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Evaluation of Solar Traffic Lights Design in Indonesia

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Abstract: The design of solar traffic lights must provide reliable service as an accurate solution to overcome congestion caused by traffic light outages due to disconnections of conventional power sources. The main problem of this system is that the resulting output instability depends largely on solar irradiation falling on the surface of the solar panels. Because it is environmentally friendly, solar power can be used as an alternative to generate electricity and unused power can be stored to lithium batteries. The purpose of this study is to evaluate technically and economically to ensure that the installed system operates according to its design specifications and find out the installation cost and compare with the cost of conventional electricity. This technical evaluation is to be able to know about the main components of solar traffic namely solar panels, batteries, and traffic lights load, while the economic evaluation is to calculate the installation cost based on a 25-year projection. Data processing by using Ms excel and RETscreen software. The evaluation results show that IRR, payback period, and NPV are feasible economically and comparison of the installation of traffic light designs using solar cell sources is cheaper than conventional sources.

Keywords: Traffic light, solar cell, techno-economic, RETScreen

I. Introduction

Nowadays, energy demand continues to increase and fossil fuel sources are decreasing, so it is important to find alternative sources such as renewable energy sources. The energy crisis occurring nowadays is due to several reasons such as the high level of pollution, the high demand on energy and the oscillating price of fuel. Moreover, the reasons behind this crisis increase with time and become more complicated.

The increasing concern for environmental pollution has encouraged humans to explore new technologies for the production of electrical energy using clean and renewable sources [1] – [3]. The biggest technological and scientific challenge is developing ways to collect, transform, store, and harness solar energy at an affordable cost [4]. Solar energy through photovoltaic panels contributes significantly to the challenges posed by the rapid growth of energy demand and environmental problems [5].

One of the important stages for implementing new technologies is to study the feasibility of a business plan using several criteria that have been developed by many managements namely that investment feasibility consists of technical and economic aspects [6]. In improving the economy of solar power systems, research efforts should focus on developing more affordable and efficient cell materials [7].

This research is to evaluate the design technically and economically with existing data. In general, this study found out how much the reduction in electricity use using solar traffic lights is compared to conventional electricity consumption. This research, hopefully, can prove that the use of renewable energy using solar panels is very efficient and cost-effective.

II. Literature

Solar power systems include different components that must be selected according to the needs of the type of system, its location, and application. The balance of systems necessary to fully form a functional system capable of supplying power and these components are:

2.1 Solar Traffic Light

Solar Traffic Lights have many uses. Solar Traffic Lights can be used in manufacturing facilities, for pedestrian safety, stop and road signs, vehicle directions, emergency instructions, parking and school zone security. The solar traffic light system as shown in Figure 2.1 consists of four main components as follows: (1) a solar panel that includes a solar cell, (2) a DC to DC converter to keep the output voltage at a constant level, (3) A charge controller to control the flow of charge through the battery and charge when needed, (4) A battery to store electrical energy and use it during the absence of sunlight [8].

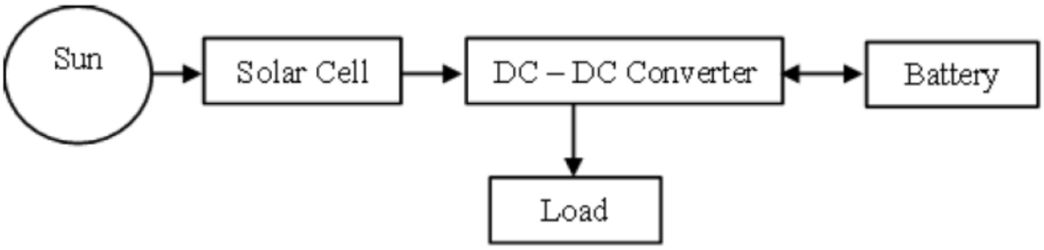

Fig. 1. Block Diagram [8]

2.2 Photovoltaic Cells

The most common material so far is monocrystalline silicon or polycrystalline. Monocrystalline silicon consists of silicon in which the crystal lattice of the entire solid is continuous, that is, it is unbroken to its edges and is free from grain boundaries. Silicon Polycrystalline consists of small crystalline cells also known as crystalline, providing a characteristic metal flake effect on the material. The ratio of cell efficiency of photovoltaic modules is: monocrystalline silicon (14-20%), polycrystalline silicon (15-18%) [9].

Fig. 2. Types of solar cells: monocrystalline silicon (top), polycrystalline silicon (bottom left) [9]

2.3 Battery

The stretching of the system is determined by the storage of the battery, which needs to provide sufficient capacity to supply the energy needs in the days of autonomy when the sun does not provide enough radiation and night.

Fig. 3. Battery

These batteries, usually lead acid are designed to gradually discharge and recharge 80% of the capacity hundreds of times and should not be used on a PV system as it is designed to discharge only about 20% of its capacity. Figure 2.3 is an example of a PV system storage battery image [10]. To estimate the required battery capacity, it is necessary to know the load requirements on the solar system in the worst months as well as the desired autonomy days. When measuring battery storage, the following should be considered as in equation 1:

$$E_{baterai} = \frac{E_{load} \times t_{autonomy}}{V_{battery} \times DOD} \quad \ldots\ldots(1)$$

Where,
E_{load} = load energy demand
$t_{autonomy}$= autonomous day

2.4 Calculation of the Number of Solar Cell

Solar panels are a combination of solar modules to meet the power needs of the load. The capacity of the panel can now be determined using the total energy required and the cumulative energy output of the panel, as in equation 2 [11]:

$$\text{Solar cell Capacity} = \frac{P\ needed}{P\ solar\ cell} \times t \quad \ldots\ldots(2)$$

Where,
P needed = required power
P solar panel = power on solar panel
t = length of effective time of solar irradiation (3-3.5 hours)

2.5 Calculation of the Number of Batteries

Batteries are used as a storage area for electrical energy. Batteries as a tool that is quite important in maintaining the continuity of the distribution of electrical energy to the load constantly, considering the fluctuations in electrical energy released as a result of the ever-changing solar radiation. The capacity of the battery in ampere-hours (Ah) can be calculated by dividing the required energy by the value of the battery voltage as shown in equation 3 below [11]:

$$\text{Battery Capacity} = \frac{N_C \times E_L}{\text{Volt Battery} \times DOD}\ Ah \quad \ldots\ldots(3)$$

Where,
N_c = time required to serve the load without energy input from the solar module (2 days)
E_L = energy demand

2.6 Calculation Battery Control Regulator (BCR)

Battery Control Regulator (BCR) is a controller that works from the solar cell charging system to the battery, if the battery is fully charged, then the BCR will cut off the current from the solar cell. 100 h charge rate for battery bank symbolized by I100, is the maximum current generated by the BCR which is formulated as follows:

$$I100 = \frac{\text{100 h rate capacity for battery bank}}{100} \quad \ldots\ldots(4)$$

2.7 Net Present Value (NPV)

NPV of an investment is another valuation methodology, that is, the difference between the present value of cash inflows and the value of cash outflows associated for investments over a period. As a general rule, a positive NPV indicates that profitable and negative investments indicate net losses and zero is a neutral investment that an investment will not gain or lose value for the company or individual. NPV is calculated according to Equation 5 [12]:

$$\text{Net Present Value (NPV)} = \sum_{t=0}^{N} \frac{CF_N}{(1+i)^t} - C_0 \quad \ldots\ldots(5)$$

Where,
NPV = Net Present Value (Rp);
CF_N = annual net cash flow (Rp);
i = discount rate (%);
t = the period of cash flows (years);
N = number of periods.
Co = initial cost

III. Method

In this paper, a technical and economic evaluation of investment feasibility was carried out. Technically, evaluate the specifics of the materials used in traffic lights. While measuring whether the investment is appropriate from the economic side, then a calculation of the cost comparison between solar and conventional power is carried out, so that it is known whether it is economical or not. In addition, the calculation of investment feasibility by the IRR, PP, and NPV method. In this paper, technical analysis and investment feasibility related to economics The data needed in evaluating technical and economic in the preparation of this article is taken from secondary data, namely data that has been provided. Data processing by using Ms excel and Retscreen software.

IV. Result and Analysis

4.1 Technical Evaluation of Traffic Light Design

The stages passed in the design of the solar traffic light system in Indonesia in this study include:

4.4.1 Load Study

In one cycle from north to west, the direction is clockwise, the traffic light lights on for 120 seconds. To search for the long running time of the solar traffic light system within 24 hours is shown in Tabel 1 as follows:

Table 1. Calculation of the load power of the traffic light

Load		Time On (hour)	Unit	P (Watt)	Total P (W)	Total Wh
Traffic light vehicle	Red	14,2	5	12	60	852
	Green	8,4	3	12	36	302,4
	Yellow	1,4	3	12	36	50,4
Light pedestrian crossing	Red	14,2	2	12	24	340,8
	Green	9,8	2	12	24	235,2
Counter Down	Red	14,2	1	18	18	255,6
	Green	9,8	1	15	15	147
Controller		24	7	20	140	3360
Total					353	5543,4

4.4.2 Solar Panel Capacity Calculation

In this traffic light study using a 100 Wp solar panel and the power used in traffic light here is 353 Watts, with an effective duration of solar irradiation of 3 hours so that the calculation of the solar panels:

$$\text{Solar panel capacity} = \frac{P\ needed}{P\ solar\ cell}\ x\ t = \frac{353}{100}\ x\ 3 \approx 11\ \text{panels}$$

4.4.2 Battery Capacity Calculation

At this solar traffic light, the power required is W or 5543.4 Wh, and the battery used is 12 Vdc 100 Ah. 353

$$\text{Battery Capacity} = \frac{2\ \text{x}\ 5543{,}3}{12\ \text{x}\ 0{,}8} = 1154\ \text{Ah}$$

So that the number of batteries needed to accommodate the battery capacity of 1154 Ah using a counter down, with a specification of 100 Ah batteries used in solar traffic lights, which requires as many as around 12 batteries.

4.2 Economic Evaluation

4.2.1 Initial Cost of Using Solar traffic lights for 25 years.

The load used in this study was a traffic light. The load profile has been outlined in Table 1. After knowing the profile of the load used in the design, then conduct an economic evaluation of the technique by calculating based on the design of the established traffic light, it can be seen in Table 2.

Table 2. Initial cost of solar traffic light

Item		**Price/unit**	**Total**		**Grand Total**
Controler	IDR	6,000,000.00	6	IDR	36,000,000.00
Solar Cell 100 watt / 12 Volt	IDR	4,500,000.00	9	IDR	40,500,000.00
Battery 12 Volt / 100 Ah	IDR	3,240,000.00	9	IDR	29,160,000.00
Lamp R-Y-G 30 cm LED	IDR	3,540,000.00	8	IDR	28,320,000.00
Lamp R-G 20 cm LED pedestrian	IDR	2,100,000.00	4	IDR	8,400,000.00
Counting down 2,5 digit	IDR	12,000,000.00	2	IDR	24,000,000.00
Item etc	IDR			IDR	95,173,200.00
Service work				IDR	47,609,632.00
Grand Total				**IDR**	**309,162,832.00**

In the operational period of 25 years, the cost of repairing or replacing components on solar traffic lights is very necessary because some components of solar traffic lights such as controllers and batteries have a shorter operating life than the operating life of solar panels, so component replacement is required. Cost of replacing or repairing auxiliary controllers shown in Table 3.

Table 3. Cost of replacing or repairing auxiliary controllers

Yearly		**Controller**
0 s.d 5	IDR	6,000,000.00
5 s.d. 10	IDR	6,300,000.00
10 s.d. 15	IDR	6,600,000.00
15 s.d. 20	IDR	6,900,000.00
20 s.d 25	IDR	7,200,000.00
Total	**IDR**	**33,000,000.00**

While the price of the battery for the initial year of installation is IDR 3,240,000.00, inflation per year is also assumed to be 1% and battery replacement is shown in Table 4.

Table 4. Cost of battery replacement/ repair

Yearly		**Battery**
0 s.d 5	IDR	3,240,000.00
5 s.d. 10	IDR	3,402,000.00
10 s.d. 15	IDR	3,564,000.00
15 s.d. 20	IDR	3,726,000.00
20 s.d 25	IDR	3,888,000.00
Total	**IDR**	**17,820,000.00**

The solar system does not use the cost of using electricity accounts, because the solar power system uses solar energy as its source of electricity which is obtained for free. The cost of using the solar power system, only the replacement of solar components, namely controllers and batteries every 5 years for a period of 25 years. The following is a comparison of the installation of traffic lights using solar power sources and conventional source shown in Table 5. The installation of traffic light designs using solar cell sources is cheaper than conventional sources.

Table 5. Comparison of traffic light installation using conventional source and solar cell

Traffic Light Conventional		Cost	Traffic Light Solar Cell		Cost
Initial cost conventional	IDR	242,002,832.00	Initial cost traffic light solar cell	IDR	309,162,832.00
Account Electricity Cost (25 years)	IDR	119,800,477.44	Repair Cost (25 years)	IDR	50,820,000.00
Total	**IDR**	**361,803,309.44**	**Total**	**IDR**	**359,982,832.00**

It can be seen in Table. 6 simulation of cost calculation of solar traffic lights installation with RETscreen software, then obtained for this traffic light, every year an NPV value of IDR 3,440,927.00 is obtained with a discount rate of 0.9%. From the calculation of the payback period for 22.1 years, an IRR of 0.99% it can be concluded that in general the use of solar panels as a source of solar electricity energy is feasibility, considering that generally the use of solar panels reaches 25 years with investment costs covered within a period of 22.1 years.

Table. 6 Simulation of cost calculation of solar traffic lights installation with RETScreen software

Financial viability		
Pre-tax IRR - equity	%	0.99%
Pre-tax IRR - assets	%	0.99%
Simple payback	yr	22.1
Equity payback	yr	22.1
Net Present Value (NPV)	IDR	3,440,927
Annual life cycle savings	IDR/yr	154,317
Benefit-Cost (B-C) ratio		1
Debt service coverage		
GHG reduction cost	IDR/tCO_2	No reduction

Can be seen in Fig. 4, it is graphic cumulative cash flows with RETScreen software. From graphic cumulative cash flows can be concluded that in general the use of solar panels as a source of solar electricity energy is feasibility, considering that generally the use of solar panels reaches 25 years with investment costs covered within a period of 22.1 years.

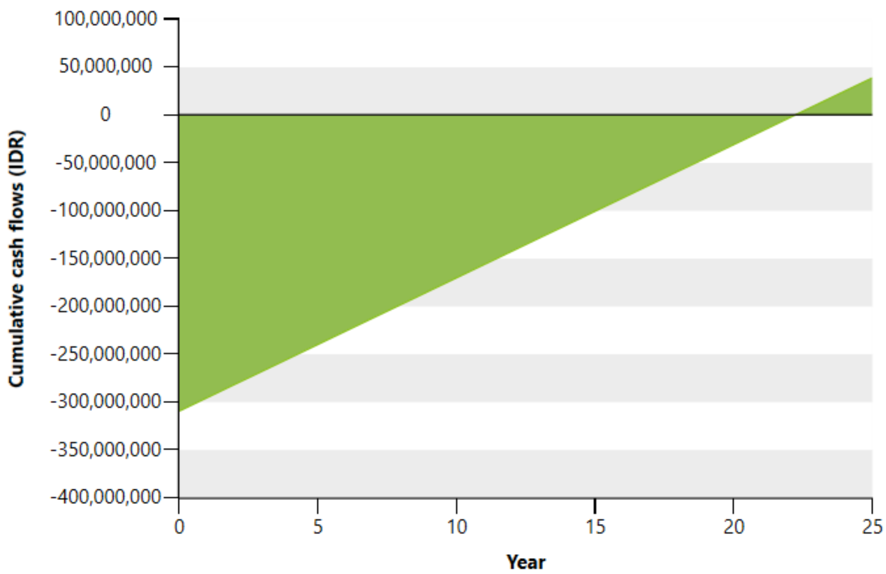

Fig. 4. Graphic cumulative cash flows with RETScreen

V. Conclusion

Based on engineering economic calculations, the investment cost of using solar traffic lights with conventional sources is little difference, but the installation of traffic light designs using solar cell sources is cheaper than conventional sources. This study shows that the cost of installing solar power sources is smaller compared to conventional sources. However, conventional power sources do not require replacement costs, whereas with solar power sources it incurs the cost of replacing equipment for replacing batteries and controllers. Looking at the overall cost in a period of 25 years the use of solar traffic lights is more economical compared to conventional sources. From the calculation of the payback period for 22.1 years, the IRR of 0.99%, and NPV value of IDR 3,440,927.00 can be concluded that in general the use of solar panels as a source of solar electricity energy is feasible, considering that the service life of solar panels reaches 25 years with investment costs covered within a period of 22.1 years.

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