Journal of Advanced Research in Applied Sciences and Engineering Technology

SEMARAK ILMU PUBLISHING

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Revolutionising Energy Generation for Agriculture Utilization in Malaysia: Photovoltaic Greenhouse Concept

Pooi Ying Choong[1], Yaw Long Chua[2,*], Pin Jern Ker[2]

[1] Department of Mechanical Engineering, College of Engineering (COE), Universiti Tenaga Nasional (UNITEN) Putrajaya Campus, 43000 Kajang, Selangor, Malaysia
[2] Institute of Sustainable Energy (ISE), Universiti Tenaga Nasional (UNITEN) Putrajaya Campus, 43000 Kajang, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 30 March 2023
Received in revised form 12 July 2023
Accepted 17 July 2023
Available online 2 October 2023

ABSTRACT

Malaysia is a fortunate country graced by abundant sunlight, potentially having success in the application of photovoltaic (PV) powered greenhouses to safeguard food security. This research seeks to develop a design basis for PV greenhouse suitable for application in Malaysia. The motivation behind this research arises from the fact that while there have been studies on the application of PV greenhouses globally, most of them have focused on Europe, the Mediterranean, and Japan. The research will include two experimental prototypes and one control prototype, all featuring identical mono-span roof PV greenhouses with a 15° tilt angle and E-W orientation which has been determined based on literature review. For stage 1 of the research, the prototypes will differ in terms of the PV array arrangements on the roof; whereas in stage 2, PV panels fitted with V-Trough Solar Concentrators will be utilized instead of ordinary PV panels. By filling the research gap by exploring the potential of PV greenhouses in Malaysia, the outcome of this research will contribute to the development of a design basis for PV greenhouses in Malaysia, revolutionising photovoltaic-powered modern agricultural technology.

Keywords:
Photovoltaic Greenhouse; Modern Agriculture; Energy Generation for Agriculture Utilization

1. Introduction

Food security has been a major topic of discussion now a days as human population across the globe is expected to exceed 9.7 billion in the year 2050 as according to the United Nations (UN) (United Nations n.d.), coupled with climate changes and the current turbulent political situations in Eastern Europe that has negatively affected the food supply chains across the globe as halt in agricultural activities and embargo of important food crop is ongoing.

On top of that, food wastage is another issue that should be looked into seriously. Logistics and time required to transport crops from farm to consumers require many resources and leaves a significant carbon footprint as farms are usually located in highlands and rural areas. Lorry transportation is necessary to transport crops and in an unfortunate event where hiccups in

* *Corresponding author.*
E-mail address: chuayl@uniten.edu.my

https://doi.org/10.37934/araset.32.3.4351

operations occur, the delays might cause the freshly harvested crops to not being able to be transported to the consumers in time, resulting in spoilage and wastage.

Urbanisation and modernisation of traditional agriculture can be a mean in ensuring food security and at the same time reduce food wastage. One approach is to utilize modern agricultural technology such as greenhouse incorporated with hydroponic system for crop cultivation. Such modern agricultural technology is a proven method to cultivate and manage crops in a controlled environment where the optimal conditions for growth, pest control and reduction of fertilizers used can be achieved, maximizing yield of crops with the minimum space required [12, 22]. With greenhouses, crop cultivations can be performed in urban settings and can even utilize spaces once thought to be of no use such as rooftop of office buildings, commercial complexes, and even at home setting.

Albeit the benefits of modern agricultural methods are vast, there are also some drawbacks. One major drawback is that greenhouses and hydroponic systems are not self-sustaining as they are reliant on electricity, making it dependent on the national grid or portable electricity generators running on fossil fuel. As of now, majority of electricity in Malaysia is generated using fossil fuel and research has shown that to maintain optimal growth conditions within the greenhouse, up to 50% of the overhead cost required to maintain and operate a greenhouse is spent on electricity bill charges [1].

Various research about photovoltaic (PV) greenhouse has been performed, yet these research are mainly focused in Europe, Mediterranean, and Japan. Photovoltaic powered greenhouses with heat pumps are available in greenhouses located in locations which experience winter, and opposite to that, greenhouse located in warm climates have cooling and ventilation system installed, maintaining the optimum growing condition within the greenhouse [13, 19, 25]. Multiple studies by various researchers to understand the effects of shading by PV modules installed on greenhouse roof has been performed in Mediterranean, Europe and North Asia [6, 7, 8, 10, 15, 23, 26, 28]. Studies on the effects of PV greenhouse orientation has also been done in Japan and Europe [7, 9]. In the Malaysian context, back in 2007 a research by Al-Shamiry *et al*., [2] was done on a PV powered greenhouse with PV panels mounted on racks installed beside the and in year 2020, a portable, mini herb plantation cabinet was developed by a team in UPM, Roslan *et al*., [18]. Despite various studies with regards to PV greenhouse has been performed at different locations, there is still an existing gap where no research on the application of PV greenhouse in Malaysia has been performed.

Malaysia is a blessed country located in the tropical region and receives abundant of sunlight and also has much fertile soil suitable for agricultural purpose. However, the usage of modern agricultural technologies such greenhouse and hydroponic cultivation should be normalized to ensure Malaysia is one step ahead in future proofing the agriculture industry, at the same time combating food security and wastage issues. By having a controlled environment and technique to cultivate crops, issues caused by climate changes for extreme weather conditions or triggers of agricultural pest can be averted [11, 20, 21]. Besides that, optimization of land for crop cultivation use can result in urbanization of agriculture, minimizing the need to exploit remaining forest land and at the same time bringing farms closer to consumers, saving on logistics and other resources.

As Malaysia is situated near to the equator and receives abundant sunlight with constant average solar irradiation, photovoltaic energy is suitable to be used as auxiliary power supply for greenhouse incorporated with hydroponic systems. Studies has been performed by researchers on the potential of PV energy application in East Malaysia was found to be satisfactory [4, 14]. The photovoltaic power potential of Malaysia is well illustrated in the solar resource map of Malaysia as illustrated in Figure 1 which is provided by Solargis which is published by The World Bank Group, financially supported by ESMAP, and contents prepared by Solargis [3]. On top of that, to further support the potential of PV energy in Malaysia, the establishments of large-scale solar farms in Malaysia recently have taken place.

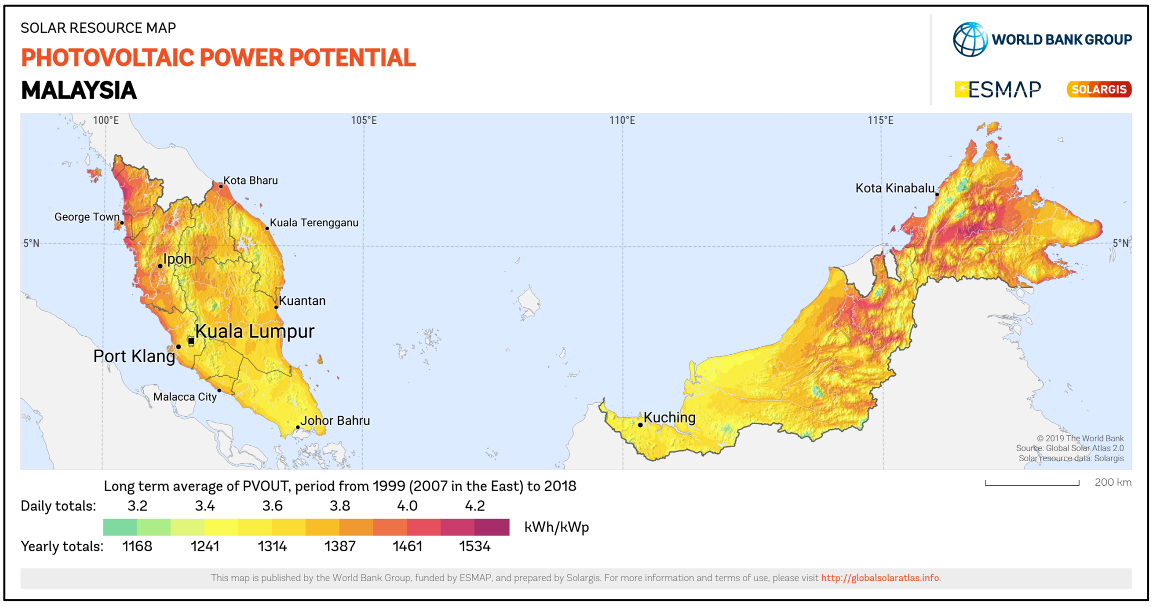


Fig. 1. Solar Resource Map of Malaysia [3].

With the incorporation of photovoltaic panels onto greenhouse roof arranged in varying configurations to provide shading needed for crop production whilst generating energy required for the greenhouse and hydroponic system is an innovative agriculture and renewable energy approach. This approach could possibly contribute towards revolutionizing photovoltaic powered modern agricultural technology in Malaysia, bringing forth a fresh and realistic model of photovoltaic greenhouse appropriate for the application in tropical countries.

2. Research Objectives

The research objectives for this proposed research are as follows:

i. To determine the optimal arrangement of PV module installed on roof of PV greenhouse in terms of power generation and Photosynthetically Active Radiation (PAR) available for crops cultivated within PV greenhouse.
ii. To develop a design basis of PV greenhouse for the application in Malaysia.

3. Methodology

The research methodology for this proposed research is outlined as per flowchart in Figure 2. The detailed explanation of the methodology will be found in the Proposed Concept section.

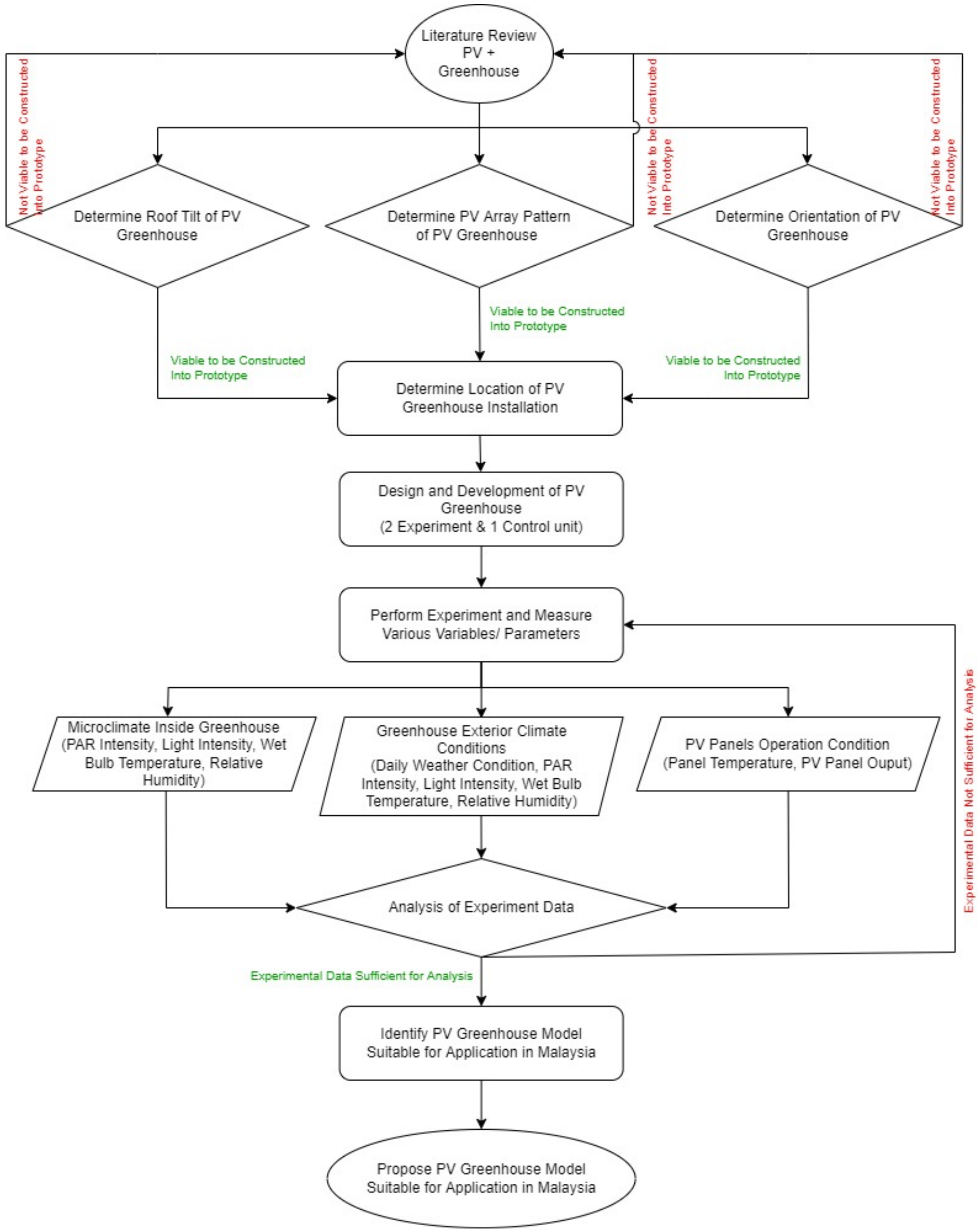


Fig. 2. Research Methodology Flowchart of Proposed Concept

4. Proposed Concept

The methodology and all design considerations of this proposed concept will be laid out then discussed accordingly in this section.

Researchers shall be well aware that Malaysia is located relatively close to the equator, well within the tropical region. The travel path of the sun for regions near the equator will be different as compared to locations located in the Southern or Northern Hemisphere. Thus, the research leading to the development of PV greenhouse for the application in Malaysia shall reflect upon the location coordinates in Malaysia.

The proposed concept will be tested within the Universiti Tenaga Nasional (UNITEN) Putrajaya Campus. The longitudinal and latitudinal coordinates of the test location is as per Table 1. The prototype shall be set up at an open field where no other structures, trees, or plants that might cast a shadow on the prototype are present. The orientation of the prototype was determined based on past research in Malaysia. Based on the mini herb plantation cabinet produced by researchers in UPM, Roslan *et al.*, [18], the optimum orientation of the greenhouse prototype is to be of E-W direction.

Table 1
Longitudinal and Latitudinal Coordinates of the Test Location

	Coordinate (in degrees and minute format, WGS84)
Longitude	2° 57.874620’(N)
Latitude	101° 43.544280’(E)

For stage 1 of the research, a custom-built, mono-span roof greenhouse prototype made from slotted angle iron will be used as the test prototype for this research. The dimension of the prototype will be 1.9m at its tallest point, 1.44m long and 1.5m wide. Two experimental test beds and one control unit will be fabricated for this research. The prototypes shall be spaced a minimum of 4m apart to prevent shadow overcast from one PV greenhouse prototype to another. The roof tilt of this prototype will be set at 15° as per previous research of optimal roof tilt for PV power generation by Mamun *et al.*, [17] and portable PV powered plant cultivation cabinet by Roslan *et al.*, [18], where both researches were performed in Malaysia.

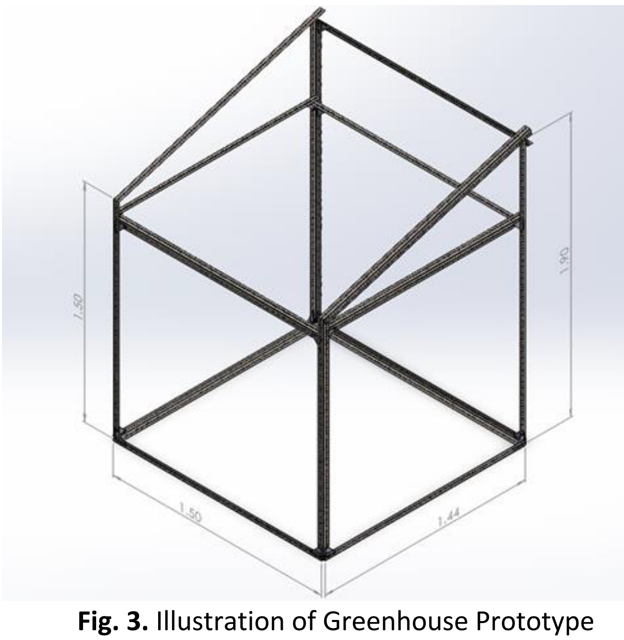
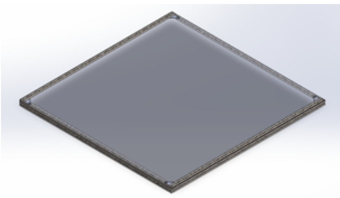
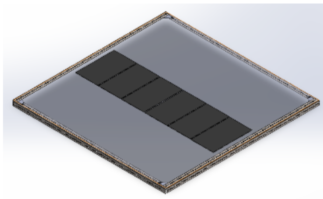
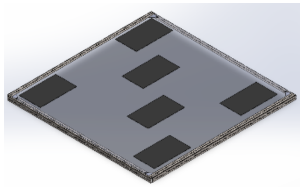


Fig. 3. Illustration of Greenhouse Prototype

The PV greenhouse will be covered with 0.15mm thick transparent greenhouse covering material made from polyolefin. The PV panels will be mounted on the roof, above the greenhouse covering based on data available from past research done. The three units of PV greenhouse prototype will be fitted with different PV module arrangements on the roof as per Table 2.

Table 2
Arrangement of PV Modules on PV Greenhouse roof prototype

	Prototype 1	**Prototype 2**	**Prototype 3**
Description	No PV panels installed on roof	Straight line PV array installation in middle of roof.	Loosely, evenly spaced PV array installation across roof.
PV Arrangement			

The photovoltaic system shall be sized according to the power requirements of the PV greenhouse and the hydroponics system in it. Preliminary studies on the power requirements required are done by identifying all appliances that require electricity supply and its kWh values.

Upon completion of the prototypes, data collection will be performed throughout a 45-day period from sunrise to sun set. A data collection period of 48 days is chosen to mimic the growth period of lettuce cultivated hydroponically in a greenhouse without artificial lighting [16]. The data to be collected can be categorized into three main categories as illustrated in Table 3.

Table 3
Data to be Collected for Research

Data Category	Data Involved
Microclimate Inside Greenhouse	- Photosynthetically Active Radiation (PAR) intensity
	- Light intensity
	- Wet bulb temperature
	- Relative humidity
Greenhouse Exterior Climate Condition	- Daily weather condition
	- PAR intensity
	- Light intensity
	- Wet bulb temperature
	- Relative Humidity
PV Panel Operation Condition	- PV panel output voltage and current
	- Panel temperature

Throughout this research, a highly specialized PAR light meter, Spectrum Lightscout 3415A Quantum PAR meter will be utilized for this research to log the PAR values inside the PV greenhouse to understand the shading effect and available PAR for the crops. The PAR light meter is capable to measure light utilized by plants to perform photosynthesis most efficiently, which are within the red and blue colored wavelength between 400 µm to 700µm [5].

Once sufficient data is successfully collected, all data will be analysed and corelated to determine the effects of different PV array configuration on PV greenhouse roof. Data analysis will mainly focus on graphs and incorporated with all observations done on site. Graphs to be plotted for analysis is as illustrated in Table 4.

Table 4
Graphs to be plotted for data analysis

Graph Title
PAR Inside PV Greenhouse and PAR Outside PV Greenhouse vs Time
Solar Irradiance Inside PV Greenhouse and Solar Irradiance Outside PV Greenhouse vs Time
Temperature Inside PV Greenhouse and Temperature Outside PV Greenhouse vs Time
Temperature of PV Surface vs Time
PV Output vs Time
PV Current – Voltage Characteristics
PV Energy and Measured Solar Irradiation

Upon completion of data analysis and correlation, the PV greenhouse prototype with optimum PV energy generation capability and microclimate within PV greenhouse will be identified. This will be the developed design basis of PV greenhouse for the application in Malaysia.

Stage 2 of the research will involve the incorporation of V- Through solar concentrator photovoltaic system installed on the PV Greenhouse roof instead of ordinary solar panels as research in Malaysia has shown significant improvement of power output as compared to a normal photovoltaic panel [27]. This will be performed only after the completion of stage 1. An example of a V-Trough Solar Concentrator is shown in Figure 4 below.

Fig. 4. V-Trough Solar Concentrator

5. Contribution of Studies

Once the PV greenhouse prototype with optimum PV energy generation capability and microclimate within PV greenhouse has been identified, a design basis of an optimum PV greenhouse model for the application in Malaysia will then be proposed.

This design basis of PV greenhouse model can contribute towards the urbanization and modernization of agricultural technology in Malaysia, allowing growers to build greenhouses which are self-sustaining in terms of electricity and able to utilize currently unused or not profitable land space on commercial building roofs for crop generation.

This will ensure food security as crops can be generated within a controlled environment, at the same time bringing forth better farm to table management of crops, reducing food wastage and resources required for logistics.

6. Conclusion

Essentially, the proposed application of PV greenhouse in Peninsular Malaysia is able to harness the benefits of modern agricultural crop generation within controlled environment and abundant of photovoltaic power available in Malaysia. The design basis of PV greenhouse specially optimised for the application in Malaysia will be able to provide growers a greenhouse that provides optimal shading and microclimate condition for plants cultivated, at the same time self-sustaining in terms of electricity without the need to rely on the national grid or generators for electricity.

Acknowledgement
This research was funded by a grant from *Yayasan Cancelor UNITEN* under grant number 202210022YCU.

References

[1] Acosta-Silva, Yuliana de Jesus, Irineo Torres-Pacheco, Yasuhiro Matsumoto, Manuel Toledano-Ayala, Genaro Martín Soto-Zarazúa, Orlando Zelaya-Ángel, and Arturo Méndez-López. "Applications of solar and wind renewable energy in agriculture: A review." *Science Progress* 102, no. 2 (2019): 127-140. https://doi.org/10.1177/0036850419832696

[2] Faisal, Mohammed, Ahmad Desa, Rashid Abdul, Aris Ishak, Janius Rimfiel, and Kamaruddin Rezuwan. "Design and development of a photovoltaic power system for tropical greenhouse cooling." *American Journal of Applied Sciences* 4, no. 6 (2007): 386-389. https://doi.org/10.3844/ajassp.2007.386.389

[3] Atlas, Global Solar. 2020. Solar Resource Maps of Malaysia. The World Bank.

[4] Azhari, Ayu Wazira, Kamaruzzaman Sopian, Azami Zaharim, and Mohamad Al Ghoul. "Solar radiation map from satellite data for a tropical environment-case study of Malaysia." In *Proceedings of the 3rd IASME/WSEAS International Conference on Energy & Environment*, pp. 528-533. 2008.

[5] Wu, Bo-Sen, Anne-Sophie Rufyikiri, Valérie Orsat, and Mark G. Lefsrud. "Re-interpreting the photosynthetically action radiation (PAR) curve in plants." *Plant Science* 289 (2019): 110272. https://doi.org/10.1016/j.plantsci.2019.110272

[6] Buttaro, Donato, Massimiliano Renna, Carmela Gerardi, Federica Blando, Pietro Santamaria, and Francesco Serio. "Soilless production of wild rocket as affected by greenhouse coverage with photovoltaic modules." *Acta Scientiarum Polonorum Hortorum Cultus* 15, no. 2 (2016): 129-142.

[7] Castellano, Sergio. "Photovoltaic greenhouses: evaluation of shading effect and its influence on agricultural performances." *Journal of Agricultural Engineering* 45, no. 4 (2014): 168-175. https://doi.org/10.4081/jae.2014.433

[8] Cossu, M., A. Yano, Lelia Murgia, Luigi Ledda, Paola Antonia Deligios, A. Sirigu, F. Chessa, and A. Pazzona. "Effects of the photovoltaic roofs on the greenhouse microclimate." In *International Symposium on New Technologies and Management for Greenhouses-GreenSys2015 1170*, pp. 461-468. 2015. https://doi.org/10.17660/ActaHortic.2017.1170.57

[9] Cossu, Marco, Lelia Murgia, Luigi Ledda, Paola A. Deligios, Antonella Sirigu, Francesco Chessa, and Antonio Pazzona. "Solar radiation distribution inside a greenhouse with south-oriented photovoltaic roofs and effects on crop productivity." *Applied Energy* 133 (2014): 89-100. https://doi.org/10.1016/j.apenergy.2014.07.070
[10] Ezzaeri, K., Hicham Fatnassi, R. Bouharroud, L. Gourdo, A. Bazgaou, A. Wifaya, H. Demrati et al. "The effect of photovoltaic panels on the microclimate and on the tomato production under photovoltaic canarian greenhouses." *Solar Energy* 173 (2018): 1126-1134. https://doi.org/10.1016/j.solener.2018.08.043
[11] Fuhrer, Jürg. "Agroecosystem responses to combinations of elevated CO2, ozone, and global climate change." *Agriculture, Ecosystems & Environment* 97, no. 1-3 (2003): 1-20. https://doi.org/10.1016/S0167-8809(03)00125-7
[12] Giacomelli, Gene A. "Engineering principles impacting high-tunnel environments." *HortTechnology* 19, no. 1 (2009): 30-33. https://doi.org/10.21273/HORTSCI.19.1.30
[13] Hassanien, Reda Hassanien Emam, Ming Li, and Wei Dong Lin. "Advanced applications of solar energy in agricultural greenhouses." *Renewable and Sustainable Energy Reviews* 54 (2016): 989-1001. https://doi.org/10.1016/j.rser.2015.10.095
[14] Ilham, Zul. "Multi-criteria decision analysis for evaluation of potential renewable energy resources in Malaysia." *Progress in Energy and Environment* 21 (2022): 8-18. https://doi.org/10.37934/progee.21.1.818
[15] Kadowaki, Masayuki, Akira Yano, Fumito Ishizu, Toshihiko Tanaka, and Shuji Noda. "Effects of greenhouse photovoltaic array shading on Welsh onion growth." *Biosystems Engineering* 111, no. 3 (2012): 290-297. https://doi.org/10.1016/j.biosystemseng.2011.12.006
[16] Majid, Maliqa, Junaid N. Khan, Qazi Muneeb Ahmad Shah, Khalid Z. Masoodi, Baseerat Afroza, and Saqib Parvaze. "Evaluation of hydroponic systems for the cultivation of Lettuce (Lactuca sativa L., var. Longifolia) and comparison with protected soil-based cultivation." *Agricultural Water Management* 245 (2021): 106572. https://doi.org/10.1016/j.agwat.2020.106572
[17] Mamun, M. A. A., M. Hasanuzzaman, and J. Selvaraj. "Impact of tilt angle on the performance of photovoltaic modules in Malaysia: A review." (2016): 97-8. https://doi.org/10.1049/cp.2016.1354
[18] Roslan, N., M. E. Ya'acob, D. Jamaludin, Y. Hashimoto, M. H. Othman, A. Noor Iskandar, M. R. Ariffin et al. "Dye-Sensitized Solar Cell (DSSC): Effects on Light Quality, Microclimate, and Growth of Orthosiphon stamineus in Tropical Climatic Condition." *Agronomy* 11, no. 4 (2021): 631. https://doi.org/10.3390/agronomy11040631
[19] Sethi, V. P., and S. K. Sharma. "Survey and evaluation of heating technologies for worldwide agricultural greenhouse applications." *Solar energy* 82, no. 9 (2008): 832-859. https://doi.org/10.1016/j.solener.2008.02.010
[20] Shrestha, Saroj. "Effects of climate change in agricultural insect pest." *Acta Scientific Agriculture* 3, no. 12 (2019): 74-80. https://doi.org/10.31080/ASAG.2019.03.0727
[21] Skendžić, Sandra, Monika Zovko, Ivana Pajač Živković, Vinko Lešić, and Darija Lemić. "The impact of climate change on agricultural insect pests." *Insects* 12, no. 5 (2021): 440. https://doi.org/10.3390/insects12050440
[22] Syed, Ali Muslim, and Caroline Hachem. "Review of construction; geometry; heating, ventilation, and air-conditioning; and indoor climate requirements of agricultural greenhouses." *Journal of Biosystems Engineering* 44 (2019): 18-27. https://doi.org/10.1007/s42853-019-00005-1
[23] Trypanagnostopoulos, G., A. Kavga, M. Souliotis, and Y. Tripanagnostopoulos. "Greenhouse performance results for roof installed photovoltaics." *Renewable Energy* 111 (2017): 724-731. https://doi.org/10.1016/j.renene.2017.04.066
[24] United Nations. n.d. Global Issue: Population. https://www.un.org/en/global-issues/population#:~:text=The%20world's%20population%20is%20expected,nearly%2011%20billion%20around%202100.
[25] Sethi, V. P., and S. K. Sharma. "Survey of cooling technologies for worldwide agricultural greenhouse applications." *Solar Energy* 81, no. 12 (2007): 1447-1459. https://doi.org/10.1016/j.solener.2007.03.004
[26] Yano, A., M. Kadowaki, A. Furue, N. Tamaki, T. Tanaka, E. Hiraki, Y. Kato, F. Ishizu, and S. Noda. "Shading and electrical features of a photovoltaic array mounted inside the roof of an east–west oriented greenhouse." *Biosystems Engineering* 106, no. 4 (2010): 367-377. https://doi.org/10.1016/j.biosystemseng.2010.04.007
[27] Chua, Yaw Long, Nicholas Yeo Ren Sheng, Tee Tiong Tay, and Yit Yan Koh. "Performance evaluation of a V-Trough solar concentrator photovoltaic system." In *AIP Conference Proceedings*, vol. 2030, no. 1, p. 020001. AIP Publishing LLC, 2018. https://doi.org/10.1063/1.5066642
[28] Zhang, Kai, Jihua Yu, and Yan Ren. "Research on the size optimization of photovoltaic panels and integrated application with Chinese solar greenhouses." *Renewable Energy* 182 (2022): 536-551. https://doi.org/10.1016/j.renene.2021.10.031