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A Reality Check on the Large Scale of Solar Energy Technology via Integrated SWOT-PESTLE-AHP Analysis

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Malaysia possesses significant potential for solar power generation due to its tropical weather and high levels of solar irradiance. This climate condition implies that solar technology, such as photovoltaic (PV) systems enable to generate more electricity per unit area, making it more economically viable for businesses and households' applications. As Malaysia pledge to support the Net Zero Emissions (NZE) by 2050 Scenario, pre and continuous evaluation on the opportunities and challenges confronting solar technology penetration as a clean and affordable energy is of significant. This work aims to perform preliminary assessment of large scale of solar technology in Malaysia via integrated SWOT (Strengths, Weaknesses, Opportunities, and Threats) and PESTLE (the Political, Economic, Social, Technical, Legal, and Environmental) approaches, combine with analytic hierarchy process (AHP) method. It can be concluded that solar energy is one of the alternative energy sources that should be developed more in the future in terms of technology to ensure clean energy can be promoted. In AHP analysis, the economic aspect has shown the highest priority. Cost of investment and operation exhibited a huge factor that may hinder the large-scale solar project in Malaysia. The semi-empirical result of this paper presents a reality check on the solar technology feasibility in Malaysia while formulate a decision-making framework for addressing clean energy technology.

1. Introduction

The trend towards solar energy has been increasing rapidly in recent years. According to International Energy Agency (IEA), global solar photovoltaic (PV) installed capacity increased from 40 GW in 2010 to over 700 GW in 2020. This growth is expected to continue, with the IEA projecting that solar PV will become the largest source of renewable electricity by 2025 (IEA, 2022). Malaysia is one of the countries that are endowed with wide variety of energy resources ranging from fossil fuels to various sources of renewable energies. Solar energy is one of the most favourable renewable energies in Malaysia due to its strategic location with abundance of sunshine for about 12 hours daily and exhibited high solar irradiation with average of 4,500 kWh/m^2 (Aziz et al., 2016). This climate advantages combine with supportive government policies and rapid growth of solar industry makes Malaysia a viable/tactical location for the full-scale deployment of solar technology. Kaoma et al. (2021) conducted a combined technique of SWOT-AHP-TOWS (Strengths, Weaknesses, Opportunities, Threats-Analytic Hierarchy, Threats, Opportunities, Weaknesses, Strengths) to evaluate the performance of existing institutional framework of bioenergy uptake based on scenario in Zambia. The finding revealed that huge investment costs of bioelectricity technologies posed a major threat with part of the strategies proposed was to deploy present multilateral and bilateral sharing platforms to disseminate the knowledge on sustainable bioenergy pathways. Agyekum et al. (2021) used PESTLE (Policy, Economic, Social, Technology, Legal, Environment)-AHP for a multi-criterion decision making of renewable energy in Ghana. They identified that the economic factor features a prioritize criteria for a decision making of renewable energy technologies, especially for a long-term investment. This was due to the immature of renewable energy sector existed in Ghana. Strategic

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geographical location was evaluated as the top rank in term of opportunity which underpinned possible penetration of solar energy technology in the country. Social influence and local market condition was identified as a vital priority for renewable energy (solar and wind) decision making in Philippines via AHP approach (Rapal et al., 2017). Similar finding and technique (AHP) were observed based on the study conducted by Yang and Harun (2022), where they found that market dynamics featured one of the critical factors in the application of renewable energy in Malaysia. In their work, solar was ranked fourth in term of the potentiality for clean power generation, after hydropower, biomass and wind. As technology evolve and public awareness spread in borderless world, solar energy has become the new king of electricity by conquering a bigger slice of global energy supply (IEA, 2022). As evident to this, pathway towards Net Zero Emission (NZE) Scenario 2050 has been developed to support clean/renewable energy practice into the power sector network. To support this pathway, Malaysia is working harder to place solar in their local energy mix. To ensure a successful and feasible implementation of full-scale solar technology, systematic analysis is required for decision-making process. Preliminary SWOT-PESTLE analysis conducted by Mokhtar et al. (2022) demonstrated that the solar technology (i.e. photovoltaic thermal system) is a viable option for clean energy transition in Malaysia compared to hydrogen fuel cell. Thus, present work evaluates the potential deployment of solar technology in commercial set up via hybrid SWOT-PESTLE-AHP approach. A reality check can be done based on the final verdict of the SWOT-PESTLE-AHP analysis. Upon the time of writing, no similar studies have been conducted related to this work, while only scares touched on the individual SWOT, PESTLE or AHP analysis (with no triplex combined method). Therefore, it highlights the novelty and significant contribution of this work in making a solar technology decision while achieving net zero emissions.

2. Methodology

2.1 SWOT - PESTLE Analysis

The SWOT- PESTLE analysis used in this study aids in creating, rational decisions on the future of large-scale deployment of solar technology in Malaysia. As a preliminary study, present work assumes that the weather is generally similar across all of Malaysia's states and regimes thus no specific area is selected for this study. The SWOT-PESTLE assessment was carried out by consulting various scholarly articles available on platforms like Science Direct, Web of Science, Journal Storage (JSTOR), Scopus and Wiley Online Library. To enhance the analysis obtained from this study, additional sources such as grey literature including policy and statistical studies, as well as government/non-government group websites, were also referenced. For instance, report on the World Energy Outlook 2020, from International Energy Agency and National Renewable Energy Policy, from Sustainable Energy Department Authority, Malaysia.

2.2 Analytical Hierarchy Process (AHP) Analysis

Analytical Hierarchy Process (AHP) is a framework for multi-criteria decision making (MCDM) that classifies problems by hierarchy (Pant et al., 2022). It is used to prioritize criteria and sub criteria for large scale penetration of solar technology in Malaysia, where selection of criteria and sub criteria are acquired from existing literatures. A set of pairwise comparisons are created for each of criteria and sub criteria, where three experts from industries are interviewed to give feedback on the identified criteria subsequently to select significant pairing using a numerical scale as tabulated in Table 1. A simple matrix algebra is used to determine the priority factor for the pairing. One can refer to Saaty (2008) for a comprehensive methodology.

Table 1: Pairwise Comparison

Numerical Rating	Definition
1	i is equally important to j
3	i is slightly more important than j
5	i is strongly more important than j
7	i is very strongly more important than j
9	i is extremely more important than j
2,4,6,8	intermediate

3. Result and Discussion

3.1 SWOT-PESTLE Analysis of Solar Technology in Malaysia

Malaysia is listed as the world's second largest manufacturers in PV module (Muthiah, 2017) after China. This situation enables Malaysia to effectively harvest solar irradiance and installing a full scale of solar technology due to its maturity in PV market. The SWOT-PESTLE analysis of solar technology in Malaysia is tabulated in

Tables 2 and 3. Articles including grey documents within the past five year of publications are referred to perform the analysis by assuming that the validity of the information and fact are still valid and up to date.

Table 2: SWOT analysis for Solar Renewable Energy in Malaysia

SWOT	Description
Strength	Malaysia's climate makes solar energy applications noticeable. It receives abundant sun radiation year-round, with most locations receiving 4.7-6.5 kWh/m^2 (Chatri et al., 2018).
Weakness	Intermittency is Malaysia's biggest renewable energy weakness. Malaysia is tropical, so the monsoon season which high rainfall occurs throughout the year, has less solar radiation (Abdullah et al., 2019). Solar PV efficiency decreases, causing instability and poor supply security (Shadman et al., 2021).
Opportunity	Malaysia's National Energy Policy 2022–2040 covers energy sector development. The policy emphasizes solar energy's role in the energy mix. The policy encourages solar energy use and expansion as a renewable energy source (McKenzie, 2022).
Threat	Energy transformation has funding and investment issues. Despite government subsidies, solar project initial costs can deter investment (Surin and Wahab, 2013).

Table 3: PESTLE analysis for Solar Renewable Energy in Malaysia

PESTLE	Description
Political	Malaysia’s Energy Transition Plan 2021-2040 projected to raise the percentage of renewable energy (RE) in its installed capacity to 31 % and 40 % in 2025 and 2035 respectively (MIDA, 2021).
Environmental	Achieving clean and sustainable energy parallel to Malaysia’s long-term objective in reducing up to 35 % of carbon intensity by 2030 (Ismail et al., 2022).
Social	Awareness regarding interest of solar energy usage shows positive response in society. Prioritization in obtaining consistent supply of electricity with low prices and maintenance (Shadman et al., 2021)
Technological	Malaysia has proactively engaged in the exploration and adoption of solar photovoltaic/thermal (PVT) technology, positioning the country as a leading influence in solar PVT research (Azad and Parvin, 2022).
Economy	Establishment of tax incentives and financial schemes such as Green Investment Tax Allowance (GITA) (MyHIJAU, 2022).
Legal	Sustainable Energy Development Authority (SEDA) is established in 2019 to commit in leading the transition towards renewable energy (SEDA Malaysia, 2023).

3.2 AHP Result of Solar Technology in Malaysia

The individual experts ranked the choices for criteria and sub criteria through a completed questionnaire based on AHP approach. The appraisal criteria for large scale solar technology implementation are structured into four primary criteria and sixteen sub-criteria, as follows: technical (efficiency, maturity of technology, infrastructure, reliability), economical (investment cost, operation and maintenance cost, payback period, service life), social (acceptability of local residence, local job creation, energy and health education, installation and rural land) and environmental (gas emission, requirement of land and water resources, visual impact, hazardous waste). The average value was used in aggregating the judgements of each criterion as each expert was given the same weight in the analysis. The normalized pairwise comparison matrix of the overall criteria based on the responses from the experts is illustrated Table 4. Table 5 shows the consistency ratio (CR) as well as priority vector for the criteria. CR is crucial in AHP analysis where the CR of pairwise comparison matrix shall be less or equal to 10 %. Detail calculation of the CR can be obtained in Algarin et al. (2017). The goal is to generate a positive reciprocal matrix that is close to consistent one since it is impossible to obtain a totally consistent judgement matrix in real-life scenarios.

Table 4: Normalized Pairwise Comparison Matrix for Criteria

Criteria	Technical	Economical	Social	Environmental
Technical	0.230	0.210	0.240	0.250
Economical	0.330	0.300	0.310	0.250
Social	0.250	0.260	0.270	0.290
Environmental	0.180	0.240	0.190	0.200

Table 5: The CR of Criteria

CR		Priority Vector	
λ_{max}	4.014	Technical	0.233
n	4.000	Economical	0.298
CI	0.020	Social	0.268
RI	0.890	Environmental	0.201
CR	0.005		

λ_{max}: Eigenvalue, n: Number of parameters, CI: Consistency index, CR: Consistency ratio

The results of AHP analysis are presented in the form of graphical representations. Figure 1 represents the priorities with respect to the four selected criteria with economics being the utmost priority at 29.8 %, considering that solar energy projects/technology require huge upfront cost including investment, operational and maintenance. This follows by social (26.8 %) and technical (23.3 %) criteria. Environmental exhibited the least priority possibly due to the perception of experts/industries which explains on the current situation of greenhouse gas emissions in Malaysia that are still under controlled or at sensible situation. This is also due to the current focus on policies and development of renewable energy to mitigate climate change by reducing emissions as referred under 10th Malaysia Plan, focusing on National Renewable Energy Policy and Action Plan (NREPAP). In addition, solar technology has been widely implemented in common household and urban areas that has been increasing, resulting in reduction of greenhouse gas emissions. Therefore, it exerts the lowest priority compared to other criteria which shall be further addressed and considered for better development of large-scale solar energy technology. Contradictory analysis was obtained by Algarín et al. (2017) where they found that technical criteria being the most favoured while risk being the least criteria based on the decision making of renewable energy planning in Columbia. One has to take note that different results are demonstrated can possibly obtain for AHP analysis due to the geopolitical-social-economic status of the analysed country.

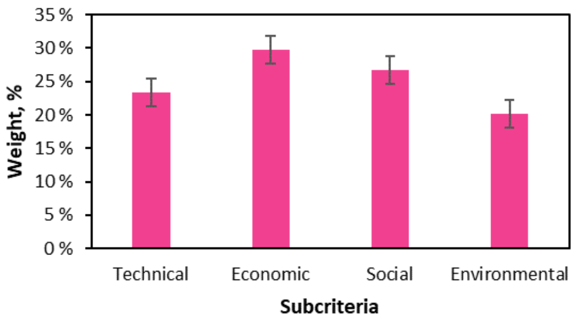

Figure 1: Priorities with respect to criteria

Figure 2a displays the priorities with respect to technical sub criteria. According to the findings, the efficiency of solar technology is the most important factor (30.9 %) followed by infrastructure (25.9 %). It correlates to the fact that high-efficiency solar technology can produce more energy per unit of solar energy, which aids in reducing the maintenance and operation expenses (Empire Renewable Energy, 2022). Figure 2b depicts the priorities with respect to economical sub criteria. Investment cost (30.3 %) and payback period (30.5 %) exhibited almost identical results, indicating that these two are highly significant factors that shall be considered when analysing the economical factor. These outcomes translated that the time required to repay the initial investment is the major driving element that should be considered and standards imposed by manufacturers to ensure for long-term operation.The priorities with respect to social sub criteria can be represented in Figure 2c. Acceptability of local residents being the most important sub criteria is at 38.6 %. The installation of solar renewable energy technology is crucial in the local neighbourhood considering the impact on the daily routine and living standard of the society. Van de Berg and Tempels (2022) found that the local communities are more likely to accept the solar renewable energy development if the benefits gained outweigh the drawbacks. For environmental sub criteria, requirement of land and water resources featured the highest priority as illustrated in Figure 2d. Scheidel et al. (2012) found that renewable energy systems have lower power density than fossil fuels. Hence, the land competition will continue to increase as the world starts to move in transitioning to alternative renewable energy sources.

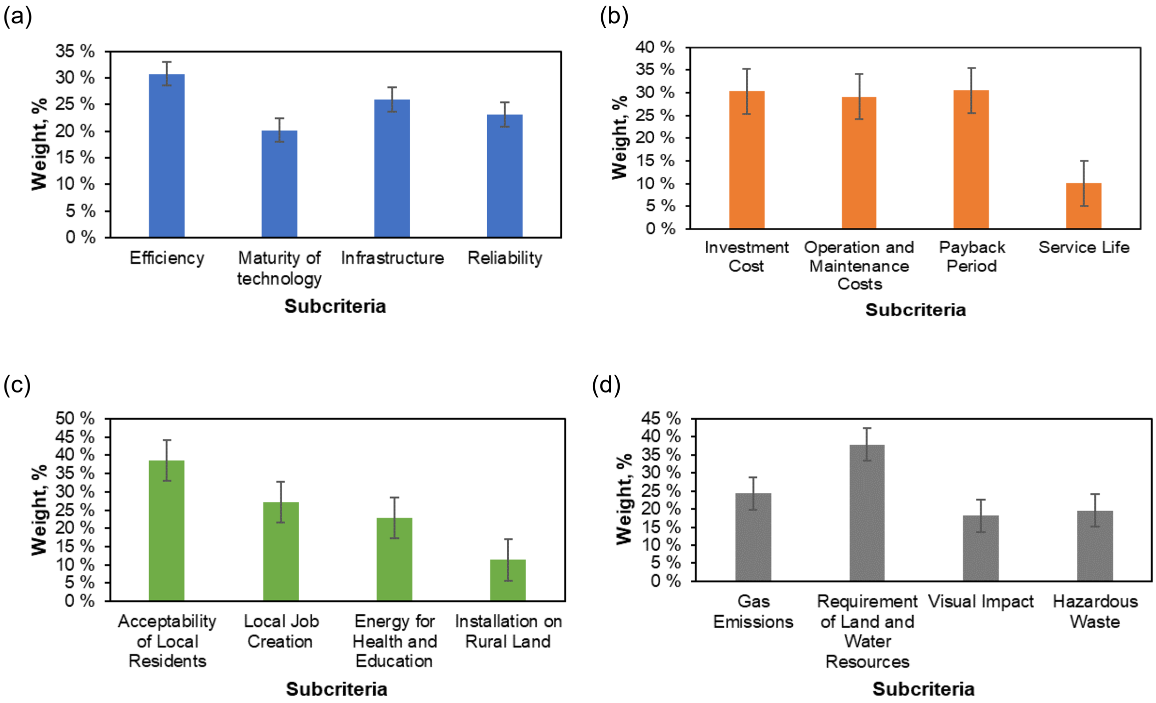

Figure 2: Priorities with respect to (a) technical, (b) economical, (c) social and (d) environmental sub criteria

4. Conclusion

Present work combined SWOT-PESTLE-AHP approach for a preliminary decision making of large-scale solar technology in Malaysia. According to SWOT analysis, there are possible solution for the identified weakness and threat such as an introduction of solar thermal/electrical battery that can be used during cloudy or night time. PESTLE analysis exhibits positive attributes towards the full-scale application of solar technology. Four criteria were defined for AHP analysis such as technical, economic, social and environment. The most important criteria for the solar technology implementation are economic and social which are aligned with study conducted by Tasri and Susilawati (2014). It is indicated that high score in the economic criteria shows that the implementation of full scale of solar technology are highly connected to economic factors with investment coast and maintenance cost being the most significant sub criteria for solar technology decision making. This may improve the economy in the long run and encourage the future investors to joint venture or invest in renewable energy project. The output from this SWOT-PESTLE-AHP analysis should be supported via comprehensive research and interviews/survey to add value on the limitation of this present work.

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