Technical, economic and social feasibility of using solar street lighting on campus

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Article Info	ABSTRACT
	A good and proper street lighting system on campus indirectly supports teaching and learning activities. However, these conditions still need to be developed at the Marine and Fisheries Polytechnic of Kupang due to the lack of these facilities. Therefore, a solar street lighting system was designed considering the good potential of solar energy in this region. The design of this system is carried out by measuring for a year, analyzing the energy potential, economics of the system, and the social impact of installing the system. The installation of solar street lighting on campus based on the results of an analysis of technical, economic, and social aspects gives good and feasible results. The results from the technical aspect provide that the utilization of this system provides a PR value of 85%, and can make savings of 15.99 MWh per year, and provide energy of 177.8 kWh per year. The results from the economic aspect of using this system provide an IRR value of 6%, SPBP for 8.93 years, and a net present value (NPV) of IDR 85,247,500.56. The results of the social aspects obtained from the respondents' answers showed different and meaningful results (p<0.05) from all categories given to respondents.

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1. INTRODUCTION

Marine and Fisheries Polytechnic of Kupang is a tertiary institution that organizes vocational education in the field of marine and fisheries within the Ministry of Marine Affairs and Fisheries, which is under and responsible to the agency that organizes the development of marine and fisheries human resources in Indonesia. In carrying out its duties, the Marine and Fisheries Polytechnic of Kupang carries out the function of preparing educational plans and programs, implementing and developing vocational education which includes teaching and training in the field of maritime affairs and fisheries. In organizing vocational education, the aim is to produce competent human resources who have a continuing entrepreneurial spirit and are environmentally sound and excel in the marine and fisheries industry. This campus is located in Kupang City, East Nusa Tenggara Province [1]. This campus has several facilities and infrastructure to support all educational activities, but until now there is still a lack of lighting around the campus. Based on the results of the interviews and questionnaires given to the users, several areas around the campus do not get any lighting at all, even though public street lighting has been installed. The installed street lighting still uses mercury-type lamps which are less bright and some don't turn on. The density of teaching and learning activities on campus until night, so more appropriate street lighting is needed [2]–[5]. This needs to get attention by improving the lighting system by adding street lighting on roads that have not yet been installed with

lighting, and replacing street lighting that still uses mercury-based State Electricity Company electricity with street lighting that utilizes solar power by street lighting standards in force in Indonesia [6]–[11]. This utilization is also in accordance with the environmental conditions in East Nusa Tenggara which are so abundant in solar energy potential [1], [12]–[14].

Utilization of street lighting using power from solar energy is an alternative form that is cheap and economical to use as a source of lighting electricity [9], [15]–[17]. Given the potential for solar energy which is always available throughout the year in East Nusa Tenggara. Public street lighting lamps with photovoltaic system are power plants that convert solar energy into electrical energy [18]–[23]. The potential for solar energy in East Nusa Tenggara is 6.78 kWh/m^2 and is always available throughout the year except during the rainy season, it is very possible to use it [1]. The use of solar street lighting indirectly supports the government's policy of saving fossil energy through the use of renewable electrical energy. The saving of solar street lighting can reach 36.9% compared to conventional street lighting which can also be one of the things in encouraging the use of this energy, although a sizable investment is required at the start of its construction.

The street lighting that will be made will be designed to spread out at several points in the campus area, then distribute electrical energy and provide lighting at night. The designed street lighting has a system that will be active against sunlight, so that when it gets dark it will automatically turn on. The vital function of street lighting is one thing that needs to be available because it serves as a navigation aid for road users and optimizes road equipment facilities in the form of street lighting, for the realization of safety, security, order and smooth traffic. The street lighting that will be installed also indirectly supports educational, economic and mobility activities on campus. In addition to carrying out a technical analysis, a social and economic analysis is carried out on the design that will be made so that it is suitable for the users. This system can also be redeveloped in the future with internet of things (IoT) technology so that solar street lighting installed on campus can be monitored and regulated in real time [24]–[32].

2.   METHOD

The methods and stages in this design use experimental which refers to the quantitative method by designing an analysis of the needs of electric power using photovoltaic (PV) system on campus. The calculation and measurement approach are then applied to the circuit design and components of the street lighting that will be used. Environmental conditions are measured for a year in 2021. The economic results are analyzed so that the savings obtained can be identified. In the economic aspect, an analysis is carried out by looking for the SPBP, NPV, and IRR values of the system created [1], [12]. The social aspect of this design is also considered by getting answers from interviews and questionnaires distributed to users. Figure 1 illustrates the relationship between the installation of a solar lighting system on campus to the technical, economic, and social aspects of the users, and Figure 2 is a design for the street lighting to be installed.

The location for installing solar energy-based street lighting on this campus uses a 100 Wp PV system. The solar street lighting installation will be influenced by the performance factors of the solar modules and taken into consideration in the design, including module temperature, sunlight intensity, wind speed, the state of the earth's atmosphere, the placement of solar panels, PV area, the power generated by the PV system, the number of modules solar panels, and performance ratio (PR).

A solar panel will be able to operate properly and optimally if the panel temperature is in normal conditions, 25 ℃. Any increase in temperature on the solar panel will weaken the resulting voltage (Voc). An increase in temperature of 1 ℃ will result in a reduction in the power generated by 0.5%. Calculation of the amount of power that decreases when the temperature around the panel increases with (1). The maximum output power of the solar panel when the temperature rises to t ℃ from standard temperature is calculated by (2). P$_{MPP}$ when t rises to t ℃ is the maximum output from the solar panel when the temperature is around panel rises from standard temperature. The temperature correction factor (temperature correction factor) is calculated using (3). Calculation of the area of the PV array, the amount of power generated, and the number of solar panel modules is calculated using (4), (5) and (6). Calculation of performance ratio (PR), which is a measure of system quality as seen from the annual energy produced. The system can be said to be feasible if the PR value is around 70-90%. Calculation of PR system using (7).

$$P_{when\,t\,rises} = 0.5\% \times P_{MPP} \times \Delta t \qquad\qquad (1)$$

$$P_{MPP\,when\,rising\,to\,t^oC} = P_{MPP} - P_{when\,rising\,to\,t^oC} \qquad\qquad (2)$$

$$TCF = \frac{P_{MPP\,when\,rising\,to\,t^oC}}{P_{MPP}} \qquad\qquad (3)$$

$$PV_{area} = \frac{W}{G_{av} \, x \, \eta_{pv} \, x \, TCF \, x \, \eta_{out}} \tag{4}$$

$$P \; Wattpeak = area \; array \times PSI \times \eta_{pv} \tag{5}$$

$$Number \; of \; solar \; panels = \frac{P_{Wattpeak}}{P_{MPP}} \tag{6}$$

$$PR = \frac{E_{yield}}{E_{ideal}} \tag{7}$$

Based on Figure 1, the feasibility of building solar street lighting on campus is carried out by conducting a comparative test with the Wilcoxon test. In this test, validity and reliability tests were carried out, then a comparative test was carried out to find out the responses from the respondents. The results of the answers from the Wilcoxon test will provide an answer whether there is a significant difference from the current situation without solar street lighting with the hope that after solar street lighting is installed.
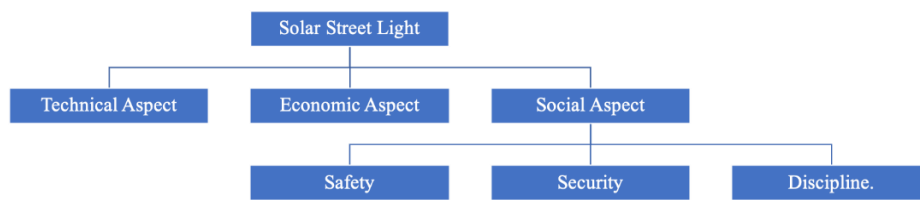

Figure 1. Flowchart the impact of installing a solar lighting system on campus on technical, economic and social aspects

Figure 2. Design of a solar lighting system on campus

3.   RESULTS AND DISCUSSION
3.1. Technical analysis of solar street lighting system

In designing a solar lighting system on campus, first collect data on solar energy potential and environmental conditions. Data was obtained for 1 year, namely from January-December 2021. The results of data collection obtained that the average potential for solar energy is 5.73 kWh/m^2/day, with the greatest energy potential occurring in October of 6.96 kWh/m^2/day. The results of data collection also obtained wind speed, temperature and humidity around the installation site, namely 2.85 m/s, 27.14 ℃ and 16.87%. The results of this measurement data are then used as a reference in designing a system that will be made to calculate the electrical energy that can be generated by a solar lighting system. Data can be seen in Table 1.

Table 1. Environmental conditions on campus

Month	Solar energy (kWh/m²/day)	Wind speed (m/s)	Temperature (℃)	Relative humidity (%)
1	4.96	2.84	26.76	85.24
2	5.15	3.37	26.10	87.79
3	5.67	2.07	26.37	84.80
4	5.66	2.99	26.21	80.96
5	5.67	3.31	26.38	74.02
6	5.17	3.02	27.02	69.99
7	5.48	3.49	26.62	65.27
8	6.09	3.61	27.42	63.72
9	6.50	3.43	28.24	63.24
10	6.96	2.28	28.91	66.68
11	6.05	1.53	28.12	76.86
12	5.39	2.25	27.57	81.02
Average	5.73	2.85	27.14	74.97

3.1.1. Load usage analysis

After obtaining data on environmental conditions, equipment specifications and load usage data, then the required load per day is calculated. The load usage of 1 piece of solar street lighting in the Marine and Fisheries Polytechnic of Kupang campus area is 0.72 kWh for 12 hours of use. The use of the load planned in this design will be used for planning solar street lighting. So that the investment is not too big, the design is only limited to reducing electricity consumption.

3.1.2. Solar street lighting module capacity

In accordance with predetermined conditions, solar panels have a decrease in the power capacity produced if they exceed the optimal temperature standard for solar panels to work. The highest temperature in the campus environment reached 28.91 ℃ in October and the lowest temperature was 26.10 ℃ in February, so the temperature increase became 3.91 ℃. Then with (1), (2) and (3) the amount of reduced power was obtained by 1.955 W, with a P_{MPP} value of 98.045 W, and TCF of 0.98 W. After obtaining all of them, then the calculation of the overall PV area capacity can be carried out with (4). From the calculation results, the PV area capacity value is 2.85 m².

$$
\begin{aligned}
P_{t=3.91℃} &= 0.5\% \times P_{MPP} \times \Delta t \\
&= 0.5\% \times 100 \text{ W} \times 3.91℃ \\
&= 1.955 \text{ W}
\end{aligned}
$$

$$
\begin{aligned}
P_{MPP\ t=28.91℃} &= 100 \text{ W} - 1.995 \text{ W} \\
&= 98.045 \text{ W}
\end{aligned}
$$

$$
TCF = 0.98
$$

3.1.3. Electric power generated by the solar street lighting system

After the array area is obtained, the amount of power generated by solar street lighting (Watt-peak) can be calculated by (5). With array area of 2.85 m², Peak sun insolation (PSI) of 1000 W/m² and module efficiency of 16.51%.

$$
\begin{aligned}
P\ \text{Watt-peak} &= \text{area array} \times \text{PSI} \times \text{npv} \\
&= 2.85 \text{ m}^2 \times 1000 \text{ W/m}^2 \times 0.1651 \\
&= 142.40 \text{ W}
\end{aligned}
$$

3.1.4. Number of solar panels

The solar cell module that will be used for solar street lighting has a capacity of 100 Wp. Based on this value, the number of solar cell modules needed by the system is calculated by (6). The analysis results show that each system requires 1 solar panel with a power of 100 Wp.

3.1.5. The output power of the solar street lighting system

The losses assumption for the solar street lighting system is 15% because all the system components used are new. These losses can come from several factors, such as dirt (dust), temperature, 10% conductor cable, and 5% factory losses.

P_i =   The amount of power used $\times$ (100% - 15%)
               =   100 W – 15 W
               =   85 W

The energy that can be produced by solar panels is related to the lowest and highest solar radiation data, so you can know the energy produced by the solar street lighting system. The lowest solar radiation is 4.96 in January and the largest is 6.96 in October.

P_{out} =   Pi $\times$ solar radiation
               =   85 W $\times$ 4.96 h
               =   421.6 Wh (minimum)
P_{out} =   Pi $\times$ solar radiation
               =   85 W $\times$ 6.96 h
               =   591.6 Wh (maximum)

Energy produced on average per year, the radiation data used is the average radiation, or called Peak Sun Hour (PSH) with a value of 5.73.

P_{out} =   Pi $\times$ Solar radiation
               =   85 W $\times$ 5.73 h
               =   487.05 Wh

Energy Yield   = $P_{out} \times$ 365 days
               =   487.05 Wh $\times$ 365 days
               =   177,773.25 Wh/year

3.1.6. Performance ratio (PR)

Based on the results of the analysis, it was found that the ideal energy and energy yields of the system made were 177,773.25 Wh/year and 209,145 Wh/year. The calculation results also show that the electrical energy that can be generated per day is between 421.6-591 Wh, with an average of 487.05 Wh as shown in Table 2. By using (7), the Performance ratio (PR) is obtained by 85%. These results indicate that the system to be made can be said to be feasible.

3.1.7. Solar street lighting system specifications

Based on the results of the analysis that has been carried out, the specifications for the solar street lighting system that will be used can be seen in Table 3. There are 90 systems that will be used spread over several points at the Marine and Fisheries Polytechnic of Kupang shown in Figure 2. Utilization of electrical energy from this system besides being able to help with lighting at night also indirectly saves electricity usage as much as 43.83 kWh/day which is equivalent to 15.99 MWh/year.

3.2. Economic aspect of solar street lighting system

The economical aspect of installing solar street lighting on campus plays an important role. This economic aspect will determine the feasibility of a development whether it is feasible to do. Economically, this plan is influenced by several factors, such as the initial investment, NPV, IRR, SPBP and others. In conducting this analysis, the bank interest rate is 4.25%, and the installation of 90 units of solar street lighting requires an investment of 540 million. Another thing that influences the planning of a development is the response from users, such as the contribution of income to the campus, operational costs, and the economic value of development.

In the construction of solar street lighting on this campus, it obtained NPV value of IDR 85,247,500.56, IRR of 6%, and SPBP of 8.93 years. From these results it can be seen that the development carried out is feasible because the payback period is relatively short and the IRR value is higher than bank interest rates. The use of solar street lighting also indirectly supports the blue economy policy by the Indonesian government. The description of the economic analysis of the installation of this system can be seen in Table 4.

Table 2. Energy output of solar street lighting and energy yield

Lowest solar radiation (Wh)	Highest solar radiation (Wh)	Average solar radiation (Wh)	Eyield (Wh/year)
421.6	591.6	487.05	177,773.25

Table 3. Solar street lighting system specifications

Parameters	Specification
Model	DL-XYZ-60
Lamp power	60 W
Solar panel	100 W
Lithium battery	120 Ah/ 3.2 V
LED Qty	100 pcs
Total lumens	9000-9600LM
LED chip brand	Phillips
Color temperature	3000 - 6500 K
CRI	$\geq$ 70 Ra
Light control voltage	2 V
Working temperature	-20 ℃ - 60 ℃
Lifespan	$\geq$ 50000 hours
Material	Aluminum alloy, die-cast aluminum
Case diameter	60 mm
Mounting height	7 m
Installation distance	25-50 m

Table 4. Feasibility of developing solar street lighting from an economic aspect

Cost and Feasibility	Description
Investment cost	IDR 540,000,000
Operational and maintenance costs/year	IDR 5,400,000
Saving-1/year	IDR 60,446,860.45
i	4.25 %
n	15 Years
SPBP	8.93 Years
Net present value (NPV)	IDR 85,247,500.56
IRR	6%

Table 5. Wilcoxon test analysis results for social aspect

Category	Test	n	Median (Minimum-maximum)	mean±sd	p
Technical	Pre-test	78	9 (5 - 15)	8.06±2.991	0.001
	Post-test	78	20(20 - 20)	24±0.000	
Economic	Pre-test	78	6 (3 - 9)	4.48±1.816	0.001
	Post-test	78	12 (12 - 12)	12±0.000	
Social	Pre-test	78	6 (6 - 18)	9.31±3.701	0.001
	Post-test	78	24 (24 - 24)	24±0.000	

3.3. Social aspect of solar street lighting system

The social aspect of installing solar street lighting on campus consists of several categories, namely technical, economic and social. In the technical category includes the light produced, the location of the placement of health and natural disasters. The social category includes providing a sense of security, supporting access to transportation, orderliness on campus, causing vandalism from other parties, supporting religious rituals, supporting cadet activities around the campus. The economic category includes contributions to campus revenue, operational costs, and economic value in the future.

In Table 5 it can be seen the results of the analysis of the social aspects of installing solar street lighting on campus. The results of the Wilcoxon test showed that different and significant results were obtained ($p < 0.05$) from all categories. These results also show that 78 respondents expect the use of solar street lighting on campus to have a good impact on them because the current lighting system they feel is still not good, so a better system needs to be made. The results of the validity of this answer also provide a valid and reliable value (Cronbach's Alpha) with a value of 0.98.

4. CONCLUSION

The installation of solar street lighting on campus based on the results of an analysis of technical, economic and social aspects gives good and feasible results. The results from the technical aspect provide that the utilization of this system provides a PR value of 85%, and can make savings of 15.99 MWh per year and provide energy of 177.8 kWh per year. The results from the economic aspect of using this system provide IRR value of 6%, SPBP for 8.93 years, and NPV of IDR 85,247,500.56. The results of the social aspects obtained from the respondents' answers showed different and meaningful results ($p < 0.05$) from all categories given to respondents.

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