Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 20, No 3, 2023, 621-632
Article available at homepage presipitasi

Regional Case Study

Exploring the Potential of Solar Energy in Mosque Buildings: A Case Study of Dumai Islamic Centre Mosque in Riau Province, Indonesia

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Abstract
This study investigated the implementation of solar panels in the Dumai Islamic Centre (DIC) Mosque, located in Dumai City, Riau Province, to reduce carbon emissions. The study presents an overview of the significance of solar energy utilization and its potential benefits in the context of mosque buildings. This research was aimed to assess the criteria for selecting the appropriate solar panel type, determine the power output and PV area required for the DIC Mosque, and estimate the carbon emissions reduction resulting from installing solar panels. The study employed a quantitative research design and utilizes the Analytic Hierarchy Process (AHP) to select the most suitable solar panel type. The results reveal that polycrystalline solar panels are the optimal choice based on efficiency, power peak, operation and maintenance, and price criteria. Installing solar panels on the DIC Mosque's roof, positioned at an optimal height, ensures maximum sunlight exposure and energy generation efficiency. Calculations demonstrate a significant reduction in carbon emissions post-installation. The carbon emissions reduction potential is estimated at 57.693 kg CO_2 eq per day or 21,057.95 tons CO_2 eq per year. This highlights the positive environmental impact of solar energy implementation in the DIC Mosque.

Keywords: Solar panels; carbon emissions; renewable energy; mosque; dumai city; riau province.

1. Introduction

Dumai City is a city in the province of Riau with significant economic growth. This growth can be seen from the rapid development of industries, which will require an adequate electricity supply (Irfan, 2017) to support these activities. One of the buildings currently under construction in Dumai City is the Dumai Islamic Centre Mosque (DIC). This mosque will be built following the architecture of the Prophet's Mosque in Medina. The large size of the mosque has the potential to increase electricity usage. Energy consumption in mosques is unique because it is continuous and varies depending on the number of people and specific periods. The electricity consumption in mosque buildings is relatively substantial due to the use of air conditioning (AC) and fans to ensure comfort during worship. (Yüksel et al., 2020). Previous study study on mosques explained that electricity consumption for AC usage accounts for 73% (Budaiwi, Abdou and Al-Homoud, 2013). The high electricity consumption increases the potential for fossil fuel usage in conventional power plants (Karmaker et al., 2020; Holechek et al., 2022). Therefore, solar power generation technology can be implemented in mosque buildings (Suparwoko and Qamar, 2022). In addition to its large size, the DIC mosque is also designed as a mosque that can be visited as a tourist attraction in Dumai City. Directly, electricity usage will be higher than in mosques solely used for regular worship, especially during holidays. Based on these conditions and the solar radiation potential in Dumai City, a solar power system can be implemented in the DIC mosque to meet its electricity needs.

Carbon emissions, mainly from burning fossil fuels, significantly contribute to climate change (Yin, Liu and Gu, 2022). Mosques, like any other buildings, contribute to these emissions through their energy consumption, primarily if they rely on fossil fuel-based electricity. Mitigate climate change and reduce the overall environmental impact by reducing utilities emissions (Suryawan and Lee, 2023). Mosques have an essential role as places of worship and community centers. Reducing carbon emissions from mosques can demonstrate their commitment to environmental stewardship and serve as role models for congregations and communities. It sends a powerful message that caring for the environment is essential to practicing one's faith and being responsible global citizens. Taking measures to reduce carbon emissions often involves improving energy efficiency (Huang and Zhai, 2021). Mosques can adopt energy-efficient technologies like LED lighting, efficient HVAC systems, and renewable energy sources like solar power. These energy-efficient technologies help reduce carbon emissions and result in cost savings through reduced energy consumption and lower utility bills. Mosques play a vital role in shaping community values and beliefs. Mosques can inspire their congregations and communities to adopt sustainable practices in their daily lives. This leadership can create a ripple effect, promoting sustainable actions beyond the mosque and encouraging others to join the global effort to combat climate change.

Solar panels can be used in mosques for several reasons. Firstly, solar panels provide a renewable energy source, harnessing the power of sunlight and converting it into electricity through photovoltaic technology (S. et al., 2022). This aligns with sustainability and environmental stewardship principles, as solar energy is clean and does not deplete natural resources or emit harmful pollutants during generation (Zhang, Khan and Zafar, 2022). Secondly, installing solar panels can result in cost savings (Rozentale, Lauka and Blumberga, 2018) for mosques by generating their electricity and reducing reliance on grid-supplied power. This is particularly beneficial for mosques with high energy demands during prayer or special occasions.

In the academic realm, the Analytical Hierarchy Process (AHP) method has been frequently employed to address challenges in renewable energy (cite a few pivotal studies here). Given its adaptability and precision, the AHP method has often been the go-to analytical tool, especially when dissecting the complexities of renewable energy systems. This study seeks to incorporate insights from these existing literature bases, extending their applications to our current context. It's pivotal to highlight that mosques, due to their unique operating dynamics influenced by attendee frequency and religious events have distinctive energy consumption patterns. Additionally, solar panels offer energy independence, ensuring stability in power supply and minimizing the impact of fluctuations in energy prices or grid disruptions (Huang et al., 2021). Moreover, utilizing solar energy significantly reduces the carbon footprint of mosques, contributing to the global effort to mitigate climate change. Mosques can demonstrate their commitment to environmental responsibility and inspire their communities to adopt clean energy practices. Furthermore, solar panels in mosques serve as educational tools, raising awareness about the benefits of renewable energy and inspiring individuals and institutions to follow suit. Lastly, the presence of solar panels on mosques symbolizes the integration of faith and environmental consciousness, serving as a tangible representation of the mosque's commitment to sustainable practices and responsible resource management. Overall, solar panels in mosques offer multiple benefits, including renewable energy utilization, cost savings, energy independence, reduced carbon emissions, educational opportunities, and symbolic representation of environmental stewardship.

The previous studies on carbon reduction and energy efficiency in mosques have generally focused on the broader context of energy consumption in religious buildings or have explored energy-saving measures in mosques (Azmi and Kandar, 2019; Azmi, Arıcı and Baharun, 2021). However, there is a gap in the literature regarding specific case studies that examine the potential for carbon reduction and energy efficiency in mosques with unique characteristics. DIC will be built following the architecture of the Prophet's Mosque in Medina. Its unique design and large size may present specific challenges and opportunities regarding energy consumption and carbon reduction. Exploring the energy efficiency measures and renewable energy integration in a mosque of this scale and design can provide valuable insights for similar mosque projects or large religious buildings is also designed as a mosque that can be visited as tourist attraction. This aspect adds complexity as electricity usage may vary significantly, especially during peak visiting periods. Examining the energy demands and potential carbon reduction strategies in a mosque that serves as a place of worship and a tourist destination can offer insights into managing energy consumption in similar multifunctional religious buildings. The case study of DIC is situated explicitly in Dumai City, in the province of Riau, Indonesia. This region may have unique characteristics and energy profiles that differ from other areas. Understanding the specific challenges and opportunities for carbon reduction in mosques within this regional context can provide localized solutions and strategies that can be replicated or adapted in similar areas. By focusing on the specific case study of DIC and considering its architectural design, tourist attraction aspect, and regional context, researchers can fill the gap in the existing literature and provide practical insights and recommendations for carbon reduction and energy efficiency in similar mosques with unique characteristics.

Beyond these operational facets, architectural and environmental factors also play a non-trivial role in shaping a building's energy profile. Absence of energy management systems, usage of non-reflective building materials exacerbating heat absorption, and local climatic conditions are potent contributors to escalated energy consumption. These factors, especially when contextualized for the DIC mosque, warrant a closer examination to fathom their cumulative impact on the mosque's energy demands.The purpose of this article, therefore, is multifaceted. Firstly, it aims to discern the energy consumption patterns of large religious edifices like the DIC mosque, particularly in the context of its unique operational and environmental dynamics. Secondly, the article aspires to leverage the AHP method, integrating findings from prior renewable energy research, to devise an optimized and sustainable energy solution for such structures. Ultimately, by weaving together analytical insights with on-ground realities, this study hopes to pave the way for energy-efficient, sustainable, and environmentally-conscious religious institutions.

2. Methods

The research conducted is in the form of quantitative research. Quantitative research utilizes numerical data as support throughout the research process, including data collection, data analysis, and data presentation (Amaratunga et al., 2002; Suryawan et al., 2023; Sutrisno et al., 2023). Generally, quantitative research is conducted in a more systematic, planned, and structured manner, with clear steps from the beginning to the end of the research, and it is not influenced by the conditions that occur in the field. In this study, both primary and secondary data are required. Quantitative research is systematic, structurally planned, and insulated from evolving field conditions. Both primary and secondary data form the foundation of this study, and their acquisition is facilitated through:

a. Observation: Observation is conducted on the roof of the DIC mosque, which will be used for installing solar panels. The observation is carried out to obtain data on the size of the mosque's roof.
b. Literature Review: A literature review is conducted to gather secondary data. This involves studying relevant books, as well as national and international journals.

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach that aids in dissecting multifaceted problems into a more digestible hierarchical form, facilitating the evaluation of criteria and alternatives' relative significance (Hasnaningrum et al., 2021; Simanjuntak, Zahra and Suryawan, 2022), specifically in choosing the appropriate type of solar panel for implementation in the DIC mosque. The endeavour to identify the most suitable solar panel type for the DIC mosque extensively employs the AHP method, encompassing:

1. Problem Structuring: The first step is defining the problem and establishing a criteria and alternatives hierarchy. In this case, the criteria represent the factors or attributes to consider when selecting a solar panel type for the DIC mosque.

2. Pairwise Comparisons: Decision-makers compare each criterion or alternative against every other criterion or alternative regarding their relative importance or preference. These comparisons are captured in a pairwise comparison matrix using a numerical scale.
3. Calculation of Relative Weights: Once the pairwise comparisons are completed, the relative weights of the criteria and alternatives are calculated. Mathematical calculations, such as eigenvector methods, are applied to the comparison matrix to determine the relative importance values of the different solar panel types.
4. Consistency Check: AHP includes a consistency check to ensure that the judgments made in the pairwise comparisons are reliable and consistent. Consistency ratios are calculated to evaluate the consistency of the judgments. If the consistency ratio exceeds a predefined threshold, adjustments may be necessary to improve the consistency of the judgments.
5. Aggregation and Decision Making: The relative weights obtained from the pairwise comparisons are aggregated to determine the overall priority or ranking of the alternatives. This aggregation provides a basis for decision-making, as the alternatives can be compared based on their calculated priorities.

For the AHP application, expert respondents were roped in, not only from the renewable energy sector but also crucial stakeholders like the owner of DIC. Their invaluable perspectives were distilled through well-structured interview, expertly crafted to elicit detailed evaluations on criteria, sub-criteria, primary stakeholders, and alternatives critical to the AHP-driven decision-making process. Given the data-intensive nature of the AHP method, manual calculation with excel were employed. These tools provided an efficient platform to manage the data deluge and guarantee precise calculations, streamlining the AHP implementation and ensuring robust results.

Upon concluding the AHP process and determining the most suitable solar panel type, the next step focused on calculating the required installation area. By intertwining the insights from the AHP method with the mosque's spatial and energy constraints, a comprehensive plan detailing the area requisites for solar panel installation was conceived. The area requirements stem from:

- Output Requirements: Based on the mosque's projected electricity needs and the chosen solar panel's efficiency.
- Roof Area Constraints: Derived from the observational data, ensuring the installation doesn't exceed the available roof space.
- Optimal Solar Panel Placement: Considering factors such as sun exposure, shading, and panel tilt angles, the optimal placement area was computed, ensuring maximum efficiency and energy yield.

To achieve this, it's imperative to employ a quantitative approach, which, in this case, is encapsulated by a series of mathematical formulas. These formulas serve as the backbone of our methodology, aiding in assessing the feasibility and efficiency of the proposed solar panel installation. From calculating the available roof area to determining the energy consumption after the solar panel's implementation and even evaluating the environmental impact in terms of emission loads, each formula plays a pivotal role. Roof Area Calculation formula is used to determine the usable area on the mosque's roof for the installation of solar panels Equation (1).

$$\text{Roof area} = (\text{length of the roof} \times \text{width of the roof}) - \text{area of the dome} \quad (1)$$

Here, the area of the roof is calculated as a rectangle (length multiplied by width). However, the dome of the mosque occupies some space on the roof, which is not usable for the solar panel installation. Therefore, subtract the dome's area to get the net usable roof area. Watt Peak Calculation represents the maximum power that a solar panel can produce under ideal sunlight conditions Equation (2).

$$\text{Watt peak (watt)} = \text{Total Energy Consumption (kWh)} \times \text{Sunlight Duration (hours)} \quad (2)$$

Here, the energy consumption of the mosque is multiplied by the average duration of sunlight to calculate the total power required from the solar panels. PV Area Calculation determines the area required for photovoltaic (PV) solar panels based on the watt peak and efficiency Equation (3).

PV area=Watt peak (watt) × PSI × ηP (3)

Here, PSI could represent a constant related to solar intensity, and ηP represents the efficiency of the solar panel. Alternative Watt Peak calculates the watt peak using the area of PV and its efficiency Equation (4)

Watt peak=PV area × PSI×ηP (4)

Number of Solar Panels helps in determining the total number of solar panels required for the installation.

Number of solar panels=Power per solar panel x Watt peak

This by dividing the watt peak by the power output of an individual solar panel. Estimated electricity consumption after solar panel installation calculates the estimated electricity consumption of the mosque after solar panels are implemented Equation (5).

Estimated electricity consumption after solar panels=Electricity consumption before−Electricity generated (5)

The total electricity generated by the solar panels is subtracted from the mosque's original consumption to estimate the new consumption. Emission Load Calculation determines the emission load based on activity data and an emission factor Equation (6).

Emission load=activity data × emission factor (6)

Enhanced Emission Load calculates the emission load considering both the original source of energy and the solar panels Equation (7).

Emission load= (activity data × emission factor) + (activity data from solar panels × emission factor of solar panels) (7)

It accounts for the emissions from the original source of electricity and adds any emissions associated with the electricity generated from the solar panels. By sequentially applying these formulas, we aim to achieve a holistic understanding of the entire process – right from gauging the physical requirements for the installation to estimating the resultant energy consumption and environmental impact. The use of these formulas ensures that our approach is not just theoretical but grounded in practical, quantifiable metrics, thus providing a robust foundation for the proposed solar panel installation at the DIC mosque.

3. Result and Discussion

The selection of the solar panel type will be based on predetermined criteria. The alternative types of solar panels are determined based on the available options readily found in the Indonesian market, including Table 1.

Table 1. Alternative types of solar panelsin the Indonesian market

No	Alternative	Solar panel description	Source
1	Monocrystalline	Monocrystalline solar panels are made from a single crystal structure, typically silicon. They are known for their high efficiency, making them a suitable option for maximizing electricity production in limited roof space. Monocrystalline panels have a uniform black appearance and are considered aesthetically pleasing. Due to their high efficiency, they can generate more power per square meter compared to other types,	(Bouzidi et al., 2020; Sun et al., 2021; Seroka, Taziwa and Khotseng, 2022)

		making them suitable for mosques with high energy demands, such as the DIC mosque.	
2	Polycrystalline	Polycrystalline solar panels are made from multiple silicon crystals, resulting in a slightly lower efficiency compared to monocrystalline panels. However, they are more cost-effective and have improved performance in lower light conditions. Polycrystalline panels have a bluish color and offer a good balance between efficiency and affordability. They can be a viable option for the DIC mosque if cost-effectiveness and performance in varying light conditions are important factors to consider.	(Sites, 2003; Ullah and Marí, 2014)
3	Thin-film	Thin-film solar panels are made by depositing a thin layer of photovoltaic material onto a substrate, such as glass or metal. They are lightweight and flexible, allowing for easy installation and integration into various surfaces. Thin-film panels have lower efficiency than crystalline silicon panels but can perform better in low-light conditions and high temperatures. Their versatility and adaptability make them suitable for unconventional installation locations or areas with limited available space. If the DIC mosque has specific architectural requirements or desires a more flexible installation approach, thin-film solar panels may be a suitable choice.	(Ramanujam et al., 2020; Yang, Li and Zeng, 2020)

These alternative types will be evaluated against the established criteria to determine the most suitable choice for implementation in the DIC mosque. The criteria of solar panel efficiency, power peak, operation, maintenance, and price are essential considerations in selecting solar panels for implementation in the DIC mosque. Considering these criteria ensures that the solar panels selected for the DIC mosque balance efficiency, power output, reliability, maintenance requirements, and cost-effectiveness. Evaluating these factors enables decision-makers to choose the most suitable solar panels that align with the mosque's energy needs, operational requirements, and available resources.

a. **Solar panel efficiency:** Solar panel efficiency refers to the ability of the panel to convert sunlight into usable electricity (Kazem, 2019). Higher-efficiency panels can generate more electricity from the same amount of sunlight (Mohamed et al., 2022), maximizing energy production. In the context of the DIC mosque, high-efficiency panels would be desirable to ensure optimal electricity generation, especially if there are space limitations on the mosque's roof. Maximizing efficiency helps to maximize the utilization of available solar resources and optimize the mosque's energy production.
b. **Power peak:** A power peak is the maximum power output produced by a solar panel under specific conditions (Sai Krishna and Moger, 2019). It indicates the panel's capacity to generate electricity at its highest potential. Understanding the power peak of different solar panel options is crucial to determine their ability to meet the energy demands of the DIC mosque. Selecting panels with a higher power peak ensures the mosque can generate sufficient electricity, particularly during high energy consumption periods.
c. **Operation and maintenance:** Operation and maintenance considerations are essential for solar panels' long-term performance and reliability. Factors such as durability, lifespan, and maintenance requirements can impact the cost and effort of operating and maintaining the panels. Choosing solar

panels with good performance and low maintenance requirements can help reduce operational costs and ensure that the panels continue to generate electricity effectively over their lifespan.

d. **Price:** Price is an essential criterion as it directly impacts the project's budget and cost-effectiveness. Solar panel prices vary depending on technology, efficiency, brand, and installation requirements. Assessing the price of different solar panel options concerning their performance and features helps find a balance between cost and quality. It allows for selecting solar panels that provide the desired level of performance while remaining within the project's financial constraints.

The solar panel criterion with the highest level of importance is solar panel effectiveness, meaning it is the most critical criterion compared to others. Solar panel effectiveness relates to the performance of the panel during weather changes. ThE criterion is selected as the most important parameter because weather fluctuations will affect the power output of solar panels. During clear weather conditions, solar panels generate maximum power. Conversely, during cloudy weather, the power output decreases (Nurfajriansyah, 2018). Therefore, it is necessary to select solar panels resilient to cloudy weather to minimize the decline in power output.

A study conducted by (Premalatha and Rahim, 2017)on the performance of different types of solar panels under clear and cloudy weather conditions, found that monocrystalline and polycrystalline panels have nearly equivalent power absorption during clear weather, while thin-film panels perform slightly lower. During cloudy weather, monocrystalline panels exhibited a drastic performance decline (Arabatzis et al., 2018). Polycrystalline panels also experienced a decline, but not as severe as monocrystalline, and thin-film panels showed a similar trend.

The second most important criteria is solar panel efficiency. Solar panel efficiency relates to the panel's ability to convert solar energy into electricity. The parameter efficiency is expressed as a percentage (%). Higher efficiency indicates a better ability of the panel to convert solar energy (Köberle, Gernaat and van Vuuren, 2015). According to (Ayadi et al., 2022) monocrystalline panels have the highest efficiency, followed by polycrystalline and thin-film. The third most important criterion is the lifespan of solar panels. The lifespan is associated with the duration of the solar panel's ability to convert sunlight into electricity. A longer lifespan ensures continued solar energy conversion over time and minimizes the need for panel replacement.

The final criterion in terms of importance is the price of solar panels. Typically, solar panels with affordable or moderate prices are chosen since they tend to be expensive. The price of solar panels increases with higher efficiency and purer composition of materials. Price is considered the last criterion because the research focuses on the power output of solar panels to reduce carbon emissions, so price is not the primary consideration. However, it remains a factor for evaluation to differentiate between the three available alternatives showed in Table 2.

Table 2. Measuring the weight of each criterion in AHP

	Solar panel efficiency	Power peak	Operation and maintenance	Price	Weight	Consistency Measure
Solar panel efficiency	0.597	0.691	0.441	0.389	0.529	4.448
Power peak	0.199	0.230	0.441	0.389	0.315	4.358
Operation and maintenance	0.119	0.046	0.088	0.167	0.105	4.057
Price	0.085	0.033	0.029	0.056	0.051	4.065
					CI	0.0773
					RI	0.9
					C Ratio	0.0859

Based on the AHP method and the selection process in equation 1, the chosen type of solar panel is polycrystalline, weighing 0.473 (Table 3). The selected polycrystalline panel has a power output of 380 Watts. The decision to use a high-wattage solar panel is based on maximizing power generation while minimizing the number of panels required.

Table 3. AHP Matrix

Alternatives	Solar panel efficiency	Power peak	Operation and maintenance	Price		Criteria matrix	Final Weight	
Monocrystalline (A)	0.591	0.231	0.213	0.080		0.529		0.412
Polycrystalline (B)	**0.334**	**0.665**	**0.701**	**0.265**	X	**0.315**	=	**0.473**
Thin film (C)	0.075	0.104	0.085	0.656		0.105		0.115
							0.051	

The solar panels are installed on the roof of the DIC mosque at a height of approximately 12 meters. The placement of solar panels on the mosque's roof is a suitable choice. This decision is based on the fact that the surrounding area of the DIC mosque is currently in the planning stage for construction, making it not recommended to install solar panels in those empty spaces. The roof of the DIC mosque can be seen in Figure 2. Placing the solar panels on the mosque's roof is advantageous because the higher position allows maximum power output. This is because sunlight can directly and unobstructedly focus on the surface of the solar panels without any barriers. The solar panels can receive optimal sunlight exposure by utilizing the unobstructed rooftop area, enhancing their efficiency and power generation capabilities (Chen et al., 2022). The final decision to affix the solar panels atop the mosque was also influenced by the potential for maximum power output afforded by this elevated position. This higher location enables the solar panels to capture sunlight directly and without obstruction, ensuring no hindrances or barriers can compromise their exposure to sunlight. This direct and unimpeded access to sunlight optimizes the solar panels' efficiency and power generation capacities, allowing them to harness solar energy to its maximum potential.

Furthermore, utilizing the mosque's roof for solar panel installation not only optimizes energy production but also preserves ground space for other crucial developments, providing a harmonious balance between sustainable energy generation and infrastructural progress. This harmonization underlines the thoughtful approach undertaken in deciding the placement of solar panels, ensuring that sustainable practices are seamlessly integrated without compromising the structural and functional integrity of the surrounding environment.

Polycrystalline solar panels offer a good balance between efficiency and cost-effectiveness (Ascione et al., 2019; Wen et al., 2019). While monocrystalline panels may have slightly higher efficiency, the difference is not significant enough to justify their higher cost. Thin-film panels, on the other hand, have lower efficiency compared to both monocrystalline and polycrystalline panels. Polycrystalline panels demonstrate better performance in overcast or partially shaded conditions compared to monocrystalline panels. In areas with fluctuating weather patterns, such as Dumai City, where sunny and cloudy days are common, polycrystalline panels can maintain a relatively stable output, ensuring consistent energy generation. Polycrystalline panels are widely available in the market, including in Indonesia. Their popularity and widespread use make them easily accessible for installation in the DIC Mosque. This availability reduces the logistical challenges of sourcing and acquiring the required solar panel systems. Polycrystalline panels have a proven track record of durability and long lifespan. They can withstand various environmental conditions, including temperature variations and humidity, making them a reliable choice for the DIC Mosque's long-term energy needs.

In the case of the DIC mosque, the solar panel requirement is determined based on the available area for installation, which is the roof area. As other constructions are planned for the empty spaces surrounding the mosque, installing solar panels can only utilize the roof area. The calculation of the roof area of the DIC mosque is as follows:

Given that the diameter of the dome is 25 m^2, we can calculate the area of the dome:

Area of the dome = πr^2 = 3.14 x $(12.5)^2$ = 490.625 m^2

Therefore, the roof area is:

Roof area = (30 m x 30 m) - 490.625 m^2 = 900 m^2 - 490.625 m^2 = 409.375 m^2.

Hence, the available area for installing solar panels is 409.375 m^2. The following calculation determines the watt peak that can be generated from the solar panels to be installed. The formula to calculate the watt peak follows equation 4-5. The optimal sunlight duration for Riau Province is assumed to be 5 hours. Therefore:

Watt peak (watt) = 615.68 kWh x 5 hours = 123.136 kW.

This means that the desired watt peak output from the solar panels to be installed is 123.136 kW. Therefore, the watt peak that the solar panel system can generate is 123.136 kW per day. Next, we can calculate the required PV area for a power output of 123.136 kW. Using equation 6, we have:

PV area = 123,136 kW x1000 W/m^2 x 0.2 = 615.68 m^2.

Since the available area is 413.375 m^2, the power generated by the solar panels will be adjusted to the available area. The power output in the installation area will be:

Watt peak = 413.375 m^2 x 1000 W/m^2 x 0.2

Watt peak = 82.675 kW.

Therefore, the power generated by the solar panels will be 82.675 kW per day. To determine the number of solar panels needed to achieve a power output of 82.675 kW

Number of solar panels =82,675 kW x 380 W = 217.565 = 218 solar panels.

The installation of solar panels reduces the reliance on regular electricity from the grid (PLN connection). Prior to the installation, the electricity consumption was 615.68 kWh. After installing the solar panels, the consumption of regular electricity is reduced with the following breakdown:

Estimated electricity consumption after = 615.68 kWh - 82.675 kWh = 533.05 kWh.

The activity data used is the electricity consumption in the DIC mosque per day, which is 615.68 kWh. The emission factor used is the carbon emission factor for electricity in Riau Province, which is 0.73 ton CO_2 eq/MWh.

Emission load = 615.68 kWh x 0.73 ton CO_2 eq/MWh

Emission load = 0.61568 MWh x 0.73 ton CO_2 eq/MWh

Emission load = 0.4494 ton CO_2 eq

Emission load = 0.45 ton CO_2 eq = 450 kg CO_2 eq.

The calculation of carbon emissions after installing solar panels is similar to the calculation before the installation. The difference lies in the reduction of electricity consumption due to the installation of solar panels. The carbon emissions from the use of solar panels are also taken into account. The activity data used in the calculation for solar panels use the Watt peak generated by the solar panels. The emission factor for solar panels is 40 g CO_2 eq/kWh.

Emission load = (533.005 kWh x 0.73 ton CO_2 eq/MWh) + (82.675 kWh x 40 g CO_2 eq/kWh)

Emission load = 0.389 ton CO_2 eq + 3307 g CO_2 eq

Emission load = 389 kg CO_2 eq + 3.307 kg CO_2 eq

Emission load = 392.307 kg CO_2 eq.

Thus, there is a potential reduction in carbon emissions of 57.69 kg CO_2 eq per day, equivalent to 21,057.95 ton CO_2 eq per year. The potential reduction in carbon emissions is equivalent to 12.82%. Based on the analysis of carbon emissions from the use of electricity in the DIC mosque, there is a potential reduction in carbon emissions after installing solar panels on the mosque's roof. Before the installation, the carbon emissions amounted to 450 kg CO_2 eq from conventional electricity consumption of 615.68 kWh. After the installation of solar panels, the carbon emissions amount to 392.307 kg CO_2 eq from the consumption of conventional electricity of 533.05 kWh and the power generated by the solar panels of 82.675 kWh. There is a potential reduction in carbon emissions of 57.693 kg CO_2 eq per day, equivalent to 21,057.95 ton CO_2 eq per year. Electricity consumption contributes the most to carbon emissions compared to other sectors, so the reduction in electricity consumption significantly impacts reducing carbon emissions (Wu et al., 2019).

The role of the government is pivotal in the implementation of renewable energy technologies, such as solar panels. Incentives, tax breaks, or subsidies can make the adoption of solar panels more feasible. In the context of the DIC mosque, the local government's policies can influence the efficiency and speed of solar panel installations. On the regulatory side, adherence to local standards ensures the safety and operational efficiency of solar installations.Solar panel installations can require significant initial investments, but they often lead to substantial savings in the long run. Understanding the financial landscape is crucial, from identifying banks offering loans for renewable projects to potential donors within the community who might support the initiative. A thorough financial analysis will consider both the costs and potential savings.The success of such renewable projects often hinges on stakeholder engagement. This includes the mosque's management, the local community, potential donors, and solar panel vendors. Engaging these groups early can facilitate smoother project execution. The local community, for instance, might support or volunteer for the project, seeing a solar-powered DIC mosque as a community achievementThe overarching principles of solar energy are consistent, but local factors can play a significant role. This includes the region's solar irradiance patterns and local customs around electricity consumption in religious institutions. For the DIC mosque, understanding the energy usage patterns, influenced by prayer times and community events, can help in tailoring the energy storage and release mechanisms, transitioning to solar energy at the DIC mosque involves considerations beyond just technicalities. It intertwines with government policies, regulations, finances, and stakeholder interests. Taking into account all these dimensions ensures a successful and sustainable solar panel implementation.

4. Conclusions

The findings indicate that solar energy offers a viable solution for reducing carbon emissions and promoting sustainability. The selection of polycrystalline solar panels based on criteria such as efficiency, power peak, operation, maintenance, and price demonstrates their suitability for the mosque. Installing solar panels on the mosque's roof at an optimal height allows for maximum sunlight exposure, leading to efficient energy generation.

One of the primary outcomes of the AHP analysis was the determination of the most suitable type of solar panel for the DIC mosque. Based on the established criteria and the feedback from the expert respondents, the analysis revealed that the Polycrystalline solar panel type emerged as the most favored choice with a priority value of 0.473. This high value indicates a strong preference towards the Polycrystalline type over other alternatives, considering the specific conditions and requirements of the DIC mosque. The carbon footprint calculations reveal a significant reduction in carbon emissions, potentially decreasing by 57.693 kg CO_2 eq per day or 21,057.95 tons CO_2 eq per year. This emphasizes the positive environmental impact and sustainability benefits of solar energy utilization.

Acknowledgment

We would like to express our sincere gratitude to the Dumai Islamic Centre (DIC) Mosque for its support and cooperation throughout this study. The contribution and assistance provided by the management and staff of the DIC Mosque were invaluable in conducting our research on the implementation of solar panels for carbon emission reduction.

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