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MORALITY BEFORE KNOWLEDGE

Estimation of photovoltaic energy potential in the Universitas Gadjah Mada area

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ABSTRACT

Background: One of alternative energy that has great potential dan is environmentally friendly is solar energy or photovoltaic. Sunlight can be converted in to electrical energy using photovoltaic panel (PV panel). Indonesia has a great potential to utilize this energy, because it is located around the equator line which causes Indonesian territory to be exposed by sunlight for 10-12 hours every day. This study aims to determine the potential of photovoltaic energy in Univeristas Gadjah Mada area, as well as the suitable location and dimension for the utilization of photovoltaic energy. **Methods:** The amount of sunlight received on a surface on earth can be estimated using spatial analysis methods. **Findings:** The slope dan aspect of a surface can be information to estimate the value of radiation received on that surface. The information needed can be obtained from a digital surface model (DSM) which is a digital model of the surface of the earth. The object that being analyzed is the roof of the building. Furthermore, it can be estimated the electrical energy potentials that is generated by multiplying solar radiation, area, and the coefficient of efficiency and performance ratio of the PV panels used. **Conclusion:** It can be seen the estimated electricity is 13,224,850 MWH in 59,893 m^2 area a year on 357 rooftops in Universitas Gadjah Mada area. 7,730,132 MWH of them are produced in 18 faculty areas. Based on electricity usage data at the 18 faculties, photovoltaic energy is estimated to save energy by 71%. This value is also proportional to the cost that can be saved to meet electricity needs. **Novelty/Originality of the Study:** The uniqueness of this study lies in its accurate spatial estimation of photovoltaic (PV) energy potential using a Digital Surface Model (DSM) to analyze the suitability of roofs across Universitas Gadjah Mada (UGM).

KEYWORDS: digital surface model; electrical energy; photovoltaic.

1. Introduction

Nowadays, the development of the world of technology is very rapid. Especially with digitalization that has penetrated all aspects, so it is called the digital era. Although many conveniences have been offered to access the digital world, energy is still needed when we want to access the digital world, namely electrical energy. The more the use of the digital world, of course, the more the use of electrical energy will be directly proportional to the use of electrical energy. Currently, the dominant electrical energy in Indonesia is electrical energy distributed by the State Electricity Company/*Perusahaan Listrik Negara* (PLN). PLN gets electrical energy from various power plants spread throughout Indonesia. Some types of power plants in Indonesia include Hydroelectric Power Plants/*Pembangkit Listrik Tenaga air* (PLTA), Gas Power Plants/*Pembangkit Listrik Tenaga Gas* (PLTG), Geothermal Power Plants/*Pembangkit Listrik Tenaga Panas Bumi* (PLTPB), Diesel Power Plants/*Pembangkit Listrik Tenaga Diesel* (PLTD), Wave Power Plants/*Pembangkit Listrik Tenaga Ombak* (PLTO), Steam Power Plants/*Pembangkit Listrik Tenaga Uap* (PLTU), and

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Solar Power Plants/*Pembangkit Listrik Tenaga Solar* (PLTS). Steam Power Plants/*Pembangkit Listrik Tenaga Uap* (PLTU) that use coal as their main material still dominate the electrical energy market in Indonesia because of their affordable prices. However, the use of fossil-based energy has the consequence that the availability of these natural resources is very limited and has a negative impact on the local and global environment. Therefore, the government has issued a National Energy Policy/*Kebijakan Energi Nasional* (KEN) which contains government policies on national energy management. In this Policy, a roadmap has been prepared towards increasing the role of renewable energy in national electricity generation and by 2025 it is expected that the role of renewable energy will reach around 5% of the total national electricity generation capacity (Kumara, 2010).

Indonesia is a country with various abundant energy resource potentials. Located around the equator, Indonesia has great potential to utilize sunlight energy which always shines on this country for 10-12 hours a day. The development of sunlight energy is one alternative to the increasing need for energy. Having an average daily radiation of sunlight of 4.5 kWh/m2 makes solar power a potential option that can be utilized to meet the need for electricity in Indonesia (Riandika et al., 2018).

Solar power (photovoltaic) in its utilization is still used in small amounts. In Indonesia, there are already Solar Power Plants/*Pembangkit Listrik Tenaga Solar* (PLTS) which are commonly used for electricity in remote villages. This type of system is commonly called SHS (Solar Home System). In fact, solar energy is renewable energy and is more environmentally friendly (Hafeez & Atif, 2015). Photovoltaic is classified as environmentally friendly and has resources that are always available. However, its utilization requires expensive technology, so accurate analysis is needed in planning the use of photovoltaic energy (Hong et al., 2017). Research on the potential of photovoltaic energy in Indonesia was previously conducted by Sunanda et al. (2017). The research conducted was to find out the potential of photovoltaics in the Bangka Belitung University campus area by taking data on the intensity of sunlight radiation using 6 50Wp PV panel units. Research on photovoltaics in the Java Island region by creating a web-based application that shows the photovoltaic potential of each district/city in Java was conducted by Riandika et al. (2018). Meanwhile, the use of Geographic Information Systems to estimate the energy that can be generated by solar power plants in South Korea has previously been carried out by Hong et al. (2014)

As one of the largest universities in Indonesia, Universitas Gadjah Mada (UGM) requires large amounts of electrical energy to meet academic and non-academic needs every day. UGM still uses conventional electricity supplied by the State Electricity Company/*Perusahaan Listrik Negara* (PLN) as the main source to meet its electricity needs. With an area of approximately 300 hectares and hundreds of buildings spread across 18 faculties and 2 schools, UGM has the potential to build a photovoltaic panel network in each of its buildings to save on the use of conventional electricity supplied by PLN. The potential for photovoltaic energy in the UGM area can be estimated using one of the 3D models of the earth's surface, namely the Digital Surface Model (Khanna, 2019).

Three-dimensional (3D) models of buildings can provide a better picture for analyzing photovoltaic systems and how much results can be obtained (Hafeez & Atif, 2015). Digital Surface Model (DSM) is one of the 3D models that can describe the condition of a building roof (Gawley & Mckenzie, 2022). DSM can be used to identify building roofs that can be installed with photovoltaic panels. However, not all parts of a building roof can be installed with photovoltaic panels. There are several criteria for installing photovoltaic panels that must be adjusted to the condition of the building roofs in the UGM area. In fact, photovoltaic panels can not only be installed on building roofs, but can also be installed on the ground that can reach direct sunlight without being blocked. However, photovoltaic panels will be more efficient if installed on building roofs so as not to interfere with the use of land that can still be used for other purposes. If the roofs of buildings that are suitable for installing photovoltaic panels have been identified, then the estimated electrical energy that can be produced can also be calculated. The need for electrical energy in the UGM area is expected to be saved by utilizing photovoltaic energy. The use of photovoltaic energy requires a high cost, so that in its planning it requires an estimated value of the electrical energy that can be produced. This study is intended for planning the use of photovoltaic panels in the UGM area so that it can save non-renewable energy effectively. This study focuses on how to obtain an accurate estimate of the power that can be produced by photovoltaic panels if installed on the roof of a building in the UGM area that meets the criteria, then visualized with an interactive presentation. It is hoped that with an interactive presentation, the information to be conveyed can be more easily absorbed. In addition, the results of this estimation can be a reference for the UGM Asset Directorate for planning the use of photovoltaic energy in the Universitas Gadjah Mada area.

2. Methods

The preparation stage before conducting the research is to conduct a literature study obtained from books, scientific journals, conference results or other literature relevant to the research to be conducted (Chigbu et al., 2023). The literature study stage can facilitate and support the implementation of the research. In addition, preparation is also needed regarding the tools and materials used so that the research objectives can be achieved. The research location focuses on the campus area of Universitas Gadjah Mada. The object studied is the roof of the building. The area in question is the area shown in Figure 1 below.

Fig. 1. UGM campus area

The tools that need to be prepared in data processing activities in this study consist of hardware and software. Details of the tools needed are as follows: the hardware used is: [a] ASUS A455L brand laptop with 10 GB Random Access Memory specifications, Intel Core i3 Processor, and NVIDIA GEFORCE 930M for data processing. [b] ADATA brand external hard disk with 1 TB capacity for data storage. The software used is: [a] Windows operating system with Windows 10 Pro 64-bit Operating System specifications, x64 based processor for data processing. [b] Agisoft PhotoScan software to process photo data into DSM data. [c] ArcGIS Pro software to perform spatial analysis. [d] Microsoft Word software to write research reports. [e] Microsoft Excel software to process attribute data. [f] ArcGIS Online to save web layers. [g] ArcGIS Scene Viewer to create web scenes. [h] ArcGIS Web AppBuilder to create web applications.

In this study, the author did not acquire the required materials or data. The author used data that was available before this study was conducted. The materials or data used in this mapping include: [a] Aerial photo data of the UGM area that was acquired on June 9 and 10, 2018 with a Ground Sample Distance (GSD) of ±5 cm. The data was acquired by: [1] Andika Anggara Pribadi (Student of Geodetic Engineering, Faculty of Engineering, UGM), [2] Dhega Wasi Wihikan (Student of Geodetic Engineering, Faculty of Engineering, UGM), [3] Hanif Muhammad Fauzi (Student of Geodetic Engineering, Faculty of Engineering, UGM), [4] Hasan Albana (Student of Geodetic Engineering, Faculty of Engineering, UGM), [5] Lantip Supratiko (Student of Geodetic Engineering, Faculty of Engineering, UGM), [6] Muhammad Wahyu Dwimulyo (Student of Geodetic Engineering, Faculty of Engineering, UGM). [b] GPS measurement data on Ground Control Points acquired on May 11, 2019 using the net method by Geodetic Engineering Students in the Geodetic Control Net (JKG) course in the even semester of the 2018/2019 academic year. [c] Data on the use of electrical energy on the UGM campus from electricity bill data at 18 faculties during 2019 provided by the UGM Asset Directorate. The data contains electricity bills which contain information on the value of electrical energy used in kWh units and the costs incurred. The electricity bill data obtained is postpaid bill data, so the data listed on the electricity bill each month is the electricity usage data for the previous month.

2.1 Implementation

Some of the main activities that will be carried out in this research include: [a] Making DSM and orthomosaic photos from aerial photo data, [b] Making slope layers, aspect layers, and solar radiation layers, [c] Selection of appropriate building roofs, [d] Calculation of estimated electricity production values for each building, [e] Analysis and presentation of information. The implementation stages are based on Figure 2 covering the processes that will be passed and the schedule of the research plan including the targeted time in carrying out the research. The flow diagram of the activity plan is expected to be a reference in carrying out research that can be structured and systematic.

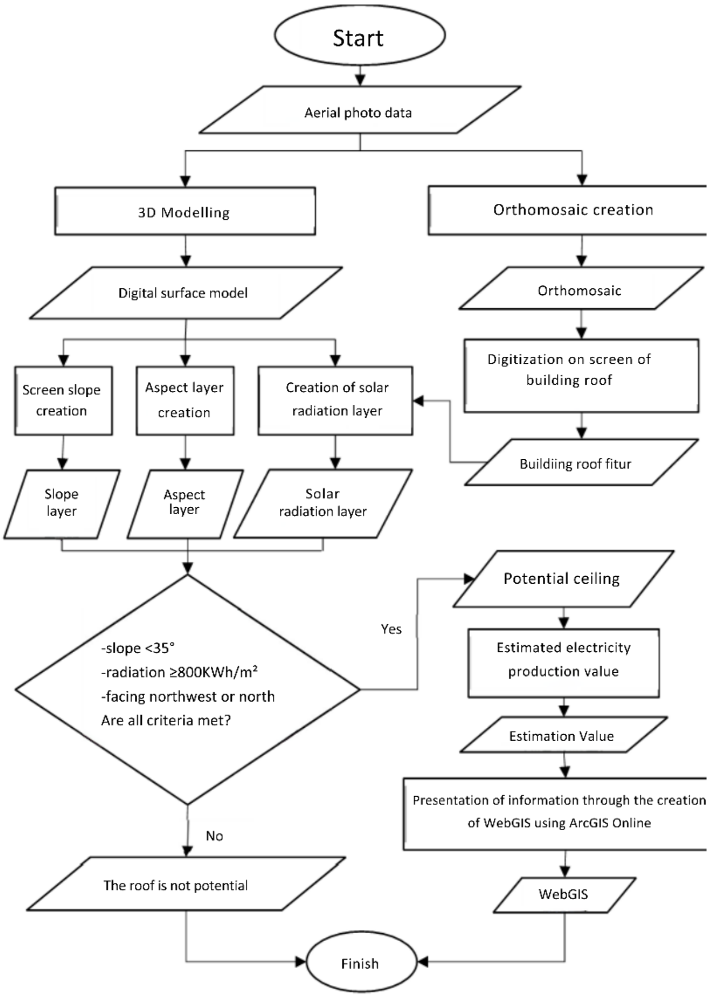

Fig. 2. Implementation flow diagram

2.2 DSM and orthomosaic manufacturing

Aerial photo data can be used to create DSM and orthomosaic (Dunne, 2015). DSM and orthomosaic are created by arranging the photos based on the available camera coordinates and GCPs, so that all the photos are connected by tie points. These tie points will later become the reference in creating the arrangement of overlapping photos. After the photos are arranged based on tie points, then by using camera depth measurement, a collection of points called a dense cloud can be created. The collection of points will later be connected to each other to form a surface that represents the shape of the object or is called DSM. In this study, the object analyzed was the roof of the building so that a texture was needed on the surface so that the roof of the building and other objects could be interpreted. Therefore, it is necessary to create an orthomosaic so that the roof of the building can be selected by on-screen digitization (Haala & Brenner, 1999).

In the Agisoft PhotoScan software, the sequence for processing aerial photo data into DSM and orthomosaic is as follows: [a] Add photos, which is to input the aerial photo data to be processed. [b] Entering GCP coordinates on aerial photos. [c] Align photos, which is arranging the photos that have been inputted so that they can be tied together. In this process, tie points will be produced. [d] Build dense cloud, which is the process of creating a collection of points that form objects in the photo based on the estimated camera position. This process calculates depth information for each camera that will be combined into one dense point cloud. In this process, a dense cloud will be produced. [e] Build mesh, which is the process carried out to connect points on the dense cloud into a surface so that it can be displayed in the form of a 3D model. [f] Build texture, which is making the surface of the object have color and also brightness levels. [g] Build tiled model, which is the process of creating responsive 3D visualizations so that the model can adjust the level of detail to the desired visualization scale. [h] Build DEM, which is creating a 3D model in raster format. The results of this process produce DSM which will be used for spatial analysis. [i] Build orthomosaic, which is creating high-resolution images sourced from input photos and reconstructed 3D models. The results obtained are orthomosaic images used to select building roof features in this study. [j] Generate reports, which is to find out information from each process carried out.

The aerial photo data used amounted to 1,250 photos, with a ground sample distance of ±5 cm, and overlap between photos of 80% and sidelap between photos of 70%. Using these data, the number of tie points was obtained as many as 827,956 points. Then by using depth measurements, a dense cloud was obtained with a number of points of 80,743,930. The resulting DSM has a size of 12049 × 10712 pixels with each pixel having a resolution of 27.4 cm. While the resulting orthophoto has a size of 35475 × 30015 pixels with a resolution of 6.86 cm.

Fig. 3. Tie points

Figure 3 shows the arrangement of tie points formed. It can be seen that the points are still rare because the function of the points is only as a tie point between photos so that dense points are not needed. Meanwhile, Figure 4 is an image of a dense cloud/point cloud that is formed. In this model, the points look denser and an object begins to look like it. These points will later be connected to form a surface.

Fig. 4. Dense cloud formed on the roof of a building

As a quality control of DSM and orthomosaic data, ground control points (GCP) are used. In this study, 3 GCPs were used with details of point 1 located around the UGM Boulevard, point 2 located in the UGM Faculty of Engineering Infrastructure Park, and point 3 located at the UGM Faculty of Veterinary Medicine Roundabout. The location of the GCP is as shown in Figure 5. The GCP can be seen in Table 1 below.

Table 1. Coordinates of ground control points

Point	Latitude (Degrees)	Longitude (Degrees)	H ell (m)	sN (mm)	sE (mm)	sH (mm)
Point 1	7° 46' 25,7239''	110° 22' 36,4285''	160,448	160,448	0.0	0.0
Point 2	7° 45' 51,7392''	110° 22' 21.2958''	166,627	166,627	4.7	7.6
Point 3	7° 46' 04,5862''	110° 23' 05.8161''	167,582	167,582	3.8	4.0

The results of the compilation of aerial photos (Figure 5) adjusted to GCP can show the quality of the data produced. This quality can be seen from the root mean square error (RMSE). The RMSE value compares the coordinates in the photo with the actual coordinates of the control point. The smaller the RMSE value, the better the data quality. The RMSE results for each point obtained in this study can be seen in Table 2 below:

Table 2. RMSE of control points

Point name	X error (cm)	Y error (cm)	Z error (cm)	Total (cm)	Image (pix)
Point 1	-11.56	0.465372	-0.278124	11.5727	0.243
Point 2	5.386	-7.3745	0.0770971	9.13226	0.258
Point 3	6.23652	6.95927	0.153954	9.34609	0.292
Total	8.19628	5.8036	0.188855	10.776	0.264

The orthomosaic and DSM data generated are then used for analysis. This study focuses on the building roof object, so feature selection is needed for the building roof object. Therefore, orthomosaic data is used as a reference in the selection of building roofs using the on-screen digitization method. This method is carried out by digitizing the building roof that appears on the orthomosaic. The results of on-screen digitization are in the form of a roof polygon shapefile (.shp). The results of this selection will facilitate the analysis of solar radiation by reducing the number of pixels analyzed by only taking into account the pixels contained in the selected building feature polygon. Meanwhile, DSM data is used to analyze slope, aspect, and solar radiation.

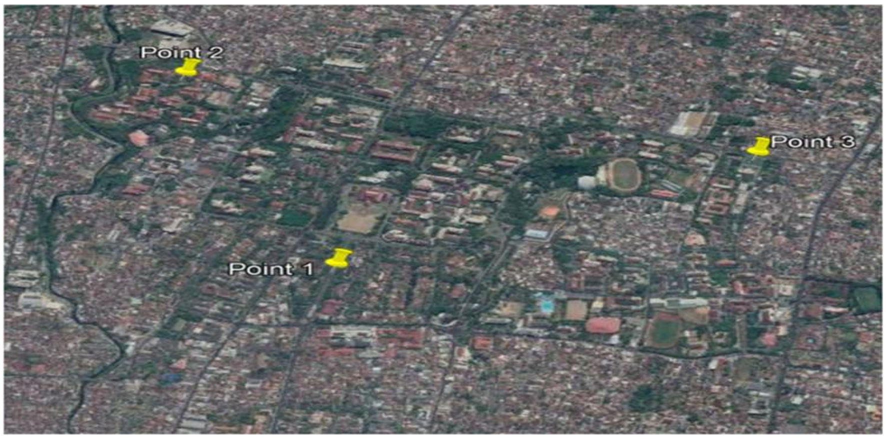

Fig. 5. Distribution of control points

2.2.1 Creating slope layer, aspect layer, and solar radiation layer

The DSM data generated from the previous process is data in raster format. Then one of the spatial analysis functions is performed, namely 3D analysis. The 3D analysis performed is to create a slope layer, aspect layer, and solar radiation layer. The creation of a slope layer requires spatial information in the form of height data for each pixel in the raster. The calculation of the slope value using the planar method uses a 3×3 grid which is calculated according to Equation (2) and Equation (3). The results of the calculation using the grid are then associated with Equation (1) so that a new pixel value is obtained in the center pixel of the grid.

$$S_{degrees} = \tan^{-1}\sqrt{\left(\frac{dz}{dx}\right)^2 + \left(\frac{dz}{dy}\right)^2} \times \frac{180°}{\pi} \quad \text{(eq. 1)}$$

$$\left(\frac{dz}{dx}\right) = \frac{(c+2f+i)\times\frac{4}{wght_1} - (a+2d+g)\times\frac{4}{wght_2}}{8\times x_{cell\ size}} \quad \text{(eq. 2)}$$

$$\left(\frac{dz}{dy}\right) = \frac{(g+2h+i)\times\frac{4}{wght_3} - (a+2b+c)\times\frac{4}{wght_4}}{8\times y_{cell\ size}} \quad \text{(eq. 2)}$$

The grid continues until all pixels have a new pixel value. This value is the slope value. Figure 6 shows the parameters used to perform slope analysis in this study. Slope analysis produces a raster that shows the slope value of a pixel. Pixel values can have units of degrees and also percentages (%). This value is obtained from the calculation results in Equation (1), namely using degrees.

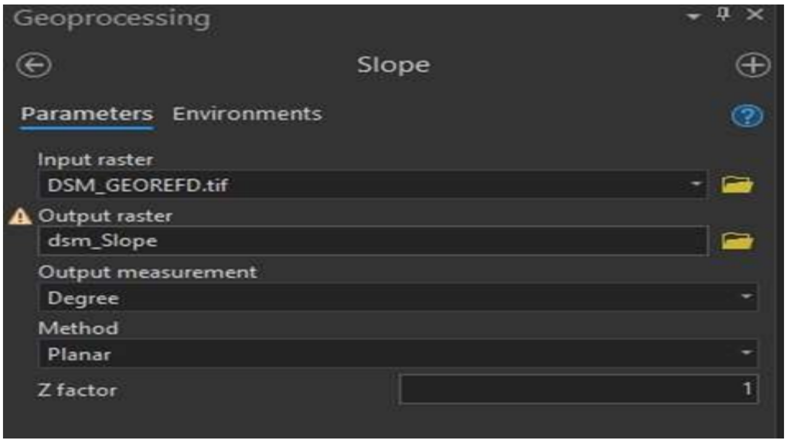

Fig. 6. Slope analysis parameters

The method used is planar, because the input DSM has a projection coordinate system in WGS 84 UTM zone 49S. Because the input raster has a projection coordinate system, the z factor value is equal to one. In the geographic coordinate system, a z factor value is needed to adjust the height value, this is because the units are different between horizontal coordinates and vertical coordinates (ESRI, 2020b). An example of the results of the slope analysis can be seen in Figure 7 below.

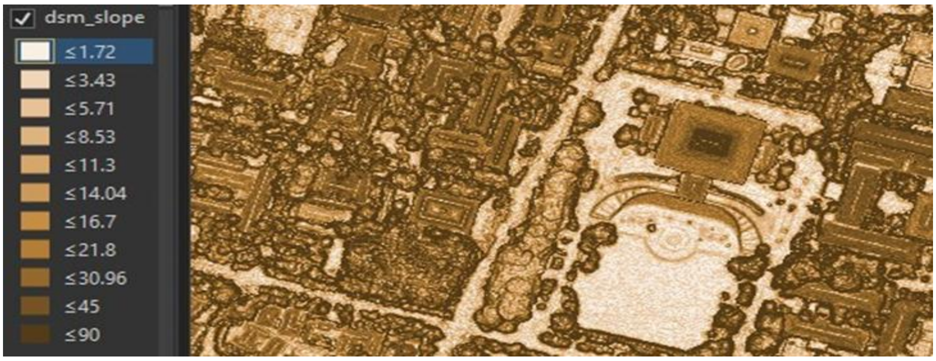

Fig. 7. Results of creating a slope layer

Figure 7 shows that the slope of a surface is shown in color gradation. The darker the color shown, the steeper the slope of the surface. On the left side of Figure 7 there is a description of the surface slope shown in degrees. This value is attached to each pixel so that it can be visualized using a color gradation symbol. If there is a surface that has a slope, there is one more spatial information that can be known, namely the direction of the slope. Using the same concept as slope, DSM can also analyze the direction of the slope. This analysis is called aspect, where the output raster will show the azimuth value of each pixel that shows the direction of the pixel. The output value ranges from 0-360 degrees with details as shown in Figure 8 below.

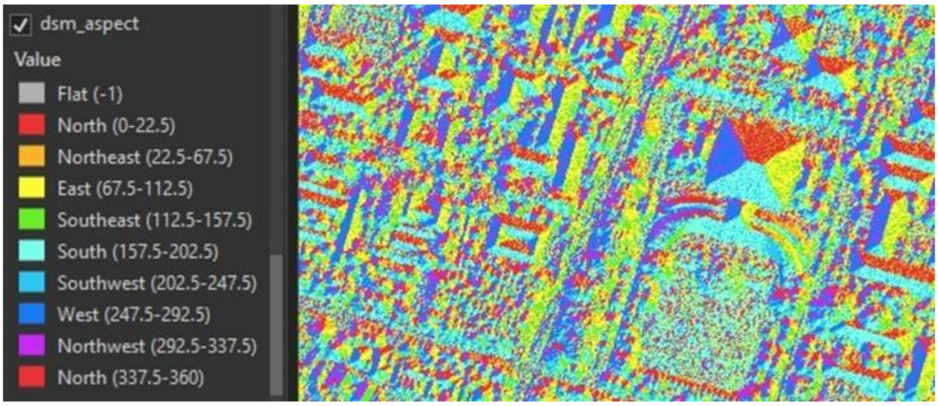

Fig. 8. Result of creating aspect layer

In this study, we want to know the area of the roof of the building that is suitable for the installation of photovoltaic panels. Therefore, the area of solar radiation tool is used based on area. The first stage of the area of solar radiation tool is to create a viewshed display. Viewshed can be the spatial information needed to determine the surface that can capture direct radiation. Then for diffuse radiation, a sky map is used as a calculation. The parameters used for solar radiation analysis are shown in Figure 9. Based on the total direct radiation and diffuse radiation results, it will provide the global radiation value received by the pixel in WH/m2 units. This process is carried out continuously until all pixels have their radiation values. This study limits the objects analyzed to the roof of the building, so the calculation of the solar radiation layer only takes into account pixels that are within the roof feature polygon of the building.

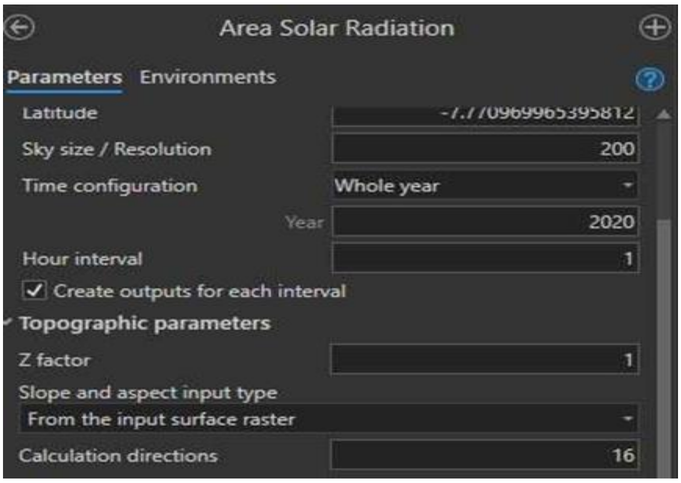

Fig. 9. Parameters for making the solar radiation layer

In this study, we want to know the amount of radiation received within a period of one year. However, the ArcGIS Pro solar radiation area tool can also determine the radiation value received each month. The radiation value received is calculated according to Equation (8) at each pixel. Each pixel is first calculated for the direct radiation value and the diffuse radiation value. The direct radiation value is calculated using Equation (4) with the centroid at the zenith angle (θ) and the azimuth (α) is calculated using Equation (5). While the diffuse radiation is calculated using Equation (6) with the centroid at the zenith angle (θ) and the azimuth (α) is calculated using Equation (7).

$$Dir_{tot} = \sum Dir\theta,_{\alpha} \quad \text{(eq. 4)}$$

$$Dir\theta,_{\alpha} = S_{const} \times \beta^{m(\theta)} \times SunDur\theta_{,\alpha} \times SunGap\theta_{,\alpha} \times cos\left(Angln\theta_{,\alpha}\right) \quad \text{(eq. 5)}$$

$$Dif_{tot} = \sum Dif\theta,_{\alpha} \quad \text{(eq. 6)}$$

$$Dif\theta,_{\alpha} = R_{gib} \times P_{dif} \times Dur \times SkyGap\theta_{,\alpha} \times Weight\theta_{,\alpha} \times cos\left(Angln\theta_{,\alpha}\right) \quad \text{(eq. 7)}$$

$$Global_{tot} = Dir_{tot} + Dif_{tot} \quad \text{(eq. 8)}$$

The radiation value received each month can be different, because the position of the sun changes every month. The position of the sun used refers to the sun map at a certain altitude, in this study the altitude of the UGM area is meant. So that later there will be 13 rasters that show the total radiation value in one year, and the radiation value per month for 12 months. The availability of monthly radiation value data can help to find out information related to the comparison of electricity use and production each month.

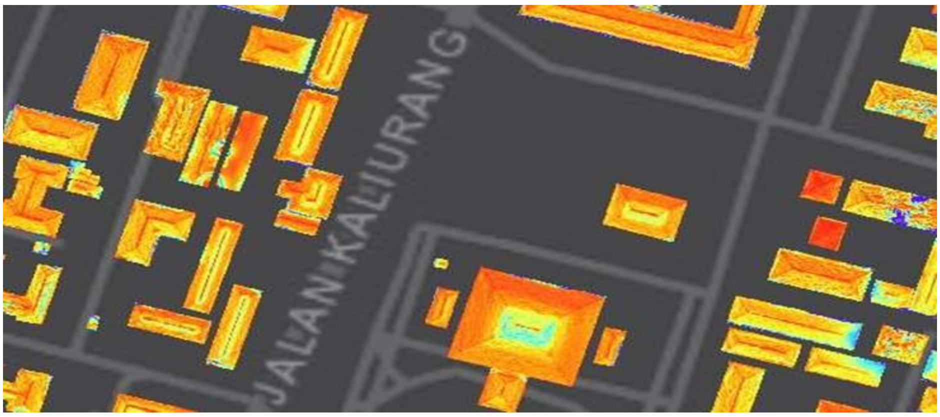

Fig. 10. Results of the solar radiation layer

Figure 10 shows one of the raster results of solar radiation analysis showing the radiation value of. In the figure, the radiation value is shown with color gradation. The redder the greater the radiation value. While the low radiation value is shown in blue. It can be seen that surfaces with steep slopes have lower radiation values than flatter surfaces. This is because the solar radiation area takes into account the angle of incidence of sunlight received by the surface. The angle of incidence of sunlight on the earth's surface is one of the dominant factors that can affect the magnitude of the radiation value received (Zhao et al., 2010).

2.2.2 Selection of building roofs that meet the criteria

Not all parts of the roof of a building are effective for photovoltaic panel installation. Certain criteria are needed for a roof of a building to be considered suitable for installation. Utilizing spatial information from the layers that have been created, criteria can be determined that are in accordance with the location of the activity area. The criteria in question are related to the slope value, direction of face, and the value of sunlight radiation. These criteria can be selected using the slope layer, aspect layer, and solar radiation layer that have been created in the previous stage.

The selection of building roofs is done by spatial analysis. The analysis carried out on the DSM to select suitable building roofs is a classification analysis. This analysis functions to classify data from existing layers into new spatial data based on certain criteria. In this study, each layer is classified into spatial data that is suitable and unsuitable for PV panels according to the criteria in each layer. Then a spatial overlay analysis is carried out to produce a new spatial data layer, where the layer is a combination of classification analysis in the previous layers. Overlay analysis is carried out by combining three layers that have been classified. In this overlay analysis, operations are made so that the resulting layer is a layer that meets all criteria. Spatial analysis is carried out using the condition tool in ArcGIS Pro. In this study, the analysis is carried out sequentially, namely by analyzing the slope of the surface (slope), then analyzing the direction of the surface (aspect), finally by analyzing the value of sunlight radiation received by the surface (solar radiation area). The roof of the building that is considered suitable is the roof of the building that meets the three criteria from each layer analyzed.

The first criterion is seen from the slope layer that has been created. The roof of the building with a slope of ≤35° (Hafeez & Atif, 2015) will be selected first as the first requirement that must be met. PV panels will be more effective in receiving radiation on surfaces that are not too steep. The flatter a surface, the better the radiation direction angle so that the radiation received will be greater (Zhao et al., 2010). Pixels on the solar radiation layer raster that have the same position as the pixels that match the desired slope conditions will be selected. Figure 11 shows that the selected pixels are only pixels that have a slope of ≤35°. Meanwhile, pixels that do not meet the criteria will be lost or have no data.

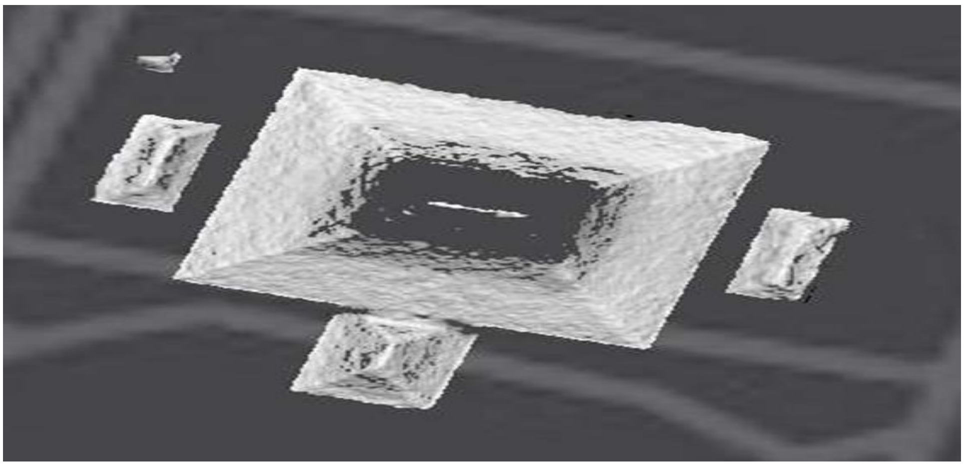

Fig. 11. Slope selection results

The radiation received by each surface is influenced by the surrounding conditions, resulting in varying values. Surfaces that receive small radiation will be detrimental if photovoltaic panels are installed. Therefore, it is necessary to select from the results of the slope selection which areas have sufficient radiation values for photovoltaic panel installation. The specified threshold is 800 KWh/m2 according to the calculation of the expected minimum electricity production (Khanna, 2019). Figure 12 shows the red circle showing a part of the roof that was not selected due to the small radiation value.

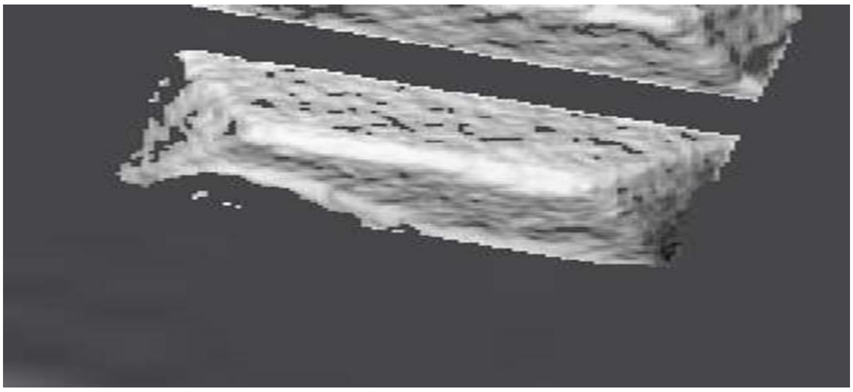

Fig. 12. Results of radiation value selection

The research area is in the southern hemisphere, so for the direction of the face (aspect) the roof of the building facing northwest and north will be selected (Hafeez & Atif, 2015) so that the PV panel faces the sun which is around the equator. This direction is indicated by a pixel value between 0-360 which has a degree unit (°), while a flat surface has a pixel value of -1. In the aspect layer, the northwest and north directions are indicated by pixel values 292.5°- 337.5° (northwest) and 337.5°-22.5° (north). However, if a surface has a relatively flat slope, then any aspect value does not have much effect on the angle of radiation incidence. A flat surface is assumed to have a slope of ≤10°. The results of the aspect layer selection are shown in Figure 13 where on a building roof only roofs with slopes facing north and northwest are selected.

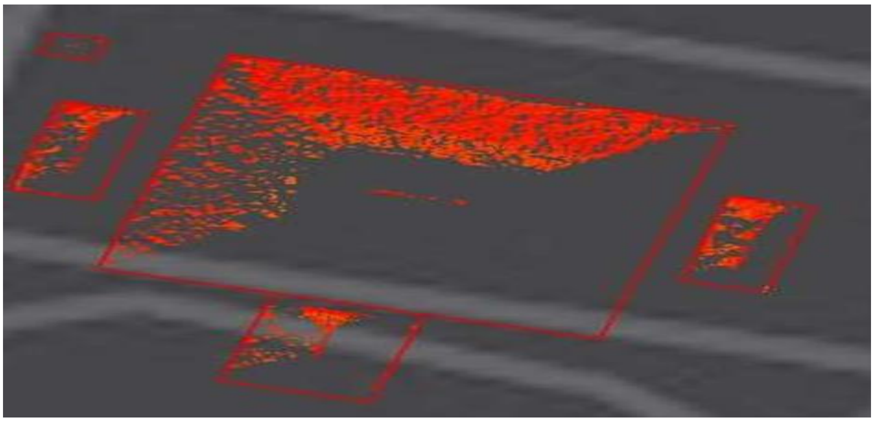

Fig. 13. Selection results for layer aspects

Then after knowing which areas on a building roof are suitable for installing photovoltaic panels, the next step is to select which building roofs can be installed. In this study, the expected photovoltaic network is a network that is large enough to help save electricity on a scale of each building. Therefore, only building roofs that have a potential PV panel area of at least 30 m^2 will be selected. In Figure 14, it can be seen that even though the roof of the building that is limited by the red line has a potential roof section, it does not have an area of ≥30 m^2. So the building is not recommended to be installed with PV panels. Meanwhile, other buildings that have an area of ≥ 30 m^2 are then calculated the estimated value of electricity production that can be generated in each building. Then given a color symbol that indicates the class based on the estimated value of electricity production.

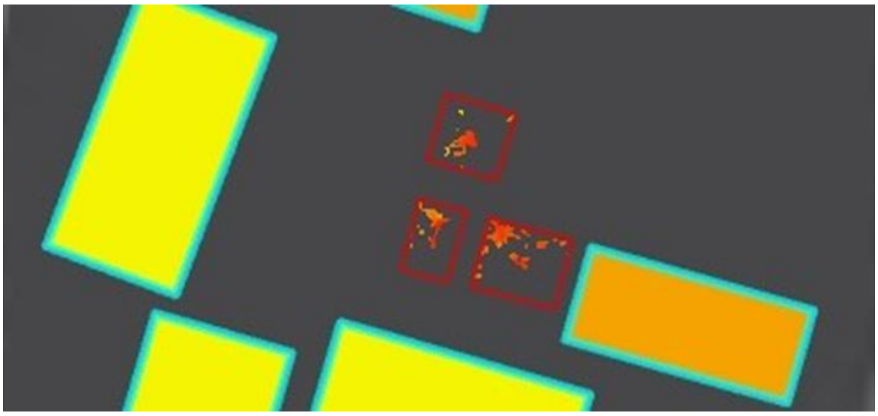

Fig. 14. Results of building roof selection

2.2.3 Calculation of estimated value of electricity production for each building

The selected building features can calculate the suitable area for photovoltaic panel installation and the average radiation value received at each pixel. So by knowing the average radiation value and the suitable area, the electricity production that can be generated can be calculated. The value of electricity production that can be generated is calculated using Equation (9). In Equation (9), information is needed regarding the area of the PV panel, the amount of global radiation, the efficiency value, and the performance ratio. The area of the PV panel is obtained from the number of pixels from the results of the slope, aspect, and solar radiation analysis contained in the roof feature polygon of the building, then multiplied by the pixel resolution. The amount of global radiation is taken from the average value of global sunlight radiation owned by the pixels located in the roof feature polygon of the building. Then the efficiency value and performance ratio refer to the United States Environmental Protection Agency (2018) which provides a conservative estimate of 15 percent efficiency and 86 percent performance ratio.

In this study, the value of electrical energy that can be generated for one year and the results obtained each month are desired. Therefore, calculations are also carried out on the raster that shows the radiation value each month on each selected building feature. The raster is also selected for the same pixels as the results of the slope and aspect analysis that have been carried out previously. So that there is consistency in the position of the PV panel installation. The units produced for data in 1 year are MWh (Mega Watt hour) while for each month interval it has a unit of KWh (Kilo Watt hour).

2.2.4 Analysis and presentation of information

The analysis was conducted to determine the location and area of each building that is suitable for photovoltaic panel installation and to determine the estimated electricity production that can be generated. The results of this analysis can be elaborated with the use of electricity from the UGM area. This analysis will later lead to the potential for electricity saving efforts. The information that has been obtained will then be displayed in the form of a web application. In this study, the application was created using the ArcGIS Online platform. In ArcGIS Online there are several features that are mutually integrated. The features used are ArcGIS Scene Viewer and ArcGIS Web AppBuilder. ArcGIS Online is also directly integrated with ArcGIS Pro.

So to upload a layer in ArcGIS Pro to a web scene in the ArcGIS Online directory can be done with the Share layer as web layer tool in ArcGIS Pro. ArcGIS Scene Viewer is used to create a web scene from the web layer that has been created. The layer in ArcGIS Pro that has been created is uploaded so that it can be accessed in the ArcGIS Online directory as a web layer. The directory is as shown in Figure II.15. In this study, there are three web layers that are included in the web scene. The first web layer is the Building layer which is a feature layer in shapefile format (.shp) to show the electricity production that can be generated from the use of photovoltaic energy in each building. This layer also shows other more detailed information in the form of a pop-up. The second web layer is the PV panel location in raster format. This layer shows potential positions for installing PV panels on the roof of the building. The last web layer is the DSM that has been created in raster format. The DSM is uploaded in ArcGIS Online in the form of an elevation layer. This is done so that when the DSM is entered into the web scene, a three-dimensional (3D) surface will be formed so that it can display the roof surface of the building as it actually is.

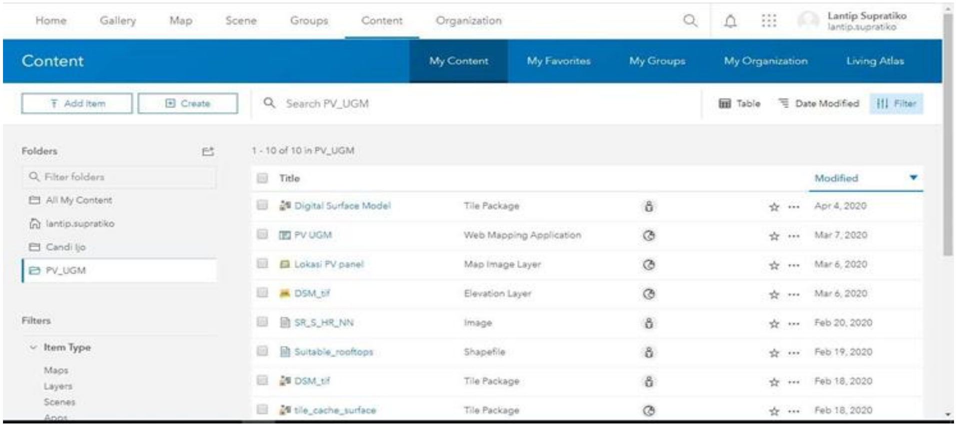

Fig. 15. Directory view in ArcGIS online

In this web scene, an imagery layer is also added to provide a base map in the form of satellite imagery that has been provided by ArcGIS Online. The created web scene can be saved in the ArcGIS Online directory. The web scene processing in ArcGIS Scene Viewer is done as in Figure 16. On the left side there is a window to select which layers you want to include. Then there are buttons to set navigation on the created web scene along with layer and legend settings.

Fig. 16. Web scene creation display in ArcGIS Scene Viewer

Then to facilitate navigation for users to access information on the web scene that has been created, it is necessary to use a web application. The application can be created with ArcGIS Web AppBuilder which is an ArcGIS Online feature used to create web applications with a display like in Figure 17. In ArcGIS Web AppBuilder, you can import from web scene data that is available in the ArcGIS Online directory. There are templates for web applications provided by ArcGIS Web AppBuilder. These templates can be modified as needed. In the template, there are several features of the web application that can make it easier for users to access information on the web scene. The web application that has been created can be saved in the ArcGIS Online directory and can be shared publicly via the internet network.

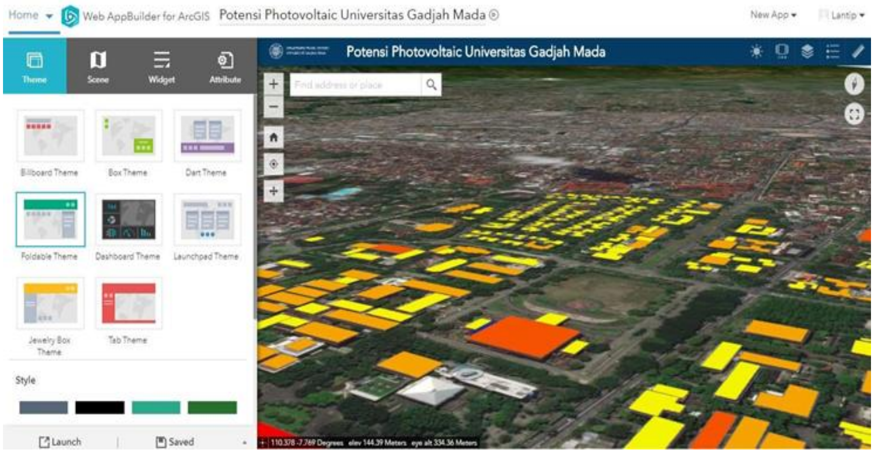

Fig. 17. Web application creation display on ArcGIS Web AppBuilder

3. Result and Discussion

3.1 Analysis of the suitable roof location and area of the building

In the results and discussion, there are several things discussed based on the process that has been carried out in this research, namely: [a] analysis of the location and area of the appropriate building roof, [b] analysis of the estimation of electrical potential, [c] presentation of information, and [d] problems encountered. The results of the spatial analysis carried out on the DSM provide information about the slope, aspect, and solar radiation at each pixel. Using this information, the part of the roof of the building that meets the criteria is obtained. This part shows the effective location for the installation of photovoltaic panels (PV panels). The location is shown in raster-based data, so that the area of each building can also be calculated.

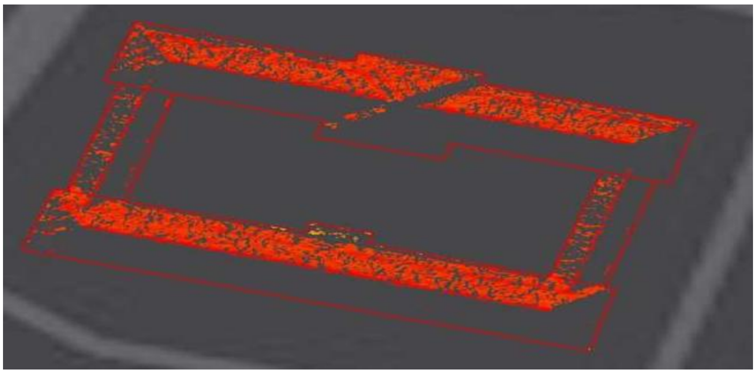
Fig. 18. Roof sections of buildings that have the potential for PV panel installation

The effective location of the roof for the installation of PV panels is shown in raster-based data as shown in Figure 18. When observed, there are parts that are perforated. This is because the DSM used still has noise originating from errors in measuring the depth of the photo. This noise produces a rough surface, so that a side of the roof of the building that should have a smooth surface becomes rougher. This rough surface causes a pixel to have errors in the slope, aspect, and solar radiation values. Each cell in the raster data has dimensions of X and Y. In the raster data showing the location of the PV panel installation, each cell has the same X and Y size, namely 27.438 cm. With this cell size, the area of the PV panel installation on each roof of the building can also be calculated. This area value will later be attached to the shapefile feature as an attribute of each object. A more complete information table regarding the area of the PV panel installation. In this study, there are 476 buildings analyzed. Based on this number, 357 objects meet the criteria for PV panel installation spread across 45 zones. The division of zones is based on faculty, directorate, block, and interpretation from the author. This zone is used to help group building objects. The zones in question are presented in Figure 19 which shows the distribution of zones.


Fig. 19. Division of UGM regional zones

The roof area of UGM buildings has a total of 281,987 m^2 while the estimated PV panel area has a total of 59,893 m^2. The noise factor from the data influences the selection of the desired area so that the calculated area value still contains errors. Referring to the percentage of potential roofs for PV panel installation from the total roof area at UGM is shown in Figure 20.

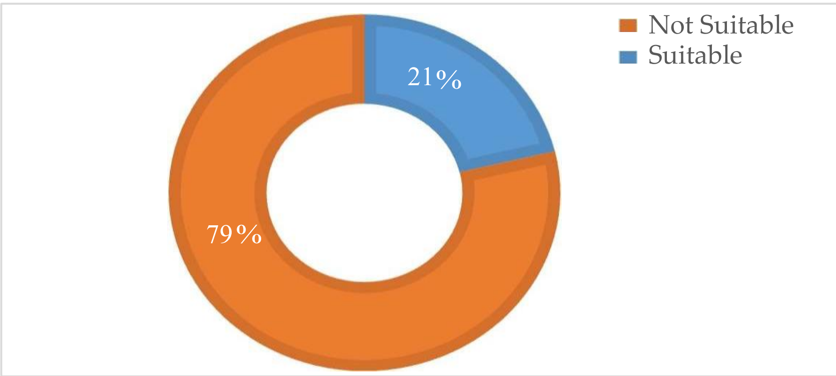

Fig. 20. Roof area diagram of a building for PV panel installation.

Figure 20 shows that there are 21% of the roof area of buildings located in the UGM area suitable for PV panel installation. While the remaining 79% are not suitable for installation. This value is obtained from the number of pixels that have met the criteria, which are then calculated based on the resolution of the pixels. More detailed data on the area that can be used for PV panel installation for each building.

3.2 Electrical potential estimation analysis

Calculating the estimated value of the potential electricity generated is done by multiplying the average radiation obtained in one object by the area of the radiation pixel. The result of the multiplication is then multiplied by the parameters of the PV panel itself. The PV panel parameters in this study refer to the United States Environmental Protection Agency (2018) which provides a conservative estimate of the PV panel having an efficiency of 15 percent and a performance ratio of 86 percent. More completely, this calculation refers to Equation (9). The results of the calculation of the estimated value of the potential electricity that can be produced will later be compared with the use of electricity. The value of electricity usage is obtained from UGM electricity bill data at 18 faculties during 2019. This comparison will later show whether a faculty can meet its electricity needs from photovoltaic energy using PV panel installations. Using electricity bill data at 18 faculties at UGM, the price value issued is 952.56 IDR/KWh. So the costs that must be incurred to meet electricity needs in 18 faculties can be calculated by multiplying the price value by the value of electricity usage.

The cost refers to electricity bill data in 2019. When compared to the cost that can be saved from PV panel electricity production, there are 4 faculties that have lower electricity usage costs than the electricity production produced, namely the Faculty of Biology, Faculty of Pharmacy, Faculty of Geography, and Faculty of Social and Political Sciences. This means that the four faculties can meet the full electricity needs by utilizing photovoltaic energy, namely using PV panels. While other faculties can save the required costs as much as the percentage shown in the Savings column (%). The Faculty of Economics and Business has the largest percentage of 98%, almost meeting the full needs. While the lowest percentage is owned by the Faculty of Agriculture with 31%. Meanwhile, for the nominal cost that can be saved, the Faculty of Engineering has the highest value with IDR 1,717,499,601.53 / year, which is still IDR 889,419,931.03 from the electricity usage needs in one year at the Faculty of Engineering. Then, even though it has the smallest nominal value of electricity production with a value of 148,641,865.54 IDR/year, the Faculty of Geography can still meet its needs, namely 100,482,696.72 IDR/year.

In total, UGM can save 63% of the cost of electricity usage in the 18 faculties. The cost of electricity usage which initially had a value of 10,353,262,237.92 IDR/year can be saved so that the cost that needs to be spent is only 3,792,718,941.33 IDR/year. This figure can still increase if accumulated with buildings other than those in the 18 faculties' zones. The following is a breakdown of the electricity that can be produced by PV panels in other zones and the costs that can be saved.

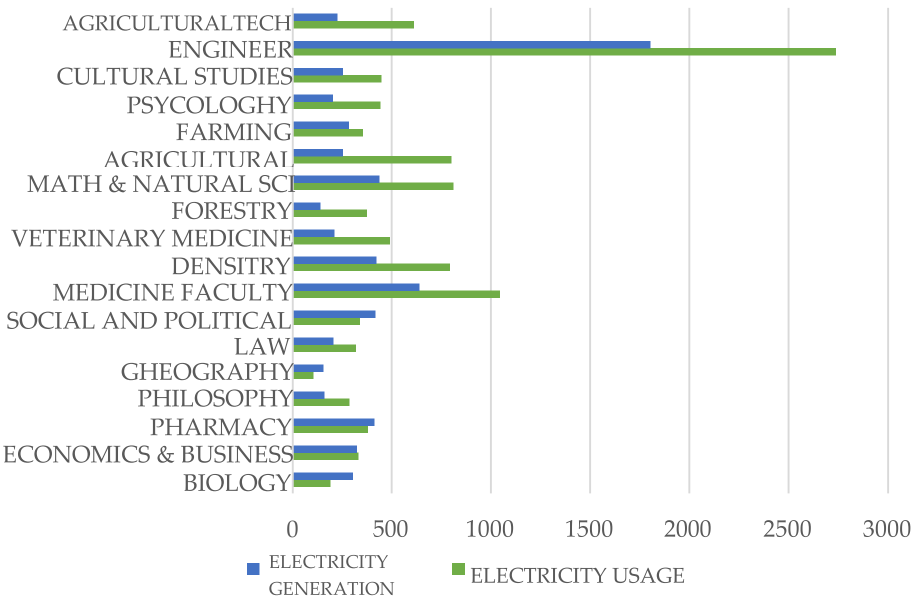

Fig. 21. Comparison diagram of electricity usage with electricity production

Figure 21 above provides a comparative overview of the electricity used with the electricity that can be generated from PV panels. The total electricity usage in the 18 faculties in 1 year is 10,868.88 MWh, while the electricity that can be generated from photovoltaic energy is 6,862.61 MWh. The Faculty of Engineering has the highest amount of electricity usage with a size of 2736.751 MWh and has the highest potential in generating electricity from PV panels with a size of 1,803.04 MWh. The Faculty of Geography has the lowest amount of electricity usage with a usage of 105,487 MWh in a year and has the smallest electricity potential with 156,044 MWh.

Referring to the data from 18 Faculties, there are 4 faculties that have a potential value of electricity from PV panels greater than the electricity usage in one year so that they have the potential to become faculties that can meet their electricity needs from PV panels in total. These faculties are the Faculty of Biology, Faculty of Pharmacy, and Faculty of Geography, as well as the Faculty of Social and Political Sciences. Other faculties still have higher electricity usage values, so it is not enough to meet all electricity needs using PV panels.

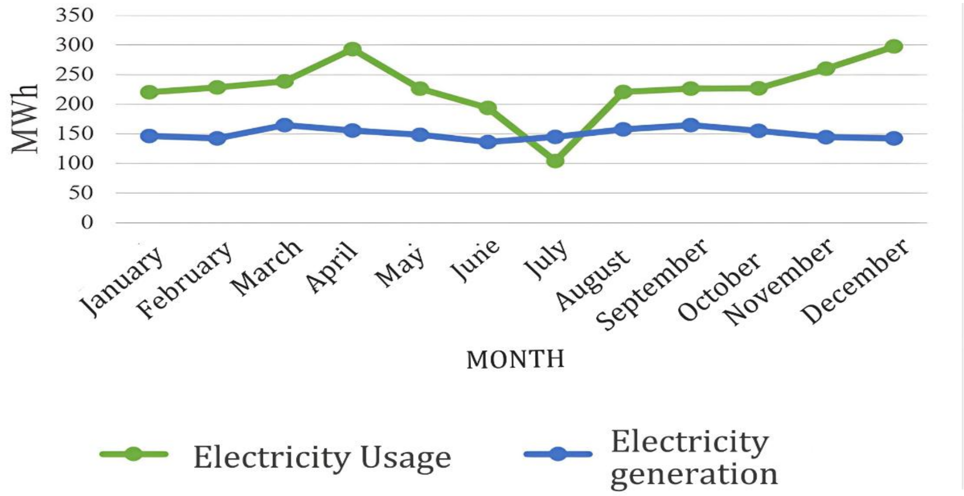

Fig. 22. Comparison diagram of PV panel electricity usage and production at the Faculty of Engineering

The solar radiation in one year has a different value in each month. Comparable to the value of solar radiation, the value of electricity production from PV panels is also different. For example, shown in Figure III.5 at the Faculty of Engineering, the electricity production results each month have a value between 185 MWh to 229 MWh. The maximum value is in March, while the minimum value is in June. However, if you look at the results on the graph, electricity production at the Faculty of Engineering is quite stable. There are no drastic changes each month. Meanwhile, electricity usage at the Faculty of Engineering also has different values each month. However, electricity usage at the Faculty of Engineering is greatly influenced by academic activities. There are quite drastic changes in the period from April to July. It is known that academic activities have a semester break in July, so the lowest electricity usage is in July with 104 MWh. While the highest electricity usage is in December 297 MWh. The results of the comparison of electricity usage and production of 18 complete.

There are 27 zones other than faculties spread across the UGM area. Vocational School is the zone that has the largest electricity production using PV panels by producing 1030.3319 MWH/year and can save costs of up to 981,452,932.57 IDR/year. Producing a total of 6,362,243 MWH/year, electricity costs for the 27 zones above can be saved by 56,060,418,192.08 IDR/year. This means that if added up, the estimated value of electricity that can be produced using photovoltaic energy in the UGM area is 13,224,850 MWH with costs that can be saved from the previous 18 faculties, the total is 12,597,462,729.42 IDR/year. The roof of the BPPT Coastal Engineering Laboratory building is the roof with the greatest electrical energy potential, which can produce 610,654 MWH/year. The average roof of a building at UGM can produce 37,044 MWH/year.

3.3 Presentation of information

The need for spatial information can now be easily accessed via the internet. Various platforms can now be easily connected to the internet, including ESRI. The ArcGIS Pro software used in this study is one of ESRI's products. ArcGIS Pro in its use is also integrated with other ESRI products, one of which is ArcGIS Online. The connection of ArcGIS Pro with ArcGIS Online makes the data processed in the software easily shared via the internet. The processed data can be uploaded to the ArcGIS Online web layer directory. The web layer can be combined and a web scene display can be created to display 3D shapes. This type can be directly uploaded in the form of Global/Local Scene from the template that is available in the ArcGIS Pro software or created by combining content that has been uploaded to the ArcGIS Online directory via ArcGIS Scene Viewer.

The research was conducted using the ArcGIS Scene Viewer feature in ArcGIS Online. So the content to be combined must first be uploaded to the ArcGIS Online directory in the form of a web layer. The web layer that you want to include in ArcGIS Scene Viewer must have hosted status. Hosted status allows content to be opened online in ArcGIS Scene Viewer. If the content does not have hosted status, local software (ArcMap or ArcGIS Pro) is needed to open the content, or in other words, the content must be downloaded first.

There are three layers needed to present information on photovoltaic energy potential in the UGM area. The first layer is the surface layer, which is raster data that can display 3D shapes of the roof surfaces of buildings and surrounding objects so that it displays information that is more similar to actual conditions. Then, to display information on potential locations for PV panel installation, a raster is needed that shows the results of the spatial analysis selection that has been carried out previously. The last layer is the building shapefile along with its attribute information to provide detailed information on the estimated electricity production from the results of the photovoltaic energy calculation. The three layers are uploaded via ArcGIS Pro using the Share as web layer tool. The uploaded layers can be seen in the ArcGIS Online directory as shown in Figure 15.

In Scene Viewer, uploaded content can be called into the scene to form a 3D scene. Then, in Scene Viewer, you can add the basemap that has been provided. Imagery basemap is used in this study because it supports displaying existing objects to be more representative of the actual situation. After the scene is composed, an application is created so that the scene can be opened easily. In ArcGIS Online, a template from the application is available to display the scene. Figure 23 shows the appearance of the Scene Viewer which is used to create or edit the desired scene.

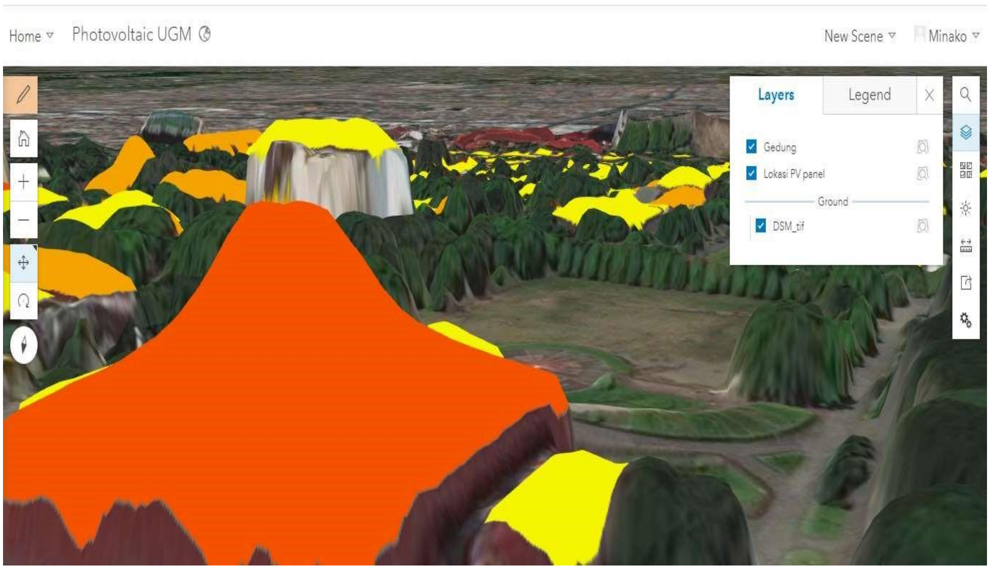

Fig. 23. View in ArcGIS Scene Viewer

Information can be accessed by users through a link connected to the application that has been created. This application can be accessed using various devices (smartphones or computers). When opening the application, the scene will automatically perform tiling, which is adjusting the details of the scene display with the perspective used. This helps so that the loading process does not take a long time. The information presented can be accessed via ugm.id/pvugm. The appearance of the application that was created can be seen in Figure 24 showing the appearance for the Building layer. Where in this layer each building is symbolized by the color of the class that is sorted based on the estimated value of the electricity production that can be generated which can be seen on the Legend tab. In addition, in this layer, attribute data from a building can be called in the form of a pop-up. The display in the form of a pop-up makes it easy for users to find out more detailed information about a building related to the name of the building, zone, potential PV panel area, total roof area, and its electricity production value.

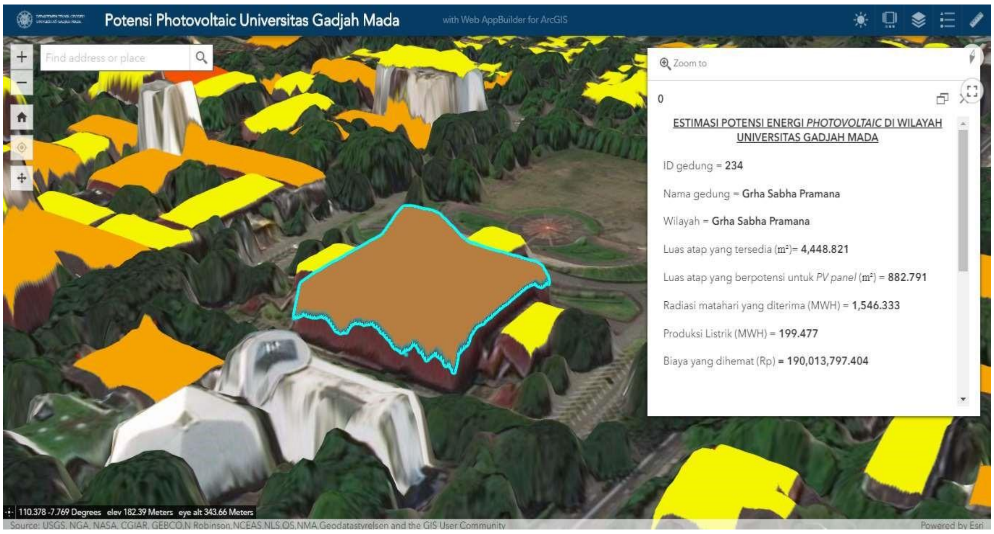

Fig. 24. Web application view showing feature attributes

Figure 25 shows that the application can show potential installation locations for PV panels. This information is found in the PV panel location layer which is based on a tiled raster. The layer is taken from the selection data from the slope, aspect, and solar radiation area analysis. This information is useful for knowing the roof section of a building that has good potential for installing PV panels. However, the presence of noise makes the display of this information still have holes.

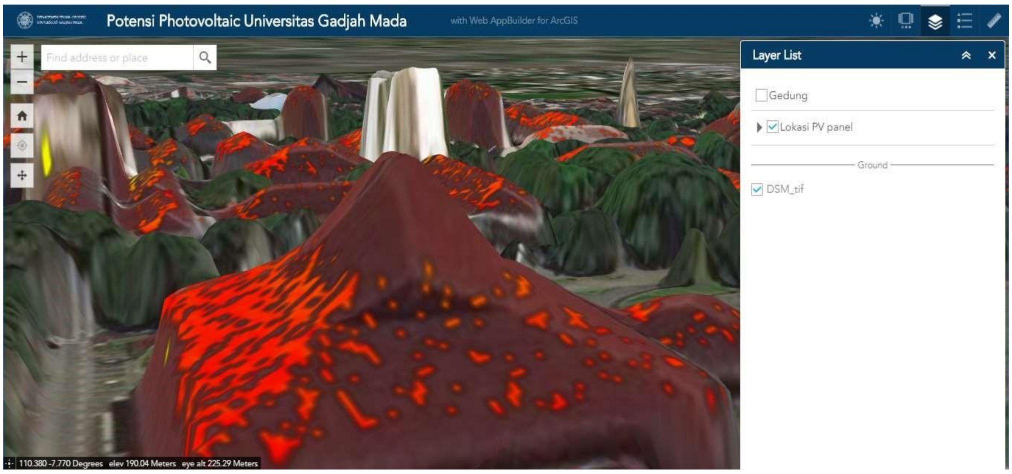

Fig. 25. Web application view showing locations for PV panel installation

With the display on the two different layers, information on the location of the PV panel installation and the estimated value of the electricity production obtained are obtained. Because the data used in the web uses spatial data, the distance and area on the web display can also be measured. This can provide more detailed and interactive spatial information. It is hoped that the existence of the web can be used as a reference in planning the utilization of photovoltaic energy potential in the Universitas Gadjah Mada campus area.

3.4 Problems encountered

The implementation of this research encountered several problems. Some of these problems are: [a] The results of DSM processing still have noise due to errors in measuring the depth of aerial photography data. [b] Lack of accurate data regarding the name of the building and its zoning. The naming of buildings and zoning in this study refers to electricity bill data, Google Maps, and the author's interpretation. [c] The existing noise causes the results of the spatial analysis to be less than optimal. There are surfaces that are actually flat but in the available data there are protrusions that cause the slope and aspect analysis to be less than optimal. This also affects the analysis of solar radiation. [d] The platform used in presenting information still depends on the license. This causes limitations when the license has problems.

4. Conclusion

Based on the results and discussion of the research that has been conducted, several conclusions are obtained as follows: [a] The estimated electrical energy that can be generated using photovoltaic energy in the UGM area is 13,224.850 MWH. The total cost that can be saved by UGM by using photovoltaic energy is IDR 12,597,462,729.42/year. Meanwhile, the cost used for electricity usage in 18 faculties in 1 year (December 2018 - November 2019) is IDR 10,353,262,237.92. Meanwhile, the cost that can be saved from photovoltaic energy is IDR 6,560,543,296.59. This means that UGM can save 63% of its electricity usage if it relies on photovoltaic energy. This value will be in line with the cost that can be saved to meet the electricity needs of the 18 faculties. [b] PV panel installations used to utilize photovoltaic energy can be installed on the roofs of 357 buildings spread across 45 zones at Universitas Gadjah Mada.

The postgraduate school has the largest number of potential buildings with 27 buildings. However, among the 18 faculties at Universitas Gadjah Mada, the Faculty of Engineering has the largest number of potential buildings with 22 buildings. Regarding the installation location on each building roof, it can be seen on the information presentation platform. The roofs of the buildings in the UGM area have a total area of 281,987 m^2. Based on this area, there are 59,893 m^2 of roof area that is potentially effective for PV panel installation. This means that there is 21% of the roof area that is effective for PV panel installation.

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Author Contribution
L.S., contributed to the literature search, interpretation, writing, and proofreading of the manuscript. The author have read and agreed to the published version of the manuscript.

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