Journal of Energy Systems

2025, 9(1)

2602-2052

DOI: 10.30521/jes.1416277

Research Article

Investigating rooftop solar energy potential in coastal area with unmanned aerial vehicle technology

Riska Ekawita*
University of Bengkulu, Faculty of Mathematics and Natural Sciences, Department of Physics, Jl. WR. Supratman, Kandang Limun, Bengkulu, Indonesia, rekawita@unib.ac.id
Ismail Fahmy Almadi
University of Mulawarman, Faculty of Fisheries and Marine Science, Jl. Gunung Tabur, Samarinda, Indonesia, ismailfahmyalmadi@gmail.com
Elfi Yuliza
University of Bengkulu, Faculty of Mathematics and Natural Sciences, Department of Physics, Jl. WR. Supratman, Kandang Limun, Bengkulu, Indonesia, eyuliza@unib.ac.id

Submitted: 08.01.2024
Accepted: 11.12.2024
Published: 31.03.2025

* *Corresponding Author*

Abstract: Bengkulu has abundant direct sunlight all year round. Nonetheless, this region faces limited energy availability. Based on its potential, there is an immense opportunity for the development of electrical energy systems based on solar energy. In the coastal area, the operation of this energy system is still too limited and vulnerable. In order to fix energy requirements, a rooftop solar photovoltaic (PV) system can be implemented. The utilization of the rooftop requires preliminary studies related to solar mapping to identify the economic potential of the rooftop solar energy system. In this study, Unmanned Aerial Vehicle (UAV / Drone) technology has been adopted to map the potential of rooftop solar PV system. The drone is used to collect aerial photographic data on the rooftop, which is then processed to acquire a two-dimensional map. This map is used to obtain rooftop parameters such as area, tilt angle, and orientation of the roof. These rooftop parameters are favorable to estimate the potential of solar energy that can be generated. Based on these parameters, an estimate is made to assess the maximum solar energy that can be generated if the building rooftop is installed with a number of solar panels. To calibrate the calculated parameters of the rooftop, we compare the calculation results with the direct measurements. It has been proven that the drone technology can give promising results on high-resolution mapping of solar potential area. In addition, direct normal irradiance measurements are also performed in the case study area by using previously developed equipment.

Keywords: *Photovoltaic, Renewable energy, Rooftop mapping, Rooftop solar system, Unmanned aerial vehicle*

Cite this paper as: Ekawita R, Almadi IF, & Yuliza E., Investigating rooftop solar energy potential in coastal area with unmanned aerial vehicle technology. *Journal of Energy Systems 2025;* 9(1): 1-11, DOI: 10.30521/jes.1416277

2025 Published by peer-reviewed open access scientific journal, JES at DergiPark (https://dergipark.org.tr/jes)

1. INTRODUCTION

Bengkulu is one of the regions of Indonesia where most of its territory is along the coastline. Based on these conditions, Bengkulu has abundant marine wealth and various other natural resources. On the other hand, this region has unfavorable economic trends and limitations in infrastructure, electrical energy, etc. In fact, if the variety of resources is optimized, these limitations can certainly be overcome. An example is the issue of energy limitations, indeed, Bengkulu receives direct sunlight all year round based on the location along the coastline under tropical climate at the vicinity of the equator [1]. If solar energy can be converted into necessary energy such as electricity, energy limitations can be overcome. Until now, the utilization of solar energy is still limited to drying various marine products and other agricultural products.

In general, solar energy is the primary source of renewable energy with abundant availability and eco-friendly, which can be converted into various types of energies needed by humans. The utilization of solar energy can be a solution to various problems related to the use of fossil fuels, such as the limitation of availability and the issue of environmental damage [2,3,4,5]. Moreover, the availability of various technologies to convert solar energy allows us to easily use its abundant energy. In terms of electrical energy, solar energy can be converted directly to electricity by using solar panels [6,7,8,9,10,11]. This device has been used in various parts of the world to convert solar energy into electrical energy.

Recently, the application of solar panel systems continues to increase and expand. This condition due to the development of solar panel technology so that the resulting panels have better efficiency and increasingly competitive supply costs [4]. Many countries across the world have been applied solar panel systems both commercially and personally, such as in Ontario [5], European Union [12,13], Canada [4], China [2,3], Japan [14]. Furthermore, the system has been integrated into the national energy system [4,5,13]. Meanwhile, in Bengkulu, the application of solar panel systems is still very limited and generally for street lighting.

In the solar energy generation system, a specific area is required for the placement of solar panels. Recently, the usage of building rooftop has become a solution for the land availability problem for solar energy plants. This architecture has several advantages such as reducing construction costs, shorten electrical transmission, optimizing the usability of the building, and avoiding attacks [4,5,12,15,16]. The construction cost and attacks are among the main issues in the development of solar panel systems in Bengkulu. Therefore, the development of rooftop solar PV systems has immense potential to be developed. However, before implementing this architecture, a preliminary study is necessary to identify the feasibility of using the building rooftop. The main parameters that need to be investigated are the topology and characteristics of the rooftop, the height of the building, and the surrounding environment [4,5,12,13]. These parameters are then used to predict the energy that can be generated if the rooftop is installed with a number of solar panels. Further, the prediction results are then analyzed to obtain the efficiency, economic value, and potential use of building rooftop in the solar energy generation system.

In general, several methods have been developed to determine the characteristics and topography of a building rooftop, such as manual measurement [16], Geographic Information System (GIS) [4,5,17], LIDAR [4,12], Artificial Intelligence (AI) [1] etc. These methods are still being used and proposed to map and obtain the characteristics of the rooftop [18,19,20,21]. In addition, in developed countries, there is a building database (building blueprint) that can be used as preliminary data in assessing the potential use of the rooftop. This condition is in contrast to Indonesia and Bengkulu in particular, especially where data on building construction plans are not available. Moreover, data on the potential use of solar energy is also still very limited. Besides the problem of initial data availability, the availability of equipment and funding for the development of this energy study is also still very limited. Therefore, the step taken to address the issue of initial data availability for building roof potential is to involve Unmanned Aerial

Vehicle (UAV) technology. UAV technology is utilized to obtain roof parameters that can affect the solar energy potential of a building, including determining the area that can accommodate solar panels and estimating the potential energy that can be generated if the area is covered with a certain number of solar panels.

In this study, we utilized UAV technology, which is widely used in mapping activities [22,23], to obtain the area and characteristics of the roof, as well as online PV applications to calculate potential energy. This application is very simple to use. Hence, the innovation of analyzing roof potential using UAVs will contribute to the accuracy of renewable energy development and provide initial data on roof potential for the transition to solar energy, as well as for sustainable urban planning strategies. The employment of UAV technology in mapping offers advantages, such as high quality results, high resolution, reliability, less time, safety, and low cost [23,24]. Therefore, in this study, we have conducted a preliminary study to obtain the parameters of rooftop that can be used in the analysis of the potential of rooftop solar PV system using drone technology. Furthermore, the obtained rooftop parameters are then used as initial data to predict solar energy potential on building rooftops. In detail, each of these steps will be discussed in this paper.

2. METHODOLOGY

This research is a preliminary study on the development of the rooftop solar PV system in a coastal area with a case study of the building rooftops at the University of Bengkulu. The selection of case study sites is motivated by the position which is in the coastal area, the availability of electricity sources, and the increasing consumption of electricity every year. In addition, the development of this research can also be a learning tool for students and increase the role of educational institutions in campaigning the use of environmentally friendly energy. The main objective of this preliminary study is to obtain the parameters of building rooftop needed to identify the potential use of rooftop solar PV system. The parameters of the rooftop are then used to simply estimate the possibility of electricity that can be generated if the rooftop is covered with solar panels. As additional data, measurements of direct normal irradiance have also been conducted using our previously developed system.

In general, to achieve the main objectives of this study, three general steps were carried out, namely the realization of a 2D map, identification of the main parameters of the rooftop, and the estimation of solar energy potential. These three steps can be divided into several sections as shown in Fig. 1. Besides, the methods and steps for producing a 2D map and calculating the main parameters of rooftops are the novelty of this research.

This study uses the general mapping methods and steps to obtain the desired parameters. These steps are interdependent and must be carried out sequentially. The first step is to create a 2D map. In creating a 2D map, aerial photographs of the object are processed using the widely used mapping software. To collect aerial photographs, drone technology has been widely applied. The drone used in this study is the Mavic Pro type, which produces aerial photographs with pixel resolution. The drone is equipped with a camera that has a 12-megapixel (MP) sensor, which means it captures photos with a resolution of 4000 x 3000 pixels. To obtain aerial photographs of the building rooftop and its surrounding conditions, the flight is performed in an automatic grid mode which is controlled using the pix4D application at a ground surface elevation of 60 m to 80 m. The choice of elevation considered the building height and safety aspects in data collection. Fig. 2 shows the type of drone and one of the data collections sites. In addition, data collection is enabled on several buildings at the University of Bengkulu.

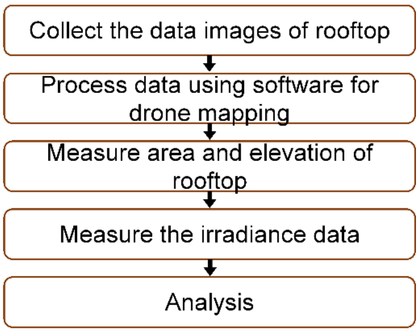

Figure 1. Flowchart of rooftop solar potential mapping.

If the aerial photographs of the object of study have been collected, the next step is to process the data to produce a 2D map. In this study, Agisoft Photoscan software is extensively used to create a 2D and a 3D map. This processing requires a computer specification with a minimum RAM of 8 GB. The selection of computer specification is linked to the speed of data processing. In general, the mechanism for creating 2D map consists of merging small aerial photographs into orthorectified aerial photographs. To obtain a 2D map, the steps are to enter the aerial photographic data that will be used and to select the treatment and treatment results that we want to display. In this 2D reconstruction, after entering the aerial photographic data, the system will retrieve the metadata from the photograph in the form of camera coordinates. These coordinate points are linked to the flight path which specified when retrieving the data for each object. In this data processing, we define the coordinates of the aerial photograph as survey data. For this study, survey data and camera positions on the study object can be seen in Figs. 3(i,ii). Based on this survey data, we can analyze the number of overlapping photographs. The overlapping amount is shown in Fig. 3(i) in blue which indicates that the overlapping photographs are higher than 9. To get a smoother and higher resolution map, we need a larger amount of aerial photographs.

Figure 2. Location for collecting data and type of drone.

Based on the survey data points, the number of aerial photographs for each building is 255 for the auditorium, 183 for the classroom, and 93 for the research center. The differences in the number of aerial photographs are linked to the flight path established according to the area of the building used as an object. The difference in the number of aerial photographs also affects the number of connection points for each object. Another form of output from this image processing is the Digital Elevation Model (DEM). Based on the DEM data, some information about the surface such as elevation and height of the surface object can be explored. Fig. 3(iii) shows the DEM data for the three data collection sites. In the DEM data, the height difference is indicated in different colors. Orange indicates an object higher than the surrounding object. The height scale of this object is indicated in the information in the color bar at the bottom right of each object. Based on the DEM data, the rooftops of auditorium and classroom are higher than the trees and other surrounding buildings, while for the research center building there are trees and other higher objects. This data can be used in an initial analysis to predict the shading effect due to trees and the presence of other objects around the rooftop. For the research center building, the existence of other objects around it is possible to cause shadows. In addition, the position of this other object is very close to the rooftop. As with the other two buildings, the rooftop is the highest level, hence the possibility shading effect is caused by the rooftop itself due to the orientation of the sun against the rooftop.

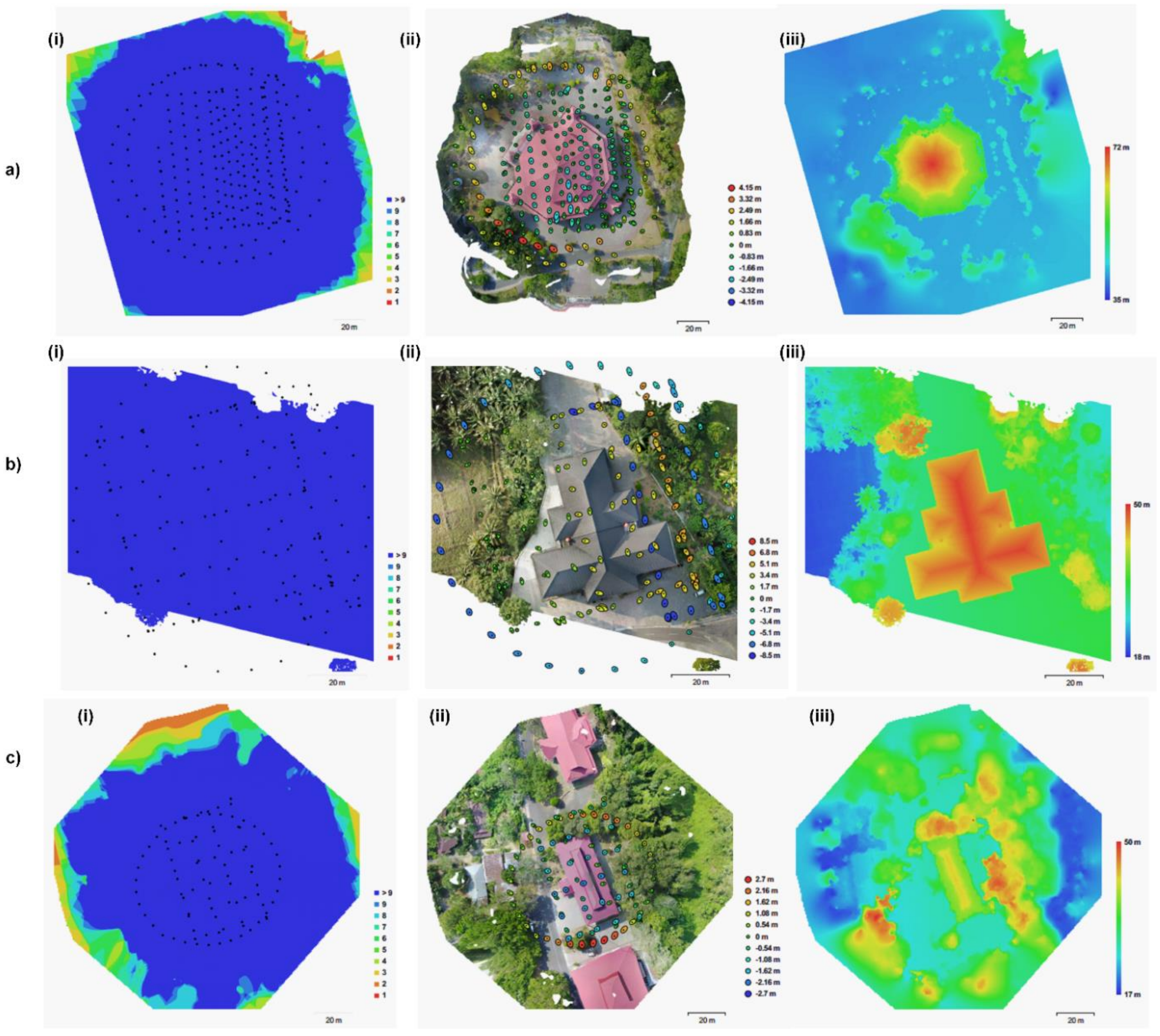

Figure 3. Survey data (i), camera location (ii), and digital elevation model (iii) for (a) Auditorium, (b) classroom, and (c) research center, respectively.

Fig. 3 shows some results, generated using Agisoft Photoscan software after entering aerial photographic data. In addition, the main output obtained using this software is 2D and 3D spatial data. To obtain the parameters of the rooftops such as tilt angle, area, and orientation of the rooftop, calculations have been performed by using the 2D spatial data. The tilt angle and area parameters are needed to estimate the potential energy that can be generated. Eq. 1 is the calculation used to determine the number of PV panels needed (n) for each building, where A_{roof} is the rooftop area and A_{PV} is the size of the PV panel used.

$$n = \frac{A_{roof}}{A_{PV}} \tag{1}$$

On the other hand, the energy estimation is obtained from an online tool for PV system analysis. The open-source software estimates the energy by taking into account various factors such as location, orientation and tilt, type of PV, and number of PV panels. By using input data, the tool calculates solar irradiance throughout the year. The output provides a detailed report on energy estimation for PV systems.

3. RESULT AND DISCUSSION

The standard parameter needed to estimate the potential electric energy of a solar PV system is the ability of the installation area to isolate sunlight [3,17]. Solar insolation is influenced by several factors such as location, altitude, shade, the position of the sun, and climate change. Each area is unique to these factors [4,5,13,25]. Therefore, in order to harness the conversion of solar energy more effectively and more efficiently, knowledge of these factors is required before installing solar panels. In the development of rooftop solar PV system, the existence of these factors suggests that not all rooftops are compatible with this system. This is the reason why the rooftop solar PV system requires knowledge related to the potential through solar mapping.

In this work, as explained in the methodology section, solar potential mapping has been conducted by using drones and mapping software. The resulting 2D spatial data is presented in Fig. 4. The selection of buildings is related to the rooftop architecture of the buildings which represents the characteristics of various building rooftops at the University of Bengkulu. The spatial data shown in Fig. 4 has been adjusted with the direction of the rooftop relative to the compass points. These spatial data are used to obtain solar insolation factors. The first factor identified is the slope and area of the building rooftop. Measurement calibration is performed by comparing the measurement data in the field with calculations using spatial data. The calculations for these areas and tilt angle factors are shown in Table 1.

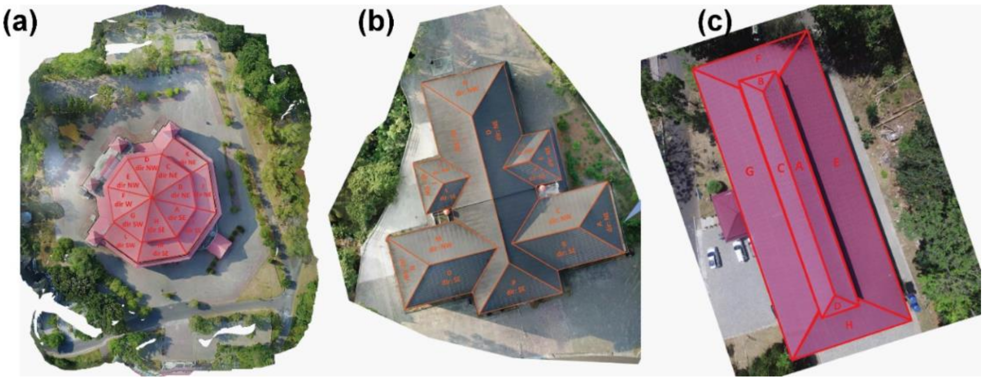

Figure 4. The image of building rooftops at the University of Bengkulu: (a) Auditorium, (b) classroom, and (c) research center, respectively.

Table 1. Area and Elevation of Rooftop

Building	Rooftop Area (m2)	Elevation (degree)
Auditorium	2850	30
Classroom	1892	35
Research center	1335	48

The area indicated in Table 1 is the total area regardless of the position of the rooftop to wind direction. The entire rooftop of the buildings could be utilized to place solar panels. The area and tilt parameters are used to estimate the energy that can be generated. A simple estimate of energy potential is performed by using open-source software, requiring only input data in the form of location coordinates of the area, the tilt angle of the rooftop, type of the solar panel, and the number of panels required. The determination of the number of solar panels took into account the area of each building rooftop. In this estimation, the solar panel type PSR-e20-327 has been used. The solar panel has characteristics such as power 327 Wp, 20.06 % of efficiency and size of 2 m x1 m. The results of the energy estimates for the three rooftops are shown in Table 2, while Fig. 5 shows the estimated monthly energy that can be generated. The simple simulation conducted shows the good potential of the building rooftop if it is covered with several solar panels.

Table 2. Estimated energy generated by solar panels

Building	Number of solar panels	Energy estimation in a year (kWh)
Auditorium	170	64575
Classroom	112	40628
Research center	80	25039

Based on the data in Tables 1 and 2, a simple analysis of the effect of tilt angle on the estimated energy can be generated and this can be performed for additional calculations. In general, the use of solar panels is proportional to the total area. Simple mathematical calculations, represented by Eq. (1), show that the ratio of the total area of the three building rooftops is proportional to the area of the rooftops. This ratio is proportional to the energy potential, that there is an increase in the energy ratio obtained for classroom and auditorium rooftops where there is an increase of 14% and 24%, respectively. This simple analysis shows that the tilt angle of the rooftop immensely influences the energy that can be harvested. Based on these three tilt angle variations (30^0, 35^0, 48^0), the rooftop with a tilt angle of 30^0 has the capacity to absorb more energy than other tilt angle variations. This result is supported by several other studies which indicate that the optimal tilt angle for installing solar panels in Indonesia is at a small angle [26].

Fig. 5 displays the monthly distribution of energy on each rooftop. The three rooftop types show the same trend of change. The highest absorption occurred in December and the lowest in June. In a study by Ref. [1], it was described that the pattern of solar radiation in Bengkulu was at its peak in August, September and the lowest in November. The results we obtained are quite different from the results of modeling conducted by Ref. [1]. This difference in results can be explained by the approach to the events of precipitation in Indonesia. Usually, starting from September, the precipitation events continue to increase until the beginning of the New Year, both in frequency and intensity. However, in recent years, the frequency and intensity of precipitation have not been concentrated in September until New Year. Moreover, several studies have also suggested that changes in the orientation of the sun also affects the potential power that can be absorbed [27,28,29]. The orientation of the sun in each region is constantly changing on a monthly scale.

In general, the power estimation results shown in Table 2 and Fig. 5 consider only the area and tilt factors and ignore other factors. However, these results indicate the good potential of the utilization of rooftops in the rooftop solar PV system. In addition, the estimation results show the effect of solar insolation in the form of elevation.

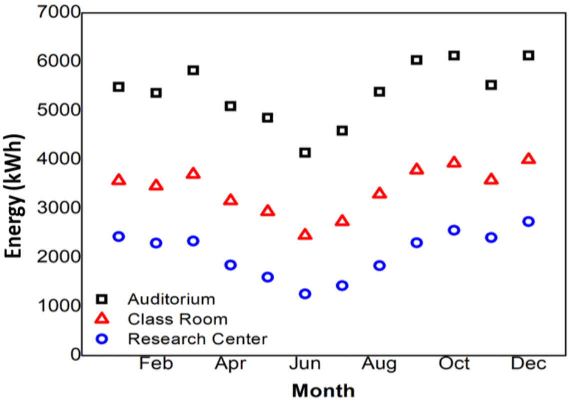

Figure 5. The estimated monthly generated energy.

Figure 6. Irradiance apparatus.

Apart from the elevation factor, the orientation of the sun against the object also affects the solar insolation capacity [29,30]. To determine the pattern of solar energy intensity, measurements of direct normal irradiance are performed by using previously developed equipment in Fig. 6. This equipment is equipped with a sensor system stimulating the system to move in accordance with the movement of the sun. The power recorded in the system is the power when the orientation of the sun is perpendicular to the solar panel installed on the system. To calculate the power generated on the DNI (direct normal irradiance) data, calculations are performed using the model developed by Moshksar and Ghanbari from Ref. [31]. The distribution of solar energy each time obtained using this tool is illustrated in Fig. 7 as in Ref. [32]. The distribution of energy data each time shows the fairly large potential power of using solar panels. Harvesting solar energy can last nearly 12 hours with peak power at 12.00 PM and 02.50 PM. In addition, the results obtained are DNI, hence the actual power that can be produced is greater than this power.

The results of the power estimation based on the parameters of building rooftop in the form of area and tilt angle measurements, as well as the DNI data, show good potential for the development of a rooftop solar PV system at the University of Bengkulu. However, when assessing sunlight, other factors to consider are the shade and location of the area. For the shading factor, an analysis can be performed based on the DEM data. For all three study objects, the research center building has higher shading factors than the other buildings. The shading effect is not only caused by itself but also by the presence of other objects around it. The level of the building which is lower than the dense trees around the building creates a fairly dominant shading effect which prevents sunlight from reaching the rooftop. Meanwhile, the design and level of the building with the lowest shadow effect is the auditorium building. For the location of the study area around the coast has a tropical climate and average solar radiation of 4.75 kWh/m^2, there is a very good potential to be exploited. Its presence on the coast with a tropical climate makes this area has a fairly high daily temperature.

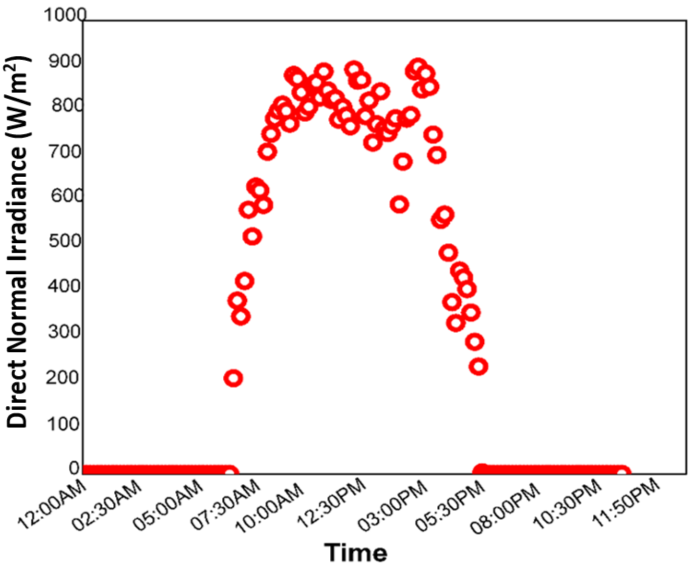

Figure 7. Irradiance data in a day.

4. CONCLUSION

This research aims to identify the feasibility of using the rooftop of building at University of Bengkulu in development of a rooftop solar PV system by using the UAV technology. The main parameters required in the rooftop solar mapping system are the characteristics of the rooftop and the surrounding environment. In this study, the application of drone technology to mapping for different purposes is adopted to obtain these main parameters. The Mavic Pro drone type has been used to collect aerial photographs of the rooftop with automatic flight in grid mode. The 2D rooftop map is produced by processing aerial photograph data using the software Agisoft Photoscan. The slope and area of the rooftop, and the surrounding environment such as shade factor are obtained by using these maps. These results also show that drone technology and image processing using Agisoft Photoscan software can be used for solar rooftop potential mapping studies with advantages such as less time, high quality, high resolution, reliability, and low cost. In addition, the buildings at the University of Bengkulu are ideally suited for the generation of electricity through the rooftop solar PV system. The development of this system has the potential to provide adequate energy. However, the power estimation results presented in this article only considers the area and tilt factor of the rooftop. The effects of climate parameters, weather, and other building shapes with more varied slopes have not been examined in this paper and require more complex data support. Therefore, further study is needed to confirm these results.

Acknowledgement

This work has been financially supported by the University of Bengkulu, Indonesia, through “National Collaboration Research Grant” with grant number: 2186/UN30.15/LT/2019 in the fiscal year 2019.

REFERENCES

[1] Rumbayan M, Abudureyimu A, Nagasaka K. Mapping of solar energy potential in Indonesia using artificial neural network and geographical information system. *Renew Sustain Energy Rev*. 2012;16:1437-1449. doi:10.1016/j.rser.2011.11.024.

[2] Cheng L, Li S, Zhang F, Ma J. Solar energy potential of urban buildings in 10 cities of China. *Energy*. 2020;196:C:1-16.doi:10.1016/j.energy.2020.117038.

[3] Ko L, Wang JC, Chen CY, Tsai HY. Evaluation of the development potential of rooftop solar photovoltaic in Taiwan. *Renew Energy*. 2015;76:582-595. doi:10.1016/j.renene.2014.11.077.

[4] Kouhestani FM, Byrne J, Johnson D, Spencer L, Hazendonk P, Brown B. Evaluating solar energy technical and economic potential on rooftops in an urban setting: the city of Lethbridge, Canada. *Int J Energy Environ Eng*. 2019;10:3-32. doi:10.1007/s40095-018-0289-1.
[5] Wiginton LK, Nguyen HT, Pearce JM. Quantifying rooftop solar photovoltaic potential for regional renewable energy policy. *Comput Environ Urban Syst*. 2010;34:345-357. doi:10.1016/j.compenvurbsys.2010.01.001.
[6] Green MA, Emery K, Hishikawa Y, Warta W. Solar cell efficiency tables (version 37). *Prog Photovolt Res Appl*. 2011;19:84-92. doi:10.1002/pip.1088.
[7] Jung J, Han S, Kim B. Digital numerical map-oriented estimation of solar energy potential for site selection of photovoltaic solar panels on national highway slopes. *Appl Energy*. 2018;242:57-68. doi:10.1016/j.apenergy.2019.03.101.
[8] Kumar V, Singh V, Umrao S, Parashar V, Abraham S, Singh A, Nath G, Saxena P, Srivastava A. Facile, rapid and upscaled synthesis of green luminescent functional graphene quantum dots for bioimaging. *RSC Adv*. 2014;4:21101-21107. doi:10.1039/c4ra01735h.
[9] Mahtta R, Joshi PK, Kumar A. Solar power potential mapping in India using remote sensing inputs and environmental parameters. *Renew Energy*. 2014;71:255-262. doi:10.1016/j.renene.2014.05.037.
[10] Martinopoulos G. Are rooftop photovoltaic systems a sustainable solution for Europe? A life cycle impact assessment and cost analysis. *Appl Energy*. 2019;257:1-13. doi:10.1016/j.apenergy.2019.114035.
[11] Yousuf M, Siddiqui M, Rehman N. Solar energy potential estimation by calculating sun illumination hours and sky view factor on building rooftops using digital elevation model. *J Renew Sustain Energy*. 2018;10(1):1-13.doi:10.1063/1.4997888.
[12] Bódis K, Kougias I, Jäger-Waldau A, Taylor N, Szabó S. A high-resolution geospatial assessment of the rooftop solar photovoltaic potential in the European Union. *Renew Sustain Energy Rev*. 2019;114:1-13. doi:10.1016/j.rser.2019.109309.
[13] Fath K, Stengel J, Sprenger W, Rose H, Schultmann F, Kuhn TE. A method for predicting the economic potential of (building-integrated) photovoltaics in urban areas based on hourly Radiance simulations. *Sol Energy*. 2015;116:357-370. doi:10.1016/j.solener.2015.03.023.
[14] Creutzig F, Agoston P, Goldschmidt JC, Luderer G, Nemet GF, Pietzcker R. The underestimated potential of solar energy to mitigate climate change. *Nat Energy*. 2017;2(9):2-9. doi:10.1038/nenergy.2017.140.
[15] Kodysh J, Omitaomu OA, Bhaduri BS, Budhendra LN. Methodology for estimating solar potential on multiple building rooftops for photovoltaic systems. *Sustain Cities Soc*. 2013;31:34-38. doi:10.1016/j.scs.2013.01.002.
[16] Lee S, Iyengar S, Feng M, Shenoy P, Maji S. Deep Roof: A data-driven approach for solar potential estimation using rooftop imagery. In: *KDD '19 Proc. 25th ACM SIGKDD Int Conf Knowl Discov Data Min*. 2019:2105-2113. doi:10.1145/3292500.3330741.
[17] Effat HA. Mapping solar energy potential zones, using SRTM and spatial analysis, application in Lake Nasser Region, Egypt. *Int J Sustain Land Use Urban Plan*. 2016;3(1). doi:10.24102/ijslup.v3i1.551.
[18] Lazarenko I, Cenky M, Bendik J. A Simplified Urban-Scale Rooftop Photovoltaic Potential Estimation. In: Proceedings of the 2024 24th International Scientific Conference on Electric Power Engineering, *EPE 2024*, 1-6. doi:10.1109/EPE61521.2024.10559532.
[19] Lodhi MK, Tan Y, Wang X, Masum SM, Nouman KM, Ullah N. Harnessing rooftop solar photovoltaic potential in Islamabad, Pakistan: A remote sensing and deep learning approach. *Energy*. 2024;304(37):132256. doi:10.1016/j.energy.2024.132256.
[20] Ni H, Wang D, Zhao W, Jiang W, Mingze E, Huang C, Yao J. Enhancing rooftop solar energy potential evaluation in high-density cities: A Deep Learning and GIS based approach. *Energy and Buildings*. 2024;309:113743. doi:10.1016/j.enbuild.2023.113743.
[21] Sander L, Schindler D, Jung C. Application of Satellite Data for Estimating Rooftop Solar Photovoltaic Potential. *Remote Sensing*. 2024;16(12). doi:10.3390/rs16122205.
[22] Boccardo P, Chiabrando F, Dutto F, Tonolo FG, Lingua A. UAV deployment exercise for mapping purposes: Evaluation of emergency response applications. *Sensors (Switzerland)*. 2015; 15(7):15717-15737. doi:10.3390/s150715717.
[23] Koeva M, Muneza M, Gevaert C, Gerke M, Nex F. Using UAVs for map creation and updating. A case study in Rwanda. *Surv Rev*. 2016;312:325. doi:10.1080/00396265.2016.1268756.
[24] Grubesic TH, Nelson JR. UAVs and Urban Spatial Analysis: An Introduction. 1st ed. Switzerland: Springer; 2020.
[25] Song X, Huang Y, Zhao C, Liu Y, Lu Y, Chang Y, Yang J. An approach for estimating solar photovoltaic potential based on rooftop retrieval from remote sensing images. *Energies*. 2018; 11(11):13172. doi:10.3390/en11113172.
[26] Jacobson MZ, Jadhav V. World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels relative to horizontal panels. *Sol Energy*. 2018; 55:166-169. doi:10.1016/j.solener.2018.04.030.

[27] Handoyo EA, Ichsani D, Prabowo. The optimal tilt angle of a solar collector. *Phys Procedia*. 2013; 166:175-182. doi:10.1016/j.egypro.2013.05.022.
[28] Jafarkazemi F, Saadabadi SA. Optimum tilt angle and orientation of solar surfaces in Abu Dhabi, UAE. *Renew Energy*. 2013; 44:49-56. doi: 10.1016/j.renene.2012.10.036.
[29] Le Roux WG. Optimum tilt and azimuth angles for fixed solar collectors in South Africa using measured data. *Renew Energy*. 2016; 60:612-619. doi: 10.1016/j.renene.2016.05.003.
[30] Yadav AK, Chandel SS. Tilt angle optimization to maximize incident solar radiation: A review. *Renew Sustain Energy Rev*. 2013; 503:512-523. doi: 10.1016/j.rser.2013.02.027.
[31] Moshksar E, Ghanbari T. Real-time estimation of solar irradiance and module temperature from maximum power point condition. *IET Sci Meas Technol*. 2018; 12(6). doi:10.1049/iet-smt.2017.0476.
[32] Habibullah AD, Lidiawati L, Ekawita R. A simple and inexpensive irradiance monitoring system using photovoltaic panel. *AIP Conf Proc*. 2021; 2320. doi: 10.1063/5.0038334.