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Economic Feasibility of On-Grid Photovoltaic Solar Power Plants at Private Universities in Indonesia

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ABSTRACT

Campus 2 of the National Institute of Technology (ITN) Malang shows its commitment to utilizing solar energy by adopting a 500 kWp photovoltaic solar power plant (PV), making it the largest in Indonesia for a private university. This research aims to evaluate the economic feasibility of photovoltaic solar power plants (PV) at Campus 2 of the National Institute of Technology Malang. The implementation of renewable energy, particularly photovoltaic solar power, is gaining attention due to its contribution to reducing greenhouse gas emissions and economic growth. However, the development of renewable energy sources faces several challenges, including the limitations of economic feasibility studies in Indonesia. A mixed-methods research approach is used, combining qualitative and quantitative data. Qualitative data are obtained from interviews with PV management staff, while quantitative data include net present value (NPV) calculations and payback periods (PBP). The research findings indicate that the on-grid photovoltaic solar power plant at Campus 2 of the National Institute of Technology (ITN) Malang has a capacity of 500 kWp, with a peak load reaching 380 kVA. The total project cost is Rp. 4,084,498,826, with annual operational and maintenance costs of Rp. 81,595,607. The price of electricity from the on-grid photovoltaic solar power plant is Rp. 930 per kWh. An NPV value of Rp. 7,789,395,602 indicates future profitability, while a PBP of 8.55 years demonstrates feasibility in terms of return on investment. In conclusion, the on-grid photovoltaic solar power plant at Campus 2 of the National Institute of Technology Malang has good economic feasibility due to factors such as controlled costs, competitive prices, a positive NPV, and a short PBP. Regular evaluations are necessary to ensure efficient operation and maximum benefits.

INTRODUCTION

Electricity is currently a vital factor in society's life and the functioning of the economy. The energy sector is transitioning from fossil fuels to renewable energy sources. In many countries, the use of renewable energy continues to increase. Renewable energy sources (RES) are replacing conventional energy sources to achieve emission-free economies (Czepło & Borowski 2024). Photovoltaic solar power generation has become an increasingly important topic in the context of energy sustainability worldwide. Photovoltaic technology harnesses solar energy to generate electricity, which is a clean and renewable energy source (Etukudoh et al. 2024). Photovoltaic technology is a suitable option for distributed power generation, which has the potential to replace conventional centralized stations and reduce network reinforcement costs (Jamil et al. 2012). According to Boruah & Chandel (2024), photovoltaic solar power generation systems (PV) are cost-effective and environmentally friendly solutions for energy conservation. In this context, it provides a significant contribution to solving some of the most urgent energy problems facing the world today.

The International Renewable Energy Agency (IRENA) reported in 2022 that global progress in renewable energy has added 257 GW of renewable energy sources, with 133 GW (>50%) of this energy coming from solar power (Huda et al. 2024). Meanwhile, the International Energy Agency (IEA) predicts a 60% increase in installed renewable energy capacity by 2026, totaling over 4800 GW. According to the report, 1,100 GW of capacity will come from photovoltaic solar power generation, doubling compared to five years prior (Minazhova et al. 2023). The significant percentage of solar energy is due to the maturity of the photovoltaic solar power generation market in terms of technology and large-scale movements toward global climate awareness. Additionally, photovoltaic solar power generation technology has gradually reduced investment costs and energy costs, making it the most cost-effective electricity source worldwide (Huda et al. 2024).

However, a significant obstacle to the development and implementation of renewable energy resources is the low level of research on local renewable resources (Obeng et al. 2020). Yet, higher education institutions can contribute to energy consumption reduction by implementing green campus policies that include the installation of medium-scale solar power systems (Kristiawan et al. 2018). According to Bouraima et al. (2024), potential challenges to sustainable photovoltaic solar power development offer four alternatives to address these challenges, focusing on energy resilience, economic growth, and greenhouse gas emission reduction. Therefore, universities should be involved in accelerating the implementation of photovoltaic solar power generation systems, especially in Indonesia, considering their potential in terms of human resource availability. Government incentives should encourage campus involvement to attract customers or campuses to install such systems (Pramadya & Kim 2024).

In the context of the research "Economic Feasibility of Photovoltaic Solar Power Generation at Campus 2 of the National Institute of Technology Malang," the importance of implementing renewable energy, such as photovoltaic solar power, in the campus environment becomes increasingly evident. Considering global trends and their potential positive contribution to greenhouse gas emission reduction and economic growth, the involvement of universities in adopting photovoltaic solar power generation systems has become increasingly necessary (Shahsavari & Akbari 2018, Al-Shetwi 2022). The existence of barriers to the development of renewable energy sources indicates the need for collective efforts to promote the adoption of photovoltaic solar power generation technology in higher education institutions as a step toward better energy sustainability (Suheri et al. 2019).

The urgency of raising research regarding the use of photovoltaic solar power plants as an attractive alternative to facing current energy and environmental challenges has become a major concern, and photovoltaic solar power plant energy continues to experience growth. According to Draou et al. (2024), this growth has the potential to result in a reduction in prices and an increase in the use of solar photovoltaic power generation systems in the country by 2030. However, from an economic perspective, solar photovoltaic power generation technology is considered expensive and requires investment. Significant start. Limitations in economic feasibility studies in Indonesia are an obstacle to increasing investment interest and community participation in investment (Huda et al. 2024). According to Hamad et al. (2024), most research focuses on analyzing location suitability and ignores considerations of assessing techno-economic potential.

This study raises and questions the economic feasibility of photovoltaic solar power plants due to the urgency of exploring the potential utilization of this technology as an attractive alternative to address the increasingly pressing energy and environmental challenges (Dehler-Holland et al. 2022). With continuous growth, photovoltaic solar power generation technology has the potential to reduce prices and increase its usage domestically by 2030, as mentioned by Draou et al. (2024). However, economically, this technology is considered expensive and requires a significant initial investment. Limitations in economic feasibility studies in Indonesia pose a barrier to attracting investment interest and public participation in the development of this technology. Haber et al. (2021) emphasize that the success of implementing new and renewable energy (NRE) requires a comprehensive understanding of economic considerations. Therefore, it is important to analyze the economic feasibility of photovoltaic solar power plants holistically to identify potential economic benefits and overcome existing investment barriers.

Referring to the data, out of the total installed capacity of new and renewable energy power plants of 12,736.7 megawatts (MW), solar power plants account for 322.6 MW. Thus, the realization of solar power plants in 2023 only contributed approximately 2.53% of the total capacity of national renewable energy power plants (Humas EBTKE 2023). Certainly, the use of solar energy is still far behind compared to neighboring countries in the Association of Southeast Asian Nations (ASEAN), such as Vietnam, Thailand, the Philippines, and Malaysia. These countries contributed 16,600 MW, 3,049 MW, 1,370 MW, and 1,787 MW, respectively, in 2022. This situation arises because the current government is unable to bear the high investment costs. Additionally, large-scale photovoltaic solar power plants require vast amounts of land. This issue is considered one of the biggest obstacles for Indonesia in infrastructure development (Pramadya & Kim 2024).

This problem must be addressed because, according to Manoo et al. (2024), expanding alternative energy sources such as solar power is a potential solution to address the problems caused by non-renewable resources. Universities play a crucial role in environmental awareness, training, research, and innovative solutions, yet university involvement in environmentally friendly energy development efforts is often overlooked (Tshivhase & Bisschoff 2024). According to Basabien et al. (2024), photovoltaic solar power plants have the potential to support the research, academic, and practical goals of a university.

Campus 2 of the National Institute of Technology Malang, a private university that adopts and uses sustainable energy, has a solar photovoltaic power generation system with the largest capacity in Indonesia, reaching 500 kWp and using an area of 0.5 hectares. Certainly, this requires significant economic resources both in terms of the development and maintenance of the photovoltaic solar power generation system. Therefore, this research is urgent to evaluate the economic feasibility of photovoltaic solar power generation systems at Campus 2 of the National Institute of Technology Malang.

The findings from Paudel et al. (2021) research indicate that installing a 1 MW photovoltaic solar power generation system connected to the electricity grid is feasible for implementation on campus. Similar results were found by Basabien et al. (2024), who found that, overall, photovoltaic solar power plants will enable the Faculty of Engineering to use renewable energy and benefit from cost savings in the long term. However, a study by Pramadya and Kim (2024) found that photovoltaic solar power plants based on Net-metering (NEM) scheme calculations are not sufficient to make the photovoltaic solar power generation system economically viable. This directly reinforces the urgency of research in considering the economic feasibility of photovoltaic solar power plants at Campus 2 of the National Institute of Technology Malang, as well as their benefits in achieving sustainable development goals and reducing the negative environmental impacts resulting from the use of fossil energy sources.

The research conducted by Mulyani et al. (2024) supports previous research findings and introduces three new topics identified in both media channels. These findings include aspects of knowledge, misconceptions, and skepticism; economically viable alternative solar panel technology; as well as government regulations and policies. Aspects such as social and visual impressions like aesthetics, hedonic motivation, and social influence were not discussed in the study. Public perceptions of solar panels vary, with mainstream media tending to present solar panel technology more positively than social media. In general, the public has a positive view of solar panels regarding their practicality, installation, safety, and information accessibility. However, there are also negative views regarding investment costs, regulations, government policies, and the perceived inadequate level of government support.

This study differs from previous studies in several aspects. First, this study focuses on Campus 2 of the National Institute of Technology Malang, which is a different location from previous research. Different locations can affect the potential of solar energy and relevant economic factors. Second, this research examines the economic feasibility of a 500 kWp solar power plant, while previous studies considered different capacities. The difference in capacity will impact the costs and profits generated. Third, this study uses an on-grid scheme with net metering, allowing the solar power plant to sell excess energy to the national electricity company and increase profit potential. Additionally, this research also considers social and visual factors such as aesthetics, hedonic motivation, and social influence, which have not been extensively discussed in previous studies. Lastly, the study by Mulyani et al. (2024) focuses on public perceptions of solar power plants in mainstream and social media, while this study does not address those aspects. Therefore, this study provides a more comprehensive analysis of the economic feasibility of solar power plants at Campus 2 of the National Institute of Technology Malang, with a greater focus on techno-economic aspects.

Based on the description above, the economic feasibility of photovoltaic solar power plants faces challenges, including limitations in economic feasibility studies in Indonesia, the low contribution of solar power plants to the total national electricity generation capacity, barriers to investment, and extensive land use. This study aims to analyze the economic feasibility of photovoltaic solar power plants (PV) at Campus 2 of the National Institute of Technology Malang in response to the urgency of exploring the potential use of this technology as an alternative to address the increasingly pressing energy and environmental challenges today.

MATERIALS AND METHODS

Research Approach

The method to be used in this research is mixed-methods research, where one issue will be analyzed using two approaches: qualitative data and quantitative data. Conceptually, mixed-methods research combines qualitative and quantitative data in analysis (Azhari et al. 2023). By employing a mixed-methods approach, this research can integrate qualitative and quantitative data to obtain more comprehensive and in-depth information regarding the economic feasibility of photovoltaic solar power generation. Qualitative data can provide contextual insights and profound understanding, while quantitative data can offer concrete numbers and supporting statistics. Additionally, combining both types of data can enhance validity and strengthen research findings (Sarie et al. 2023). By corroborating findings from both data sources, we can ensure that the research results are stronger and more reliable.

Data Source

Qualitative data will be obtained through interviews with the staff members responsible for managing the photovoltaic solar power generation plant at the National Institute of Technology Malang. The interviews will focus on information related to initial investment costs, operational costs, and maintenance costs, as well as the energy costs of the photovoltaic solar power generation plant produced. This information can provide a deeper understanding of these aspects. Meanwhile, quantitative data will be obtained from the calculation of the net present value (NPV) and payback period (PBP) to evaluate the economic feasibility of the photovoltaic solar power generation plant project. This research was conducted from December 26, 2023, to January 26, 2024.

Data Collection Technique

This is done by conducting structured interviews with relevant informants to gather qualitative data. Interviews are conducted either in person or via telephone.

Data Analysis

1) **Qualitative data analysis**

   Qualitative data from interviews will be analyzed using the qualitative analysis technique known as thematic analysis. The data will be categorized, coded, and interpreted to identify patterns, themes, and relevant findings related to the initial investment costs, operational and maintenance costs, as well as the energy costs of the photovoltaic solar power generation plant.

2) **Quantitative data analysis**

   The quantitative data obtained from the NPV and PBP calculations will be analyzed using economic statistical analysis. The results of these calculations will be used to evaluate the economic feasibility of the Photovoltaic Solar Power Generation Plant project at the National Institute of Technology Malang, such as whether the project yields positive value, adequate return rates, and the period required to recoup the initial investment.

Using this mixed-methods approach, the research will combine in-depth insights from interviews with objective quantitative analysis, thus providing a more comprehensive and accurate picture regarding the economic feasibility of the photovoltaic solar power generation plant project at the National Institute of Technology Malang.

RESULTS AND DISCUSSION

This study analyzes two important aspects at Campus 2 of the National Institute of Technology Malang. Firstly, it analyzes the existing electrical load on the campus. Through this analysis, we can understand the magnitude of the electrical load that needs to be handled at Campus 2 of the National Institute of Technology Malang. Secondly, it conducts an economic feasibility analysis of photovoltaic solar power generation at Campus 2 of the National Institute of Technology Malang (Fig. 1). In this analysis, it evaluates whether photovoltaic solar power generation at the campus is economically feasible. Considering various factors such as initial investment, operational costs, and potential energy savings, it aims to determine whether photovoltaic solar power generation is an economical solution to meet the campus's electricity needs.

Based on this image, the installation location of the on-grid photovoltaic solar power generation plant with a capacity of 500 kWp is situated at Campus 2 of the National Institute of Technology Malang, Tasikmadu, Malang City. It can be observed that the installation is done in an empty field, allowing for the use of a ground-mount photovoltaic solar power generation plant installation. Approximately 5000 m2 of land area is required for the construction of this photovoltaic solar power generation plant. Additionally, at the installation location, there are no tall trees or buildings that could cause shading on the solar modules, ensuring the efficiency of the system.

From the perspective of access to Campus 2 of the National Institute of Technology Malang, it is relatively easy as it is close to the Singosari Toll Exit, facilitating transportation and logistics during the installation and maintenance process of the photovoltaic solar power generation plant. In terms of temperature, the surrounding area of Campus 2 of the National Institute of Technology Malang has a tropical climate with temperatures ranging from 24.7°C to 32.8°C. The duration of sunlight exposure at the National Institute of Technology Malang ranges from 8 to 10 hours, creating ideal conditions to maximize the potential of the photovoltaic solar power generation plant's energy output.

Electric Load at Campus 2 of the National Institute of Technology Malang

Based on the data obtained, the total power capacity at Campus 2 of the National Institute of Technology Malang is 465 kVA. Peak load occurs during the daytime when all activities in the building are operational in almost all sectors. At night, only a few rooms are still operational using electric energy. In peak load conditions, the total power consumed

(Source: Google Maps).

Fig. 1: Photovoltaic solar power plant at the National Institute of Technology Malang.

is 380 kVA. Since the building operates 24 hours a day, the daily energy consumed by the load throughout the building is approximately 380 kWh. Based on interview results, informants revealed that:

> *"..., after the installation of solar photovoltaic power plants, it is able to fulfill all operational energy needs of the campus. Therefore, at present, the campus only pays the basic load bill from the State Electricity Company (Perusahaan Listrik Negara/PLN)".*

The project installation of a 500.850 kWp grid-connected photovoltaic solar power plant at Campus 2 of the National Institute of Technology Malang utilizes 1113 monocrystalline JA solar photovoltaic modules with a capacity of 450 Wp each. It is capable of generating daily energy, reaching 680,980 kWh per year. Four inverters will convert direct current (DC) electricity into alternating current (AC), with each inverter having a capacity of 100 kW. The DC/AC ratio obtained is 1.25, considered ideal for enhancing the conversion rate of current before distribution to the loads. The output distribution of the inverters will supply power to the loads at Campus 2 of the National Institute of Technology Malang and the Rusunawa Building. The grid-connected photovoltaic solar power plant system is equipped with protection devices such as MCBs, arresters, and energy meters, as well as monitoring systems to monitor voltage, current, frequency, power, and energy consumption by the loads.

Data in the report document of the grid-connected photovoltaic solar power plant at the National Institute of Technology Malang shows that Campus 2 of the National Institute of Technology Malang requires 380 kWh of energy per day for its operations. On the other hand, the grid-connected photovoltaic solar power plant at the National Institute of Technology Malang is capable of producing 1865.7 kWh of energy per day, indicating that the campus experiences an energy surplus. The energy generated by the photovoltaic solar power plant is converted into power through inverters, with the output voltage of each inverter being 95.1 kW. Each inverter experiences a power decrease of 1.9 kW due to losses in the AC cables. The total power generated by the four inverters is 372.8 kW. Out of this amount, 257.3 kW is directed to the Campus 2 Building of the National Institute of Technology Malang and 64.9 kW to the Student Dormitory Building. Meanwhile, the excess power of 50.6 kW is exported to the State Electricity Company (PLN). This means that 13.57% of the total power generated by the grid-connected photovoltaic solar power plant at the National Institute of Technology Malang is supplied to the State Electricity Company (PLN).

In an interview with an online media outlet, the rector of the National Institute of Technology Malang stated that some of the energy generated by the grid-connected photovoltaic solar power plant at the National Institute of Technology Malang can be supplied to the State Electricity Company. This brings efficiency benefits to the electricity financing of the Campus 2 Building of the National Institute of Technology Malang, which is 10–15% lower compared to the previous electricity payment to the State Electricity Company. The process of exporting energy has a significant positive impact on managing the campus building's electricity costs. Thus, the grid-connected photovoltaic solar power plant at the National Institute of Technology Malang is capable of generating energy that is converted into power to meet the campus's needs and send excess power to the State Electricity Company.

The most important thing to understand is that in the energy transaction process with the State Electricity Company, cash transactions are not used. This was revealed by the informant:

> *"The electricity from the on-grid photovoltaic solar power plant that is not used by the customers will automatically be sent to the State Electricity Company's grid and counted as exported electricity. The State Electricity Company will recognize this exported electricity as a deduction from the electricity bill in the following month, but only at 65% of the total kWh recorded on the export meter. This concept is known as net billing in the rooftop solar power plant scheme without using batteries, in accordance with Regulation of the Minister of Energy and Mineral Resources Number 49 of 2018. With net billing, there are no cash transactions involved in the calculation of electricity exports and imports for rooftop solar power plant customers."*

The implementation of solar power plants at Campus 2 of the National Institute of Technology Malang has brought significant benefits in terms of economic feasibility. With the ability of the solar power plants to meet the campus energy needs and generate surplus energy that can be exported to the State Electricity Company, the electricity costs of Building Campus 2 of the National Institute of Technology Malang can be reduced by up to 10-15% compared to before. The energy export process without cash transactions through the net billing concept also has a positive impact on managing the campus building's electricity costs. Thus, the Solar Power Plant at the National Institute of Technology Malang not only provides a sustainable energy solution but also contributes to improving the economic feasibility of campus operations.

Feasibility Analysis of a Photovoltaic Solar Power Plant at Campus 2 of the National Institute of Technology Malang

The economic feasibility of a photovoltaic solar power generation plant at Campus 2 of the National Institute of Technology Malang is inseparable from the chosen investment mechanism because the installation project requires significant investment. Therefore, a flexible and affordable investment scheme is required. This flexible investment scheme provides clients with the flexibility to adjust the rental costs of the photovoltaic solar power generation plant according to their abilities. By using a flexible investment scheme, clients only need to pay the rental costs of the photovoltaic solar power generation plant. The rental costs of the photovoltaic solar power generation plant can be adjusted based on the client's abilities, allowing the installation project to be carried out more affordably.

The flexible and affordable investment scheme is the chosen option by Campus 2 of the National Institute of Technology Malang to facilitate the installation of a photovoltaic solar power generation plant more affordably and efficiently. With this flexible investment scheme, it is hoped that the installation project of the photovoltaic solar power generation plant at Campus 2 of the National Institute of Technology Malang can be successfully implemented and provide optimal long-term benefits in the installation project at Campus 2 of the National Institute of Technology Malang, PT. Sun Energy acts as the developer.

This analysis will involve several important aspects that need to be comprehensively evaluated. The objective of this analysis is to assess whether investing in a photovoltaic solar power generation plant at Campus 2 of the National Institute of Technology Malang is an economically sound decision and provides long-term benefits. Here are some aspects that will be examined in the economic feasibility analysis of the photovoltaic solar power generation plant at Campus 2 of the National Institute of Technology Malang. The economic feasibility analysis of the photovoltaic solar power generation plant at Campus 2 of the National Institute of Technology Malang includes several aspects, including:

Initial investment costs: Evaluation of the costs required to build the photovoltaic solar power generation plant system at Campus 2 of the National Institute of Technology Malang. Based on the interview results and document research provided, the initial investment cost of the centralized photovoltaic solar power generation plant reaches IDR. 4,084,498,826 (Table 1). The breakdown is as follows:

The total project cost of the solar power generation plant at Campus 2 of the National Institute of Technology Malang amounts to IDR 4,084,498,826, which is divided into six main components. The main component, including solar modules and inverters, has a cost of IDR 3,005,825,216. The monitoring system, including the remote monitoring system, Huawei Smart Logger, RS485 cable, SPD RS486, and monitoring box, has a cost of IDR 51,921,500. Cable and Conduit covering DC cables, AC cables, grounding cables, and cable trays costs IDR 256,567,504. Switchgear and Protection, including fuse, MCB DC, circuit breaker, AC and DC distribution panels, and external lightning protection, costs IDR 25,921,500. The mounting system, with mounting rails, end clamps, mid clamps, splices, and

Table 1: Initial Investment Costs for Solar Photovoltaic Power Plants.

Price	Component	Information
IDR 625.695.000	Services	-
IDR 91.568.106	Mounting System	Mounting rails, end clamps, mid clamps, splices, and brackets, along with installation costs
IDR 25.921.500	Switchgear and Protection	Fuse, MCB (miniature circuit breaker), DC circuit breaker, AC and DC distribution panels, and external lightning protection.
IDR 256.567.504	Cable and Conduit	DC cable, AC cable, grounding cable, and cable tray.
IDR 51.921.500	Monitoring System	Remote Monitoring System, Huawei Smart Logger, RS485 Cable, SPD RS486, and Monitoring Box.
IDR 3.005.825.216	Main Component	solar modules and inverters
Total Price = IDR.4.084.498.826,-		

brackets, along with installation costs, costs IDR 91,568,106. Finally, services have a cost of IDR 625,695,000. All these components contribute to the significant total project cost for implementing the solar power generation plant at Campus 2 of the National Institute of Technology Malang.

Operational and maintenance (O&M) costs: Knowing the costs associated with the operation and maintenance of the photovoltaic solar power generation plant after construction is crucial. According to the managers of the solar power generation plant at Campus 2 of the National Institute of Technology Malang, interview results reveal that maintenance of the solar power generation system is vital to maintaining the reliability and sustainability of the system. Therefore, in carrying out the operation and maintenance of the solar power generation plant, there are separate costs that need to be considered. The annual operational and maintenance (O&M) costs for the photovoltaic solar power generation plant amount to IDR 81,595,607, demonstrating a commitment to maintaining the performance of the photovoltaic solar power generation plant to remain optimal and efficient in generating electricity from solar energy.

Cost of Energy from photovoltaic solar power plants: Estimating the cost of energy generated by the photovoltaic solar power plant at Campus 2 of the National Institute of Technology Malang. Based on interview data, the total electricity price analysis from the Solar Power Plant system at Campus 2 of the National Institute of Technology Malang is obtained by summing up the price per kWh of each component (Table 2), as detailed below:

Table 2: Analysis of Total Electric Energy Prices for Solar Photovoltaic Power Plants Campus 2 National Institute of Technology Malang.

Component	Cost [Rp. kWh^{-1}]	Information
A	780	Initial investment value
B	120	Operation and maintenance costs (2% of the total price)
C	30	Unexpected fees (0.5%)
Total	930	Total cost of electricity per kilowatt-hour

Therefore, the total price per kWh of electrical energy from the Photovoltaic Solar Power Plant system at the National Institute of Technology Malang is IDR 930, calculated by considering the contribution of each component A, B, and C as provided.

Calculation of the net present value (NPV) of the photovoltaic solar power plant at the National Institute of Technology Malang: Calculating the net present value (NPV) of the cash flow generated by the photovoltaic solar power plant to evaluate the project's financial feasibility. In computing the net present value (NPV) of the solar power plant project at the National Institute of Technology Malang campus, the difference between discounted revenues and expenditures is calculated. Here is the interview data regarding the NPV calculation results:

"*The net cash flow is IDR 11,873,894,464 calculated over the lifetime of the solar power plant project at the National Institute of Technology Malang campus, which typically spans 25 years. The total investment cost is IDR 4,084,498,862*".

Based on the data, determine the NPV value of the photovoltaic solar power plant at the National Institute of Technology Malang campus based on the following formula:

NPV = Net cash flow -Total investment

NPV = *IDR* 11.873.894.464 – *IDR* 4.084.498.862

NPV = *IDR* 7.789.395.602

Nilai NPV Pembangkit Listrik Tenaga Surya Kampus 2 Institut Teknologi Nasional Malang adalah IDR 7.789.395.602. Nilai NPV yang positif menunjukkan bahwa proyek tersebut menghasilkan keuntungan di masa depan. Karena nilai NPV > 0, maka Pembangkit Listrik Tenaga Surya Kampus 2 Institut Teknologi Nasional Malang layak dijalankan. Semakin besar nilai NPV, semakin besar keuntungan yang diharapkan.

Calculation of the Payback Period (PBP) for the Photovoltaic Solar Power Plant at the National Institute of Technology Malang: Calculating the time required to recover the initial investment in the photovoltaic solar power plant to evaluate the speed of the investment return. In the Payback Period (PBP) analysis for the on-grid photovoltaic solar power plant at Campus 2 of the National Institute of Technology Malang, based on the data of net cash flow amounting to IDR 477,561,959. The calculated PBP result is as follows:

PBP = Initial investment / Net cash flow

PBP = IDR 4.084.498.862 / IDR 477.561.959

PBP = 8.55 Years

Based on the calculations conducted, it can be concluded that the on-grid photovoltaic solar power plant at Campus 2 of the National Institute of Technology Malang has a payback period of 8.55 years, equivalent to 8 years and 6 months. A shorter PBP compared to the device's lifespan indicates that the photovoltaic solar power plant project at Campus 2 of the National Institute of Technology Malang is deemed feasible in terms of the payback period for the initial investment. This suggests that the investment in the photovoltaic solar power plant can be recovered in a relatively short time, demonstrating the project's efficiency in generating savings on electricity costs. Therefore, the on-grid photovoltaic solar power plant project at Campus 2 of the National Institute of Technology Malang can be considered a profitable and sustainable long-term investment.

The on-grid Photovoltaic Solar Power Plant at Campus 2 of the National Institute of Technology Malang demonstrates good economic feasibility. The energy generated annually is 680,980 kWh/year, with the annual operational and maintenance (O&M) costs reaching IDR 81,595,607. This indicates the commitment of Campus 2 of the National Institute of Technology Malang to maintain the performance of the Photovoltaic Solar Power Plant to remain optimal and efficient in generating electricity from the sun. These costs are relatively low compared to the long-term benefits when compared to the annual operation and maintenance (O&M) costs of the Solar Power Plant at the Regional Hospital (RSUD) of Mimika Regency, which reached IDR 100,477,114, with an annual energy output of 90,474 kWh. $year^{-1}$ (Kariongan & Joni 2022).

The total price per kWh of electricity from the photovoltaic solar power plant system at Campus 2 of the National Institute of Technology Malang is Rp 930, which is considered competitive compared to the electricity price from the State Electricity Company (PLN). Economic analysis values indicate a positive net present value, and energy costs can be averaged over 25 years (Ennemiri et al. 2024). This indicates that photovoltaic solar power plants can be a more economical alternative energy source. The difference in the total price per kWh, according to Wang et al. (2024), can be the right choice based on its energy consumption to reduce energy bills. According to Tarigan (2024), the photovoltaic solar power plant system will not only reduce its electricity bills but also balance energy for 10 years.

The net present value (NPV) of the photovoltaic solar power plant at Campus 2 of the National Institute of Technology Malang is IDR 7,789,395,602, indicating that the project yields future profits. Based on the net cash flow data, the payback period (PBP) of the photovoltaic solar power plant at Campus 2 of the National Institute of Technology Malang is 8.55 years from the lifespan or device age of the solar panels. This indicates that this positive NPV value serves as a strong indicator that the photovoltaic solar power plant project is viable. Additionally, the initial investment in photovoltaic solar power plants will be recouped in a relatively short time. This short PBP enhances the project's attractiveness to investors. These research findings align with Zebua and Huda's (2024) study, which found that on-grid photovoltaic solar power plants have a larger NPV and a smaller PBP value. In essence, investing in photovoltaic solar power plant technology is quite profitable for universities (Ali & Alomar 2023).

Thus, the benefits of the economic feasibility of the on-grid photovoltaic solar power plant at Campus 2 of the National Institute of Technology Malang include: 1) generating clean and environmentally friendly electricity; 2) saving electricity costs in the long term; and 3) enhancing the image of the National Institute of Technology Malang as an institution that cares about the environment. Therefore, the National Institute of Technology Malang needs to conduct periodic studies and evaluations of the performance of the photovoltaic solar power plant to ensure and optimize its maximum operation.

CONCLUSIONS

Based on the analysis conducted, it can be concluded that the on-grid photovoltaic solar power generation plant at Campus 2 of the National Institute of Technology Malang is economically feasible. Factors such as controlled operational and maintenance costs, competitive electricity prices, a positive net present value (NPV), and a short payback period indicate that this project is viable to proceed with. The success of this photovoltaic solar power generation plant project can also provide significant economic benefits to the National Institute of Technology Malang while enhancing the institution's image as an environmentally conscious educational institution. However, to ensure the sustainability and optimization of the performance of the photovoltaic solar power generation plant at the National Institute of Technology Malang, periodic studies and evaluations are needed. This is aimed at ensuring that the photovoltaic solar power generation plant operates efficiently and provides maximum economic benefits to the institution. Thus, these measures will support the National Institute of Technology Malang in achieving sustainable goals and making positive contributions to the surrounding environment.

The implications of this research for future practice and research are significant. First, the study demonstrates that the implementation of photovoltaic solar power plants (PV) is economically feasible, particularly in campus environments. This serves as an encouragement for other higher education institutions to adopt similar technologies as part of their efforts to promote energy and environmental sustainability. Second, the research underscores the need for further investigation into addressing economic barriers associated with the development of photovoltaic solar power plants, such as significant initial investments and limitations in economic feasibility studies. Future research could focus on developing innovative business models and financial strategies to promote investment in photovoltaic solar power plants (PV). Third, the study highlights the importance of regular evaluation and monitoring of the performance of photovoltaic solar power plants (PV). Further studies could explore more advanced and effective evaluation methods to ensure the efficient and optimal operation of photovoltaic solar power plants (PV). Lastly, this research provides a foundation for higher education institutions to serve as role models in the adoption of renewable technologies and contribute to global efforts to reduce greenhouse gas emissions. This expands the scope of future research to understand the social, economic, and environmental impacts of using photovoltaic solar power plants (PV) in various higher education contexts.

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