Design and Development of Photovoltaic Planning Installation Using an Unmanned Aerial Vehicle Image in Politeknik Kuching Sarawak

Lee Kong Fah[1], Christopher Suresh Martin[1], and Bong Siaw Wee[2*]

[1]Department of Civil Engineering,
Politeknik Kuching Sarawak,
KM 22, Jalan Matang, Petra Jaya, 93250 Kuching, Sarawak, Malaysia.

[2]Department of Electrical Engineering,
Politeknik Kuching Sarawak,
KM 22, Jalan Matang, Petra Jaya, 93250 Kuching, Sarawak, Malaysia.

*Corresponding Author's Email: bongsw@poliku.edu.my

Article History: Received 11 March 2025; Revised 29 May 2025;
Accepted 28 June 2025; Published 30 June 2025

Abstract

As global efforts intensify towards adopting more sustainable energy solutions, solar energy has emerged as a leading renewable resource due to its abundance, long-term viability, and increasing accessibility. Among the most widely utilised technologies for harnessing solar energy are solar photovoltaic (PV) systems, which convert sunlight directly into electrical energy. Despite their growing deployment, identifying optimal locations for PV installation remains a significant practical challenge, especially on the rooftop. Conventional methods, such as manual rooftop surveys, are often time-consuming, costly, and may pose safety risks. This issue is particularly evident at Politeknik Kuching Sarawak where such limitations have hindered effective planning and implementation of solar PV systems. To address this challenge, the present study proposes an Unmanned Aerial Vehicle (UAV)-based approach to improve the efficiency and safety of the installation planning process. UAVs, commonly known as drones, were employed to capture high-resolution aerial images of the campus buildings. These images were subsequently processed using photogrammetry software to assess the suitability of rooftop areas for PV panel installation. Compared to conventional methods, this UAV-based technique offers several advantages, including improved safety, reduced labour costs, and significantly faster data acquisition. The results demonstrated that the system effectively identified suitable rooftop areas for PV panel installation with a high degree of visual recognition accuracy. This study highlights the practical benefits of integrating UAV technology into solar PV planning and suggests its broader potential in accelerating the transition to low-carbon energy systems, particularly within educational and institutional settings.

Keywords: Unmanned Aerial Vehicles, Solar Photovoltaic, Solar Energy Technologies, Drones, High-Resolution Aerial Images

1.0 Introduction

Since the Industrial Revolution, population growth and sharp increases in productivity have led to a boom in the need for energy [1], [2], [3]. One sustainable method of lowering carbon emissions is through renewable energy, especially solar electricity [4], [5]. Solar energy is being promoted more and more in line with the 2030 Agenda for Sustainable Development due to its efficiency, capacity, and applicability [6], [7], [8]. Malaysia, which is close to the equator, benefits from abundant sun radiation with an average of 4500 kWh/m² per day [9]. Despite the high cost of solar energy, government programs and companies such as Petronas and Tenaga Nasional Bhd. encourage its expansion through strategic plans and incentives [10], [11].

In Malaysia, coal and natural gas remain the dominant energy sources for power generation [12], [13], [14]. However, these fossil fuels contribute significantly to climate change and global warming due to the carbon emissions released during combustion [15], [16]. Additionally, as non-renewable resources, coal and natural gas are finite; their continued use will eventually lead to resource depletion [17]. Malaysia is exploring alternative energy options, particularly solar energy, to reduce dependency on such non-renewable sources [18], [19].

A deep learning-based tool has been developed to estimate rooftop solar potential using satellite imagery and publicly available solar irradiance data [20], [21], [22]. While satellite images can cover large areas and provide valuable data. They frequently do not have the spatial resolution required for accurate rooftop measurements at wide geographic scales for solar potential assessment. Hence, it can be difficult to estimate rooftop dimensions precisely, and using low-resolution photos may lead to estimation errors. Conducting terrestrial surveys for this purpose is costly and time-intensive, making satellite imagery a more feasible, though imperfect, solution.

Recently, solar photovoltaic (PV) systems have been increasingly adopted to support clean energy goals, but the process of identifying suitable rooftop locations for PV installation remains inefficient and labour-intensive. Traditional inspection methods are time-consuming, costly, and may lack the spatial resolution needed for accurate rooftop assessment. Although UAVs (drones) have been introduced for solar inspection, limited studies have integrated high-resolution UAV imagery with automated detection techniques specifically for rooftop PV planning in educational institutions like Politeknik Kuching Sarawak. There is a lack of a scalable, efficient, and precise methodology for site assessment that also supports ongoing monitoring and fault detection of solar panels.

Therefore, high-resolution Unmanned Aerial Vehicle (UAV) imagery for Photovoltaic (PV) panel mapping was proposed and developed in this research to develop and evaluate a UAV-based approach for high-resolution mapping and assessment of rooftop areas suitable for solar photovoltaic (PV) panel installation at Politeknik Kuching Sarawak. The research objectives are to acquire high-resolution aerial imagery of building rooftops at Politeknik Kuching Sarawak using Unmanned Aerial Vehicles (UAVs), to process and analyse UAV imagery using photogrammetry software for accurate rooftop mapping, and to identify and map potential locations suitable for PV panel installation based on visual interpretation and spatial data.

Unmanned Aerial Vehicles (UAVs), also known as drones able to improve solar field inspections by cutting down on inspection times and effectively taking high-quality pictures [23], [24], [25]. Armed with drones and Near-Infrared (NIR) cameras, find problems like shading and corroded connectors, which will improve solar panel efficiency, lower operating costs, and speed up testing [26], [27]. PV panel detection is made possible by UAV imaging, which also provides better spatial resolution. High recognition accuracy is achieved through the visual interpretation of UAV photos. Exploring methods to combine UAV imagery with automated detection could provide a more practical approach for large-scale photovoltaic planning.

The remains of the paper are organised as follows. The methodology for using an Unmanned Aerial Vehicle (UAV) imagery for Photovoltaic (PV) panel mapping is clearly explained in Section 2. The results and the study findings are discussed in Section 3. The research conclusion is summarised in Section 4.

2.0 Methodology

Figure 1 shows the process of developing the photovoltaic planning installation using an Unmanned Aerial Vehicle (UAV) Image. This process is separated into four phases: Phase 1 is preliminary study, Phase 2 is data acquisition, Phase 3 is data processing, and Phase 4 is results and analysis.

Phase 1: Preliminary Study

To comprehend important theories and bolster the goals of the study, a great deal of research, including journals and articles, was carried out. The previous research that was undertaken has proven to be valuable in establishing a connection and resolving the issue outlined in this study.

Phase 2: Data Acquisition

The process of gathering and organising data for analysis from a variety of sources is known as data acquisition. Sensors are frequently used to transform analogue signals into a digital format. This stage of data gathering allows researchers to carry out each stage of the investigation. The DJI Air 2s is used in this research to capture the UAV image of the academic area of Politeknik Kuching, Sarawak. The height of 100m and 70% side and forward overlap are set for the image. The drone flies for 8 minutes to complete the session.

Phase 3: Data Processing

The subsequent stage involves the processing of data. In this section, researchers will elucidate the methodology employed for data collection and subsequent transformation into meaningful and actionable information, commonly referred to as "data processing". The data captured by the drone will be processed using Pix4D, which will be utilised for the generation of DSM. To generate a DSM using Pix4D, begin by capturing overlapping aerial images of the area of interest, ensuring 70-80% overlap for good coverage. Open Pix4Dmapper, create a new project, and import the images. Access the "Processing Options," select "DSM, Orthomosaic, and Index," and configure the DSM settings, specifying the desired resolution. Start the processing to generate the DSM and orthomosaic. Finally, export the DSM and orthomosaic as shown in Figure 2.

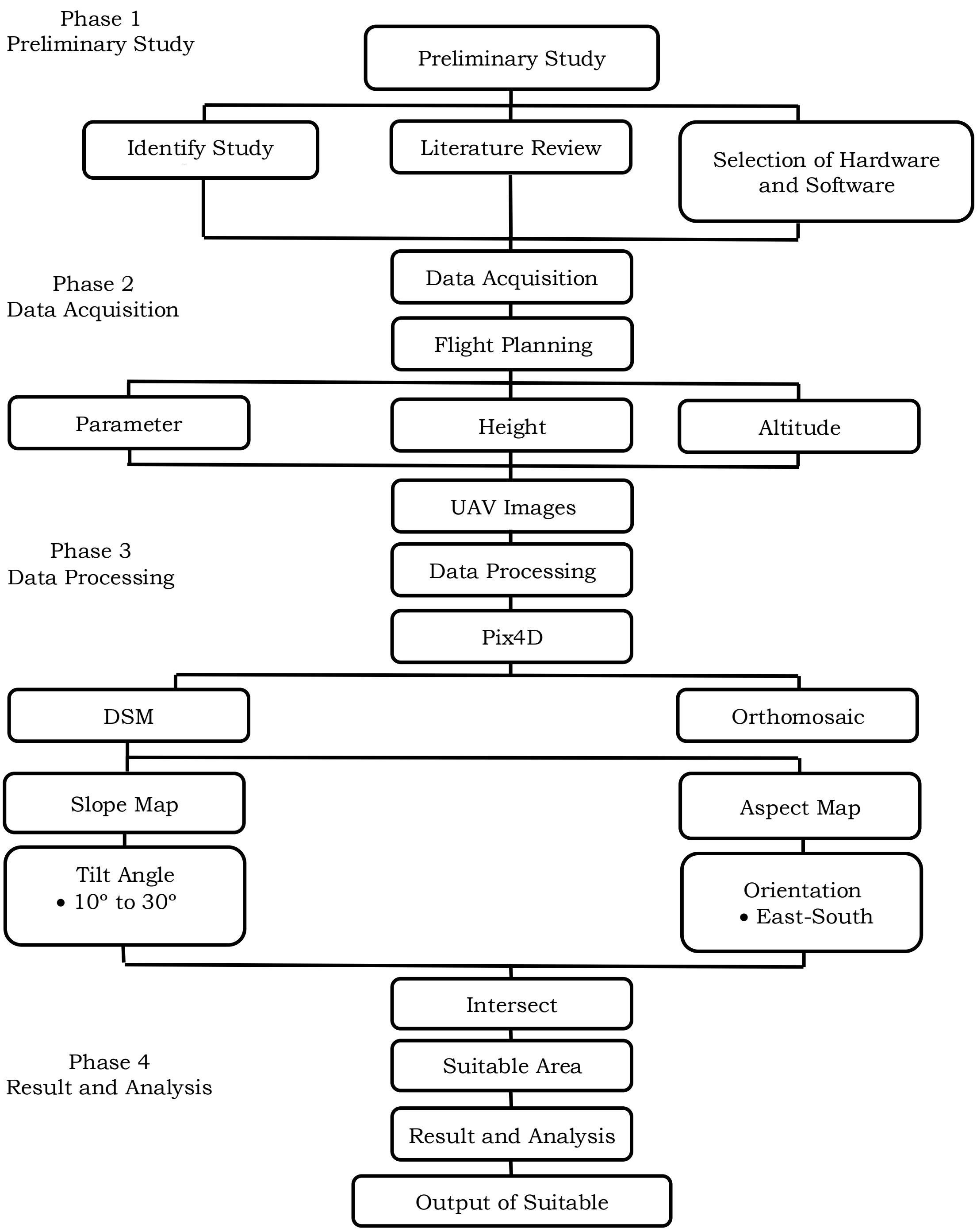

Figure 1: The process of developing the proposed method

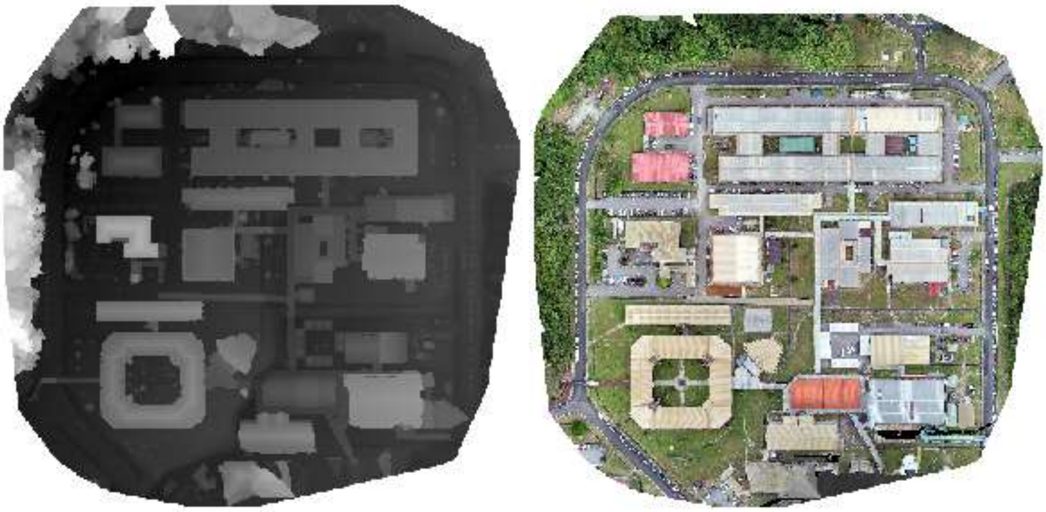

Figure 2: DSM and orthomosaic

(a) Creating Slope Map

Researchers can analyse to identify appropriate areas for solar panel installation after producing the slope. To create a slope map in ArcGIS Pro, first ensure this project includes a DSM. Navigate to the 'Analysis' tab, select 'Tools,' and search for the 'Slope' tool in the Geoprocessing pane. In the Slope tool dialogue box, set the input raster to your DSM. Researchers use degrees as the unit. Click 'Run' to generate the slope map as shown in Figure 3.

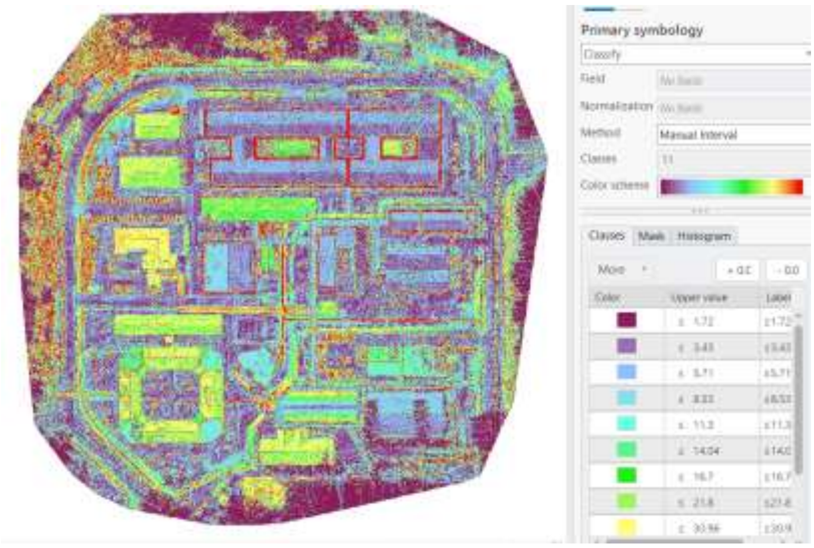

Figure 3: Slope map

(b) Reclassify Slope Map

To reclassify a slope map in ArcGIS Pro, open the Reclassify tool, select the slope map as the input, and set reclassification ranges for slopes under 45° for solar suitability. Specify the output location, name, and click "Run" to identify suitable areas as shown in Figure 4.

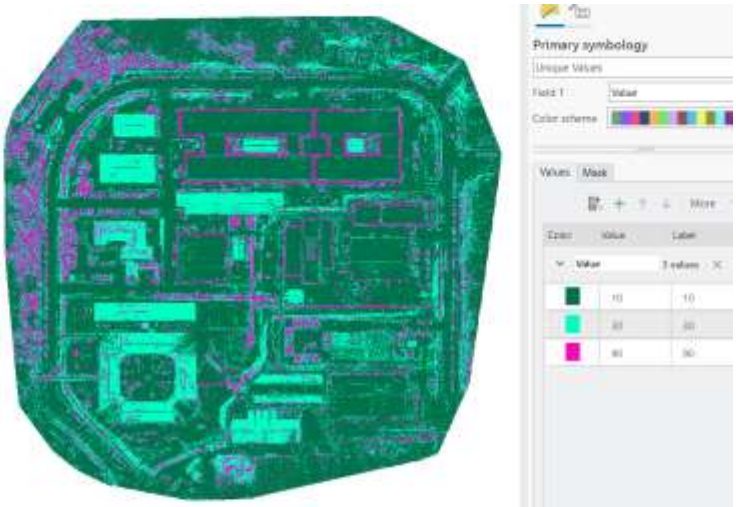

Figure 4: Reclassify slope map

(c) Creating the Aspect Map

Areas that receive the most solar exposure during the day can be found with the use of aspect. For solar panel installation, south-facing slopes in the northern hemisphere generally receive more sunlight and are preferred for solar photovoltaic installation. To create an aspect map in ArcGIS Pro. Go to the 'Analysis' tab, select 'Tools,' and search for the 'Aspect' tool in the Geoprocessing pane. In the Aspect tool dialogue box, set the input raster to DSM, specify the location and name for the output raster, and choose the output measurement unit. Click 'Run' to generate the aspect map as shown in Figure 5.

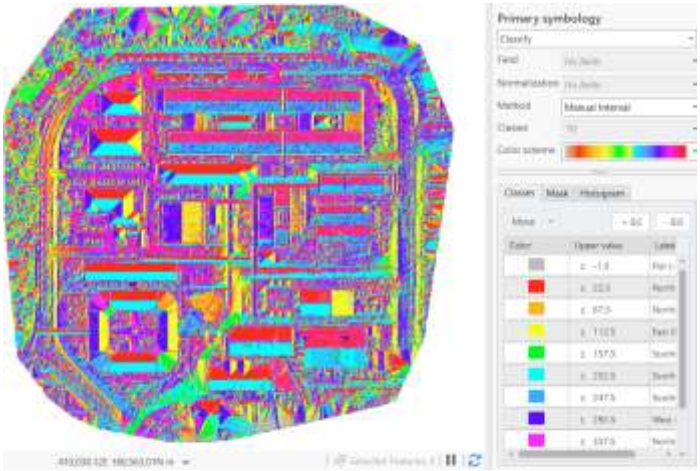

Figure 5: Creating an aspect map

(d) Reclassify the Aspect Map

To reclassify an aspect map for southern orientations in ArcGIS Pro, Open the Reclassify Tool by going to the 'Analysis' tab, clicking 'Tools', and searching for the 'Reclassify' tool in the Geoprocessing pane. Set the input raster by selecting your aspect map. Define the reclassification rules by setting the reclassification ranges: assign a new value to the southern aspect range 67.5°

to 202.5°. Finally, run the Reclassify Tool by specifying the output raster's location and name, then clicking 'Run'. These steps will reclassify the aspect map to highlight southern orientations as shown in Figure 6.

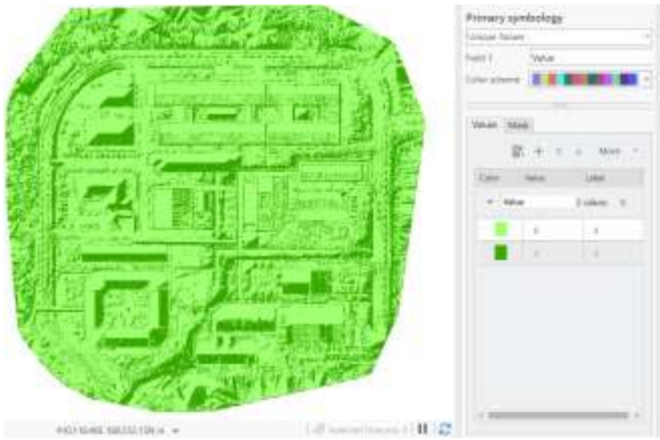

Figure 6: Reclassify aspect map

(e) Convert Binary Raster to Polygon

Convert the map format using the 'Raster to Polygon' tool to get polygon features as shown in Figure 7. Navigate to the 'Analysis' tab, click 'Tools', search for the 'Raster to Polygon' tool, and convert both the slope and aspect maps to polygon features.

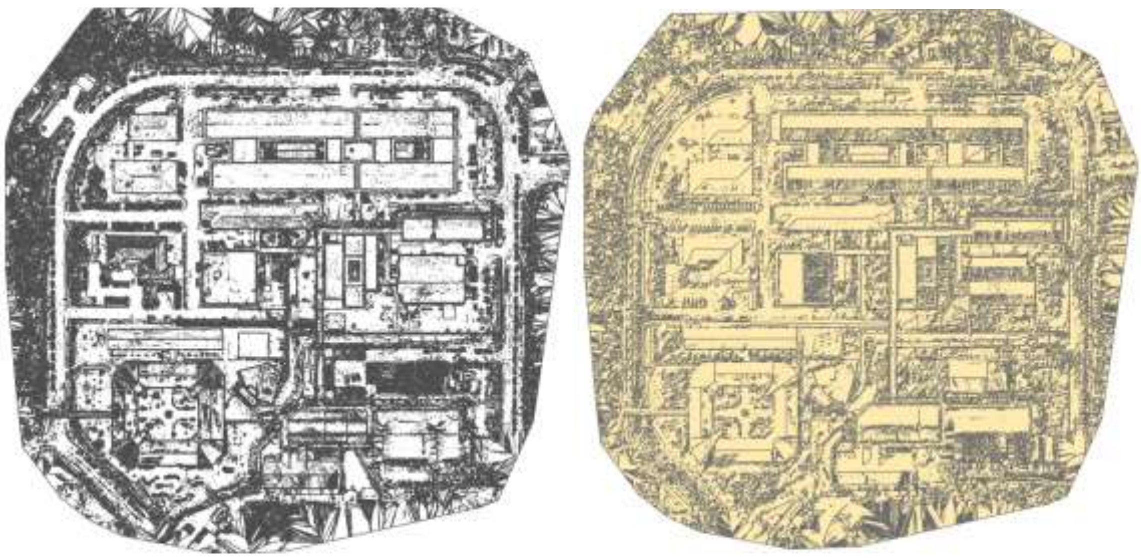

Figure 7: Vector map for aspect and slope map

(f) Intersection Slope Map and Aspect Map

To perform an intersection between a slope map and an aspect map in ArcGIS Pro, start by ensuring both maps are loaded into the project. Go to the 'Analysis' tab, click 'Tools', and search for the 'Intersect' tool. Set the input features to the polygon layers of slope and aspect maps and specify the output feature class location and name. Click 'Run' to execute the tool, which will create a new layer showing the intersection of the slope and aspect maps, highlighting areas where the specified conditions from both maps overlap. Finally, review the output layer to ensure it accurately represents the combined areas of interest, and use the symbology and attribute table to analyse the results as shown in Figure 8.

Figure 8: Output layer

(g) Selection Suitable Rooftop for installing Solar PV

After performing the intersection to combine your slope and aspect maps in ArcGIS Pro, researchers need to determine the specific criteria for selecting suitable areas for solar panel installation, as shown in Figure 9. Right-click on the intersected layer in the contents pane and select Attribute Table to open it. In the Select by Attributes, pick the intersected layer that working with and choose a new selection. Once the area is created, create a new layer with just those selected features. Simply right-click on the intersected layer in the Contents pane, go to 'Data', and choose export features. In the export features, pick selected features, then set the output location and name for your new layer. Click run, and a new layer containing only the areas suitable for installing solar panels.

Figure 9: Selection suitable rooftop for installing solar PV

(h) Building Name

Open the attribute table and click on fields in the design group to open the Fields view. In the field name column, type the name of the new field. In the data type column, choose the data type for the field. For building names, select Text. Click save to apply the changes and add the new field to the attribute table as shown in Figure 10.

Figure 10: Setting the building name

Phase 4: Results and Analysis

The concluding phase of this research entails the development of a map. The primary objective of this study is to generate a map illustrating the solar PV panel potential across the rooftops of the Politeknik Kuching Sarawak.

3.0 Results and Discussion

Solar potential at rooftop level and creating rooftop dimensions at Politeknik Kuching Sarawak was carried out in this research to plan photovoltaic installations.

3.1 Suitable Solar PV Location using 10˚ to 30˚ Slope Angle

Figure 11 shows a suitable solar PV Location using a 10˚ to 30˚ slope angle. The maximum area for solar panels depends on key factors: available installation space, rooftop panel efficiency, higher efficiency needs less space, and desired power output, higher output requires more panels. Solar designers use these considerations to optimise installations. For institutional solar PV systems, previous studies recommend panel sizes between 1.6 m² and 2.5 m², due to most commercially available solar panels fall within this size range. For example, a typical 60-cell panel is about 1.6 m²–1.7 m², while 72-cell panels (commonly used in large installations) are closer to 2.0 m² –2.2 m². These sizes are widely produced, cost-effective, and easy to source.

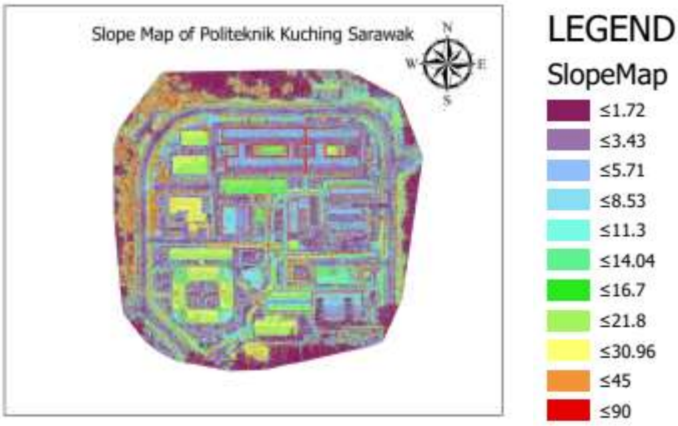

Figure 11: Suitable solar PV location

3.2 Aspect Map of Politeknik Kuching Sarawak

From the raster DSM files, the result of an aspect map has been generated. Aspect is quantified in degrees clockwise from 0°, representing due north, to 360°, circling back to due north. There are 9 facing directions with their range of angles. A flat area is denoted with a grey colour valued at -1, signifying no specific facing direction. Each ground feature is distinguished by a unique colour corresponding to its downslope direction as shown in Figure 12.

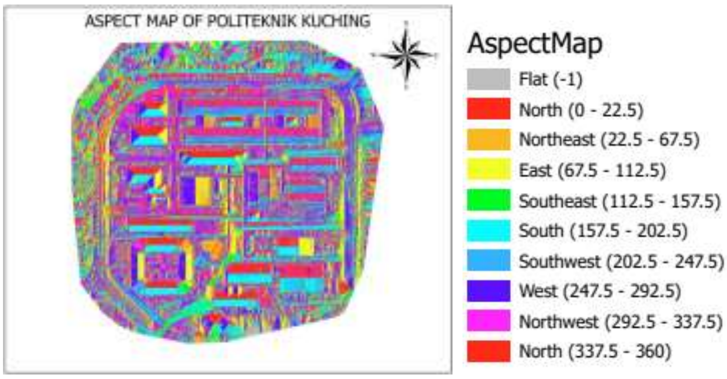

Figure 12: Aspect Map of Politeknik Kuching Sarawak

3.3 Reclassify Slope Map of Politeknik Kuching Sarawak

A slope map is a visual representation of the slope variations across a particular area, as shown in Figure 13. By reclassifying the slope map, researchers can identify areas with slopes that are most suitable for solar panel installation. This typically involves defining ranges within the slope map that correspond to ideal angles for sun exposure. In this study, the researchers classified the area into three categories.

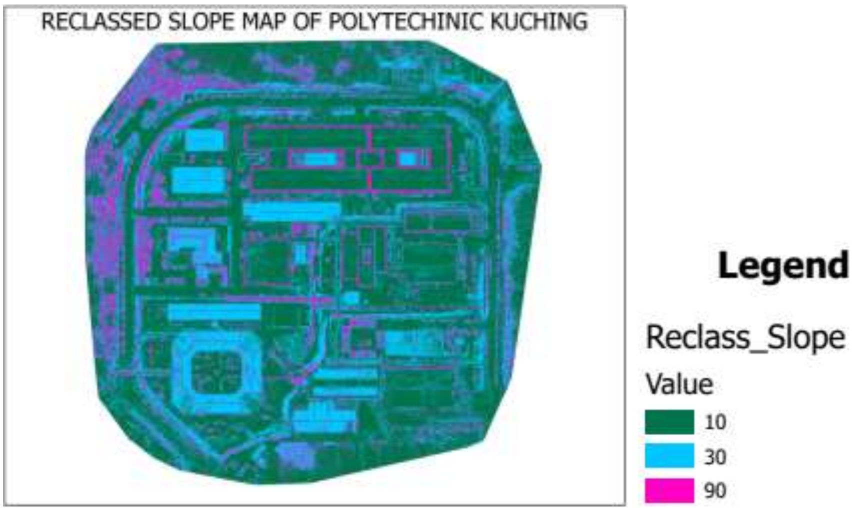

Figure 13: Reclassify slope map of Politeknik Kuching Sarawak

3.4 Reclassify the Aspect Map of Politeknik Kuching Sarawak

Figure 14 shows the reclassify aspect map of Politeknik Kuching Sarawak. This aspect map shows the direction of a surface face. East to south-facing surfaces typically receive the most sunlight in the northern hemisphere. By checking the aspect map, researchers can view which areas of the roof face south and get the most sunshine. Solar PV generates electricity from sunlight. The angle at which sunlight hits the panels significantly impacts how much electricity they produce. Ideally, solar PV should face the sun most of the day for maximum sun exposure.

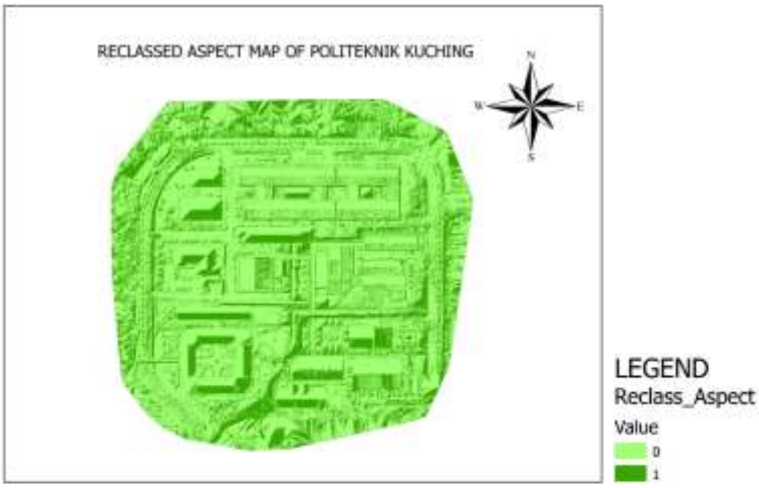

Figure 14: Reclassify aspect map of Politeknik Kuching Sarawak

3.5 Name of Building: Suitable Solar PV Installation

Based on the results, the PV potential of rooftop buildings in Politeknik Kuching shows that several areas are suitable for installing solar PV based on their characteristics, as shown in Table 1.

Table 1: Suitable locations for solar PV installation

Number	**Name of Building**
1	Pentagon College Building
2	Green Lecture Building
3	Department of Petrochemical

3.6 Output Map of the Suitable Solar PV Location

Figure 15 shows the suitable places to locate the solar panel, and the number of solar panels that can be installed in a certain area. The findings indicate that the goals and purposes of this research investigation were successfully achieved. The findings are important when compared to earlier studies, which found that the best aspects for capturing the most insolation are south-facing downslopes, and the optimal slope ranges between 10 and 30 degrees.

Figure 15: Output map of the suitable solar PV location

4.0 Conclusion

In conclusion, the high-resolution Unmanned Aerial Vehicle (UAV) images for accurate Photovoltaic (PV) panel mapping at Politeknik Kuching Sarawak have been developed. A UAV technology for solar PV installation planning offers several advantages compared to traditional methods. The use of high-resolution UAV imagery enabled precise mapping of rooftop surfaces, helping identify optimal PV installation locations at Politeknik Kuching Sarawak. This technology is able to provide a cost-efficient alternative to manual roof surveys, reducing labour costs and the time required for data collection. Data acquisition through UAVs is significantly faster than traditional methods, accelerating the planning process for solar PV installations. Pentagon College Building, Green Lecture Building, and the Department of Petrochemical are the three (3) places in Politeknik Kuching Sarawak that are suitable locations for solar PV installation. This research also shows that the best aspects for capturing the most insolation are south-facing downslopes, and the optimal slope ranges are between 10 and 30 degrees. As future work, this research can be implemented with machine learning or image processing algorithms to automatically detect suitable PV locations from UAV imagery for scalability.

Acknowledgement

The authors would like to express their gratitude to everyone who contributed directly or indirectly to this study. Special and deep appreciation to all colleagues from Politeknik Kuching Sarawak for the moral support and continuous assistance in making this research successfully executed.

Author Contributions

Lee Kong Fah: Conceptualisation, Methodology, Software, and Writing-Original Draft, Project Administration;
Christopher Suresh Martin: Initial Study, Investigation, Methodology, Hardware, Data Curation, Formal Analysis;
Bong Siaw Wee: Software, Validation, Writing – Review & Editing, Resources.

Conflicts of Interest

The manuscript has not been published elsewhere and is not under consideration by any other journals. All authors have approved the review, agree with its submission, and declare no conflicts of interest in the manuscript.

References

[1] S. Barca, "Energy, property, and the industrial revolution narrative," *Ecological economics*, vol. 70, no. 7, pp. 1309-1315, 2011.

[2] E. Saouter, and T. Gibon, "A World Full of Energy," in *All You Need to Know About the Next Energy Revolution: Solutions for a Truly Sustainable Future*, Cham: Springer Nature Switzerland, pp. 1-29, 2024.

[3] T. Bradford, *Solar revolution: the economic transformation of the global energy industry*. MIT Press, 2008.

[4] A. Razmjoo, L. Gakenia Kaigutha, M. V. Rad, M. Marzband, A. Davarpanah, and M. J. R. E. Denai, "A Technical analysis investigating energy sustainability utilizing reliable renewable energy sources to reduce CO2 emissions in a high potential area," *Renewable Energy*, vol. 164, pp. 46-57, 2021.

[5] E. M. A. Elsadek, H. Kotb, A. S. Abdel-Khalik, Y. Aboelmagd, and A. H. A. Elbatran, "Experimental and techno-economic analysis of solar PV system for sustainable building and greenhouse gas emission mitigation in harsh climate: A case study of Aswan educational building," *Sustainability*, vol. 16, no. 13, pp. 1-31, 2024.

[6] A. G. Olabi, N. Shehata, H. M. Maghrabie, L. A. Heikal, M. A. Abdelkareem, S. M. A. Rahman, S. K. Shah, and E. T. Sayed, "Progress in solar thermal systems and their role in achieving the sustainable development goals," *Energies*, vol. 15, no. 24, p. 1051, 2022.

[7] N. A. Osman, S. B. M. Norani, and N. F. M. Sayuti, "Design and Development of Wireless Solar Powered Router for the Rural Area," *Politeknik & Kolej Komuniti Journal of Engineering and Technology*, vol. 6, no. 1, pp. 121-133, 2021.

[8] M. Mustaffa, J. A. Besar, and B. Mustapha(2023), "A Study of a Hybrid Renewable Energy System: Solar PV And Wind Energy with Battery Storage," *Politeknik & Kolej Komuniti Journal of Engineering and Technology*, vol. 8, no. 1, pp.13-24, 2023.

[9] H. Almamun, "Feasibility analysis of grid tied solar park in coastal region," (2021).

[10] M. A. Afham, and M. A. Razali, "Scenario of energy policy and act in Malaysian energy building efforts for sustainable development: A review," *Journal of Mechanical Engineering and Sciences*, pp. 10330-10349, 2024.

[11] M. T. Sarker, M. H. S. M. Haram, G. Ramasamy, F. A. Farid, and S. Mansor, "Solar photovoltaic home systems in Malaysia: A comprehensive review and analysis," *Energies*, vol. 16, no. 23, p.7718, 2023.

[12] A. Latif, S. Norasyiqin, M. S. Chiong, S. Rajoo, A. Takada, Y. Y. Chun, K. Tahara, and Y. Ikegami, "The trend and status of energy resources and greenhouse gas emissions in the Malaysia power generation mix,"*Energies*,vol. 14, no. 8, pp. 1-26, 2021.

[13] R. Ali, I. Daut, and S. Taib, "A review on existing and future energy sources for electrical power generation in Malaysia," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 6, pp. 4047-4055, 2012.

[14] Z. Zulkifli, "Malaysia country report," in *Proceedings of the 17 th AsiaConstruct Conference*, pp. 170-190. 2021.

[15] D. J. Soeder, and D. J. Soeder, "Fossil fuels and climate change," *Fracking and the Environment: A scientific assessment of the environmental risks from hydraulic fracturing and fossil fuels*, pp. 155-185, 2021.

[16] S. Singh, "Forest fire emissions: A contribution to global climate change," *Frontiers in Forests and Global Change*, vol. 5, pp. 1-11, 2022.

[17] B. Freedman, W. Dorsey, A. Frazier, M. Kambhampati, J. Galiotos, and S. Mukherjee, "Renewable and Non-renewable Energy Sources," *Environmental Science*, 2024.

[18] S. Basri, S. U. Zakaria, and S. K. Kamarudina. "Review on alternative energy education in Malaysia," *Jurnal Kejuruteraan,* vol. 33, no. 3, pp. 461-472, 2021.

[19] N. S. M. Izam, Z. Itam, W. L. Sing, and A. Syamsir, "Sustainable development perspectives of solar energy technologies with focus on solar Photovoltaic—A review," *Energies*, vol. 15, no. 8, pp. 1-15, 2022.

[20] S. Lee, S. Iyengar, M. Feng, P. Shenoy, and S. Maji, "Deeproof: A data-driven approach for solar potential estimation using rooftop imagery," in *Proceedings of the 25th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining*, pp. 2105-2113, 2019.

[21] H. Ni, D. Wang, W. Zhao, W. Jiang, E. Mingze, C. Huang, and J. Yao, "Enhancing rooftop solar energy potential evaluation in high-density cities: A Deep Learning and GIS based approach," *Energy and Buildings*, vol. 309, 2024.

[22] H. Jiang, L. Yao, N. Lu, J. Qin, T. Liu, Y. Liu, and C. Zhou, "Geospatial assessment of rooftop solar photovoltaic potential using multi-source remote sensing data," *Energy and AI*, vol. 10, p. 100185, 2022.

[23] G. E. M. Abro, A. Ali, S. A. Memon, T. D. Memon, and F. Khan, "Strategies and challenges for unmanned aerial vehicle-based continuous inspection and predictive maintenance of solar modules," *IEEE Access*, vol. 12, pp.17665-176629, 2024.

[24] K. Milidonis, A. Eliades, V. Grigoriev, and M. J. Blanco, "Unmanned Aerial Vehicles (UAVs) in the planning, operation and maintenance of concentrating solar thermal systems: A review," *Solar Energy*, vol. 254, pp.182-194, 2023.

[25] S. A. H. Mohsan, N. Q. H. Othman, Y. Li, M. H. Alsharif, and M. A. Khan, "Unmanned aerial vehicles (UAVs): Practical aspects, applications, open challenges, security issues, and future trends," *Intelligent service robotics*, vol. 16, no. 1, pp.109-137, 2023.

[26] A. R. E. Eddin, "Automatic Inspection of Photo-Voltaic Systems with Thermal Im-Aging Drones," M.S. thesis, Faculty of Information Technology and Communication Sciences, Tampere University, Finland, 2021.

[27] B. O. Olorunfemi, O. A. Ogbolumani, and N. Nwulu, "Solar panels dirt monitoring and cleaning for performance improvement: a systematic review on smart systems," *Sustainability*, vol. 14, no. 17, pp. 1-27, 2022.