Technical, economic, and social impact of photovoltaic at dormitory building

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ABSTRACT

Marine and Fisheries Polytechnic of Kupang is one of the educational centers located in East Nusa Tenggara. The location of the campus is in an area with the potential for solar energy throughout the year and it is very possible to utilize this energy as a source of electrical energy. As a form of energy-saving and utilizing the existing potential in accordance with existing policy directions, this electrical energy potential will be utilized for 3 dormitories with a hybrid system with State Electricity Company. The utilization of renewable energy as a source of electrical energy can produce 44,294.20 kWh/year. The results of economic analyses are encouraging to intensify the use of such PV systems since the payback period is 8.79 years, and the internal rate of return is 9%. The results of the Spearman test of the relationship between technical, social, and economic gave a significant correlation ($p<0.05$). This shows that the use of photovoltaic PV systems on campus has a social and economic impact. The use of this renewable energy is expected to reduce the use of fossil energy which has a negative impact on the environment and assist government policies to support the use of renewable energy.

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1. INTRODUCTION

The need for electrical energy every year is always increasing. These needs come from households, government, business, and also the world of education [1]–[3]. In the world of education, electrical energy is useful for supporting all facilities and infrastructure in the learning process, both in the classroom, laboratory, and workshop [4]. This energy requirement of course plays an important role so that the sustainability and reliability of the system need to be considered optimally [2], [5], [6].

Marine and Fisheries Polytechnic of Kupang is an educational institution under the Ministry of Marine Affairs and Fisheries Republic of Indonesia that prioritizes marine and fisheries science. Marine and Fisheries Polytechnic of Kupang which is heading to a world-class university have adequate and international standard facilities and infrastructure. To optimize the use of facilities and infrastructure in the process of learning activities, a large supply of electrical energy is needed. Stable energy is needed to support performance and the process of learning activities [7]–[9]. However, electrical energy which sometimes experiences problems with the cut-off of electricity disrupts the use of learning facilities, which mostly use electrical energy. This, of course, can greatly hinder the learning process, both technical and non-technical. In addition, the existence of classroom mining certainly affects the addition of electronic equipment which increases in usage load. Therefore, a sufficient and reliable electricity supply is needed [2], [10].

Along with the development of increasingly modern technology, several renewable energy sources such as the sun can be used to produce electrical energy [9], [11], [12]. This utilization can be used by using a solar power plant. This energy is converted through a device that can then produce electrical energy [13], [14]. Based on the measurement results, it is found that East Nusa Tenggara has a solar energy potential of 5.43 kWh/m^2/day. From the results of previous research, the potential for solar energy in East Nusa Tenggara can be utilized for activities in the marine and fisheries world. This research has been carried out on the utilization of fishing boats and also vaname shrimp ponds. From the results of these studies electrical energy generated from the sun can be utilized optimally.

The placement of solar panels around the campus environment by utilizing the available land area as the placement of solar power plant devices, especially solar panels, is considered very effective because it can be exposed to sunlight [14]–[16]. The utilization of solar power plant at Marine and Fisheries Polytechnic of Kupang is expected to increase the efficiency of using electricity supplied from State Electricity Company (PLN) and generators. Planning for the installation of this solar power plant in the future can overcome the need for electrical energy for lighting in the dormitory as a form of energy efficiency and can economically reduce the cost of energy consumption [17], [18]. In addition, this utilization is also expected to illustrate how the influence of the relationship between the PV system on the socio-economic environment in the campus [4], [7], [19]–[22].

Therefore, to utilize this renewable energy source, it can be used as an off-grid or combine with the system that was been made, which will later provide benefits in the field of energy efficiency and optimize the potential of solar energy [10], [23]–[25]. The results of this study are expected to be developed again with current technological advances. One of these technologies is a control system, where this system can regulate and monitor the process and results of energy [25]–[29]. This energy utilization is of course expected to help with electricity problems that often experience blackouts due to poor network quality.

2. METHOD

The research was conducted from January 2019 to December 2020 at the Marine and Fisheries Polytechnic of Kupang. This research was carried out in an applied manner, namely directly implementing the tool made, then testing its effectiveness. The research method used is correlational and experimental. The correlation relationship that is carried out in this study is to determine the technical, social, and economic relationship of solar PV installations in dormitories. A brief overview of the research can be seen in Figure 1.

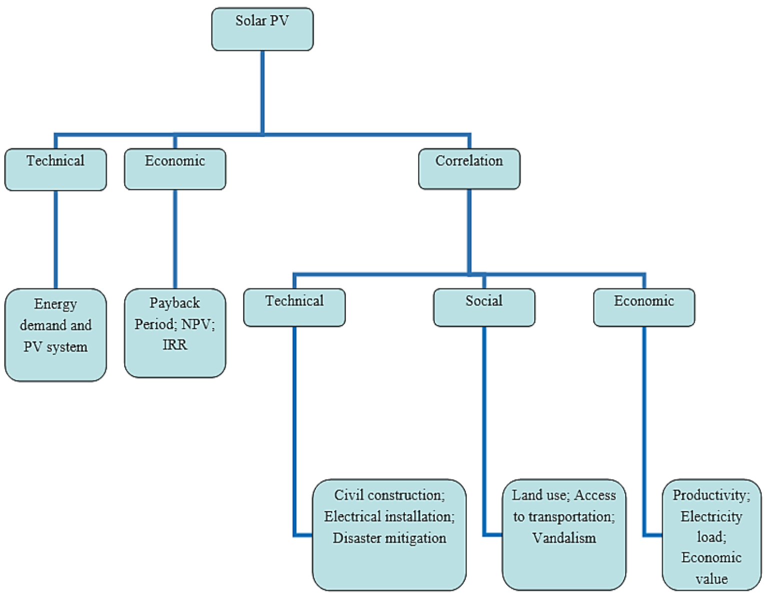

Figure 1. Overview of the use of PV systems

2.1. Technical and performance evaluation

The design of this solar power plant was carried out at the Marine and Fisheries Polytechnic of Kupang. This location was chosen because it has a large renewable energy potential and wants to save on the cost of purchasing electricity. This research was conducted by collecting data directly in the field and several literature books. Data of solar energy and environmental conditions are measured for one year, from January

2020 to December 2020, while data on electricity expenses and payments are measured for 2 years, from January 2019 to December 2020.

This study will discuss the use of renewable energy in dormitories and how it can be applied so that it can be more useful for campuses. The collected data will be analyzed. The results of the analysis will be used to create a system that will be implemented. The data is also analyzed with PVsyst 7.1 to get a design of the planning that will be carried out. The results of this analysis include the need for a hybrid system as a source of electrical energy in the dormitory. The need for solar power plants and State Electricity Company is adjusted to the needs of the electrical load.

2.2. Economic impact of PV installation

Economic analysis is an important part of PV project because it is an indicator for the project recovery and project profit. To determine the profitability of the installation PV system on campus, we preferred to use the payback period method and net present value or cash flow (NFC) method. The calculation of simple payback period (SPBP) method describes how long it takes the project to recover its initial investment. This method depends on annual saving from electricity total bill and the capital cost of the PV system, it can be calculated as the following [4], [15], [16], [30]:

$$SPBP = Investment\ or\ capital\ cost / \ saving\ cost\ per\ year \tag{1}$$

The NPV value, obtained from an embedded formula from Excel, will tell how much profit the project will generate in present value. The function simply requires cash flow input net cash flow (NCF) from all years of operation of the solar plant, and cash flow output including capital, maintenance and replacement cost as a negative amount. The discount rate (r) usually in Indonesia it can be 4.25% and based on the provisions of the Regulation of the Minister of Energy and Mineral Resources No. 17 of 2013, regarding the purchase of electricity by PLN from photovoltaic solar power plants, amounting to US$25 cents/kWh.

$$NPV = Income\ cash\ flow – Outcome\ cash\ flow \tag{2}$$

In this design, the internal rate of return IRR calculation is also carried out. IRR calculation is useful to help provide comparisons on the rate of return in determining the form of investment that is expected to be more profitable.

$$IRR = \sum_{t-1}^{t} \frac{C_t}{(1+r)^t} - C_o \tag{3}$$

2.3. Validity test

A valid instrument means a measuring instrument that can be used to obtain data (measure) what should be measured. The results of the research are valid if there is a similarity between the data collected and the actual data that occurs in the object under study. This study used instruments. A questionnaire to measure attitudes whose answers range from very positive to very negative.

After the results of the collected questionnaire answers were tabulated, then the validity test was carried out with factor analysis, namely by correlating the number of factor scores with the total score. To calculate it, the person product moment formula is used. In the research the validity results show valid results. Validity testing here is done using the statistical package for the social sciences SPSS program.

2.4. Reliability test

A reliable instrument is an instrument used several times to measure the same object that will produce the same data results. Reliable research results, if there are similarities in data at different times. To test the reliability of the instrument in this study, the Alpha Cronbach correlation coefficient was used. If r Alpha is positive and greater than r table then the variable is reliable. General guidelines for determining the reliability of questions if the Cronbach's Alpha value is above 0.497. The higher the alpha coefficient, the higher the consistency of the measured reliability. Reliability testing using SPSS program. The results of the reliability obtained the results of 0.681.

2.5. Associative test

Associative test is used to find and determine the relationship between variables in the study. In this study, the relationship was carried out using a correlation test. The relationship sought in this study is the technical, social, and economic relationship of the existence of a PV system from the results of questionnaires distributed to 16 selected respondents. The correlation test is the spearman test. The results of the correlation test analysis will obtain a p value. The next value is used to test the hypothesis and draw conclusions about the relationship between variables or to state that there is no relationship between variables. If the p value < 0.05, then there is a relationship between the two variables. Associative testing was carried out using the SPSS program.

3. RESULTS AND DISCUSSION

The abundant potential of solar energy in East Nusa Tenggara is certainly something that needs to be utilized optimally. This utilization can be applied in the campus of Marine and Fisheries Polytechnic of Kupang environment. The purpose and benefits of the activity help overcome the limitations of electrical energy in the dormitory and help preserve the environment. This implementation also indirectly supports the policy of the Ministry of Marine Affairs and Fisheries Republic of Indonesia in the blue economy in terms of the world of education. This will be a new thing and a breakthrough in one of the educational centers marine and fisheries in the use of renewable energy.

3.1. Electrical load and solar energy potential

In planning a system, it is necessary to have data on electrical energy demand and electricity payment of Marine and Fisheries Polytechnic of Kupang. From Figures 2 and 3, based on data from 2019–2020, it can be seen that the average monthly electricity demand is 17,770 kWh with a payment of IDR 26,074,767.17. Based on these data, it can be seen that the largest use of electrical energy in 2019 occurred in December of 19,127.56 kWh, while in 2020 it occurred in March of 22,410,28 kWh. This difference is caused because in 2020 there was a Covid-19 pandemic that affected the teaching and learning process on campus.

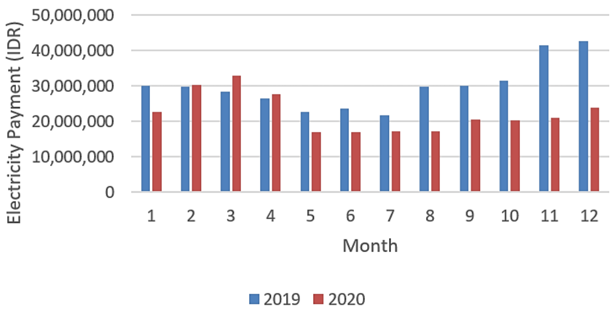

Figure 2. Electricity payment of Marine and Fisheries Polytechnic of Kupang

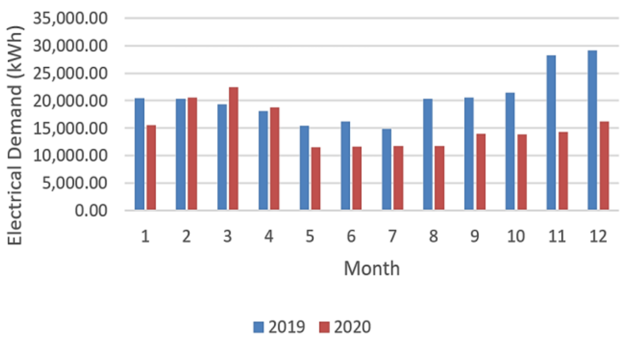

Figure 3. Electrical demand of Marine and Fisheries Polytechnic of Kupang

Table 1 is the result of measuring environmental conditions. Potential for solar energy is 5.43 kWh/m^2/day. The largest amount of solar energy produced occurred in October, at 6.42 kWh/m^2/day and the smallest in January at 4.24 kWh/m^2/day. This data is used as a basis for calculating energy in the manufacture of solar power plants.

Table 1. Measurement of the potential of solar nergy in East Nusa Tenggara

Month	Temp (ºC)	Humidity (%)	Solar Radiation (kWh/m^2/day)	Wind Speed (m/s)
January	27.7	80.7	4.24	1.60
February	27.3	82.2	4.89	1.59
March	27.3	82.6	4.93	1.70
April	27.2	79.9	5.13	2.00
May	26.9	76.1	5.26	2.30
June	25.6	75.7	5.06	2.60
July	25.6	71.5	5.42	2.70
August	25.8	70.0	5.54	2.70
September	26.5	73.5	6.10	2.60
October	28.3	71.8	6.42	2.40
November	28.3	77/3	7.24	2/29
December	28.1	76/8	4.88	1.90

3.2. Energy consumption of dormitory building

Results of measurements in the field when the full load, the total load requirement for the three dormitories is obtained. From the data, it was found that the male dormitory is the dormitory with the largest electrical load, which is 22.806 kW, while the female dormitory with the smallest electrical load is 21.868 kW. Dormitory electrical load data can be seen in Table 2 and Table 3. In this design, the use of electrical energy from solar panels is prioritized to turn on the lighting. While other loads still use electrical energy sourced from State Electricity Company (PLN). Solar power plant system design data can be seen in Table 4.

Table 2. Dormitory building load

Dormitory	Load	Spesification	Quantity
Female	SM Light	2 x LED 20W/1PH/220V	4
	Wall light	2 x LED 4W/1PH/220V	4
	Downlight	LED 7W/1PH/220V	67
	Hanging Lamp	150 W/ 1PH/220V	1
	Downlight	LED 4W/1PH/220V	41
	Garden Light	LED 13W/1PH/220V	5
	Surface Mounted Fluorescent	22 W/1PH/220V	2
	Emergency Light	LED 7W	14
	Panel Box Room	835 W/room	24
Male 1	SM Light	2 x LED 20W/1PH/220V	4
	Wall light	2 x LED 4W/1PH/220V	4
	Downlight	LED 7W/1PH 220V	82
	Hanging Lamp	150 W/1PH/220V	2
	Downlight	LED 4W/1PH/220V	42
	Garden Light	LED 13W/1PH/220V	8
	Surface Mounted Fluorescent	22 W/1PH/220V	4
	Emergency Light	LED 7W	10
	Panel Box Room	835 W / room	24
Male 2	SM Light	2 x LED 20W/1PH/220V	4
	Wall light	2 x LED 4W/1PH/220V	4
	Downlight	LED 7W/1PH/220V	82
	Hanging Lamp	150 W/1PH/220V	2
	Downlight	LED 4W/1PH/220V	42
	Garden Light	LED 13W/1PH/220V	8
	Surface Mounted Fluorescent	22W/1PH/220V	4
	Emergency Light	LED 7W/220V	10
	Panel Box Room	835W/room	24

Table 3. Measurement energy consumption of dormitory building

Dormitory Building	Floor	Load (Watt)			Total Load (Watt)
		R	S	T	
Female	1st	3,729	3,538	4,121	11,388
	2nd	3,542	3,446	3,472	10,480
Male 1	1st	3,743	3,539	4,121	11,403
	2nd	3,743	3,539	4,121	11,403
Male 2	1st	3,743	3,539	4,121	11,403
	2nd	3,743	3,539	4,121	11,403

Table 4. Energy consumption of dormitory building for PV system

Quantity	Specification	Load (W)	Use Hours per Day (h/d)	Energy (Wh)
120	LED Lamp	5	24	14,400
20	LED Lamp	5	24	2,400
1	Backup 10%			1,680
Total Energy				18,480 Wh/day
Total Energy 3 Dormitory				55,440 Wh/d

3.3. Specifications of solar power plant

Based on the data in Table 4, it is known that the amount of electrical energy demand for dormitories is 55,440 Wh/day. Therefore, in planning the system designed 65% of the prepared power of the solar module. From these results obtained a solar power generation system with a power of 9.6 kW to supply the electrical energy needs of each dormitory. The system created can work for 24 hours with autonomy for 2 days without the sun. System specifications can be seen in Table 5 and Figure 4.

For utilization factor is defined as the ratio of the real energy output for the system vs. load consumption. The impact of implemented PV system with PR is 78%. The daily energy production of energy output PV for the system vs. load consumption of the building is calculated as: i) Yearly actual PV yield = 44,294.20 kWh, and ii) Yearly building energy consumption = 20,235.6 kWh. The PV system covered about 218.89 % of the total energy consumption of dormitory buildings.

Table 5. Specifications of solar power plant

Electrical Item	Specification	Quantity
Solar Panel	OSDA Solar 400Wp	72
Solar Module Frame	9,6 kWp PV Support	3
Off-Grid Inverter	iXceed 3 kVA	3
Solar Charge Controller	Vario Track VT 80	6
Battery	OPzV 1500Ah EverExceed	72
PV Junction Box	PV Junction Box	3
Battery Fuse Box	Battery Fuse Box	3
PV AC Box	PV AC Box	3
Installation Cable -Connection	Installation Cable – Connection	3
Grounding Set	Grounding Set	3

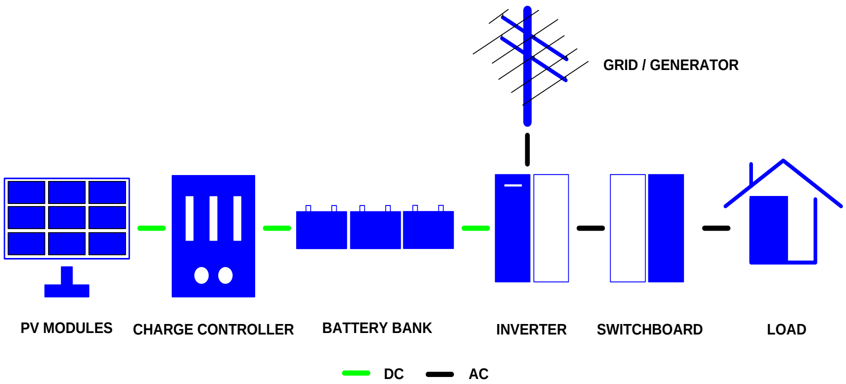

Figure 4. Scheme of dormitory building renewable energy system

3.4. Economic impact of PV installation

To consider the feasibility of investing in solar power plants as renewable energy in the dormitory at Marine and Fisheries Polytechnic of Kupang, it is necessary to do an analysis economy. The feasibility of solar power plants investment is determined based on the results of the calculation of payback period (PP), net present value (NPV), and internal rate of return (IRR), shown in Table 6.

From the table, it can be seen that using solar panels as a source of electrical energy in the marine and fisheries polytechnic dormitory of Kupang with an IRR of 9% is very possible. This will certainly be one of the solutions in saving financing and helping the government in utilizing renewable energy where this potential is very abundant in East Nusa Tenggara.

This economic result can be compared with Palestine which is very rich in solar resources with an annual average of 5.4 hours of peak sunshine and has great potential for PV powered projects. This system works for 12 months from a PV system connected to a 7.68 kWp grid on the rooftops of each of the three schools in Palestine: Al-Razi Boys School, Almueh Boys School and Khawleh Bent Al Azwar Girls. The performance of the implemented PV system shows that the average performance ratio (PR) is 78%, the average annual energy generated by each system is equal to 10,930 MWh/year. The results of the economic analysis encourage to intensify the use of the PV school system because the payback period of the system is <5 years, the resulting kWh cost is about 0.1 US$, the internal rate of return is about 20%. In addition to these results, this paper also presents the impact of the school PV system on the power grid which is represented in reducing losses, and increasing voltage levels, and the effects of PV systems on the environment [4]. The difference in these results may be due to the difference in the price of PV systems which are still relatively expensive in Indonesia.

Table 6. Energy cost calculation and feasibility solar power plant investment

Variable	Description
Investment Cost	Rp. 1,426,385,400.00
Operational and Maintenance Costs/ year	Rp. 14,263,854.00
Saving-1/year	Rp. 162,191,644.64
i	4.25 %
n	25 Years
SPBP	8.79 Years
Net Present Value (NPV)	Rp. 925,717,832.54
IRR	9%

3.5. The technical, economic and social impact of solar power plant

The solar power plants design that will be installed previously is tested first by knowing the relationship from a technical, social, and economic point of view. The technical aspect consists of civil construction, electrical installation, disaster mitigation. The social aspect consists of land use, access to transportation, and vandalism. The economic aspect consists of productivity, electricity load, and economic value. The results of the relationship test can be seen in Tables 7 and 8.

The results with the Spearman test for the technical and social relationship of the PV system obtained a significance value of 0.003 which indicates that the correlation between the use of the PV system on the social is significant (p<0.05). Spearman correlation value of 0.697 indicates that the direction of the correlation is positive with strong strength. In this correlation, it can be interpreted that there is a strong relationship between technical and social with the existence of a PV system. The direction of the positive correlation, indicates the direction. Where the greater the technical value of PV, the greater the social value of the PV user community.

Table 7. Spearman test results for technical and social of PV system

		Social
Technical	r	0.697
	p	0.003
	n	16

Table 8. Spearman test results for technical and economic of PV system

		Economic
Technical	r	-0.730
	p	0.001
	n	16

The results with the Spearman test for the technical and social relationship of the PV system obtained a significance value of 0.001 which indicates that the correlation between the use of the PV system on the economic is significant (p <0.05). Spearman correlation value of -0.730 indicates that the direction of the correlation is negative with strong strength. In this correlation, it can be interpreted that there is a strong relationship between technical and economic with the existence of a PV system. The direction of the negative correlation, indicates the direction. Where the greater the technical value of PV, the smaller the economic value will be. Although the economic value of the solar power generation system gives a negative value, this could be because for now the electricity system provided by the State Electricity Company is more profitable. This could also be due to the fact that currently the solar power generation system in Indonesia is still relatively expensive. but if viewed from the other side, this utilization indirectly helps the government in utilizing new renewable energy and green building at the campus level.

From another social point of view, the use of solar energy as electrical energy also indirectly reduces the damage to health and climate change associated with the production of electricity from fossil fuel sources. Based on research conducted in the United States, educational institutions consume 11% of the US building's electricity consumption and 14% of the building's floor area. These buildings generate 4% of the total US CO_2, thus playing an important role in climate mitigation strategies. Solar PV utilization in educational institutions in the US can provide 100TWh of electrical service annually, and meet 75% of a building's current electrical energy consumption. Utilizing rooftop solar PV electricity services at educational institutions could reduce the damage to health, the environment, and climate change by about $4 billion per year [7]. This will certainly be a good consideration for the application of this technology in Indonesia, especially at the Marine and Fisheries Polytechnic of Kupang.

4. CONCLUSION

The utilization of renewable energy as a source of electrical energy in dormitories can produce 44,294.20 kWh/year. The system used is the hybrid system. The results of the economic analysis encourage intensifying the use of the campus PV system because the payback period is 8.79 years, and the internal rate of return is 9%. The results of the Spearman test of the relationship between technical, social, and economic gave a significant correlation ($p < 0.05$). This shows that the use of solar power plants on campus has a social and economic impact. The use of renewable energy in buildings in dormitories is expected to reduce the use of fossil energy which has a negative impact on the environment and assist government policies to support the use of renewable energy which has great potential in East Nusa Tenggara. From a technical and social point of view, this utilization has a good impact, but from a technical and economic point of view it is still not suitable because it is compared to electricity from the State Electricity Company. However, the use of renewable energy in the Kupang Marine and Fisheries Polytechnic dormitory is expected to be further improved because this area has good potential. The use of renewable energy in buildings in dormitories is expected to reduce the use of fossil energy which has a negative impact on the environment and assist government policies to support the use of renewable energy.

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