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Techno-economic Study of Solar Energy Implementation in Hospitals in Malaysia

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ABSTRACT

As the demand for energy in hospitals continues to increase, there is a favorable opportunity for Malaysia to embrace solar energy. This research paper examines the potential of solar photovoltaic (PV) systems in hospitals by evaluating factors such as payback period, return on investment (ROI), and savings. A total of 42 hospitals in Malaysia were selected for the study and categorized as large, medium, and small based on their bed capacity. Initially, a background analysis of these hospitals is conducted, followed by an estimation of their rooftop area. Subsequently, the energy consumption of the hospitals is determined using the building energy index approach. The PVsyst software is utilized to simulate the energy output generated by solar PV systems. The findings reveal that two hospitals can fully meet their energy demand through solar energy generation, while the remaining 40 hospitals achieve average savings of 38.76%, 37.48%, and 52.58% for large, medium, and small hospitals, respectively. These results underscore the considerable benefits of implementing solar PV systems in a significant portion of the hospitals, with some being able to cover their entire energy requirements. In conclusion, this study provides valuable insights into the viability of solar PV systems in Malaysian hospitals.

Keywords: Solar Energy, Renewable Energy, Green Energy, Sustainable Energy, Hospitals
JEL Classifications: Q42, Q47, Q56

1. INTRODUCTION

Electricity generation heavily relies on coal, oil, and natural gas as primary energy sources. However, the combustion of these fossil fuels significantly contributes to the ongoing global warming and climate-related challenges (Kapsalyamova and Paltsev, 2020). In countries like Malaysia, the demand for energy is rapidly increasing, particularly in developing nations, leading to a higher consumption of fossil fuels and consequently, an alarming rise in carbon dioxide emissions (Mohammad Ismail et al., 2020). According to the Energy Commission of Malaysia, the total electricity generation in 2019 reached 171,672 GWh, indicating a 5.1% increase compared to the 163,366 GWh generated in 2018. Among the different sources in the energy mix, coal remained the preferred choice, representing 44.5% of the total share. Natural gas accounted for 38.6%, while hydropower contributed 15.3%. Renewable energy sources and oil constituted 1.2% and 0.5% of the total generation, respectively (National Energy Balance, 2019).

The utilization of electricity is primarily attributed to three key sectors: industrial, commercial, and residential (Saidur et al., 2009). In 2019, there was a remarkable increase of 5.2% in electricity consumption within the commercial sector compared to the previous year. The commercial sector comprises establishments such as hotels, offices, hospitals, and shopping malls, and accounted for 28.8% of the overall electricity consumption (National Energy Balance, 2019). Notably, hospitals require a substantial amount of electricity daily due to the extensive use of medical equipment and facilities (Al-Rawi et al., 2023). Given the annual growth in electricity demand in hospitals, it becomes imperative for them to explore renewable energy resources and identify available space for on-site electricity generation (Vaziri et al., 2019). By adopting such measures, hospitals can effectively reduce utility costs and mitigate the emission of greenhouse gases (GHGs) (Sánchez-Barroso et al., 2020).

The performance of photovoltaic (PV) systems is dependent on solar irradiance, which represents the amount of solar energy reaching the Earth's surface per unit area (Muneer and Kotak, 2015). Malaysia due to its strategic location, is considered an ideal country for the implementation of solar PV systems (Saleheen et al., 2021). Malaysia receives an average solar irradiance of approximately 1,581-1,911 kWh/m^2. This value is comparable to the average solar irradiance observed in Southeast Asia, which ranges from 1,500 to 2,000 kWh/m^2 (SEDA Malaysia, 2021). A recent study found that solar power generation can meet a significant portion of the energy needs of the chemical and metal manufacturing plants in Malaysia (Kian and Lim, 2023). For comparison, India, which has a significant installed solar capacity of around 30 GW, experiences solar irradiance ranging from 1,200 to 2,200 kWh/m^2 (Sharma, 2019). With single axis tracker, an improvement of solar energy yield of 15% can be expected (Dawoud and Lim, 2021). Yet, transition to RE such as solar may still be dampened by issues such as unattractive tariff rate and lack of incentives for the utility (Vaka et al., 2020).

Hospitals rely on continuous operation of various equipment, such as HVAC systems, kitchen appliances, pumps, and biomedical devices, which run 24 h a day (Abdul et al., 2015). Consequently, the extensive usage of medical equipment, HVAC systems, and lighting in hospitals leads to high electricity consumption and significantly increased utility costs (Hu et al., 2004). As a result, hospitals and healthcare facilities are substantial electricity consumers and play a crucial role in promoting the adoption of renewable energy sources (Bakaimis and Papanikolaou, 2017). Implementing solar energy systems in hospitals offers multiple advantages, including environmental preservation, reduced utility expenses, and improved energy efficiency (Soto et al., 2022).

Moreover, considering the projected growth in hospital energy demand and the eventual depletion of non-renewable energy sources used for electricity generation, renewable energy options like solar PV systems are considered potential solutions to address the challenges posed by the gradual depletion of fossil fuels and the issue of global warming.

The objective of this study is to conduct simulations of the power generation output of a photovoltaic (PV) system based on the size of the rooftop. The aim is to determine whether the electricity generated from the solar PV system is sufficient to meet the energy demand of hospitals. Additionally, the study aims to evaluate the economic feasibility of implementing PV systems in hospitals. This assessment will involve analyzing the costs of PV modules and inverters, as well as the potential savings achieved through reduced utility expenses. By considering both the technical and economic aspects, the study intends to provide valuable insights into the viability and benefits of utilizing PV systems in hospital settings.

2. LITERATURE REVIEW

2.1. Comparison of Monocrystalline and Polycrystalline Solar Module

In India, the solar PV industry is experiencing rapid growth, with an increasing range of solar PV technologies dominating the market (Adithya, 2016). The effectiveness of solar PV panels and systems is influenced by various factors, including solar radiation, weather conditions, ambient temperature, cell temperature, wind speed, humidity, orientation, and tilt angle (Gregg et al., 2005). This study focuses on evaluating the performance of monocrystalline and polycrystalline solar modules in Raipur, located in the east-central part of India (Baghel and Chander, 2022). The key metrics used to assess module and system performance are power output, efficiency, energy generation, and performance ratio. According to the author, solar radiation is the most significant environmental factor impacting the performance of solar PV modules (Baghel and Chander, 2022). It is observed that the efficiency of the modules is lower than the standard test conditions (STC) value even when irradiance levels approach 1000 W/m^2. This is primarily due to ambient temperature and cell temperature exceeding the STC value. During the winter months, both types of modules exhibit higher performance ratios (PR), with a mono-Si module achieving an overall PR of 0.89 and a poly-Si module reaching 0.86 (Baghel and Chander, 2022). Based on the results, the mono-Si PV module demonstrates greater effectiveness than the poly-Si PV module across different weather conditions in the studied region of India. Regarding thermal losses, the author notes that these losses are higher when module temperature is elevated. As module temperatures increased from December 2020 to March 2021, thermal losses gradually rose (Baghel and Chander, 2022). Furthermore, the temperature rise of the poly-Si module was found to be higher compared to the mono-Si module, resulting in greater thermal losses for the poly-Si module. In conclusion, at low irradiance levels around 400 W/m^2, the difference in power generation between the two types of panels is <1% (Baghel and Chander, 2022). The mono-Si PV module exhibits higher efficiency, performance ratio, energy yield, and lower thermal losses compared to the poly-Si PV module. Consequently, the mono-Si PV module outperforms the poly-Si module. However, it is important to note that the mono-Si module is generally more expensive than the poly-Si module (Shi et al., 2021).

In a study conducted in (Vilas and Mahesh, 2019), a comparison was made between poly-Si and mono-Si PV modules with the same rating. It was observed that at a temperature of 52°C and an irradiance of 865 W/m^2, the monocrystalline PV module exhibited a maximum output power of 8.25 W and an efficiency of 7.79%, whereas the polycrystalline PV module demonstrated a maximum output power of 6.72 W and an efficiency of 6.34% (Vilas and Mahesh, 2019). However, when the temperature and irradiance decreased to 46°C and 720 W/m^2, respectively, the monocrystalline module recorded a maximum output power of 8.48W and an efficiency of 9.62%, while the polycrystalline PV module reached a maximum output power of 6.88W and an efficiency of 7.80%. Another study found that the performance of monocrystalline PV array is superior under partial shading condition (Vunnam et al., 2021). Last but not least, the authors in (Jiang et al., 2020) also concur that monocrystalline solar cells have a higher solar power generation yield than polycrystalline cells with the same number of modules. In summary, when considering output power and efficiency, the monocrystalline PV module exhibits a clear advantage over the polycrystalline PV module. Additionally, throughout the study, the authors noted that the output current of the PV module is directly proportional to the solar irradiance (Vilas and Mahesh, 2019).

2.2. Performance of PV Module Based on Different Tilt Angle

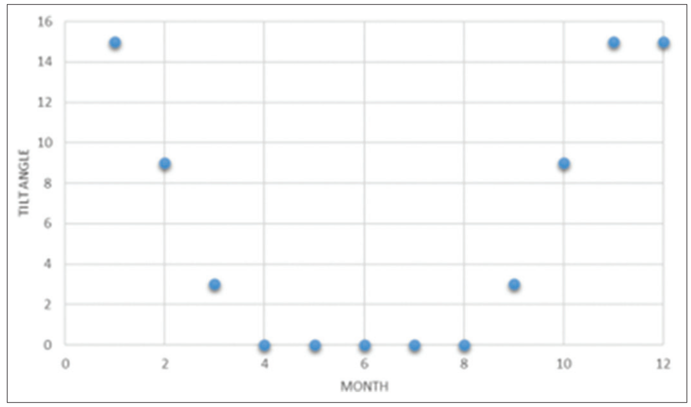
It is commonly understood that solar panels positioned to continuously face the sun would receive the highest amount of solar irradiance. However, achieving this requires the implementation of a sun tracker system, which can be costly. The tilt angle of a PV module plays a crucial role in determining the amount of solar energy it generates (Balouktsis et al., 1987). Therefore, for fixed panels to maximize their solar power output, the tilt angle needs to be adjusted accordingly. In (Fahmi et al., 2022), Kajang and Kota Bahru were selected as the locations of interest. The findings indicate that in order to obtain the maximum energy output from a PV panel, the tilt angle should be adjusted on a monthly basis, as depicted in Figure 1. Consequently, it is suggested that the optimal tilt angle to capture the highest solar irradiation ranges between 0° and 2° (Fahmi et al., 2022). Although this recommended angle may not yield the highest level of solar radiation when compared to other optimum angles identified in the results, it provides coverage for a longer duration of months.

The author's conclusion suggests that for solar systems, a recommended tilt angle falls within the range of 0°-15° (Fahmi et al., 2022). To ensure the capture of maximum irradiance for over half of the months in a year, the optimal tilt angle range applicable to both study locations is found to be between 0° and 2° (Fahmi et al., 2022). Another study investigates the utilization of a fixed tilt angle for stand-alone solar systems through monthly optimized tilt angles (Fadaeenejad et al., 2015). This study examines three villages situated in Sabah, Sarawak, and Selangor. The findings indicate that the optimal slope of PV panels during the period from March to October is 0° for all three villages. The study provides irradiation data for slopes ranging from 0° to 90°, and it becomes evident that the range of 0°-15° is suitable for maximizing solar radiation in any location across Malaysia. Specifically, the recommended fixed tilt angles for the villages in Sarawak, Sabah, and Selangor are 0°, 5°, and 0°, respectively. Thus, a fixed tilt angle ranging from 0° to 15° is deemed favorable for solar systems installed in rural buildings in Malaysia (Fadaeenejad et al., 2015). In conclusion, optimizing the azimuth angle, orientation, and tilt angle are crucial factors for enhancing the performance of PV panels.

3. POTENTIAL OF PV SYSTEMS IN COMMERCIAL BUILDING

The feasibility of implementing solar PV rooftop systems in various commercial establishments such as shopping malls, offices, hotels, and hospitals in Saudi Arabia (SA) was explored in (Ghaleb and Asif, 2022). Commercial buildings, including shopping malls, hotels, and hospitals, often have substantial energy requirements due to standard practices such as HVAC systems and energy-consuming equipment like refrigeration (Teke and Timur, 2014). Among the building types studied, shopping malls showed the highest energy usage, with the PV systems covering 23.3% of their energy consumption. This was followed by office buildings at 18%, hotels at 15.4%, and hospitals at 9.4% (Ghaleb and Asif, 2022). The utilization factor (UF) is defined as the potential of a roof for solar PV installation, representing the proportion of the roof's gross area that can be utilized for PV applications, taking into consideration factors such as hurdles, maintenance requirements, and shading impacts (Izquierdo et al., 2008). The results revealed that shopping malls had the highest UF, with a value of 0.53, followed by hospitals, offices, and hotels with respective values of 0.35, 0.34, and 0.23 (Ghaleb and Asif, 2022).

Figure 1: Monthly optimum tilt angle in Kajang (Fahmi et al., 2022)



Additionally, the utilization of PV systems in the 105 buildings studied led to a reduction of approximately 72,533 tons of CO_2 emissions (Ghaleb and Asif, 2022). Simulation results indicated that despite the high energy demand of commercial buildings, especially hotels and retail centers, due to their substantial energy consumption, the implemented PV systems can help the commercial buildings in achieving their energy demand (Ghaleb and Asif, 2022). According to (Saad and Wei, 2020), the return on investment (ROI) of solar systems in commercial buildings can be even higher via the revised Net Energy Meeting (NEM) scheme compared with the rest.

4. ANALYSIS OF PV SYSTEMS IN HOSPITALS

In the United States, the energy consumption level by healthcare facilities has risen by 21% since 2003 (Bawaneh et al., 2019). A group of hospitals in the southwestern region of Spain installed a photovoltaic self-consumption system. In 2019, the final energy consumption of the tertiary sector, including office buildings, health facilities, commercial establishments, hotels and restaurants, education institutions, and other services, amounted to 10,177 ktoe, accounting for 11.8% of the total final energy consumption in Spain. This sector ranked third in energy consumption after the transport and industry sectors

(Montero et al., 2022). According to the author's research, approximately 60-65% of the rooftop area in commercial buildings is suitable for PV power generation. Furthermore, buildings with a floor area exceeding 800 m^2 can allocate up to 50% of their space for solar PV installations (Montero et al., 2022). Significant correlations were found between the number of beds and energy usage, as well as between floor area and energy usage (Montero et al., 2022). The average annual electricity consumption rates were calculated for all hospitals in the region, resulting in 25.96 MWh/bed, 0.43 MWh/m^2 of roof area, and 0.14 MWh/m^2 of built-up area. The author argues that hospitals have a higher potential for self-consumption in photovoltaic installations compared to residential buildings because their operational hours align with peak solar productivity. By utilizing 30% of the rooftop space, hospitals can achieve self-consumption rates exceeding 90%, directly utilizing the renewable energy they generate. Additionally, using 20-30% of the rooftop space can lead to a 20% reduction in CO_2 emissions (Montero et al., 2022).

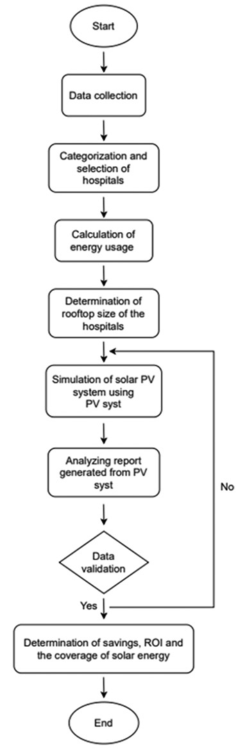
Another study reveals that air-conditioning systems consume the biggest portion of energy in a hospital (Shen et al., 2019). The authors' findings demonstrate the significant potential of hospitals in generating energy through solar PV systems. However, government action is necessary to facilitate the wider implementation of solar PV systems in hospitals. The work presented in (Isa et al., 2017) demonstrated the benefits of NEM to hospitals' owners by lowering their utility bills.

To conclude, prior studies indicate that the installation of solar PV systems in Malaysian hospitals holds significant potential for reducing carbon emissions, improving energy efficiency, and promoting sustainability. While there are certain obstacles to overcome, such as high initial costs, limited public awareness, and regulatory issues, the overall benefits of implementing solar PV systems outweigh these challenges. However, despite the considerable amount of research conducted on solar energy, there remains a lack of studies specifically addressing the deployment of solar energy systems in Malaysian hospitals. More research is needed to identify the challenges and potential opportunities for adopting solar energy in healthcare facilities, which would contribute to the development of supportive policies and the transition toward a sustainable healthcare system in Malaysia. Additionally, although there has been extensive research on determining the optimal tilt angle for solar panels in Malaysia, there has been a lack of discussion on how to compare and determine the ideal angle across different locations in the country.

5. METHODOLOGY

Figure 2 illustrates the sequential process of the entire project as a flowchart. The initial step involves gathering data from all the hospitals. This data includes information such as bed sizes and energy consumption, which can be obtained through a comprehensive background study of each hospital. Once the necessary data is collected, the hospitals are then classified into three categories based on their bed sizes: large hospitals, medium hospitals, and small hospitals. For this study, a total of 42 hospitals have been selected as participants, with 17 falling into the large hospital category, 13 categorized as medium hospitals, and the remaining 12 classified as small hospitals.

Figure 2: Flow of study



To obtain a comprehensive list of public and private hospitals in Malaysia, the Ministry of Health (MOH) website (Portal Rasmi Kementerian Kesihatan Malaysia, 2022) and the Association of Private Hospitals of Malaysia (APHM) website (Location of private hospitals in Malaysia, 2022) are utilized. This information is then organized for further analysis. Subsequently, a thorough investigation of each hospital's background is conducted to collect specific data, including bed sizes and energy consumption.

Based on an article from Gallagher Healthcare (Gallagher Malpractice, 2018), hospitals can be classified according to the number of beds they have. For instance, hospitals with more than 500 beds are categorized as large hospitals, those with bed sizes ranging from 100 to 499 are considered medium hospitals, and hospitals with <100 beds are classified as small hospitals. In Malaysia, there is a total of 300 hospitals, with 149 being public hospitals and 151 being private hospitals. These hospitals will be categorized based on their bed sizes, as depicted in Figures 3 and 4.

To estimate the energy consumption of certain hospitals, the Building Energy Index (BEI) formula will be utilized. This formula, as shown in (1), is chosen due to the challenges in accessing specific data related to energy consumption. By employing the BEI formula, an estimation of energy consumption can be derived, providing insights into the energy efficiency and consumption patterns of the hospitals under study. This estimation-based approach is adopted to overcome the challenges associated with limited accessibility to precise energy consumption data.

Figure 3: Percentage of public hospitals in each category (Malaysian Medical Resources, 2022)

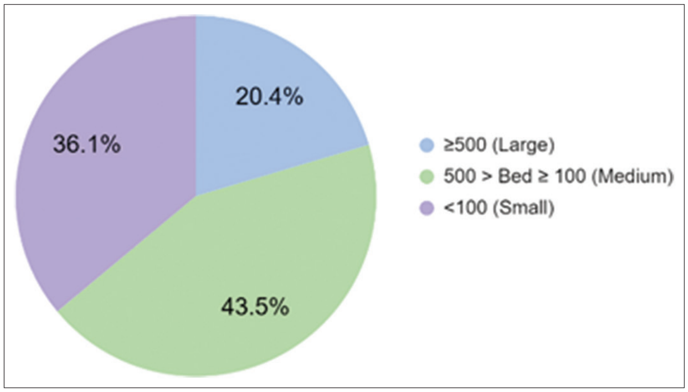
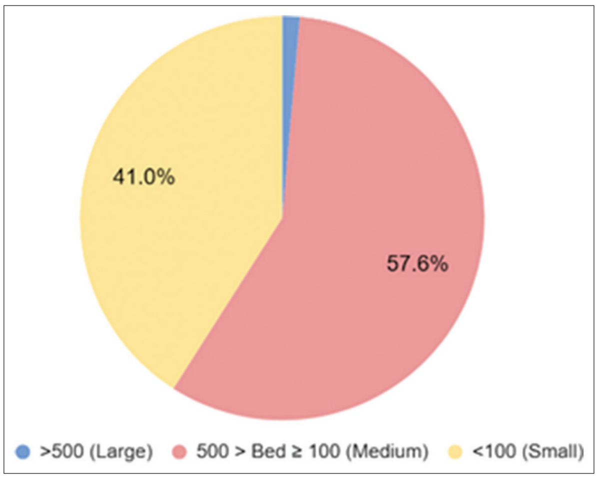


Figure 4: Percentage of private hospitals in each category (Location of private hospitals in Malaysia, 2022)



$$BEI = \frac{Energy\,usage}{Bed\,size} \quad (1)$$

In this study, a self-consumption photovoltaic (PV) system is simulated and installed on the rooftops of hospitals. The area of each hospital's rooftop is estimated using Google Earth. This estimation method allows for an approximate calculation of the available rooftop space for installing the PV system. Google Earth provides satellite imagery that can be used to measure the dimensions of the rooftop area accurately. By utilizing this data, the study can assess the feasibility and potential size of the PV system installations on each hospital's rooftop.

Simulation of the PV system is done by using the PVsyst software. It allows for detailed modeling of various system components, such as PV modules, inverters, and shading effects, to accurately predict the energy output of the system under different conditions. Several parameters are under analysis, including energy yield, DC/AC ratio, and the ratings of the PV module and inverter. The energy yield represents the amount of energy produced by the PV system within a specific timeframe, which will be compared to the estimated energy consumption of each hospital. Additionally, a manual calculation of energy generation was conducted using (2) to validate the simulated energy yield obtained from PVsyst.

$$E = Area \times \eta \times irradiance \times PR \quad (2)$$

Gaining a comprehensive understanding of the risks and financial advantages associated with investments in solar systems is of utmost importance. This understanding enables the optimization of savings and facilitates meaningful comparisons between different solar energy systems and financing options. Therefore, it is critical to assess the potential savings, return on investment (ROI), and coverage of energy needs provided by solar power before installing a solar system. Evaluating the savings yielded by the solar system offers valuable insights into the potential reduction in utility bills, which can be utilized to offset the initial cost of the solar system or even generate additional income. The formula outlined in (3) is utilized to compute these savings.

$$Savings = Energy\ usage \times Tariff \quad (3)$$

The payback period signifies the time it takes for the cumulative savings to offset the total system cost. In this research, the system cost solely includes the expenses associated with the PV panel and inverter. Other associated charges and fees, such as maintenance fees, PV module mounting racks, cables, and labor fees, are not considered. The payback period is determined using (4).

$$Payback\ period = \frac{Cost\ of\ the\ system}{savings} \quad (4)$$

ROI, or return on investment, is a financial metric that assesses the profitability of a solar system over its lifespan, rather than focusing on the time required to recoup the initial investment. It evaluates the total monetary returns and savings generated by the system as shown in (5).

$$ROI = \frac{Savings}{Cost\ of\ the\ system} \quad (5)$$

6. RESULTS AND DISCUSSION

6.1. Energy Analysis

Figures 5-7 depict the energy consumption and estimated energy generation in large, medium, and small hospitals, respectively. Among the 17 large hospitals examined, only LH14 is capable of meeting 100% of its energy requirements through solar generation. On average, the solar systems in large, medium, and small hospitals have the potential to generate approximately 7 GWh, 2,800 GWh, and 900 GWh of energy, respectively. Solar systems in small hospitals can cover 52.5% of their energy usage, followed by large hospitals at 38.76%, and medium hospitals at 37.48%. These findings suggest that the amount of energy generated by solar systems is influenced by the available rooftop area for installing solar panels. A larger rooftop area provides more space for solar panel installation.

6.2. Economic Analysis

Figures 8-10 display the percentage of achievable savings through solar PV systems. On average, the percentage of savings in large, medium, and small hospitals is 38.76%, 37.48%, and 52.58%, respectively. Figure 9 reveals that most large hospitals

Figure 5: Energy usage and estimated energy generated in large hospitals

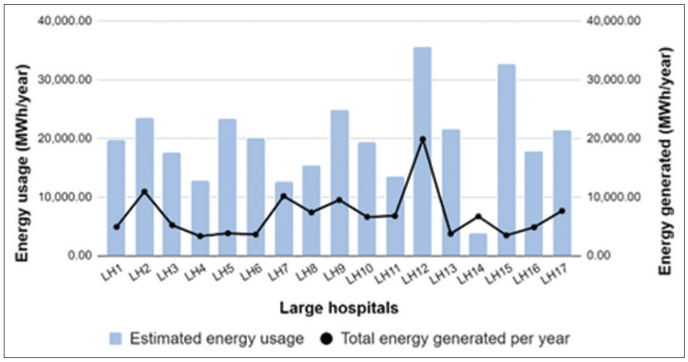


Figure 6: Energy usage and estimated energy generated in medium hospitals

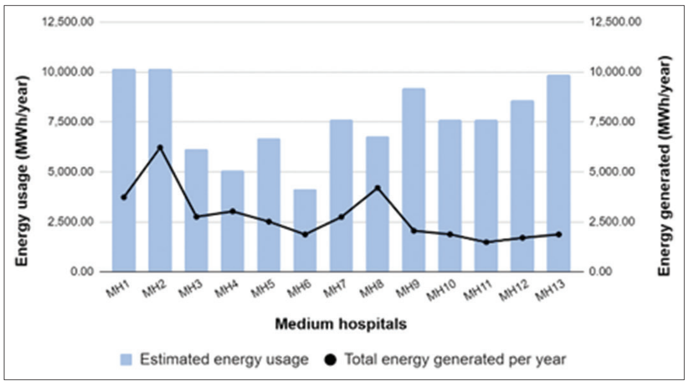


Figure 7: Energy usage and estimated energy generated in small hospitals

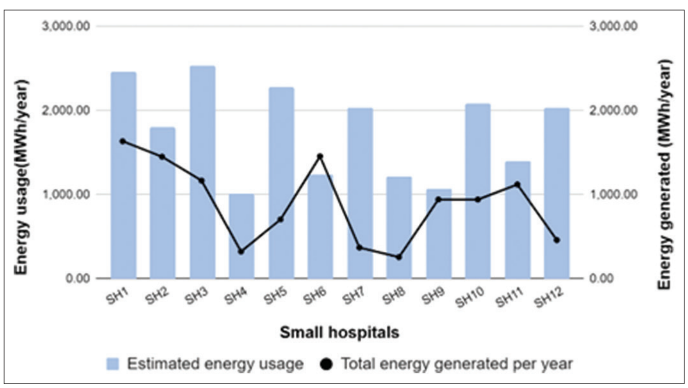


Figure 8: Percentage of savings in large hospitals

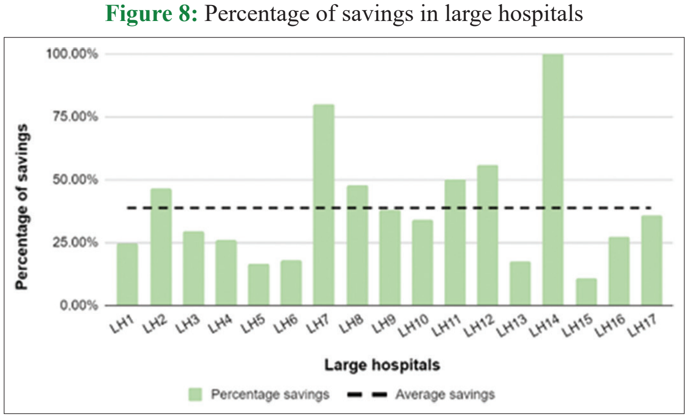
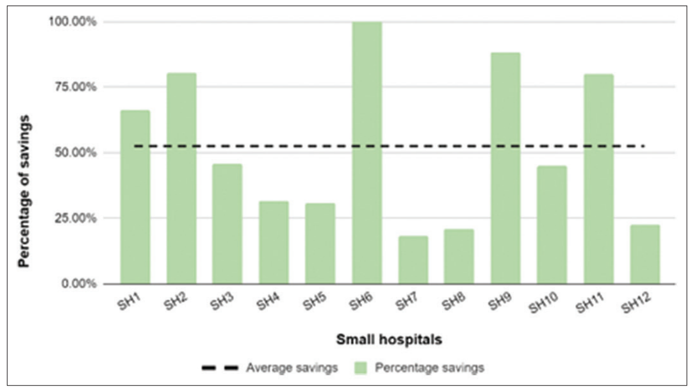


Figure 9: Percentage of savings in large hospitals

Figure 10: Percentage of savings in large hospitals



have savings below 50%, except for one hospital that achieves 100% savings. This variation arises due to the relatively lower energy consumption of these hospitals, resulting in higher energy generation from solar systems and substantial savings. Furthermore, among medium hospitals, the highest percentage of savings is 61.72%. Most medium hospitals can save between 30% and 60% on their electricity bills. Additionally, one of the solar systems designed for small hospitals can cover their entire annual energy consumption, leading to significantly higher savings compared to other hospitals. Notably, 5 out of 12 small hospitals have savings above 65%. As a result, the average savings of small hospitals surpass those of large and medium hospitals. One contributing factor is the lower energy consumption in small hospitals compared to large and medium hospitals.

Figures 11-13 display the charts illustrating the ROI and payback period of large, medium, and small hospitals respectively. The relationship between ROI and payback period can be observed from the charts. A higher ROI corresponds to a shorter payback period, indicating a faster cost recovery for the solar system. The highest payback periods observed are 4.15 years for large hospitals, 3.07 years for medium hospitals, and 3.83 years for small hospitals. Conversely, the average ROI calculated is 41.68% for large hospitals, 44.50% for medium hospitals, and 39.95% for small hospitals. The findings demonstrate that most hospitals in the study have ROIs ranging from 30% to 55% and payback periods between 2 and 4 years. It is worth noting that the ROI values in this study are relatively high, primarily due

Figure 11: ROI and payback period for large hospitals

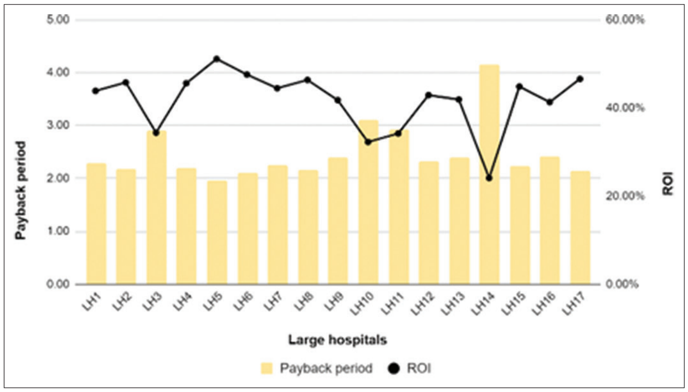


Figure 12: ROI and payback period for medium hospitals

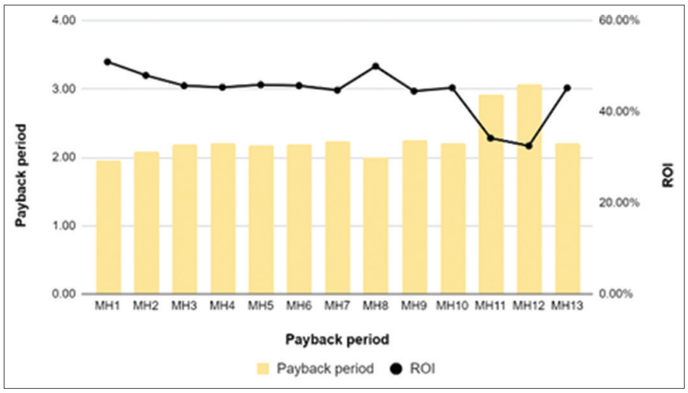
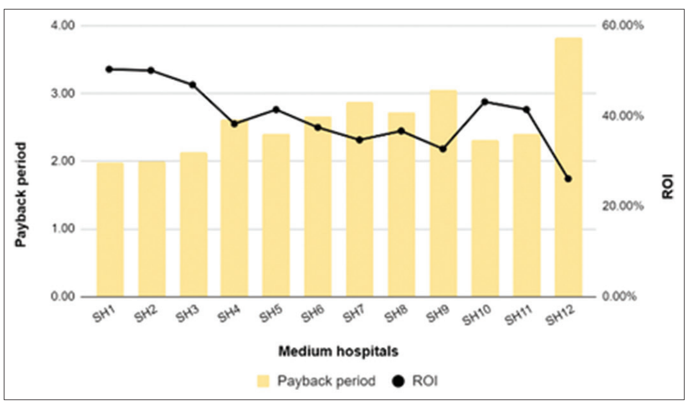


Figure 13: ROI and payback period for small hospitals



to the inclusion of only the cost of the PV panel and inverter in the calculation.

7. CONCLUSION

In conclusion, the potential for solar energy utilization in Malaysian hospitals is substantial and holds promise. Previous research has demonstrated the abundance of solar resources in Malaysia. The simulation results indicate that the integration of solar energy can help hospitals reduce their dependence on grid electricity. Although the energy generated from solar systems may not fully cover hospitals' energy requirements, significant savings of 10-15% can be achieved in large, medium, and small hospitals. On average, the savings for large, medium, and small hospitals amount to 38.76%, 37.48%, and 52.58% respectively. It should be noted that the relatively high ROI calculated in this study is due to the exclusion of additional costs such as the PV panel rack, wiring, small components, and installation expenses. These findings provide valuable insights into the potential of solar energy in Malaysian hospitals and can serve as a reference for future research. By embracing solar energy, hospitals can reduce their reliance on fossil fuels, contribute to sustainable development, and support Malaysia's clean energy transition. Therefore, solar energy can be considered a viable energy source for supplying electricity to hospitals.

8. ACKNOWLEDGMENTS

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