



## **OPTIMAL SITE ATTRIBUTES FOR SOLAR FARM DEVELOPMENT IN MALAYSIA: A CONCEPTUAL FRAMEWORK**

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### **Abstract**

Defining an optimal site for the development of solar farms is crucial for the long-term success of renewable energy projects. However, selecting suitable locations present challenges in Malaysia due to diverse environmental, geographical and socio-economic factors. Therefore, this paper aims to develop a conceptual framework focusing on important attributes that should be considered in defining an optimal site for solar farm development. This study embarks a systematic literature review (SLR) to identify key site selection attributes based on PRISMA guidelines and draws from databases including Emerald Insight, Scopus and ScienceDirect. The result illustrates a conceptual framework incorporating environmental (solar irradiance, soil quality, biodiversity conservation), geographical (land availability, topography, infrastructure access), and socio-economic (public acceptance, legal frameworks, long-term economic sustainability) attributes. This framework provides direction to decision makers, policymakers, and investors to promote an organized, well-informed site selection process, which ultimately lays the path for the long-term profitability of solar farm development.

**Keywords:** Solar Farm Development, Environmental Attributes, Geographical Attributes, Socio-economic Attributes, Conceptual Framework

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## **INTRODUCTION**

With the growing demand for energy being increasingly more global, finding cleaner and more sustainable sources has been searched. It was spurred further by climate change concerns, the diminishing supplies of fossil fuels and commitments from nations around the world to reduce greenhouse gas emissions which have accelerated the transition to renewable energy. In particular, solar energy has become very powerful because it is abundant, has minimal environmental impact and the technological costs are in rapid decline. Solar energy, meanwhile, continues to be a cornerstone of global renewable energy policies, motivating photovoltaic technology innovation in PV technologies, grid integration and energy storage solutions in line with government and industry momentum toward carbon neutrality.

However, it has necessitated a shift toward alternative energy platforms that are sustainable, efficient, and environmentally friendly. Alternative energy encompasses a broad range of renewable sources, including solar, wind, hydropower, geothermal, and biomass, which offer viable solutions to reduce carbon emissions and mitigate climate change impacts (Sahid et al., 2021). Many countries have recognized the urgency of transitioning from conventional fossil-based energy to clean energy alternatives to meet their net-zero emissions targets and ensure long-term energy security.

Among various renewable energy sources, solar energy has emerged as a leading alternative due to its vast availability, declining costs, and technological advancements in photovoltaic (PV) systems. Countries with high solar irradiance, such as Malaysia, stand to benefit significantly from large-scale solar farm development. Apart from that, beyond solar energy, hybrid energy systems that combine multiple renewable sources, such as solar-wind or solar-hydro, are gaining traction as they enhance grid stability and provide continuous power supply. Additionally, emerging energy storage technologies, such as battery storage systems and hydrogen fuel cells, are revolutionizing the way renewable energy is managed, addressing issues related to intermittency and reliability (Adeyinka et al., 2024).

Therefore, Malaysia has aggressively promoted advancements in renewable energy through the use of National Renewable Energy Policy and Action Plan, the Feed into Tariff (FiT) and the Large Scale Solar LSS program. Nonetheless, solar farm placement sites face some challenges, which include site selection based on a weighed series of factors for energy production that creates environmental sustainability as well as socio-economic feasibility. In addition, the current approval process for large-scale solar developments in Malaysia particularly in Johor has identified that there is lacking comprehensive guidelines, leading land administrators to use telecommunication tower development as a benchmark for approving these projects (Sahid et al. (2021).

Hence, balancing environmental, geographical and socio-economic considerations, the decision whether to treasure suitable locations for solar farms is a complex decision-making process. Additionally, land availability; solar radiation levels; topography and proximity to electrical grid are important for site viability (Kereush & Perovych, 2017). It is also important to realize that the establishment of large-scale solar farms, impacts on biodiversity, water resources and land use changes will need to be considered. A poorly thought through solar project may deforest, cause habitat loss, or collide with agricultural land use, compromising the sustainability aspirations.

Other than that, the socio-economic considerations are equally vital for solar farm site selection. Assessment of land acquisition, community acceptance and long-term socio-economic benefit is necessary to guarantee project success. Land insufficiency and competing land use demands especially for agriculture and urban development impedes solar farm expansion in Malaysia. Moreover, solar projects do not come without an element of opposition from the local community as it can generate resistance due to land displacement, aesthetic impacts and a belief that they bring no advantages for local communities. However, when community participation and equitable distribution of benefits is possible, public acceptance can be increased and long-term socio-economic development can also be facilitated.

Selection of sites of solar farms is a complicated process taking into account the technical feasibility only (Joseph et al., 2016). Suitability of a location for solar farm development depends on key factors include environmental conditions, land use, and socio-economic impact. This process is quite challenging in the case of Malaysia because it needs to mesh together a set of diverse and often inconsistent considerations, such as environmental conservation, legal regulation, restrictions related to climate conditions and the socio-economic needs of the local communities (Kereush & Perovych, 2017). Poor site selection further economically depletes solar projects in terms of cost, delays, environmental harm, and community resistance, all of which negatively impacts the feasibility and longevity of the projects (Akkas et al., 2017). Furthermore, poor planning could lead to inefficient land use, disturbance of native ecosystems and unintended socioeconomic effects like displacement of local people or loss of productive land.

On the other hand, the fact that there is no standard data driven framework to site selection worsens these problems, as it intensifies the inconsistency of project results and increases financial risk for investors and stakeholders. To address these issues, a structured procedure for identifying optimum sites of solar farm development has to be developed that merge environmental impact assessments with socio-economic evaluations.

However, given these complexities, a holistic and consistent site selection approach to solar farms is needed. The purpose of this paper is to propose a conceptual framework for use in decision regarding Malaysia's solar energy sector which emphasizes integration of environmental, geographical and socio-economic factors. Then, the proposed framework aims to help policymakers, investors, and the stakeholders help promote solar energy projects that are also economically sound, environmentally sustainable and socially responsible. Adopting measures to overcome these site selection challenges of solar farms would allow Malaysia to increase its renewable energy resources and assist in achieving global reduction of carbon and lend to a cleaner and more sustainable future of energy (Joseph et al., 2016).

## **LITERATURE REVIEW**

Solar farms, known as solar power stations, plants, or complexes, are largescale infrastructures composed of individual solar panels specifically designed to capture sunlight and convert it directly into electricity. Solar farms are predominantly established on agricultural land or unoccupied industrial sites, with an increasing trend of employing builders for their development, particularly in the south-west and southeast regions of England (Jones et al., 2014; Mackey, 2023). Factors like solar radiation, ambient temperature, and photovoltaic (PV) module qualities define the electricity output of a solar farm (Barani et al., 2020).

Solar, wind power and other forms of renewable energy sources have received a lot of attention in the world today. The implementation of Photovoltaic (PV) technology has been because of the increasing energy demands and the effects of greenhouse gases that result from the conventional energy generation. A photovoltaic system or solar power system use semiconducting materials in the photovoltaic process to convert sunlight to electricity thus providing an additional means of generating electricity (Zeman, 1987). According to the International Energy Agency in 2014, world's developed countries such as USA, Germany, Spain, Japan and UK have adopted the use of solar power and have put it to good use in every aspect either individually or integrated into the power grid. However, the growth rate of the utilization of solar energy in developing countries such as Malaysia is still relatively slow despite the country's having abundant physical resources of solar energy.

The drive that calls for the utilization of solar energy as an alternative source of power in Malaysia is informed by two factors. To begin with, global and local environmental news outlets reported that in 2013, the country released 226988.90 CO<sub>2</sub>-kt/yr of CO<sub>2</sub> to the atmosphere (Emissions Database for Global Atmospheric Research - EDGAR, 2013). Research conducted by different authors (Ali et al., 2012; Chua and Oh, 2010; Noh, 2012; Ong et al., 2011) showed that Malaysia gets 95% energy form fossil fuel including oil, coal and natural gas.

The forecast is even more devastating; the release, according to the forecast is estimated at about 500 megatons of CO<sub>2</sub> by year 2020 in the absence of any form of control measures (Ahmad et al., 2011; Ang et al., 2013; Wee et al., 2008).

Secondly, the demand for electrify rises than the capacity to supply it and this situation has evoked the above problem. The total power output in the year 2013 was 111,020 GWh according to the report of Energy Commission in 2014, to the maximum level of the national energy consumption in one year was 16,562 MW. From the research conducted by Ali et al. (2012) the rate of increase in power consumption was estimated to be at 4.7% per annum because of industrial and commercial development. The peak electricity demand is expected to reach near 274 TWh in the year of 2030. Sustainability of fossil fuel in generation of electricity has always been a critical issue mainly due to the expectation that the source of gas would be exhausted by 2046 (Ali et al., 2012; Ong et al., 2011). These factors have promoted precautionary activities and have encouraged the attempt to expand sources of renewable energy such as wind and solar energy.

The Malaysian energy policy also puts into consideration the generation of renewable energy with an achievement of 20% in 2025 mostly from solar energy. On the national level, by 2025 they seek to feed 1.25 gigawatts (GW) of solar power into the grid, matching about 14% of renewable energy generating capacity. To facilitate this goal, in 2015, the large scale solar (LSS) programme was initiated (Nguyen et.al, 2017).

In regards to achieve this goal, the selection of optimal sites for solar farm development has been extensively studied, driven by the growing global emphasis on renewable energy. In this regard, there are alternative renewable energy sources has been reviewed such as wind, hydro and biomass. Hence, it is suggested that solar energy is particularly viable in Malaysia due to its geographical positioning and policy support. However, inadequate site selection can lead to environmental degradation, community resistance and economic inefficiencies. Previous research highlights the multifaceted nature of solar farm site selection, involving technical, environmental, and socio-economic dimensions that vary depending on geographical context. This paper explores the main themes emerging from research on environmental, geographical, and socio-economic considerations in solar farm site selection, with a particular focus on studies relevant to Malaysia and other tropical regions.

### **Environmental Attributes**

Environmental attributes have a major influence in site selection for a solar farm. Solar farm development can have large impacts on natural environment through land use, ecosystem and resource consumption. Ghimire & Johnston (2017) emphasize the substantial influence of climate condition, especially the solar

irradiance as well as recommend the locations of solar farms should be aligned with areas that receive constant solar exposure. But they also say that solar farm development should stay away from sensitive ecologies to minimize the loss in biodiversity and habitat fragmentation. Soil quality and water availability are also relevant other environmental considerations. Moreover, Tsoutsos et al. (2019) pointed out that soil type can influence the performance and lifetime of solar panels as can access to water resources for cleansing and preservation of big solar plantations, particularly in arid regions.

A study by Liew et al. (2020) have demonstrated that tropical climate in Malaysia provides excellent solar irradiance for energy generation but challenges on environmental such as deforestation, habitat destruction, and water management, are still significant. Deforestation to clear land for solar farms can make up for the urge to create renewable energy; likewise, it can help take profit from the clean energy. Furthermore, Malaysia's rich biodiversity with many endangers species requires a planned implementation to avoid disrupting important habitats or ecological corridors when solar farm projects are developed.

Land deficiency is also a very important environmental consideration. Unprivileged site selection and land preparation practices may result in soil erosion, low soil fertility, and increased surface runoff which exacerbate local hydrological cycles. Additionally, climate resilience is closely tied to the long-term sustainability of solar farms. Heavy rainfall, strong winds and prolonged drought can play havoc on the performance and lifespan of solar infrastructure. Adaptive design, climate responsive maintenance and integrated with other renewable energy source strategies can increase the resilience of solar farms to environmental fluctuations.

As a result, these environmental complexities are necessary to be used in a holistic approach of framework development through environmental impact assessment, land suitability analysis and sustainable site planning. To maintain Malaysia's shift to renewable energy, energy production must be balanced with environmental conservation, keeping ecological damage to a minimum as coverage of clean energy maximization.

### **Geographical Attributes**

One of the keys for the viability of solar farms are geographical attributes, including solar irradiance, land availability, topography and pipeline to infrastructure. Solar irradiance is an important factor in many of studies and is critical to the calculation of the energy output of solar farms. Al Garni and Awasthi (2017) developed a GIS based solar energy potential assessment model with a focus on geographical features, such as topography and land use, in addition to solar irradiance. Further they emphasize that solar farms should be installed on flat or gently sloping land because it reduces installation costs and

aids orientation of the panel. Roads and transmission lines, as well as access to infrastructure such as water, are also important not only to bring down costs but to make operations run on time. Nordin et al. (2021), in research conducted in Malaysia, suggest that solar farm development may be most efficiently situated in regions currently capable of supporting such development due to an existing level of good infrastructure (such as in Peninsular Malaysia) and high solar irradiance. The problem with competing interests, such as agriculture, urbanization and conservation are that land availability is a major obstacle. Hilly areas can offer more available land; however, the terrain of these areas is not parallel and hence are technically challenging to install solar farms (Liew et al., 2020).

Additionally, Geographic Information System (GIS) and remote sensing technologies could help improve site selection accuracy by supplying geospatial detailed data of terrain, land use and distance to infrastructure. A review into studies has indicated that analysis of geographical parameters at areas for a greenfield project can aid in identifying the most appropriate location by minimizing the conflicts of the developed land uses (Ahmed et al., 2022). Land conversion is also another important consideration since repurposing agricultural or forested land to solar farms open up to socio environmental trade-offs. Lucrative renewable energy development and food security through sustainable land use planning must be balanced.

### **Socio-economic Attributes**

Besides socio-economic attributes, technical evaluations generally fail to take them into account in order to approximate a successful solar project. The long-term viability of solar farms is also stressed by a number of studies, in particular regulatory frameworks, public consultation and community engagement. According to Sgroi et al. (2014) when the concerns and interests of local communities are not being considered during the consultation regarding a solar farm, then public opposition will follow. They also note that licensing, zoning laws and land rights are equally important for the successful project execution, because unresolved land disputes may slow down or increase costs.

Abdul Hamid et al. (2021) note that public engagement and socio-economic factors such as job creation, local economic development and community benefits are important to get local support for solar farm projects in Malaysia. Additionally, public acceptance is greatly increased by transparent policies on revenue sharing and long-term economic contributions. Licensing processes in Malaysia have been more streamlined over the years, but are still being hampered by zoning regulations and land rights in rural areas. Additionally, through the National Renewable Energy Policy and Action Plan (2010), solar farm developments must follow national sustainability goals in order to help

support the country's local economic growth while at the same time minimizing any adverse socio-economic impacts.

## RESEARCH METHODOLOGY

This research utilized a Systematic Literature Review (SLR) using PRISMA guidelines to gather data from databases. The databases used are Emerald Insight, Scopus, and ScienceDirect. A broad range of studies addressing environmental, geographical and socio-economic aspects of solar farm site selection were analyzed to identify key factors relevant to Malaysia.

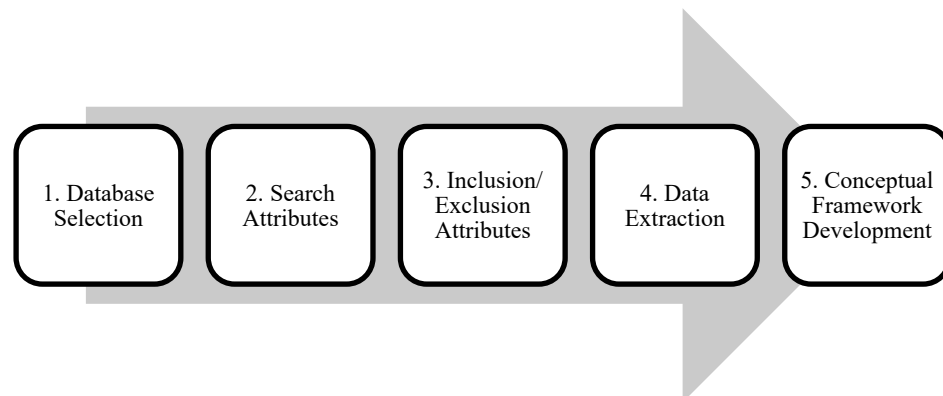


**Figure 1:** Systematic Literature Review (SLR) Using PRISMA Guidelines  
*Source: Moher, et al. (2015)*

Figure 1 shows the steps of conducting SLR by using PRISMA guidelines. There are five stages in PRISMA guidelines (Moher, et al., 2025) which are 1) Selecting Database; 2) Searching attributes; 3) Inclusion or exclusion attributes; 4) Extracting data; and 5) Developing conceptual framework. For the first stage, journal articles were traced from Emerald Insight, Scopus, and ScienceDirect. Then, followed by second stage which selected keywords such as “solar farm site selection”, “renewable energy Malaysia”, “Environmental Attributes”, “Geographical Attributes” and “socio-economic attributes” were used for searching the right attributes specifically for solar farm development in Malaysia. After that, the articles were reviewed and the inclusion or exclusion process have been made to fit with solar farm development. In this process, only peer-reviewed journal articles, government reports and policy documents which related to solar farm development published between 2015 and 2023 were included. Non-English articles and non-relevant studies were excluded. Next stage is extracting data which all the relevant studies were categorized based on environmental, geographical and socio-economic attributes. Then, for the final stage is developing conceptual framework. In this process, the

findings were synthesized into conceptual framework integrating all key factors (Guillaume, 2019).

## ANALYSIS AND DISCUSSION

Figure 1 shows a conceptual framework for solar farm development which emphasizes the importance of balancing environmental, geographical, and socio-economic factors to ensure the successful distribution of solar energy projects. This multi-dimensional approach is essential for creating a sustainable, economically viable, and socially accepted solution for the growing energy demands in Malaysia.

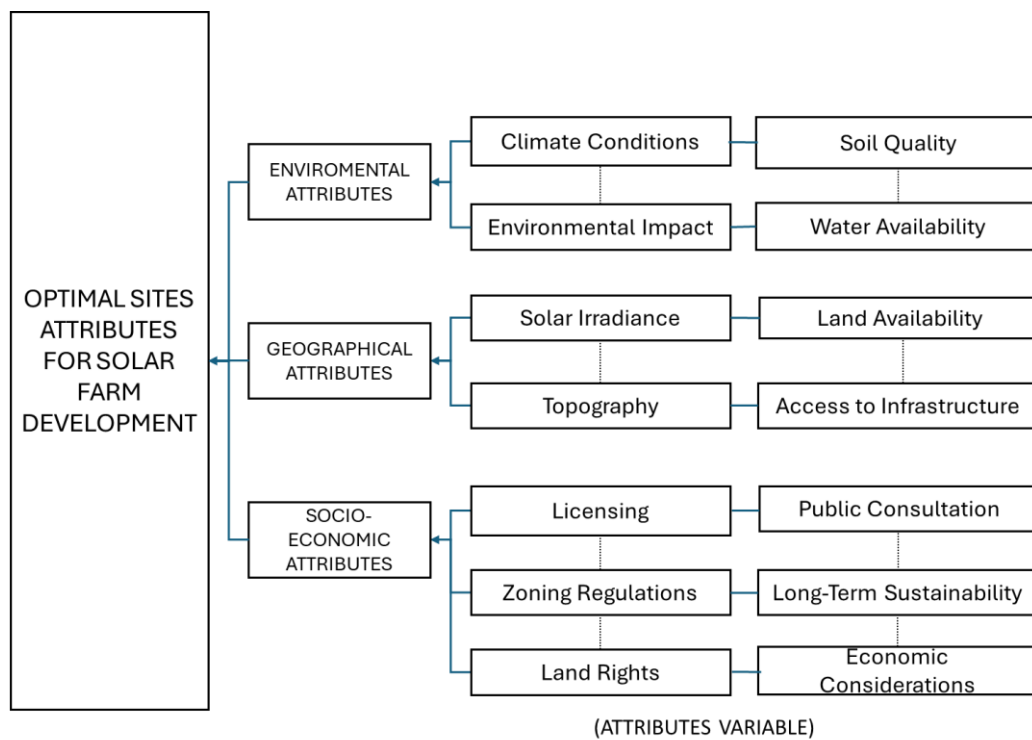


**Figure 1:** Conceptual Framework of Optimal Sites Attributes  
for Solar Farm Development  
*Source: Author (2024)*

Based on this figure, there are a few elements that have been considered in order to develop the framework. The crucial elements that have been considered are as follows:

### **Environmental Considerations**

Some of the basic factors that can be used to make the ecological footprint of solar farms are environmental factors. Sites are also carefully selected to avoid environmentally sensitive areas, for example, rainforests, areas of protected wildlife; or wetlands. Solar farm development should impact biodiversity as much as possible, given that development could disrupt local flora and fauna, particularly where the system is sensitive to disruption.

In addition, the selection of a site should allow for the prevention of exploitation of vital natural resources, such as near water availability for cooling purposes or for irrigation of nearby agricultural land (for instance, in arid areas). The environmental sustainability of the energy produced by solar farms is a concern beyond land use. The efficiency of solar panels and the entire environmental footprint of the materials used in the construction, including rare earth minerals in production of solar panel, have to be assessed (Akkas et al., 2017).

### **Geographical Considerations**

With high solar irradiance levels especially in the central and northern region of Malaysia, geographically the country provides a good opportunity for solar energy development. Malaysia is situated close to the equator and has high potential to utilise the solar irradiance (Vaka et al., 2020), which means that solar irradiance is the amount of solar power that comes per unit area. Moreover, the topography of Malaysia is highly favourable for the widespread deployment of solar panels due to the flat and expansive land areas in specific areas.

The ideal solar radiation levels, however, are not enough to make solar farms successful. Therefore, key geographical factors like land availability and accessibility are key to the feasibility of these projects. Given Malaysia's rapid process of urbanization, particularly along its west coast, competition for land between agricultural, residential, industrial and renewable energy areas is becoming imminent. Thus, there is great need to find locations that offer the highest solar energy potential with little impact on current land use. Moreover, being close to such infrastructure such as a road for transport and that for power grids. Lower transportation and connection costs, typically of considerable proportions in remote areas, are made more accessible due to roads and nearby electrical infrastructure. Vast amounts of land are needed for solar farms to be economically viable, which means there is a trade-off between optimal solar conditions and conflicts with land use. These constraints also pit them against the high upfront capital investment associated with solar farm construction.

### **Socio-economic Considerations**

Similarly, establishing a long term successful solar farm also hinges on the socio-economic factors. It is very crucial to the reduction of local resistance and the winning of the community support. Projects involving interested local communities early in the planning process with information that cites environmental benefits, energy security, and economic benefits (such as jobs created) are more likely to be accepted by surrounding communities. Also, worries about land use and local impacts can put resistance to discourage project approval and ease the process and avoid delays.

Besides, both legal and regulatory frameworks are also socio-economic factors. Clear zoning regulations can ensure that land rights are secured, then in this way avoid legal disputes. For projects, it is sometimes difficult to get zoning and legal support, and without it, projects can hit many potholes including land ownership issues and land use conflicts. Regulatory guidelines are clear to keep project execution smooth, and help safeguard investment through the minimization of unforeseen legal challenges (Akkas et al., 2017). In fact, solar farm developers particularly in Malaysia also face several significant challenges especially related to land use and legal framework. The challenges are in terms of land development approval, land use management and legal uncertainty (Sahid et al., 2021).

The economic sustainability of the project is another important socio-economic factor. Solar energy is a capital-intensive business and long-term profitability is required to sustain the financial viability of a solar farm project. The project must be economically feasible throughout its operational life, so it has to be assessed by factors such as profitability, risk and the cost of capital, and payback period. More specifically, job creation in the local community, together with the economic benefit created by infrastructure development (roads, utilities, etc), can serve to enhance public support and add to regional economic growth. But successful solar projects not only help to fuel the energy supply, they also generate jobs in construction, maintenance, and operation. Such an environment allows for local population engagement within the renewable energy sector possibility, which will additionally trigger the continuing support of the population to expansion in terms of project.

### **Integrated Approach for Successful Solar Farm Development**

The framework has integrated these three factors – environmental, geographical and socio economic – in order to create a comprehensive strategy to determine the best locations for the development of solar farms in Malaysia. The interrelated nature of these attributes, points that the process for site selection should not be entirely dependent on any one attribute, as a whole picture is to be viewed. A particular site claims high solar irradiance but no access to the infrastructure.

Such a site may be undesirable unless infrastructure is additionally developed. Then, a site with strong community support and desirable economics may be able to overcome more marginal irradiation results if located proximate to existing power grid infrastructure.

The framework's strength lies in its holistic approaches, which take into account factors like socio-economic balance, geographic advantage, and environmental impacts, all of which are necessary for the development of successful solar farms. A factor is also involved not only in determining the feasibility of a project, but also in guaranteeing that solar farms, once beyond the planning phase, will make a positive contribution to Malaysia's long term energy goals and promote local community and economic development.

Overall, the conceptual framework demonstrates the intricacy in the interconnected factors of the process of the development of solar farm in Malaysia. For a successful, sustainable and widely accepted solar energy project in the Country, the framework would consider environmental sustainability, geographical suitability and socio-economic considerations to come up with a thorough and integrated evaluation process.

## **CONCLUSION**

The developed framework in this study conceptually integrates environmental, geographical and socio-economic attributes to propose framework for solar farm site, and is of great value to decision makers in Malaysia. It stresses the significance of taking account of not just the technical and environmental feasibility of solar farm projects as well as their long run sustainability and socio-economic impact. Unlike conventional approaches that primarily focus on technical and environmental feasibility, this framework emphasizes a holistic assessment that ensures the long-term sustainability and socio-economic viability of solar projects. By incorporating multiple critical factors, it provides decision-makers with a structured methodology to balance energy expansion with environmental conservation and societal well-being.

Apart from that, the framework presented here enables policymakers, future investors, and other stakeholders to take informed decisions in promoting the expansion of renewable energy in Malaysia without fighting against the environmental protection and people's well-being. This framework is the founding stone for solar farms that are both viable and sustainable in the long term. Besides, by laying a strong foundation for evidence-based decision-making, this framework contributes to a more resilient and sustainable energy infrastructure. It also provides a basis for future research and policy refinements, ensuring that Malaysia's renewable energy transition remains adaptive to evolving technological, economic, and environmental challenges.

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