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Digital Earth Surface Model for The Estimation of Solar Panel Electric Power Towards Renewable Energy

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Abstract

The development of Geographic Information Systems (GIS) is able to create future value in various sectors and become a solution to the problem of limitations and disparity of electricity resources in Indonesia. This condition encourages GIS to be an analytical solution to the problem of electricity resources, which is by utilizing solar radiation as a source of renewable energy. This study aimed to optimize GIS in the use of solar radiation on the slope of building roofs which affects the estimated number and average electric power. This study used the mixed method. Research data includes aerial photos, which were analyzed digitally using the area of solar radiation and the slope angle of building roofs so as to produce a spatial analysis of the utilization of solar panels on Derawan Island. The data analysis showed that buildings in Derawan Island can produce 17,355.254 mWh per year with each building producing an average of 28,686 kWh annually. The result of the study is expected to encourage the realization of the use of renewable energy as part of the SDGs by utilizing solar panels as a source of electricity, replacing fossil-derived energy. This study is also expected to be applied in other small inhabited islands to support the sustainability of electricity use and increase the use of renewable energy.

1. Introduction

Utilization of sustainable energy is an important issue in the 21st century, especially in the face of climate change that has a massive impact on people's lives (Missoum & Loukarfi, 2021; Zawadzki et al., 2022). On the other hand, development that is constantly encouraged in various aspects certainly requires energy as the main raw material supply (Guenther, 2018). One of the fundamental energy to support development and encourage economic growth is the fulfillment of electricity needs (Ahmad & Byrd, 2013). In reality, around 25 million Indonesian people live without electricity. At the same time, electricity is limited in several inland areas, border areas, and small islands (Adam, 2016; Setyowati, 2021). Several studies and data showed that up to now, the fulfillment of electricity in Indonesia is largely still sourced from fossil energy (Erdiwansyah et al., 2021; Guenther, 2018). The limitation of fossil raw materials that is non-renewable is certainly a problem. Besides, the residue of the burning of fossil fuels has adverse implications, leading to the damage to the atmosphere that triggers global climate change (Hasan et al., 2012). The use of solar energy is hoped to help reduce CO_2 and SO_2 emissions, an important part to suppress the rate of climate change (Wattana & Aungyut, 2022).

The challenges and targets for the use of renewable or environmentally friendly energy have been agreed by various countries and are outlined in the Paris Agreement and SDGs (Elavarasan et al., 2022; Grubler et al., 2018; Setyowati, 2021). In response to the agreement, Indonesia aims to change the utilization of renewable energy by 25% in 2025 (Guenther, 2018). For this reason, innovations in the use of environmentally friendly energy or sustainable energy need to be developed, one of which is through the use of solar panel energy to maintain electricity supply in various regions, both for remote settlements and even urban areas (Ahmad & Byrd, 2013; Guno et al., 2021). Indonesia's location on the equator is an advantage in optimizing solar panels. Several studies have shown that the average solar radiation potential is around 4.8 kWh/m2 per day (Khotama et al., 2020; Kurniawan & Shintaku, 2021; Nasruddin et al., 2018).

The technology development of Geographic Information Systems (GIS), remote sensing, and photogrammetry through Unmanned Aerial Vehicles (UAVs) can be used to analyze the potential use of solar power (Mallon, 2019). This system has the advantage to be operated directly at the same time; the distance and the flying height can be adjusted by the controller, resulting in higher spatial resolution images following the area sought; the time needed is faster; and it can be processed directly (Stewart & Martin, 2020). UAVs are indispensable for identifying buildings in detail that will be analyzed using the solar radiation. A Digital Surface Model (DSM) as a model of the earth's surface shows all the details on the face of the earth in the form of land, buildings, and vegetation in real appearance as seen in satellite imagery, including details of buildings and land cover as well as their height. DSM images has a difference with Digital Elevation Model (DEM) and Digital Terrain Model (DTM) images. DEM and DTM images usually only display the height of the ground level without the buildings or vegetation on it.

To analyze the effect of the slope of building roofs on solar radiation, a DSM is needed. Analysis of the use of DEM data that provides information on the height of the natural landscape of the earth's surface has been carried out by Nusantara & Dewanto (2020). The analysis is combined with a map source on Open Street Map (OSM) which visually displays buildings in 3D. Meanwhile, Desthieux used a vertical sky view factor (SVF) model to calculate the radiation of a single point located on the roof, ground, and facade of buildings (Desthieux et al., 2018). Boz et al. (2015) in their study used Light Detection and Ranging (LIDAR) to determine suitable buildings to install solar panels. The planning automation model conducted by (Boz et al., 2015) is only limited to determining suitable roofs using GIS with slope analysis without calculating the amount of electricity that can be generated through the photovoltaic system. In another study, (Song et al., 2018) conducted a similar analysis of the potential of solar energy on flat roofs using DSM data and Google Maps imagery in the Chinese plain through GIS by paying attention to several factors such as wind direction on the roofs, shadows generated due to obstruction with buildings or vegetation, slope, and the type of the roofs.

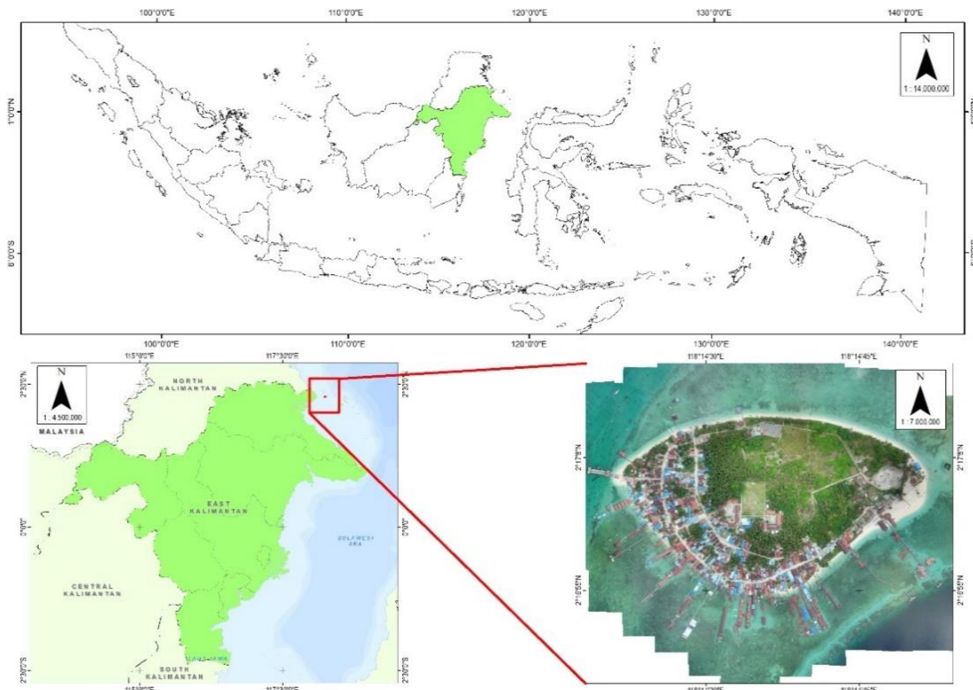
Based on previous studies above, it can be seen that DSM and DEM data sources provide different information details. In this study, the researchers used DSM data, which does not only display information about the elevation of the earth's surface, but also on the slope of building roofs. In this study, the researchers also paid attention to the analysis of the use of solar panels to be installed or placed on the roof of buildings, so that the data on the roof slope in the form of the degrees produced were able to answer whether the roof of the building is feasible to install solar panels. Thus, the researchers initiated a new idea, namely to use roof slope data from aerial photos that were processed into 2D and DSM images.

In addition, based on several previous studies as mentioned above, there was an opportunity for the researchers to calculate the amount of electric power produced on each roof of the building so that an assumption could be made whether a building is feasible and eligible to be installed with solar panels and whether electricity demand of the building can be met. The purpose of this study was to estimate the electrical power produced by solar panels on the building roofs on Derawan Island using the results of aerial photographs which are analyzed at an advanced level into DSM as the basis for determining the slope of building roofs and solar radiation as the basis for determining the absorption of sunlight on building roofs.

2. Data and Methods

2.1. Study Area

Derawan Island has an area of 44.6 ha and is part of the Derawan Archipelago, located in Berau Regency, East Kalimantan Province. It is located between 2° 17' 3.00" north latitude and 118° 14' 39.00" east longitude. The abundant natural potential and natural beauty under the sea have made Derawan Island a tourist attraction that interests domestic and foreign tourists, so half people who live are fishermen and divers (Febriyanto et al., 2021) as well as others in the tourism sector such as homestays, restaurants, and boat rental. In 2018, there was an increase in the amount of tourists who visited Berau Regency with an achievement target of 253% higher than the previous year (Dinas Pariwisata Berau., 2020).This indicates that Derawan Island needs more renewable energy supplies considering the amount of tourists, small areas, marine tourism, and maintaining marine conservation. Figure 1 is location of study area,

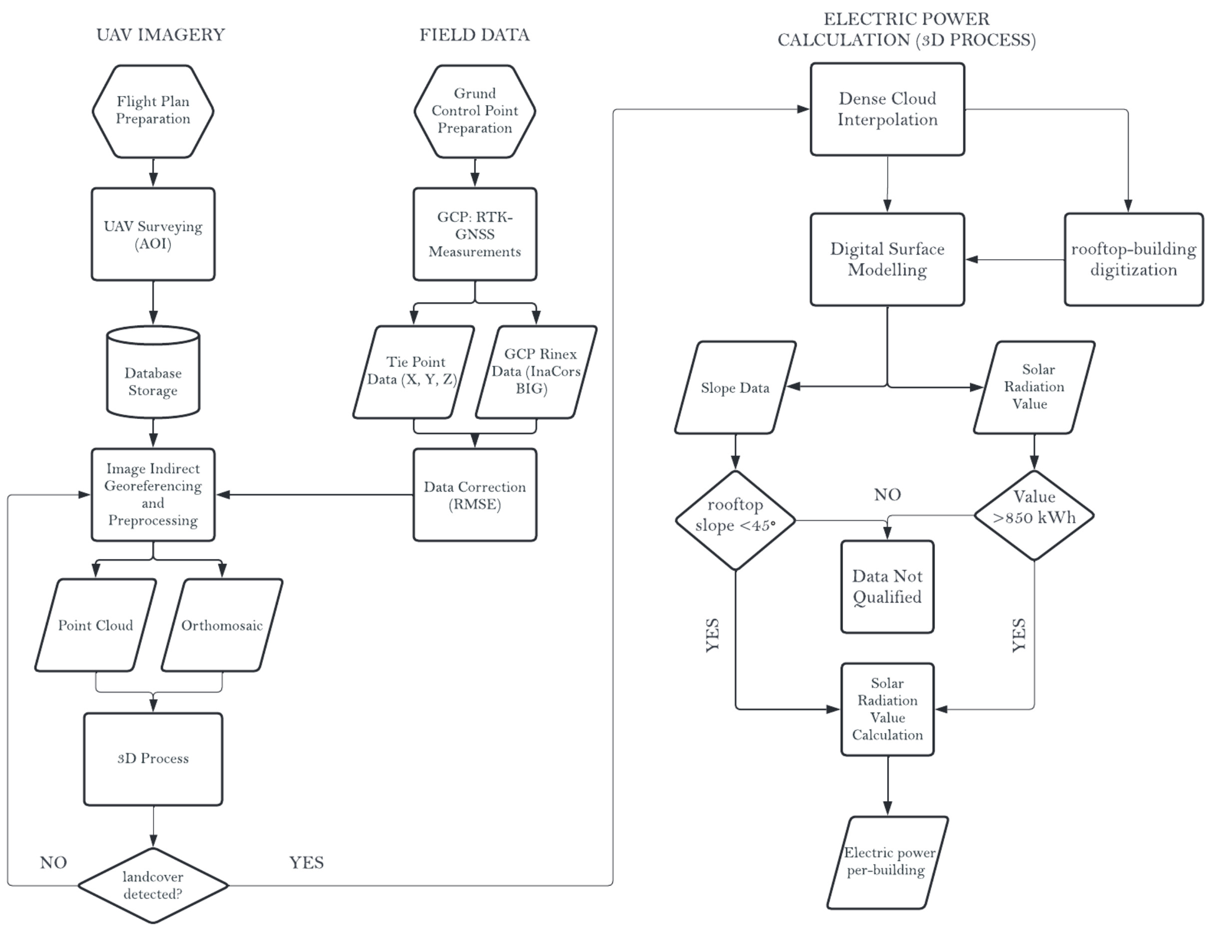


Source: Data Analysis Results, 2021

Figure 1. Location of Study Area

2.2. Method

The method was to use the mixed method in which the quantitative method to calculate and estimate total electric energy for each building roofs from spatial analysis by using aerial photos with a spatial approach (Muryono & Utami, 2020), whereas the qualitative method was used when data collection and analysis were done (Tarfi & Amri, 2021) then reviewing the function of installing solar panels become the renewable energy as a solution of electricity problem by using literature review. There are two types of data collection, namely primary and secondary data collection. Primary data collection was obtained by field observation by taking various data in order to make spatial-based decisions in determining electric power estimation. Secondary data was obtained from books, websites, and journals that were relevant to the research writing as a support for strengthening spatial analysis and its effect on stakeholders from various aspects. This activity began with (i) the installation and processing of ground control points (GCPs) as an air quality control of actual coordinates on the earth's surface, (ii) the photographing and processing of aerial photos using UAVs/drones to produce 2D and DEM images in accordance with the current land cover appearance, and (iii) performing advanced GIS analysis by rapid mapping by performing a combination of processing in the form of building digitation (to get the right value), solar radiation area (the amount of solar radiation emitted for a full year), and slope (the degree of the slope angle of the building roofs). In addition, the description process needed to be carried out to further elaborate on the impact of the use of solar energy as renewable energy in reducing carbon emissions and supporting the implementation of Sustainable Development Goals (SDGs) in the form of the transition of non-renewable energy consumption to environmentally friendly energy and reducing the effects of climate change. Figure 2 is a flowchart of research that illustrates the process of determining electric power estimation carried out on Derawan Island.



Source: Data Analysis Results, 2021

Figure 2. Workflow Diagram

2.3. GCP Installation and Processing

Preparation of aerial photos began with the installation of ground control points or GCPs at the location of the shoot. A GCP generates planimetric coordinates (x, y) and elevation (z) by trilateration, triangulation, polygon, and GPS methods (Subakti, 2017). A GCP is a coordinating point found at the aerial photo shoot location in the form of a cross-shaped pre-mark with tarpaulin or wood material. A pre-mark must have a color that contrasts with its surroundings to be visible during aerial photo processing (Prayogo, et al., 2020). The next stage was the implementation of GCP data collection by installing a GNSS receiver on top of the pre-mark that had been installed. Data collection was carried out by recording data statically by making several parameter settings in the form of a coordinate system, recording time, and the type of Rinex data used.

2.4. Aerial Photoshoot

The aerial photo shooting using UAV was done both manually and automatically using a control radio that had been programmed through a flight path designed using Ardupilot software. The flight process requires good flight path planning with regard to the mathematical modelling formulation consisting of network, UAV technical, environmental, decision variables, sets, and constraints on AOI (Thibbotuwawa et al., 2020). The results of the aerial photo shooting must be processed to become ready-to-use raster images.

2.5. Aerial Photo Processing

The aerial photo processing needed in this study were 2D and DSM photos using Agisoft Metashape Professional software. The photo processing steps consisted of nine steps: (1) adding photos, (2) aligning photos, (3) inputting GCPs, (4) building a dense cloud, (5) building a mesh, (6) building the texture, (7) building a DEM, (8) building orthomosaic images, and (9) exporting.

2.6. Aerial Photo Accuracy Test

Based on the Regulation of the Geospatial Information Agency No. 6 of 2018 concerning the Basic Map Precision Technical Guidelines, to realize the standard of map precision, technical guidelines are needed to produce accurate, reliable, trustworthy, and accountable calculations. The value of root mean square error (RMSE) of the processed aerial photos is required, which can be known by comparing the GCP coordinate value as the processing result with the GCP coordinate value as seen in the aerial photos. The purpose of searching for RMSE values was to obtain CE90 values that served to determine the quality of aerial photos as a base map. Table 1 shows the classification of the scale and the CE90 value, where the smaller the CE90 value, the better the quality of the aerial photos that are aligned with the scale value.

Table 1. Classification of Base Map Precision

No	Scale	Contour (m)	Map Precision					
			Class 1		Class 2		Class 3	
			Horizontal (CE90 in m)	Vertical (LE90 in m)	Horizontal (CE90 in m)	Vertical (LE90 in m)	Horizontal (CE90 in m)	Vertical (LE90 in m)
1	1:1,000,000	400	300	200	600	300	900.0	400
2	1:500,000	200	150	100	300	150	450.0	200
3	1:250,000	100	75	50	150	75	225.0	100
4	1:100,000	40	30	20	60	30	90.0	40
5	1:50,000	20	15	10	30	15	45.0	20
6	1:25,000	10	7.5	5	15	7.5	22.5	10
7	1:10,000	4	3	2	6	3	9.0	4
8	1:5,000	2	1.5	1	3	1.5	4.5	2
9	1:2,500	1	0.75	0.5	1.5	0.75	2.3	1
10	1:1,000	0.4	0.3	0.2	0.6	0.3	0.9	0.4

Source: Geospatial Information Agency Regulation Number 6 of 2018

2.7. Processing of Determination of Electric Power Estimation

This is in line with the use of DSMs that can be applied to the identification of buildings on Derawan Island in determining the installation of solar panels on each roof. The calculation of solar radiation entering the earth's surface used the Area Solar Radiation tool in ArcGIS Pro by entering DSM raster. The determination of the sun position was carried out for a full year with time intervals throughout the day. To provide profits, solar panels were set to produce at least 850 kWh of power (Aybar et al., 2018). To identify building roofs that comply with the above criteria, the Remap tool was performed on ArcGIS Pro by eliminating (No Data) each cell that has a value below 850 kWh.

The slope calculation in the DSM was done to determine building roofs suitable for receiving solar radiation using the Slope tool in ArcGIS Pro. The slope of the solar panels installed on the building roofs should not be more than 45° with respect to the wind which puts pressure on the solar panels and tends to receive less sunlight (Stathopoulos, Xypnitou, & Zisis, 2012). To identify this, the Remap tool was used on simplified raster with a value of 1 for each cell with an appropriate slope (below 45°) and No Data for each cell with an inappropriate slope (above 45°).

The next stage combined solar radiation raster with slope raster using the Times tool in ArcGIS Pro to identify the results that matched the criteria described above. The next process was to find the vector value of the amount of solar radiation per building using the Zonal Statistics as Table tool by combining combined raster and digitized shapefiles. The type of value used was the mean, which was used to get the average value of all cells in the same zone. For the calculation of electric power estimation, area (m^2) and mean (kWh) values must be combined with vector data using the Join Fields tool.

Each generator has a capacity of 1 Kwp for 10 m^2(Boz et al., 2015). The suitability of the building roof area above 10 m^2 was identified using Select Layer by Attribute and Export Features tools. Furthermore, the creation of a new field to determine the total amount of solar radiation received per year by each building was done by multiplying the "area" field by the "mean" field. Changes in the value of solar radiation was made to obtain total electric energy for each building roof by creating a new field and (Kohak et al., 2019)entering the formula below:

$$E = A * r * H * PR \qquad [1]$$

Where:

E = Energy in kWh unit

A = Roof area of each building using the "area" field.

r = Efficiency of solar panels around 15.2%, which is considered as the best percentage based on The National Renewable Energy Laboratory (NREL) in 2019

H = Average value of solar radiation on the roof of each building using the "mean" field

PR = Performance ratio and loss coefficient of 86%; this value was calculated using PVWatts Calculator with the location of Derawan Island.

3. Result and Discussion

3.1. Results and Analysis of GCP Observation

On Derawan Island, there was no basic point of technique or benchmark (BM) found to be made as base stations, so the binding of GCP data recording was carried out on the InaCORS BIG Berau Station with coordinates of 2° 08' 58' 'N, 117° 29' 49" E, 64.2 m based on the SRGI 2013 reference system. The GNSS receiver used in the GCP was a CHCNav with a long recording time of about 90-120 minutes because the location of the base station was very far from the GCP. GCP data processing used the post processing method with Trimble Business Center software. The post processing calculation used the trilateration mesh method, so that GCP points mutually made data quality corrections with fellow GCP points and base stations to obtain precise and accurate coordinate values. The coordinate system used was transverse mercator 3° zone 50.2 which can be seen

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in Table 2. GCPs with five pre-marks were spread evenly across Derawan Island. GCP 1 was located in the east in the open area and away from buildings. GCP 2 was in the south on the side of the road, close to the mosque, and not obstructed by buildings and vegetation. GCP 3 was located in the southwest on the side of the road and not obstructed by buildings and vegetation. GCP 4 was located in the north on an empty land. GCP 5 was located at the center of Derawan Island on a football field.

Table 2. Results of GCP Processing Coordinates

Code	Coordinate		
	x (m)	y (m)	h (m)
GCP 1	171,878.829	1,752,600.182	67.888
GCP 2	171,326.557	1,752,440.109	61.932
GCP 3	171,156.305	1,752,512.844	61.935
GCP 4	171,577.123	1,752,785.756	62.895
GCP 5	171,416.955	1,752,567.219	64.630

Source: Data Analysis Results, 2021

The determination of CE90 was based on United States National Map Accuracy Standards (US NMAS) with CE90 =1.5175 x RMSEr. The RMSEr value was obtained by summing the RMSEx and RMSEy values divided into two. RMSEx and RMSEy values were obtained by the square root of the difference in aerial photo coordinates and the actual coordinates divided by the number of GCP points. Table 3 shows the calculation results of planimetric coordinates for aerial photos, obtaining a CE90 value of 0.294 m, which means that the horizontal precision accuracy test falls into the 1:1,000 scale map category, namely the class 1 (good), with a maximum precision of 0.3 meters. A scale of 1:1,000 means 1 cm in aerial photos, which equals to 10 m in reality, so that these aerial photos can be used for large-scale mapping, specifically building modeling.

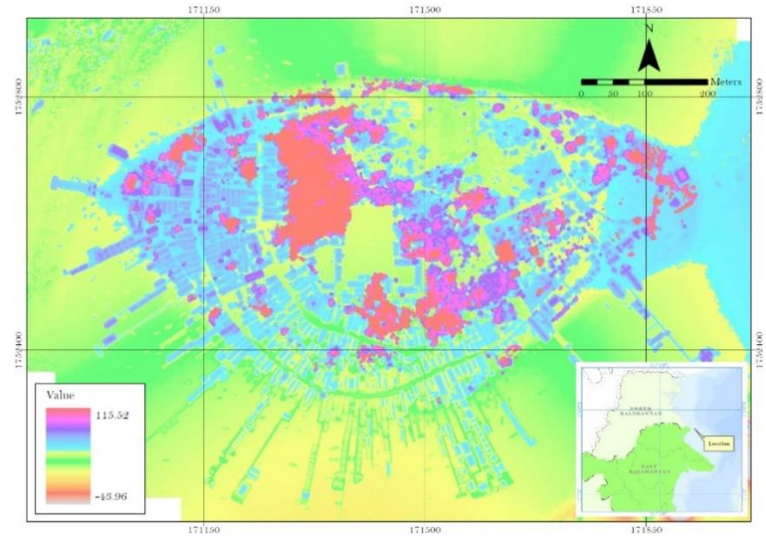
Table 3. Horizontal Precision Test

Code	x GCP (m)	y GCP (m)	x Photo (m)	y Photo (m)	Difference of x (m)	Difference of y (m)	RMSE of x (m)	RMSE of y (m)	CE90 (m)
GCP 1	171,878.829	1,752,600.182	171,878.588	1,752,599.980	0.241	0.202	0.111	0.277	0.294
GCP 2	171,326.557	1,752,440.109	171,326.596	1,752,440.019	-0.039	0.090			
GCP 3	171,156.305	1,752,512.844	171,156.348	1,752,512.949	-0.043	-0.104			
GCP 4	171,577.123	1,752,785.756	171,577.113	1,752,785.683	0.010	0.073			
GCP 5	171,416.955	1,752,567.219	171,416.945	1,752,567.782	0.010	-0.563			

Source: Data Analysis Results, 2021

3.2. Results and Analysis of DSM Processing

DSM processing based on the aerial photo dense cloud is able to provide the most accurate results when compared to other data sources. DSM processing was done using Agisoft Metashape Professional on DEM Build tool, but it could also be generated by setting up the point classes. The processing results show that the DSM resolution obtained is 29.4 cm/pixel with a resolution below the orthophoto because the DSM is the result of the dense cloud interpolation process of aerial photo extraction. Based on the DSM, it can be seen that the height of the area of interest is (-43.96) m-115.523 m. The description of DSM results is shown in Figure 3, where the lowest location is marked in grey with existing conditions in the form of coral reefs to the deep ocean. The green area in the form of beaches, reefs, roads, and vacant land is very dominating. The blue area appears to be buildings and shrubs. The red and purple area have a higher value with the highest of 115.523 m and the area is a coconut grove.

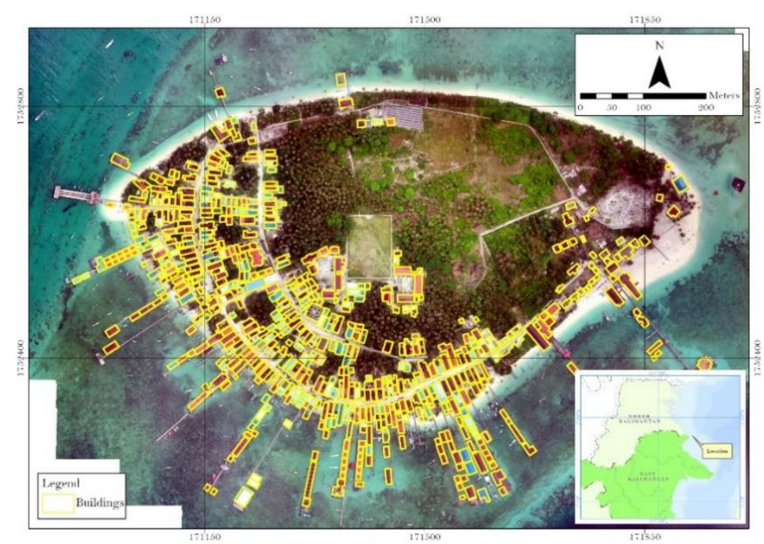


Source: Data Analysis Results, 2021

Figure 3. Digital Surface Model Aerial Photo Visualization

3.3. Results and Analysis of Orthophoto and Building Digitation

Aerial photo processing used DSM data as photo reconstruction to produce the most optimal orthophoto compared to other data. The aerial photo resolution is 7.35 cm/pixel. The resolution value of aerial photos is much higher than that of DSM images due to the incorporation of aerial photos from the acquisition results. The digitation of the building was done manually using ArcGIS Pro software to provide the right shape and area in determining building roofs in the process of electric power estimation. As a result, 625 buildings on land and in water with an area of 30 m^2-861 m^2 were obtained as shown in Figure 4. Buildings visible on land consist of homestays, community houses, places of worship, educational facilities, government buildings, and other supporting facilities, while buildings on the water are hotels.



Source: Data Analysis Results, 2021

Figure 4. Visualization of Building Orthophoto and Digitation

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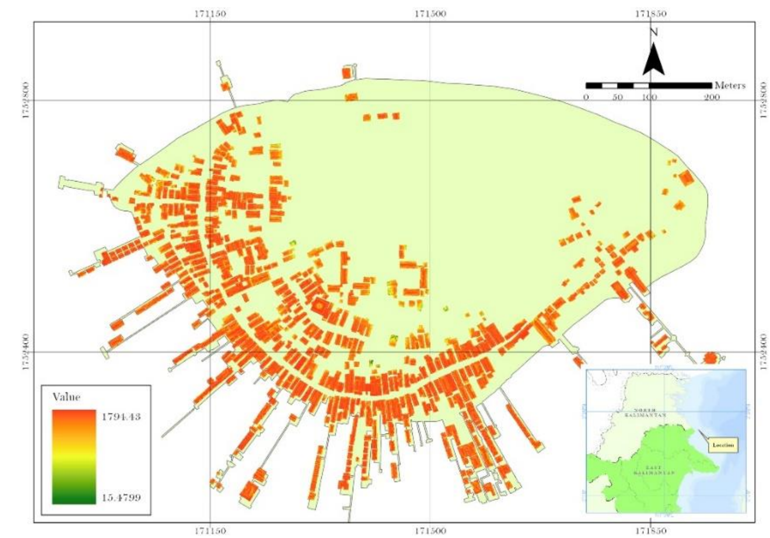
3.4. Results and Analysis of Solar Radiation Areas

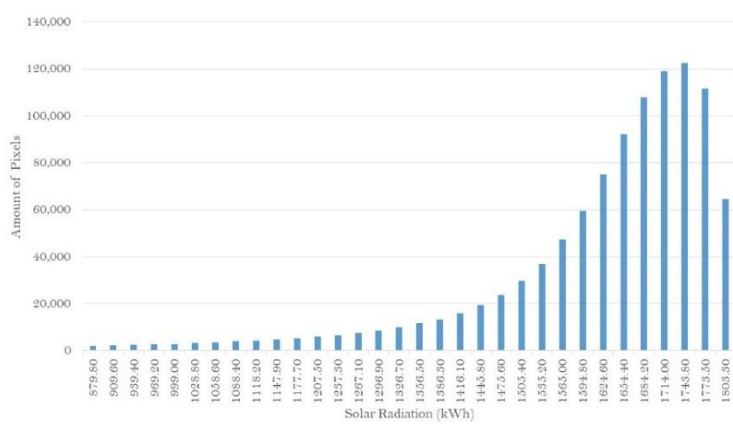
The processing of solar radiation on Derawan Island produces a radiation value of 15.4799 kWh-1,794.43 kWh. Figure 5 shows that the dominating colors on the building roofs are red and orange, which indicate that the amount of solar radiation received is quite high. Yellow and blue indicate a lower amount of radiation. This is because buildings facing north tend to receive less solar energy than those facing south, west, and east. In addition, the roofs of buildings that detected covered by vegetation, others buildings, and other factors receive little solar radiation.



Source: Data Analysis Results, 2021

Figure 5. Results of Solar Radiation Processing Using DSM Rasters

Figure 6 shows the results of solar radiation that was adjusted to the criteria for solar panels with a minimum value of 850 kWh. The distribution of radiation values on the building roofs ranges from 850 kWh to 1,794.43 kWh with an average of 1,609.97 kWh. The results of this analysis show that the radiation produced on Derawan Island as a whole is quite large as presented in Figure 6. This analysis shows that the higher the diagram, the greater the kWh value, with the highest value at 1,714 kWh.

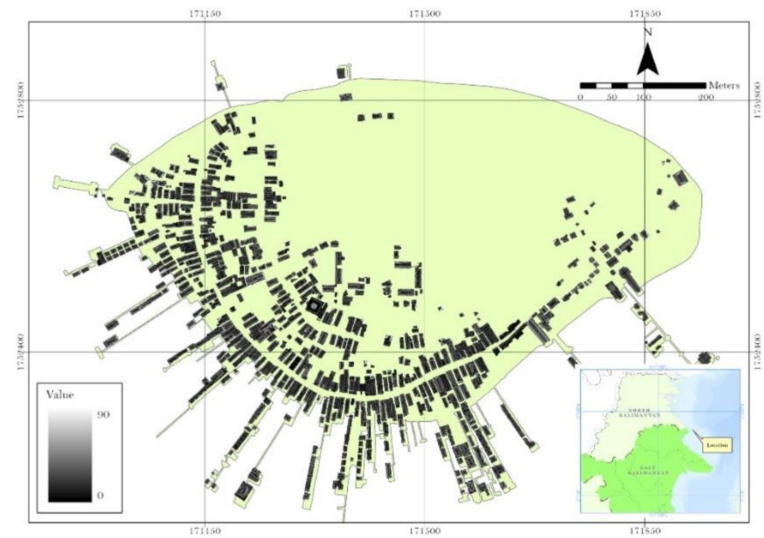


Source: Data Analysis Results, 2021

Figure 6. Histogram of Solar Radiation Rasters

3.5. Results and Analysis of the Slope

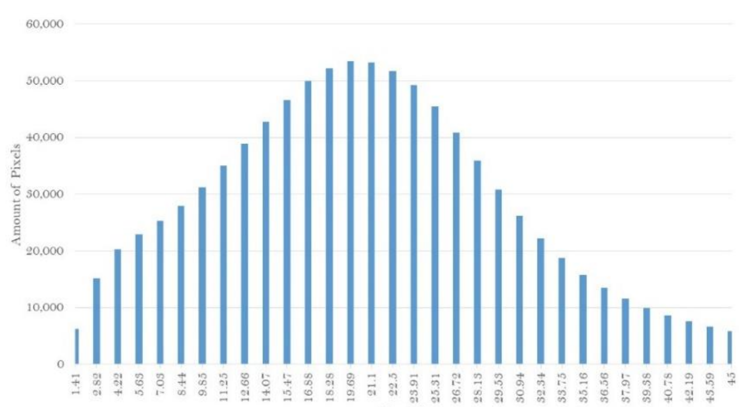
The slope processing on Derawan Island resulted in a value of 0°-90°. The angle value of 90° has a steep or vertical slope: the lower the degree, the flatter the slope, and at 0° it has no slope at all (flat). Figure 7 shows the black area dominating the building roofs which shows a low slope. Roofs with a maximum slope angle of 45° is very good for the installation of solar panels.



Source: Data Analysis Results, 2021

Figure 7. Results of Slope Processing Using DSM Rasters

Figure 8 shows the slope results that were adjusted to fulfil the requirement for the installation of solar panels, which is with a slope angle of 0°-45°. The slope angle starting at 0° increases steadily and reaches the highest in quantity at an angle of 21.1°, then there is a slow decrease up to an angle of 45°. As seen in Figure 8, the highest number of cell quality is at an angle of 16°-24°, which shows that buildings on Derawan Island have relatively flat roofs.



Source: Data Analysis Results, 2021

Figure 8. Histogram of Slope Rasters

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3.6. Results and Analysis of Electric Power Estimation

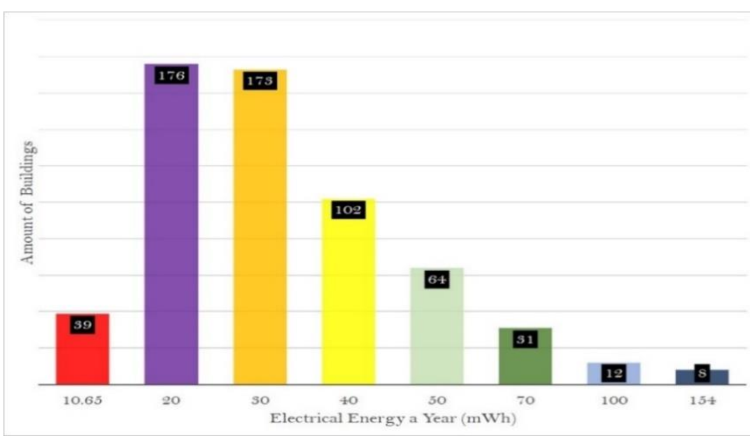
Estimation of electric power was carried out through the analysis of the combination of solar radiation and the slope, which was by multiplying the two rasters as seen in Table 4. Based on the tested analysis, only the first row produces a matched value, while the other one does not. Based on the table below, it can be explained that solar radiation that has a value above 850 kWh with a slope below 45° is included in the most appropriate category in the installation of solar panels on the building roofs. Solar radiation that has a value below 850 kWh does not meet the criteria even though it has a slope below 45°. Solar radiation that has a value above 850 kWh is within the criteria because it has a slope angle above 45°. Solar radiation that has a value below 850 kWh and has a slope angle above 45° does not meet the criteria for solar panel installation. The implementation of DSM and solar radiation data in Derawan Island has been in line with the study that has been developed by (Song et al., 2018) on the use DSM data in 3D building and solar radiation reconstruction processing in satellite images in the Chao Yang District of Beijing, China.

Table 4. Results of Solar Radiation and Slope Classification

Appropriate Solar Radiation	x	Appropriate Slope	=	Corresponding Result
≥ 850 kWh		≤ 45 °		✓
≤ 850 kWh		≤ 45 °		×
≥ 850 kWh		≥ 45 °		×
≤ 850 kWh		≥ 45 °		×

Source: Data Analysis Results, 2021

Based on the classification in Table 4, it can be found that from a total of 625 buildings, 605 buildings meet the criteria for solar panel installation, so only 4% of buildings on Derawan Island do not meet the criteria. The data analysis shows that the amount of electric energy produced by 605 buildings on Derawan Island for a full year is up to 17,355.254 mWh or 17,355,254 kWh. The energy produced annually has an average of 28.686 mWh or 28,686 kWh per building. In this study, to determine the distribution of electric energy in a year, the following classification was carried out: 1) power of 0-10,649 kWh of 39 buildings; 2) 10,650 kWh-20,000 kWh of 176 buildings; 3) 20,001 kWh-30,000 kWh of 173 buildings; 4) 30,001 kWh-40,000 kWh of 102 buildings; 5) 40,001 kWh-50,000 kWh of 64 buildings; 6) 50,001 kWh-70,000 kWh of 31 buildings; 7) 70,001 kWh-100,000 kWh of 12 buildings; and 8) 100,001 kWh-154,000 kWh of 8 buildings. An overview related to the classification of electric energy is presented in Figure 9 below.



Source: Data Analysis Results, 2021

Figure 9. Diagram of Number of Buildings and Electric Energy Classification

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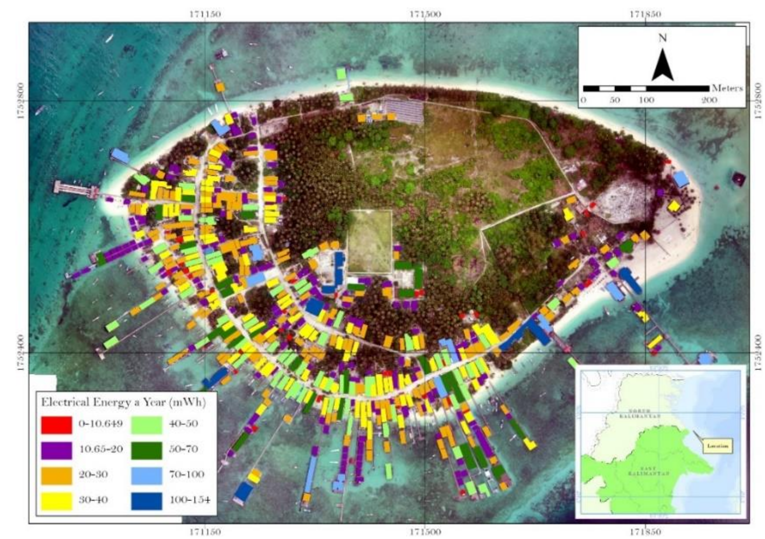
Based on a study from the Energy Information Administration (EIA), the average annual electricity consumption for households in the United States in 2020 was 10,649 kWh (Hayibo et al., 2020). Electricity demand in the United States can be a comparative data to the electricity produced on Derawan Island. Table 5 shows that 39 buildings generate less than 10,649 kWh of electricity, which means that there is insufficient household electricity. The analysis shows that there are more buildings that produce electricity above 10,649 kWh, namely 566 buildings, so that the need for electricity is not a big problem in the implementation of solar panel installation in Derawan Island. In this study, a mapping of electric power estimates as presented in Figure 10 was also carried out to determine the distribution of electric power generated by each building. The coloring of the electric energy classification in Figure 9 is equated with the electric power estimation map presented in Figure 10 due to its classification range using the same data.

The shapefile data which used the "area" field and the interpretation of aerial photos as displayed on the electric power estimation map shows a red area in the form of community houses covering an area of 30 m²-56 m². A quite dominating purple area consists of houses and resorts with an area of 57 m²-10 m². The orange area that is also dominating the map has an area of 101 m²-150 m² is in the form of homestays, resorts, and community houses. The yellow one has an area of 150 m²-190 m² in the form of homestays, resorts, and community houses. The light green area consists of homestays, community houses, and dining houses with an area of 191 m²-280 m². The dark green area consists of homestays, resorts, community houses, dining houses, and educational facilities with an area of 281 m²-350 m². The light blue one has an area of 351 m²-485 m² consisting of resorts, village offices, and other supporting facilities. The dark blue area has an area of 486 m²-861 m² in the form of resorts, educational facilities, and mosques.



Source: Data Analysis Results, 2021

Figure 10. Map of Derawan Island Electric Power Estimation

The Map of Derawan Island Electric Power Estimation as shown in Figure 10 shows that the number of buildings and the amount of power estimation analyzed are very diverse due to different types of buildings. The classification results as displayed show the following: 1) power energy of 0-10,649 kWh (6.4%) consisting of houses; 2) power energy of 10,650 kWh-20,000 kWh (29.1%) consisting of houses and resorts; 3) power energy of 20,001 kWh-30,000 kWh (28.6%) consisting of homestays, resorts, and houses; 4) power energy of 30,001 kWh-40,000 kWh (16.85%) consisting of homestays, resorts, and houses; 5) power energy of 40,001 kWh-50,000 kWh (10.57%) consisting of homestays, houses, and dining houses; 6) power energy of 50,001 kWh-70,000 kWh (5.12%) consisting of homestays, resorts, houses, restaurants, and educational facilities; 7) power energy of

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70,001 kWh-100,000 kWh (1.98%) consisting of resorts, village offices, and other supporting facilities; and 8) power energy of 100,001 kWh-15,000 kWh (1.32%) consisting of educational facilities, resorts, and mosques.

3.7. Renewable Energy as a Solution to Electricity Problems

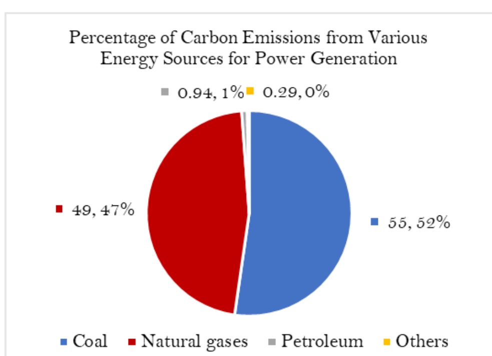
Climate change triggered by greenhouse gas (GHG) emissions causes hot temperatures to be trapped in the earth's atmosphere (Fawzy et al., 2020) Greenhouse gas emissions are influenced by various aspects where CO_2 emissions sourced from fossil sources contribute a fairly high number, in addition to some human activities such as land transfer, increasing urbanization, industrial activities (Eickemeier et al., 2014; Fawzy et al., 2020; Lin & Zhu, 2019), and natural conditions, namely volcanic activity, which also contributes to (Fawzy et al., 2020; Xi-liu & Qing-xian, 2019). Based on the report of the Intergovernmental Panel on Climate Change (IPCC) on 2018, he increase in earth's temperature since 2018 to date has reached 0.8°C to 1.2°C and is expected to reach 1.5°C by 2030 to 2052 (Fawzy et al., 2020; IPCC, 2018). Efforts to suppress global warming will not be successful if industrial activities along with economic and business development are still carried out as usual without land, energy, and environmental sustainability management plans (Hellin & Fisher, 2019). As an effort to address climate change, various studies, action plans, conferences, monitoring of extreme weather changes, Sustainable Development Goal agendas, and the Paris Climate Change Agreement have been conducted. As part of mitigation efforts in addressing the impact of climate change, 161 out of 188 member countries of Paris Agreement agree on sectoral policies to curb the rise in greenhouse gas emissions (Fawzy et al., 2020; Nieto, Carpintero, & Miguel, 2018)

Table 5. Types of Power Generation Energy and CO2 Emissions from Power Utilities

	Power Generation	Carbon emissions		
	Million kWh	*Million metric tons*	*Million short tons*	*Pounds per kWh*
Coal	757,763	767	845	2.23
Natural gases	1,402,438	576	635	0.91
Petroleum	13,665	13	15	2.13

Source: U.S. Energy Information Administration, 2021

Data from the U.S. Energy Information Administration shows that the use of electric energy sourced from the combustion of coal, natural gases, and petroleum fuels accounts for very large CO2 gas emissions (Lai et al., 2017). Table 5 is data related to carbon emissions caused by electricity generation with non-renewable energy. The fuel supplies 62% of fuel use for electric energy in the United States, pollutes the atmosphere, and accounts for 99% of carbon emissions generated (Administration, 2021). The power of fossil energy produces the amount of emission gases such as Carbon dioxide (CO_2), Nitrogen oxide (NO_x), and Sulfur dioxide (SO_2) on a large scale (Shahsavari & Akbari, 2018).



Source: U.S. Energy Information Administration, 2021

Figure 11. Percentage of Total Carbon Emissions from Various Energy Sources for Power Generation

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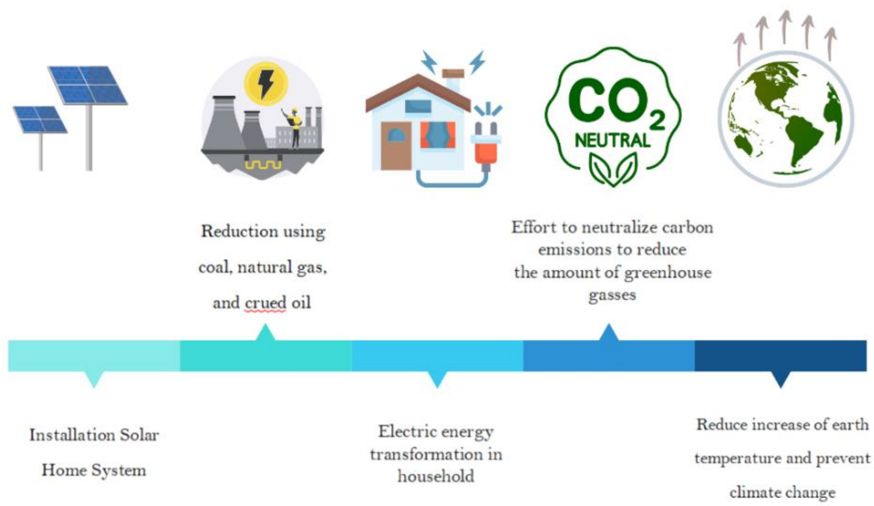
Based on the data display in Figure 11, efforts to replace fossil-fueled electricity are important to be pursued. As the study of Rodriguez & Barau (2018) revealed, people must change old patterns and get used to utilizing non-renewable energy as wisely as possible. This idea of renewable energy is believed to reduce greenhouse gas emissions, where Fawzy et al. (2020) propose several climate change mitigation measures, one of which is conventional mitigation that can be done by diverting fuel and encouraging the realization of new and renewable energy. In this study, it is stated that the effort to manifest renewable energy is carried out through the transition of the utilization of fossil energy as a source of electric energy to the utilization of sunlight through the use of solar panels as a source of electricity and storage of backup electric energy. The use of solar panels that is proven to be clean energy, do not cause pollution, and can suppress the use of fossil energy will prevent environmental damage as well as produce low carbon emissions and less pollution (Hellin & Fisher, 2019; Mitra, 2021). An illustration of the utilization of solar energy is presented in Figure 12.



Source: Data Analysis, 2022

Figure 12. Benefits of Using Solar Home System to Slow Climate Change

Utilization of solar energy through solar panel technology is the implementation of the 7th SDGs, namely Clean Energy (CE) that is affordable, efficient, and safe (Santika et al., 2020). In accordance with the Concept of Renewable Energy Technology Innovation (RETI) initiated by (Lin & Zhu, 2019) , it was revealed that ideas and innovations regarding technology development are needed to encourage the transition to renewable energy sources. This energy should encourage the concept of carbon neutral or low carbon footprint production. By the transition of renewable energy, using solar panels has improved decrease from carbon emission which this emission could happen when gas released from the combustion of carbon containing compounds, such as CO2, coal burning, diesel, and so on. Table 6 are the carbon footprint levels produced by solar panels in various empirical literature in various countries.

This technological change allows the construction of solar panels to be carried out on each house (Sharma & Goyal, 2020) with cheaper materials (Al-Shahri et al., 2021). Various efforts have been made to support the energy transition (Lucas, Carbajo, Machiba, Zhukov, & Cabeza, 2021) and suppress the adverse effects of the use of fossil energy whose availability is increasingly limited (Al-Shahri et al., 2021)) The geographical location of Indonesia as a tropical country crossed by the equator with a daily intensity level of solar radiation of 4.8 kWh/m2 should be optimally made use of so that energy sustainability can be realized. (Wullandari & Hakim, 2021) stated that the intensity of solar radiation is a factor determining the success of the work of solar cells contained in solar panels. With this condition, Indonesia has a high chance of success in optimizing solar panels as an environmentally friendly source of electricity and renewable energy (Wullandari & Hakim, 2021).

The development of a clean energy concept that produces zero carbon emission (Aste et al., 2020) is a challenge for many countries. Measuring the success of the utilization of Geographic Information Systems through DEM analysis becomes one of the alternative solutions. The accuracy of building roof selection by considering the level of slope and the consideration of the intensity of sunlight is one approach to determine how much energy is generated and how far the level of adequacy is. SHS can be a solution to be implemented to address the complex problems of fossil fuel scarcity and environmental pollution (Rigo et al., 2020). In addition, due to its easy-to-install shape, this technology can be installed on various types of building roofs so that it can reach even the most remote houses and can become a technology to fulfill the 100% electrification goal in various parts of the world (Rabuya et al., 2021). This effort that requires multi-stakeholder cooperation is expected to be successful and able to be used by all groups so that the transition from fossil energy to clean energy can be achieved following the SDGs' 7.1 target (Santika et al., 2020). This study and several other empirical studies prove that the use of solar panels as a technology based on solar energy is part of the efforts to reduce carbon emissions and earth's temperature to prevent climate change (Al, 2022).

Table 6. Empirical Studies on Large Carbon Emissions Generated by Solar Panels

Method	Empirical Study	Result
Life-Cycle Analysis (LCA), Energy Payback Time (EPBT), Greenhouse Gas Emission Rate (GHGe-rate)	Constantino, Freitas, Fidelis, & Pereira, 2018 a study in Brazil	The emission rate generated by solar panels for a 25-year validity period is only about 911$CO_{2\text{-eq}}$/kWh for each m2
Data Envelopment Analysis (DEA)	Ren *et al.*, 2020 a study in China	The use of solar panels reduces CO_2 emission level by 0.5468
Life-Cycle Analysis (LCA)	Olek, 2021 a study in Poland	For a validity period of 25 years, solar panels produce 55 gCO2*eq*/kWh for every 1222kWh/m2/year
Life-Cycle Analysis (LCA)	Shahsavari & Akbari, 2018 a study in several countries.	The operation of solar panels results in zero gas emission, but the installation process will produce approximately 4 Gigatonnes of carbon emissions from a total of 4600 GW for a period of up to 2050.

Source: Literature Review Results, 2022

4. Conclusion

The goal of this study was observed an estimated total electric power using GIS utilizing slope of the buildings, aerial photography data quality for DSM model, and criteria of solar radiation received by the roof. The main result found that the energy produced per year is 17,355.254 mWh or 17,355,254 kWh and an average power per building of 28.686 mWh or 28,686 kWh. As a comparison, the average annual electricity consumption for households in the United States was 10,649 kWh in 2020. According to the EIA, only 39 out of a total of 566 buildings on Derawan Island produce below average electric energy. Based on the number of buildings and electric power, there are eight classifications as described in the results. In this classification, it was found that buildings in the form of community houses, resorts, and homestays have an estimated electric power of 0-40,000 kWh. The total number of identified buildings is about 490 buildings with a dominant percentage of 80.95%: 64 buildings (10.57%) consisting of homestays, community houses, and dining houses of 40,001 kWh-50,000 kWh; 31 buildings (5.12%) consisting of homestays, resorts, community houses, dining houses, and educational facilities of 50,001 kWh-70,000 kWh; 12 buildings (1.98%) consisting of resorts, village offices, and other supporting facilities of 70,001 kWh-100,000 kWh; and the largest total energy power in the range of 100,001 kWh-154,000 kWh is estimated in 8 buildings (1.32%) consisting of resorts, educational facilities, and places of worship (mosques).

The successful implementation of the Solar Home System can have positive impacts, marking the transition to clean energy as well as becoming a real implementation to reduce the use of fossil fuels that has adverse effects on the environment and to slow the increase in earth's temperature. This big effort that requires the cooperation of the society on all levels is expected to go along with by the assertiveness of the government in carrying out the regulation of fossil user industries to participate in the transition to clean energy.

As precise calculating continues to grow, as long as technologies, we expect more tools for the future could measure the solar radiation accepted on roof to estimate electric power on top of the building. Fulfilled the demand from our emergencies in sustainable energies and help island people communities such as Derawans to supply electrify needs in easy and cheap. Research continues could using high-tech equipment and tools to obtained precise, accurate, and great quality data of the building roofs, such as LiDAR. Also, to get and maintain actual data, the research could involve the surrounding communities as participants.

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