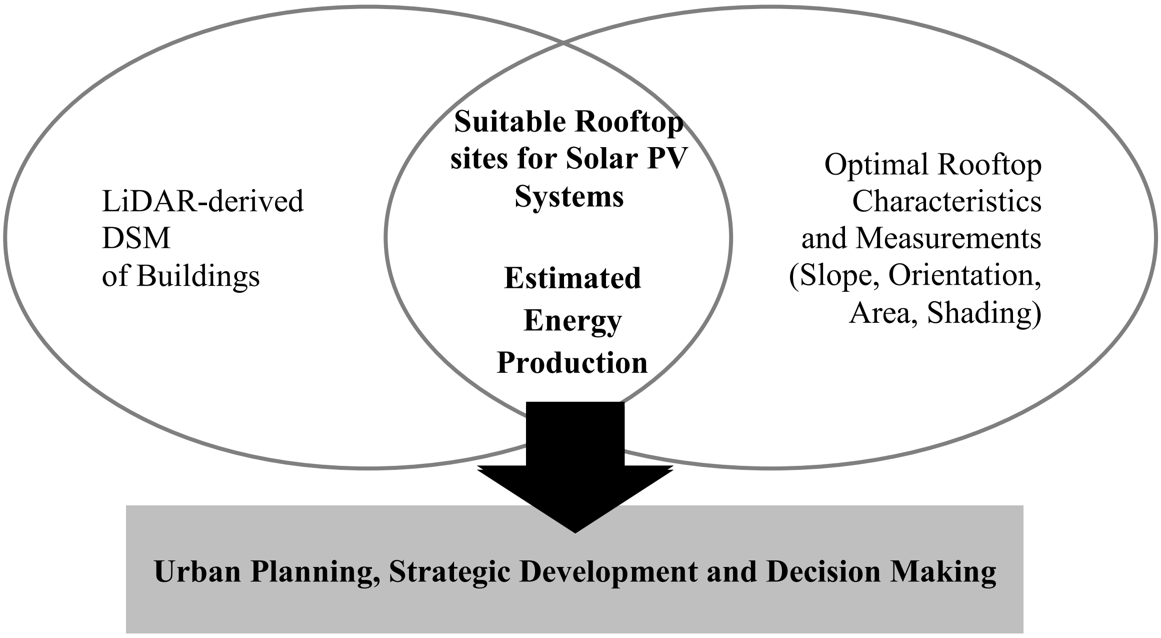


Figure 1: Conceptual framework in identifying suitable sites for Solar PV system installations in Toril District, Davao City.

3. OBJECTIVES

The purpose of this study is to locate and map out the potential rooftop sites for photovoltaic installations in Toril District, Davao City using LiDAR data and building footprint data. Specifically, the study aims to (1) Locate potential rooftop sites based on four rooftop characteristic namely, slope, aspect, surface area and shading, (2) Produce maps of the resulting datasets based on each of the four characteristics and a general map showing the rooftop sites in Toril District, Davao City suitable for PV system installations, (3) Estimate the potential solar energy production.

This study is limited only in studying solar panels attached on roofs and assessing rooftop solar potential using LiDAR derived DSM together with the available building footprint of Toril area. The buildings included in this study from which the building polygons were extracted are assumed to be in good condition and has the capacity to host solar PV systems.

4. REVIEW OF LITERATURE

4.1 Solar Industry in the Philippines

In the Philippines, various laws and energy policies and regulations have been established to propel the utilization and development of renewable energy. Led by the Department of Energy (DOE), the recently passed Renewable Energy Act (Republic Act 9513) of 2008 as well as its support mechanisms, the Net Metering scheme and the feed-in tariff and net metering paved the way for the development of Renewable energy and later accelerated the growth of solar industry in the country (Fajardo et. al. 2014).

As such, DOE together with other government and non-government partners, released administrative procedures to guide project developers, decision making body, individual consumers, and stakeholders of solar projects and to ensure efficient implementation, and also, to increase investment and boost solar industry.

From 2010 to 2030, the DOE is seeking to triple the capacity of RE to 15, 304 MW as presented in the National Renewable Energy Program by prioritizing the implementation of RE Act support mechanisms such feed-in tariff and net-metering schemes. With an optimistic target of 1, 528 MW, the solar industry is expected to contribute a large portion in the future energy mix of the country. DOE put an emphasis to this goal of escalating the installation target for solar by increasing the feed-in tariff capacity to 500MW updated last 2015 which was previously 50MW last 2012 as outlined under the FIT system. Solar industry in the Philippines is expected to have a radical growth within the few next years (Fajardo et. al. 2014).

4.2 Solar Photovoltaics

A solar photovoltaic system consists of various components such as solar panels, mounting frames, inverters, electrical wiring, and switches and among others that collectively allows the conversion of sunlight to electricity and be used by the consumer (Asian Development Bank, 2014). When a number of solar panels are installed together in one place, it is referred to as a solar array and can be placed on the ground or mounted on the roof.

Specifically, a solar panel is composed of semiconductors called photovoltaic modules or panels that convert the photons from the sun into electricity by moving unattached electrons through conducting wires across an electric field. This process is known as the photovoltaic effect. The mounting frames are attached to the modules for security as it is placed on the roof. Inverters are used to convert direct current (DC), which is the output of the modules, into alternating current (AC). Once the conversion is done the electricity can then be used as energy on the spot, sent to a battery for storage or transmitted directly to an electricity network (Asian Development Bank, 2014).

4.3 Optimal Rooftop aesthetics and conditions for Solar PV Installation

To set a strong foundation for the coming of solar projects identifying potential solar sites is necessary, in this case rooftop sites in an urban environment. One can always place a solar panel under the sun, however there will also a greater power output if the panels are placed on an optimal site. Buildings are made differently, to maximize the amount of solar energy, various factors have to be considered, namely such as the following: (a) Geographical Location (b) Material and sustainability (c) Surface topography (d) influence of atmospheric attenuation by molecular absorption (e) shadowing effects (Luka et. al. 2014).

In a literature study conducted by National Renewable Energy Laboratory, four rooftops characteristics were identified as important factors to consider in assessing rooftop potential. These are slope, orientation, shading and size (Melius et. al. 2013). The optimal tilt or slope of solar panels usually depends on the geographic location of where the system is to be installed. Calculations must be done to find the ideal tilt of the panel. In the local setting, the minimum slope must be equal to the angle above the equator up to a maximum tilt which can be computed as angle = latitude + 15 degrees. This is to consider the tilt angle of the earth and to capture the sunlight even in its lowest point. In Davao City, the general latitude is 7 degrees, thus the solar panels must be tilted 7 degrees up to 22 degrees (Ducut, 2010). For the orientation, solar panels installed in the Philippines should be faced south since the sun threads on an East-West direction from the South (Ducut, 2010). According to a literature study conducted by the National Renewable Energy L, the minimum rooftop space requirement for a typical residential solar powered building is 10 m^2 (Melius, 2013). For the shading, ideal location must be exposed to direct sunlight for a minimum of 5 hours per day (Solar Systems Philippines, 2011).

4.4 LiDAR data for Solar PV Rooftop Assessment

Various studies on assessing potential rooftop sites for solar PV installation has already been made from all over the world. Majority of these studies make use of GIS-based methods wherein the ideal values for rooftop characteristics are used as input to a computer model and process these data in a GIS software to determine the areas with high suitability (Melius et.al. 2013).

In recent researches, LIDAR technology is one that is predominantly used in order to assess solar potential. LiDAR which stands for Light Detection and Ranging is a remote sensing technology that captures accurate topographic data by emitting focused light beams on a target area, computes the distance and the time it takes for laser lights to be detected by the sensor (NOOA, 2012). This emerging technology is a promising tool for applications that requires spatial data, mapping, geographical assessment and monitoring which greatly benefit states and regions for further development and/or resilience.

5. MATERIALS AND METHODS

A wide range of techniques has been used in determining suitable rooftop sites for solar PV systems in an urban setting. In this particular study, the procedures implemented were mainly based on the method devised by Bayrakci Boz, etal. (2015) wherein the resources used also coincides with the available data and software.

5.1 Study Area and Datasets Used

Toril District (7.0150° N, 125.4979° E) is the chosen area for this study. It is one of the 11 administrative districts of Davao City and is among the 5 districts under the Third Legislative District of Davao which is mainly located in the southwestern part of the city. Toril has been selected as area of interest for this study because its LiDAR and building data are available and because of its location, since areas located in the southern part of the City has higher solar potential (Teves, J., et al., 2016).

The method implemented in this study is highly dependent on the data availability forToril. The main data used were the LiDAR derived Digital Surface Model (DSM) of Toril in 1-meter spatial resolution and the available building footprint shapefile digitized in Universal Transverse Mercator (UTM) Zone 51 projection. These data were acquired from UP Mindanao PHIL-LiDAR 1 project.

5.2 Process Flow

The methodology of this study is divided into three (3) major parts: (1) LiDAR data processing using the Geoprocessing tools in ArcGIS to acquire the slope, aspect, area and shading rasters and polygons of the digitized buildings in Toril; (2) Identification and filtering of potential rooftop sites that satisfies the slope, area, aspect and shading values that are optimal for solar PV installation; (3) Estimation of the energy yield that can be generated assuming the total area of identified sites will be utilized for solar energy production. All geo-processing was conducted within the ArcGIS environment. The comprehensive workflow of the study is shown in Figure 3.

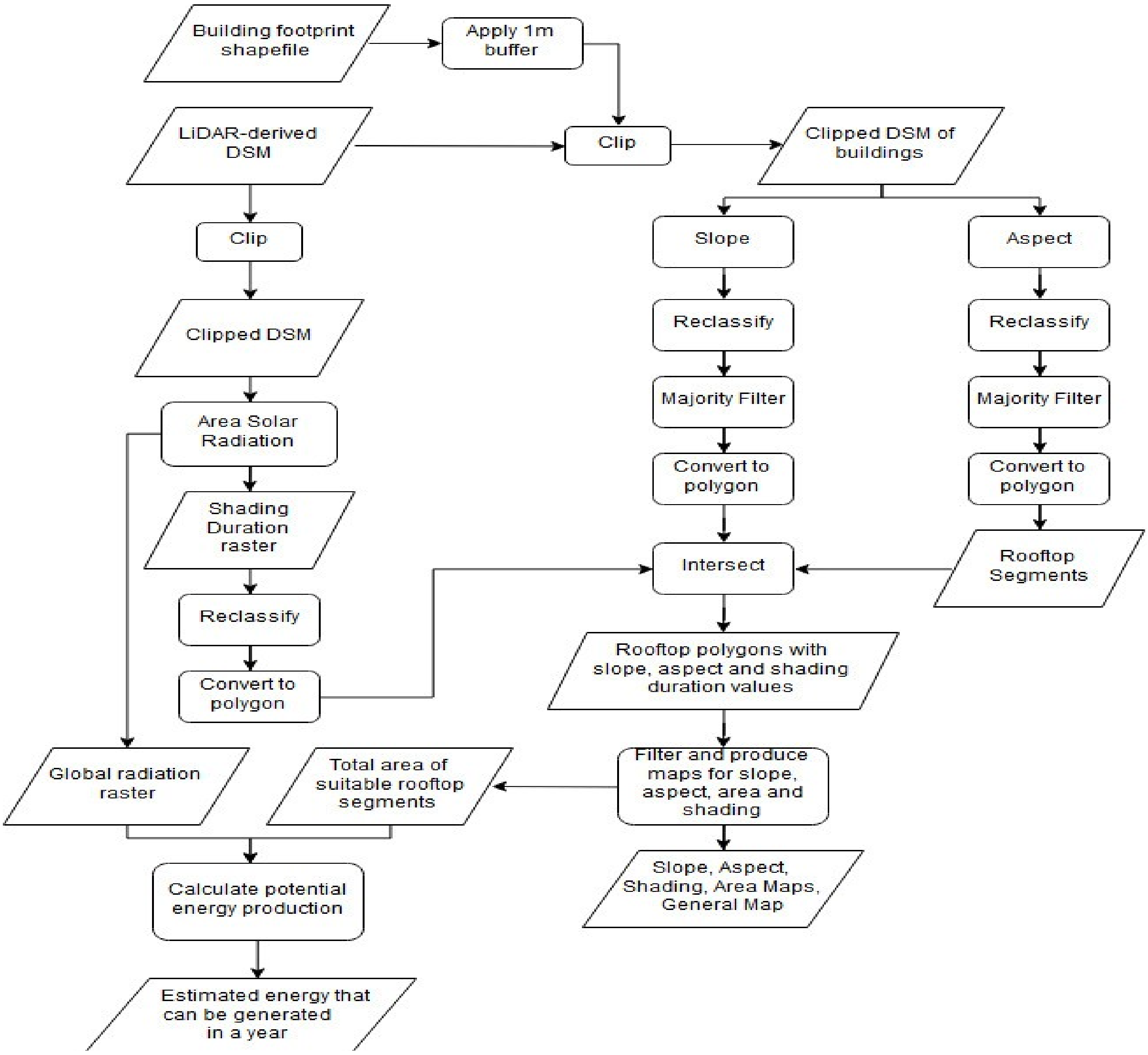
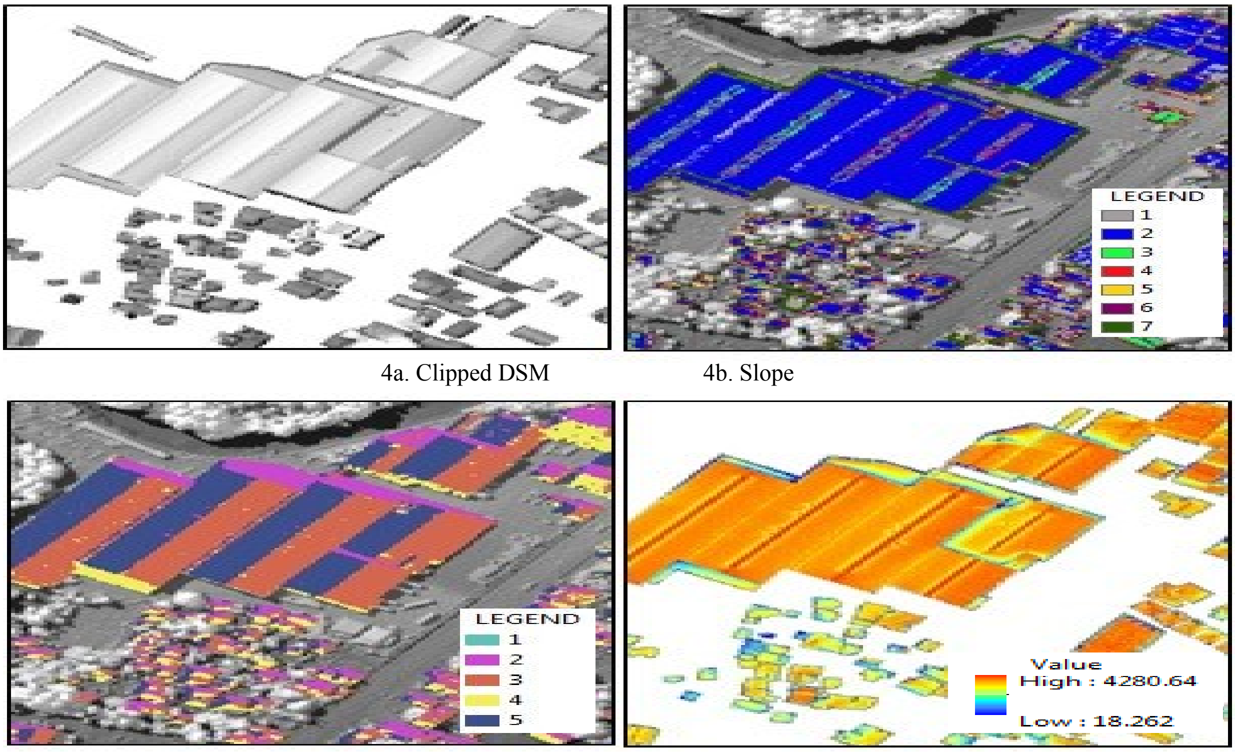


Figure 3: Workflow in identifying suitable sites for solar PV and potential energy estimation.

5.2.1 DSM Processing

The LiDAR DSM was prepared for processing in ArcGIS. Since the first part of processing is only focused on the rooftops, the DSM was clipped using the building shapefile. First, a 1-meter buffer was applied to the building footprint shapefile since the edge of the buildings may not be thoroughly defined in the DSM and so to remove the noise in the data. The DSM clipped using the buffered building shapefile is shown in Figure 4a.



4a. Clipped DSM 4b. Slope

4c. Aspect 4d. Direct Solar Radiation

Figure 4: Thumbnail images showing the stages in data processing.

5.2.1.1 DSM Processing: Slope

Slope tool in the Spatial Analyst toolbox was used to calculate for the slope of the DSM focused only on the buildings. This process identifies the rate of maximum change in z-value from every cell of a raster surface. The output produced can be measured in degrees or percent rise, in this case the output was in the unit of degrees. A slope raster was then obtained and organized to a more disaggregated classification as listed in Table 1. The reclassification of the resulting dataset is important in the identification of suitable surface locations for PV systems since the slope requirements may vary with the latitude.

Slope (Degree)	Class
0 – 7	Class 1
7 – 22	Class 2
22 – 30	Class 3
30 – 40	Class 4
40 – 50	Class5
50 – 60	Class 6
60 – 90	Class 7

Table 1: Reclassification of Slope

With the LiDAR data, slope values may differ across a rooftop plane with the same actual slope due to some error in data acquisition or in the LiDAR point cloud data conversion. To minimize this occurrence, the classified slope raster was run through the Majority Filter to replace these apprehensive values based on the 8 contiguous neighboring cells and acquire more uniform values across each plane. After filtering the data, the slope raster was then converted into polygon using the Raster to Polygon Tool in the Conversion Toolbox to obtain a shapefile containing the slope values. The result of the slope analysis is shown in Figure 4b.

5.2.1.2 DSM Processing: Aspect (Azimuth)

Aspect is the direction on which a rooftop plane is oriented. It is usually measured by degrees from 0 to 360 degrees in a clockwise direction. The values of North, East, South and West is 0, 90, 180 and 270 degrees respectively. In the aspect tool in ArcGIS, if the cell value is flat then the resulting value is -1. The clipped DSM was processed using the aspect tool in the Spatial Analyst Toolbox to acquire the aspect raster. The resulting data was then reclassified into 5 classes as shown in Figure 5.

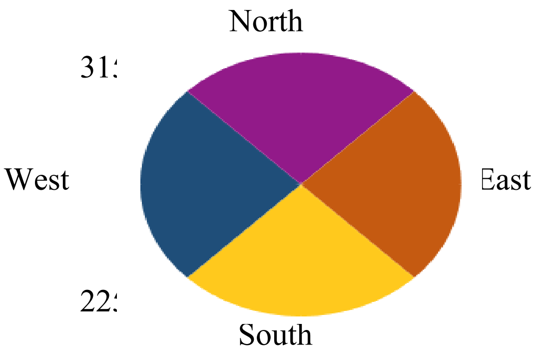


Figure 5: Reclassification of Aspect values: Class 1 (Flat): -1, Class 2 (North): 315 – 45 degrees, Class 3 (East): 45 – 135 degrees, Class 4 (South): 135 – 225 degrees, Class 5 (West): 225 – 315 degrees.

After classification, the data noise in the aspect raster was filtered through the Majority Filter to acquire a uniform aspect value for every rooftop plane. The raster was then converted into polygon using the Raster to Polygon tool to obtain a shapefile with the aspect values. This shapefile also represents the rooftop segment data. Figure 4c shows the output of the aspect analysis.

5.2.1.3 DSM Processing: Shading

Shading is one of the important factors to be considered in locating suitable sites for installing solar systems since the goal is to capture as much solar energy as possible and shading can greatly affect the system's power generation (Bayrakci Boz, et al. 2015). Thus, locations with the ideal shading are those that are hit by direct sunlight in longer duration. In this analysis, the Area Solar Radiation (ASR) tool in ArcGIS was used to compute for the sun hours or the duration in which rooftop areas are hit by direct radiation of the sun. The DSM of Toril was clipped to focus the process only on the area covered with the digitized buildings to lessen the run time. The input used in the ASR model is the clipped DSM along with the parameters latitude and time or period for the calculation. The latitude used as parameter was automatically generated by the ASR tool since the DSM used was already been projected. As for the time configuration, whole year with monthly interval was used for the period parameter and an hourly interval for the time parameter. The resulting raster represented the duration of incoming direct solar radiation in the units of hours. The shading raster was then reclassified into 10 classes (Table 2).The classification was based on the overall sun hours of the Philippines as stated in the literature in the previous section. After classification, the shading raster was converted to polygon then a shapefile with the shading class values was obtained. The output for the shading analysis is shown in Figure 4d.

Table 2: Reclassification of shade values.

1 Year Direct Solar Duration (hours)	Classes
2555<	Class 1
2372.5 – 2555	Class 2
2190 – 2372.5	Class 3
2007.5 – 2190	Class 4
1825 – 2007.5	Class 5
1642.5 – 1825	Class 6
1460 – 1642.5	Class 7
1277.5 – 1460	Class 8
1095 – 1277.5	Class 9
0 – 1095	Class 10

5.2.2 Identifying rooftop sites for PV system installation

Suitable sites for solar panels have specific configurations and requirements. In determining those locations, the necessary characteristics must be defined. However, these configurations often depend on the location, and its position on the globe considering the fact that the sun's energy is not evenly distributed on the earth's surface. For this study optimal rooftop requirements as described in the literature is summarized in the table below (Table 3).

The slope, aspect and shading polygons were combined using the intersect tool in the Spatial Analyst Toolbox of ArcGIS. This process produced a shapefile containing all the slope, aspect and shading data of the rooftop segments. In the attribute table of this shapefile another parameter named Area was added which values were automatically generated through geometric calculation in ArcGIS.

Rooftop segments with slope, aspect, shading and area values that satisfies the requirements listed in Table 3 was then selected and then exported to produce the final polygon with the rooftop segments that are suitable for solar PV systems.

Parameter	Value
Slope	$7 \leq Slope \leq 22$
Aspect	$135^o \leq$ Aspect $\leq 225^o$
Area	Area$\geq 10m^2$
Shading	Direct Radiation$\geq$ 5.0 hours/ day Direct Radiation$\geq$ 1825 hours/ year

Table 3: Optimal Rooftop Configuration for solar PV installation.

6. DISCUSSION OF RESULTS & CONCLUSION

Out of the total 19,195 digitized buildings of Toril, a total of 181,745 rooftop segments were identified, 98,060 segment qualified for a slope of 7 to 22 degrees, 45,802 were south facing, 173,576 receives equal to or more than 5 hours of direct sunlight and 66,889 rooftop planes has an area of 10 square meters or more. Out of the total number of identified rooftop planes, 14,981 passed all the requirements and were found to be suitable locations with a total area of 497,046 square meters. On average it was found that about 12.13% of the total number of identified rooftop planes are suitable for PV systems and would generate approximately 28,905 MWh of energy per year.

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