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Techno-economic Analysis of Solar-powered Lighting of Bali above Seawater Toll-road

NM Karmiathi[1], INS Kumara[2], WG Ariastina[3], IW Gunarta[4]
[1]Faculty of Engineering, Udayana University, Indoneisa
[2.3]Department of Electrical Engineering, Faculty of Engineering, Udayana University, Indonesia
[4]Department of Bali Nusra Operation, PT. Indosat, Tbk, Indonesia
*Corresponding author, e-mail: [1]made.karmiathi@yahoo.com, [2]satya.kumara@unud.ac.id,
[3]w.ariastina@unud.ac.id, [4]iwgunarta@yahoo.com

Abstract

The objective of this studywas to obtain atechnical and economic analysis of solar-powered lighting (SPL) implementation at Bali above Seawater Toll-Road. The SPL was designed to operate 12Hours/day with average illumination ≥15-lux. Those requirements can be met byan SPL unit that consists of 2-pieces 87-W LED lights mounted on 10-m double arms pole with 2.37-m arm length and 15º tilt angle. Each LED light was powered by a 260-Wp solar panel, 24V-180AH battery and 10-A solar charge controller. Every SPL unit should be installed on the toll-road median with 22.5-m pole-spacing and required 361-units to illuminate throughout 8,122.5-m toll-road length. Benefits of SPL implementation wereelectricity saving 256.15MWh/yr and carbon emission reduction 217.98TonesCO_2/yr. However, the SPL electrical-based costwas 3.9 times more expensive than conventionalstreet lighting. And based onthe investment feasibility analysis using NPI and PI techniques showed that the SPL implementation was not feasible.

Keywords*: renewable energy, photovoltaic, street lighting, solar-powered lighting, carbon emission, net present value, profitability index*

1. Introduction

Lighting represents almost 20% of global electricity consumption. This consumption is similar to the amount of electricity generated by nuclear power. International Energy Agency (IEA) reported that total savings potential in residential and services lighting was more than 2.4 EJ (Exa Joule) per year by 2030. Recently, several cities have sought to reduce energy consumption and emissions by replacing the aging streetlights with newer technology [1]. As global concern about the negative impact of conventional-based street lighting increases, various research and development on the use of renewable energy for this field continue to develop.

By the end of 2016, there were 205,940 public street lighting (PSL) systems throughout Indonesia that consumed 3,498 GWh of electricity. The electricity cost was IDR4.7 Trillion (USD 341 Million) and released 2.98 Million Tons of CO_2 emission into the atmosphere [2]. Therefore, to save energy and cost as well as to support the government's commitment to reduce GHG emissions in 2020 by 26% (self-effort) and 41% (if assisted by international support) [3], research and development of efficient technology in the PSL sectorhave developed in the country. A study conducted by the Center for Electrical Power Technology and New Renewable Energy and Energy Conservation Ministry of Energy and Mineral Resources reported that the application of efficient street lighting technology could obtain energy savings of up to 65% [4].

Efficient street lighting technology can be obtained by using efficient energy lighting technology and renewable energy source as apower supply. The advance of lighting technologies has produced many types of new lighting devices for roadway lightings. The most promising lighting technologies for roadway lighting includes the light emitting diode (LED), induction, plasma, and metal halide (MH) lighting systems as a substitute for currently high-pressure sodium (HPS) lighting systems [5]. LED luminaires have the potential of increasing illumination uniformity and glare reduction, which improves both the eye comfort and visual discrimination ability of car drivers [6].

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Meanwhile, the possibility of using renewable energy source depends on its availability on a specific location. Among all types of renewable energy source in the country, solar electricity has huge potential and has been utilized slowly both in industrial-type of application or stand-alone applications. The advantages of solar energy are contributed to its sustainability, cleanliness, ease of maintenance and absolute zero noise characteristics [7]. Moreover, there are many tropical countries in this world which receive direct solar irradiation around 1000 W/m^2 [8].

Considering the enormous potential of solar energyfor electricity generation in Indonesia including Bali that reaches 5.33 kWh/m^2/day [9] and availability of LED light, and the fact the government has planned to increase the national capacity of PV through various application has encouraged us to research the implementation of solar-powered lighting at Bali above Seawater Toll-Road. On this research, technical and economic feasibility analysis will be carried out. The objective is to produce detail design of the solar powered lighting for Bali above seawater toll-road which meets the technical requirements and including its economic feasibility.

The techno-economic study for solar street lighting system has been developed in much scientific research works as described in [1], [10], [11], [12]. These studies confirmed that energy consumption ofstreet lighting system is considerably reduced with PV power source, although its initial investment higher than conventional street lighting. Therefore, there is need to know the potential use of solar-powered lighting for toll-road in the case of Indonesia as the implementation of such project is affected by the country's technical standard and also depends on the energy tariffs as well as other factors. The technical analysisis started with the determination of minimum average illumination according to the Indonesian National Standard (SNI). Based on this then lamp capacity is calculated manually and verified using DIAL uxapplication software. Then, the capacity of solar module, battery, and solar charge controller can be determined. While for economic studythe investment feasibility will be carried out using net present value and profitability index techniques.

2. Research Method

This research was conducted at Bali above seawater Toll Road owned by PT. Jasa Marga Bali Tol within period February-July 2016. Data collection includes: (a). Field Observation to obtain geographic coordinate data of the project location, dimension of the toll road, the operation time of street lighting; (b). Literature review to collect data from various relevant sources such as regulations related to toll-road lighting, solar insolation data, light technical data, solar panel, solar charge controller, battery, and others; and (c). Interview with the related partyat the company.

The stage of works carried out in this study includes: reviewing the toll-road lighting system specification according to SNI and related literature. Second: conducting technical analysis that consists of: (a). Determination of light source, i.e., initial flux, lamp type, and capacity manually and verified using Dialux Software; (b). Calculation of electrical components, i.e. solar panel, solar charge controller and battery; and (c). Determination of supporting structure components, i.e. pole height, arm length and tilt angle. Third: analysis of energy conservation. Fourth: analysis ofthe cost of energy and investment feasibility. And finally, the conclusion of the results and discussion.

3. Results and Analysis

3.1. Technical Data of Bali above Seawater Toll-Road

The toll road is located above the Sea of Benoa Bay Bali with coordinate 8.745ºS/ 115.196ºE which connects Ngurah Rai Airport, Benoa Harbor, and Nusa Dua Tourism Area. The toll road has two paths, the East path with traffic direction from Benoa to Airport or Nusa Dua and West pathin the opposite direction. Each path has 3 Sub-lines, Motorcycle Sub-line with 3.2-mwidth, Outer Shoulder Sub Line with 2.5-m width and Four-Wheels Vehicle+Inner Shoulder Sub line with 7.5-m width. These two paths are separated by 2-m median width. The total length of this toll road construction is 8,122.5-m [13]. To ensure the comfort and safety of toll road users, especially atthe night or dark conditions, refer to SNI 7391:2008, the street lighting of the toll road is required to have lighting quality specification such as illumination average ≥ 15-Lux and uniformity > 0.3 [14]. The toll road lighting planned to operate 12 hours/day (6:00 AM- 06:00 PM).

3.2. Technical Analysis of Solar-Powered Street Lighting

3.2.1. Determination of Initial Flux and Capacity of Lamp

Firstly, we will determine initial flux, ϕ of the lamp that required for toll road manually, using equation [15]:

$$\phi = \frac{\mathrm{E}ave \text{ x } \mathrm{Ps}\ x\ WR}{Cu\ x\ MF} \tag{1}$$

Where,

a. E_{ave}, minimum average illumination, has been determined 15-Lux in section 3.1;
b. P_s, Pole spacing, the distance between thepole of street lighting: n x distance of piles of the toll road (for structure stability reason, the pole must be mounted above of pile, while the distance between piles is 7.5-m). On this project selected n = 3, so P_s = 3x7.5m = 22.5-m;
c. W_R, total width of the road forone-way path: 13.2-meter (i.e.: road width of motorcycle sub-line + outer shoulder sub-line + four-wheels vehicle & inner shoulder sub line);
d. M_F, maintenance factor = *LLD* x *LDD*, which *LLD* (Lamp Lumens Depreciation) for LED lights: 0.7 [16], while *LDD* (Luminaire Dirt Depreciation) is assumed to be equal to 1, in respect of lamp installed on top of pole above of toll-road over the sea, where the lamp cover always considered in a clean condition from dust. So that M_F = 0.7.
e. C_U, the coefficient of utilization; obtained from the Utilization Factor Curve of the lamp by the ratio of road width to pole height (*H*) of the lamp (W_R/H). The pole height is chosen 10-m so that W_R/H= 1.32, if the lamp to be used is Philips LED, using the Curve Utilization Factor in [17], then CU can be obtained equal to 0.6.

So if all of the values above are inserted into equation (1), then ϕ = 10,607-Lumens.

Considering that LED light has a high efficiency or luminous efficacy, a good color rendering Index and a long lifetime then referring to [17], a luminaire or lamp type will be selected which can provide an initial flux more than 10,607 lumens, then for this project to be selected Philips LED 87W (BGP322 T35 1xGRN114-3S/657 DN).

Furthermore, the results of manual calculation will be verified using DIALux 4.12 application [18], a software application of lighting design and planning. By entering toll-road profile, maintenance factor, and selected lamp type, then we got the output as follow:

a. Summary of road profiles and luminaire arrangement consists of luminaire type and capacity, initial flux, pole height, placement and spacing, arm length and angle as shown in Figure 1.

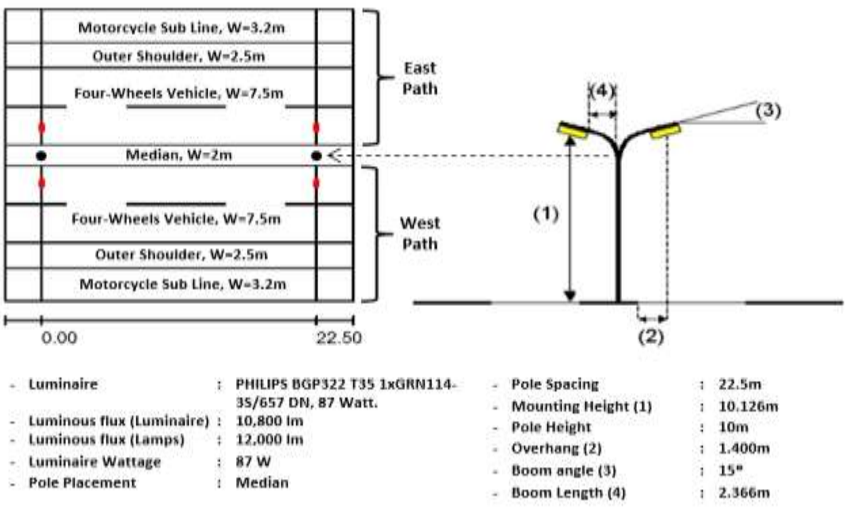

Figure 1. Summary of road profiles & luminaire arrangement

b. Valuation Field as shown in Figure 2, where the average illumination, E_{ave}, and uniformity, E_{min}/E_{max} per sub-lineof both east and west paths respectively are obtainedas follow: motorcycle line: 15Lux and 0.710; Outer Shoulder line: 20Lux and 0.691; Four-Wheels Vehicles line: 22Lux and 0.358.

Based on the manual calculation and DIALux verification, there can be concluded the proposed SPL design can meet the requirements. The toll-road lighting specifications are to generate average illumination of ≥ 15-Lux and uniformity of greater than 0.3. The SPL design consists of 87-W LED light, 10-meter double-arms pole with 2.366-meter length arm and tilt angle of 15°, the pole is placed on the toll-road median with a 22.5-meter pole spacing.

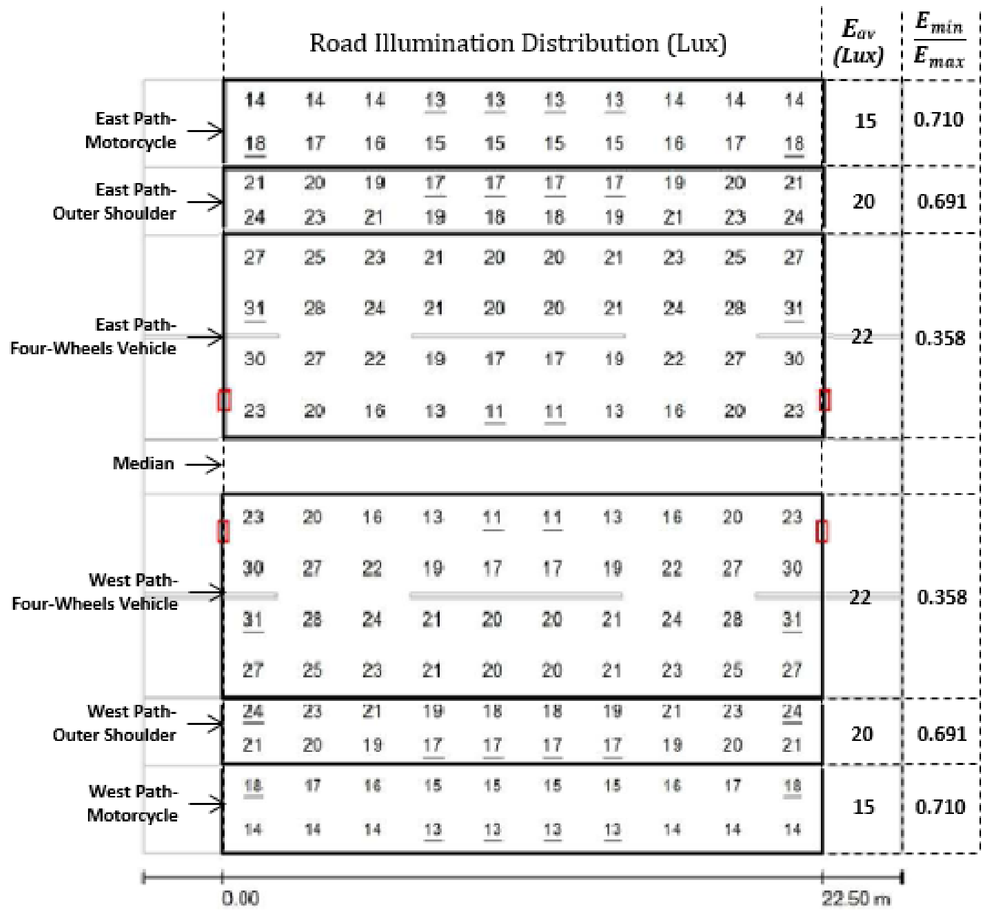

Figure 2. Valuation field-illumination distribution

3.2.2. Power Supply Determining

3.2.2.1. Solar Panel

The Solar Panel or photovoltaic area, PV_{Area} that needed to power up the road lighting can be calculated using equation [19]

$$PVArea = \frac{E_L}{G_{av}\, x\, \eta_{PV}\, x\, T_{CF}\, x\, \eta_{Out}} \quad (2)$$

Where,

E_L, the average daily energy requirement of a single point of street lighting point can be calculated from the lamp power capacity (87-W) multiplied by the operating time of the lighting (12 hours/day) then E_L= 1.044kWh.

G_{av}, the daily solar insolation value at toll-road location obtained from NASA data as shown in Table 1 [9]. The minimum insolation value on July was 4.79kWh/m2/day is selected, to ensure the system normally works under the worst conditions.

Table 1. Monthly Averaged Insolation Incident on Toll-road Location (kWh/m2/day)

Lat: -8.745 Long: 115.196	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-Year Average	4.93	5.04	5.43	5.39	5.19	4.84	4.79	5.33	5.95	6.19	5.67	5.28	5.33

η_{PV}, Solar panel efficiency, is determined at 16% referring to the datasheet of Solar panel [20] chosen for this project. While the T_{CF} (Temperature Correction Factor) value can be calculated using equation [21] as below:

$$T_{CF} = \frac{P_{\mathrm{MPP\ at\ t°C}}}{P_{MPP}} \quad (3)$$

P_{MPP}, solar panel maximum peak power is 260Wp in STC (standard test condition) at module temperature 25°C with 1000W/m^2 solar irradiation, according to solar panel datasheet [20]. The solar panel TCP (temperature coefficient of power) is -0.41%/°C, so solar panel output power will decrease by 0.41% every increase per 1°C of module temperature. Considering that solar panel will be mounted on lighting pole above of seawater toll-road with free air under the panel for optimal cooling, then it is assumed that solar panel will work at not more than maximum value of Nominal Operating Cell Temperature (NOCT: 45±3°C) of 48°C or experience a temperature rise of 23°C compared to STC at 25°C. Thus, a decrease of the solar panel power output in the event of module temperature rise to 23°C is 24.518Watt, obtained using following equation [21]:

$$P_{at\ T\ rise\ 23°C} = TCP\%/°C \times P_{MPP} \times \text{Temperature rise (°C)} = 0.41\%/°C \times 260W \times 23°C = 24.518\text{Watt},$$

Then $P_{MPP\ \mathrm{at\ 48°C}}$, solar panel maximum peak power when the module temperature reaches 48°C is 235.482Watt, obtained from calculation using equation [8]:

$$P_{MPP\ at\ 48°C} = P_{MPP} - P_{at\ T\ rise\ 23°C} = 260-24.518 = 235.482 \text{ Watt}$$

Thus, T_{CF}Temperature Correction Factor calculated using equation (3) is 91%.

The output efficiency (η_{out}) is determined by the multiplication efficiency of SCC (solar charge controller) and battery [19]. From the MPPT 75/10 BlueSolar datasheet (SCC selected in this project), the SCC's efficiency is 98% [22] while the battery efficiency is 95%, got from the 24-V 180AH Lithium Iron Edison datasheet in [23], then η_{out} = 93.1%.

By entering the values of E_L, G_{av}, η_{PV}, T_{CF} and η_{out} into equation (2), we obtain the Solar Panel area, PV_{Area}=1.616m^2. The minimum peak power that must be generated by the solar panel to be used in this project can be calculated using equation [21]:

$$Watt_{\ peak} = PV_{Area} \times PSI \times \eta_{PV} \quad (4)$$

In which, PV_{Area} of 1.616m^2, PSI (Peak Sun Insolation) of 1,000 W/m^2 and the efficiency of thesolar panel selected η_{PV} of 16%, then using equation (4), we obtain $P_{Wattpeak}$of 258.5*Wp*. After PV_{Area} and $P_{Wattpeak}$ are known, thena solar panel with appropriated dimensions and capacityis selected. Due to this reason, the most efficient solar panel is mono-crystalline silicon [24], we select mono-crystalline 260-Wp Solar panel.

While the number of solar panels required can be calculated using equation [21]: Number of solar panels = $\frac{P_{watt\ peak}}{P_{MPP}}$ =0.995≈1pc. For maximum solar energy capture, the azimuth angle of the solar panel should be chosen based on geographical location of the module. Since toll road project is located in the south of the equator, then azimuth angle of zero is used, or effectively solar panel faces to thenorth. To enable the natural cleaning process of the solar panel surface with the help of raindrops, thesolar panel will be installedat atilt angle of around 5° to 15° [24].

3.2.2.2. Battery Sizing

The lithium battery has various advantageous characteristics such as high energy density so that its sizeis smaller and easily installed in a box mounted on street lighting pole. Also, it has a stable performance at high temperature (>33ºC). This is useful since it will be installed in a box, where practically its temperature is approximately 10-15ºC higher than outside air temperature (28ºC in average). Moreover, it has a long life cycle and a high deep of discharge (DoD) so that does not require a frequent replacement which affectsto operational costs during project lifetime (up to 20 years). It has high efficiency of charging which is important as it functions as energy storage. Due to these characteristics then Lithium battery is selected.

The capacity of the battery (C_{batt}), is calculated using equation [19]:

$$C_{batt} = \frac{N\ x\ E_L}{V_S\ x\ DOD\ x\ \eta out} \quad (5)$$

Where, N, the number of autonomy days or when the battery can keep the system remain normal under thecondition when there is no power generated by a solar panel (in heavy cloudy or raining continuously), assumed for 3 days;

E_L, energy requirements of toll-road lighting have been calculated at 1.044 kWh; V_S, Bus voltage or voltage between the battery terminals is selected for 24V. DoD, Deep of Discharge is determined from the battery life cycle graphics based on DoD Lithium batteries found in [23]. From the graph in [23], DoD is set at 80%. While output efficiency (η_{out}) which is a multiplication of battery efficiency and SCC, has been calculated previously by 93.1%, then calculated using equation (5), C_{batt}, battery capacity that required is 175.2Ah. Therefore, we select1-unit Lithium Iron Battery of 24V-180Ah.

3.2.2.3. Solar Charge Controller Determination

Solar charge controller (SCC) functions to regulate charging and discharging of the battery, providing protection system to protect battery and lamp and have timer function to ensure operating hours of lighting. Regarding capacity, SCC must be able to handle the maximum current capacity of Isc short circuit, Peak Power (Wp) of thesolar panel as well as selected bus voltage.

According to the above discussion, it has been determined that the selected Solar Panels are LEN 260Wp Monocrystalline which has the following specifications: (a). Short circuit current (Isc) of 9.15A; (b). Peak Power, Pmax of 260Wp. Then the selected SCC must have a specification equal to or greater than the above value. Therefore, for this project, we select MPPT 75/10 BlueSolar Charge Controller which has following specification [22]: (a) short circuit current 10A, (b). peak power at voltage 24V, 270Wp and (c). battery charge voltage: 12V/24V.

3.2.2.4. Support Structural Components

The solar-powered street lighting structure component consists of supporting pole, double arms, solar panel support as well as for battery and SCC box. The selection of these structural components consider the load to be handled, i.e. the weight of lighting lamp (16.9Kg) [17], solar panel (2x19.5Kg) [20], SCC (2x0.5Kg) [22], battery (2x77.11Kg) [23], and battery & SCC box (2x10Kg) with total weight of 248.02Kg and wind load of these components. Also, the selection of materials to be used should consider using anti-corrosion materials since the location of toll road above of seawater.

Therefore, pole type that to be selected is octagonal pole which is at least able to carry total component load 248.02kg. To ensure the lifetime of the structure during the project and to consider the location of the project in the corrosion area due to sea water, the selected steel material protected by hot deep galvanized.

As for the dimensions of the structural components based on the results of verification using DIALux application has been determined that the pole height was 10m, the length of double arms 2.366-meter respectively with arm tilt angle of 15° where the pole mounted on the median toll-road with 22.5-meter pole spacing. So that based on the discussion in section 3.2, all components of solar-powered toll-road lighting can be summarized as shown in Figure 3.

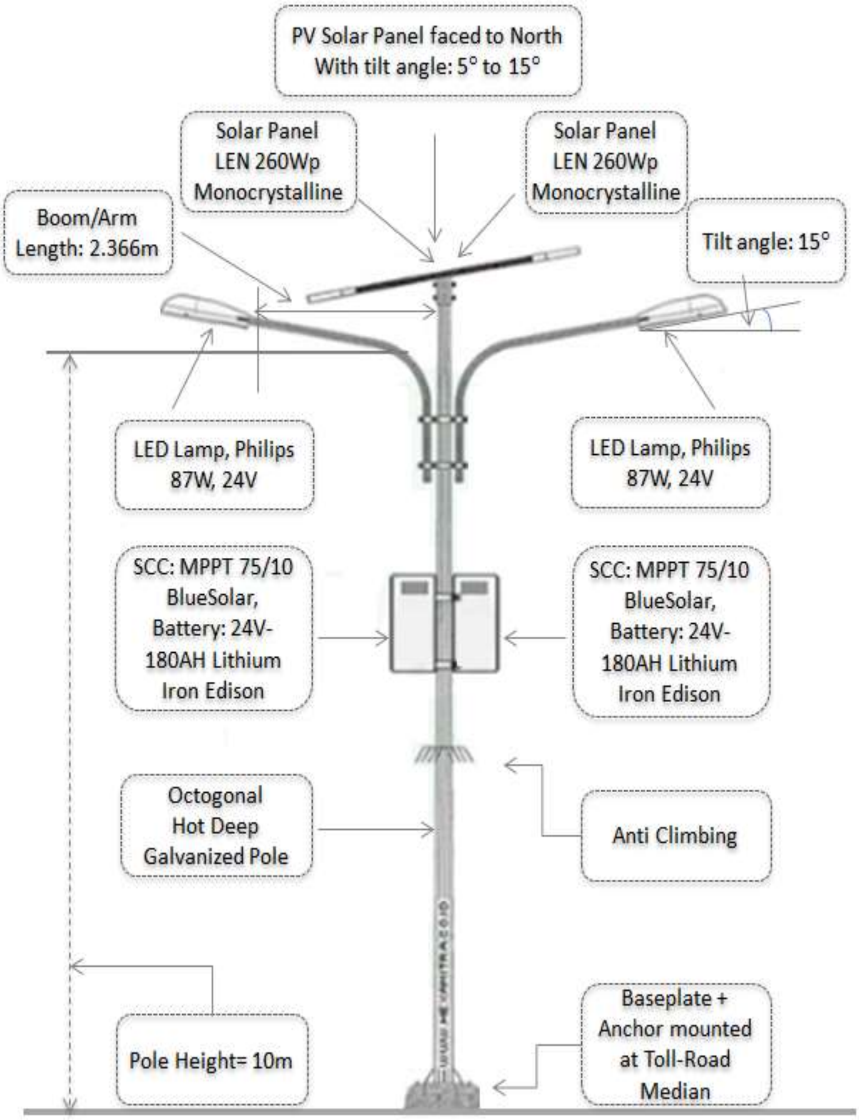

Figure 3. Summarized of solar-powered toll-road lighting design

3.3. Energy Conservation Analysis

The amount of annual electrical energy consumed by street lighting can be calculated using the equation:=Lamp Wattage x Number of Lamps per Pole x Number of Poles x Operation Time per Day x Number of Days in a Year = 275.13MWh.

From the following variables i.e.: lamp wattage is 87W; number of lamps per pole is 2 (using pole with double arms); number of poles are 361 units (toll-road length (8,122.5m) divided by pole spacing (22.5m)); operation time is 12Hours/Day, and number of days in a year is 365.

By the implementation of solar-powered lighting on the toll-road, above electrical energy consumption will become a potential of energy saving of 275.13MWh per year which is equivalent to a cost saving of IDR369,487,802.25 per year (calculated using PLN basic electricity tariff April 2016, IDR1,342.98/kWh). Referring to 2016 Indonesia average grid emission factor of 0.851kgCO_2/kWh [25], carbon emissions that can be reduced by implementation of solar-powered toll-road lighting on this project is 234.13TonesCO_2/year.

If the carbon emission reduction is sold through emission trading system (ETS) mechanism using effective carbon rate of 30Euro/Ton [26] and with an exchange rate of IDR14,408.45/Euro [27], then the amount of estimated sales proceeds of carbon emissions reduction is IDR101,204,224.01.

3.4. Economic Analysis

3.4.1. Life Cycle Cost

Lifecycle cost (LCC) is a method that calculates the overall cost of a system from planning, development, operation & maintenance and equipment replacement over the life of the system. LCC can be calculated using formula or equation [21]:

$$LCC = C + M_{PW} + R_{PW} \quad (6)$$

Where, C is the capital expenditure or initial investment cost of solar-powered lighting. The initial investment cost per unit of double arms solar powered lighting in this project is shown in Table 2. So the total investment cost required for total 361 units of SPL is IDR14,188,924.500. $\boldsymbol{M_{PW}}$, the present value of maintenance costs which can be calculated by equation [28]:

$$M_{PW} = M\left(\frac{1+i}{1+d}\right)\left[\frac{1-\left(\frac{1+i}{1+d}\right)^N}{1-\left(\frac{1+i}{1+d}\right)}\right] \quad (7)$$

Which are: ***M***is maintenance cost of SPL, assumed to be 1% of total investment cost of IDR141,889,245 per year; ***N*** is project life time for 20 years based on the duration of the solar panel warranty given by the manufacturer; ***d*** is the discount rate applied in this project is determined based on the average prime interest rate of corporation loan of BI (Bank of Indonesia) end of March 2016 at 10.45% [27]; and ***i*** is inflation rate, taken from the average value January 2014 to November 2016 of 5.51% [24]. Then using equation (7), $\boldsymbol{M_{PW}}$ that obtained is IDR1,816,916,802.41.

R_{PW}, the present value of component replacement cost over the project lifetime. It is assumed that some components lifetime such as solar panels and structural components are more than 20 years. While for battery and LED lighthaveto define separately. Refer to the datasheet, Philips LED 87W has a lifetime 50.000hour which is equivalent to 11 years for 12 hours per day operating time. So, for 20 years of project lifetime, LED light requires for replacement as much as one time, i.e., at the beginning of the12th year. According to the graph in [21], if the battery is designed to work on DoD 80%,hence life cycle equal to 2,000-cycles.The battery is planned to work one cycle per day which means charging during daytime and discharging at night) hence the battery life is 2,000 days or around five years. So, for 20 years of project lifetime, it will take batteries replacement once every five years for three times ,i.e., the beginning of 6th, 12th and 18th years. Thus, $\boldsymbol{R_{PW}}$ can be calculated using the equation:

$$R_{PW} = R_{PW(LED\ light\ 12thYear)} + R_{PW(Battery\ 6th\ Year)} + R_{PW(Battery\ 12th\ Year)} + R_{PW(Battery\ 18th\ Year)} \quad (8)$$

Where,

$R_{PW(LED\ light\ 12th\ Year)}$, the present value of the LED light replacement on the 12th year, calculated by equation [21]:

$$R_{PW(LED\ light\ 12th\ Year)} = R_{(LED\ light)}\left(\frac{1+i}{1+d}\right)^N \quad (9)$$

$R_{(LED\ light)}$, the initial investment cost of purchasing LED lights for IDR2,129,900,000 (obtained from 361 Units SPL x IDR5,900,000-refer to Table 2); N = 12 (12th year of LED light replacement) and previously determined d=10.45% and i=5.51%. So from equation (9), we obtain $R_{PW(LED\ light\ 12th\ Year)}$ =IDR1,229,968,665.33. $R_{PW(Battery\ 6th\ Year)}$,the present value of battery replacement on the 6th year, calculated by the equation [21]:

$$R_{PW(Battery\ 6th\ Year)} = R_{(Battery)}\left(\frac{1+i}{1+d}\right)^{N} \quad (10)$$

$R_{(Battery)}$, the initial investment of battery isIDR4,197,708,000 (obtained from 361 units SPL x IDR 11,628,000-referring to Table 2); *N*=6 (6th year of battery replacement) and the same value for ***d*** and ***i***as above, then from equation (10), $R_{PW(Battery\ 6th\ Year)}$= IDR3,189,918,901.59

With the same manner, by substitute *N*=12and 18(12th and 18th year of battery replacement), we get $R_{PW(Battery\ 12th\ Year)}$= IDR2,424,080,617.02 and $R_{PW(Battery\ 18th\ Year)}$= IDR1,842,105,401.14 respectively. Then from equation (8), we will get R_{PW} of IDR8,686,073,585. So finally, from equation (6), we will get LCC of IDR24,691,914,887.49.

3.4.2. Unit Electrical Cost

UEC, Unit Electrical Cost of Solar-Powered Street Lighting can be calculated by applying equation [19]:

$$UEC = \frac{ALCC}{A\ kWh} \quad (11)$$

Where,

ALCC, annual basis of the SPL life cycle can be calculated by equation [9]:

$$ALCC = LCC\frac{\left[1-\left(\frac{1+i}{1+d}\right)\right]}{\left[1-\left(\frac{1+i}{1+d}\right)^{N}\right]} \quad (12)$$

With N=20 (refer to project lifetime), *i*, *d* and *LCC* have been defined previously, then using equation (12) *ALCC* that obtained isIDR. 1,842,031,746

Akwh is the electrical energy consumed by SPL to operate for one year, has been calculated in section 3.3, i.e., by 275,125.32kWh. So, by using equation (11), we can get the Unit Electrical Cost of Energy *UEC* of solar-powered toll-road lighting is **IDR. 6,695.25/kWh**. This value is approximately **3.9 times** more expensive than the rate charged for conventional street lighting (using April 2016 PT. PLN Basic Electricity Tariff, IDR 1,342.98/ kWh).

3.4.3. Investment Feasibility Analysis

The investment feasibility analysis technique that will be used to analyze SPL investment in this project is NPV (Present Net Value) and PI (Profitability Index).

(a) NPV (Present Net Value)

Net Present Value investment feasibility, *NPV* can be calculated using equation [21]:

$$NPV = \sum_{t=1}^{n} PVNCF_t - C \quad (13)$$

With the criteria: if NPV>0 then the investment is considered to be feasible, and if NPV<0 then Investment is considered to be not feasible. Meanwhile, $PVNCF_t$, present value net cash flow, obtained from equation [21]:

$$PVNCF_t = NCF_t.DF_t \quad (14)$$

Where: NCF_t, net cash flow from the first year to nth year, obtained by subtracting Cash-In by Cash-Out:

$$NCF = Cash\text{-}In - Cash\text{-}out \quad (15)$$

Cash-In or Cash flows entry into this project consists of two parts: (a) the result of electrical energy cost savings and (b) the sales proceeds of carbon emissions reductions that calculated in section 3.3-in the amount of IDR369,487,802/year and IDR101,204,224/year respectively.

Table 2. Initial Investment Cost of Double Arms Solar Powered Toll-Road Lighting

No	Components	QTY	Unit	Unit Price (IDR)	Total Price (IDR)	Composititon
1	LED lamp-philips BGP353 T15 1xGRN107-35/740 DN	2	pc	2.950.000	5.900.000	15%
2	Solar panel-len 260Wp monorcrystalline	2	pc	3.238.000	6.477.000	16%
3	Solar charge controller-MPPT 75/10 blue solar, 10A	2	pc	2.350.000	4.700.000	12%
4	Battery-24V 180AH lithium iron Edison	2	pc	5.814.000	11.628.000	30%
5	Power Cabling 2x2,5mm NYHY & accessoris	2	set	612.000	1.224.000	3%
6	Octogonal pole-double arms 10m	1	set	4.641.000	4.641.000	12%
7	Box for SCC & battery	2	pc	1.402.000	2.805.000	7%
8	Installation cost	1	lot	1.929.500	1.929.500	5%
	Total Cost				**39.304.500**	

Cash-Outor expense of this project consists of: (a) Maintenance Cost, *M* amounting to IDR141,889,245/yr; (b) LED light Replacement Cost, $R_{(LED\ light)}$ 1 time on the 12th year of IDR2,129,900,000; and (c) Battery Replacement Cost, $R_{(Battery)}$ 3 times on the 6th, 12th and 18th year of IDR4,197,708,000 respectively. *DF*, adiscount factor which can be calculated by equation [21]

$$DF_t = \frac{1}{(1+d)^t} \tag{16}$$

Where *d* is the discount rate or the interest rate of 10.45%

t is the project lifetime period from 1st to 20th years.

C, capital expenditure or initial investment value of SPLS has been set at IDR14,188,924,500. If all the above values are tabulated, it will be arranged according to Table 3.

From Table 3, it is known that at the end of the 20th year the Accumulated Present Value of Net Cash Flow, $\sum_{t=1}^{20} PVNCF_t$= -IDR2,218,029,498. So by using equation (13) we obtain NPV = -IDR16,406,953,998. Since NPV value is negative, then according to the criteria of NPV, then the investment is considered not feasible.

(b) PI (Profitability Index) Profitability Index (PI) investment feasibility technique is calculated using equation [21]:

$$PI = \frac{\sum_{t=1}^{n} PVNCF_t}{C} \tag{17}$$

With the criteria: if PI>1 then investment is considered to be feasible, and if NPV<1 then Investment is considered to be not feasible. By entering the Accumulated Present Value of Net Cash Flow $\sum_{t=1}^{20} PVNCF_t$= -IDR2,218,029,498 and C = IDR14.188.924.500 into equation (17), then we get the value of profitability index, PI = -0.156. Since PI value is less than 1, according to the criteria of decision making for Profitability Index technique, this investment is considered not feasible.

Based on the result of economic investment feasibility studies above, it is known that the UEC is very expensive and the investment is considered not feasible. The high value of UEC (IDR6,695.25/kWh) refer to equation (11) and (6) is caused by the high cost of initial investment, C - which in turn affects maintenance costs and the cost of replacing batteries and LED lights, which is quite high compare to annual electricity energy consumed by SPL.

The SPL investment is not feasible according to NPV and PI techniques since the initial investment cost is much greater than the cumulative present value of net cash flow (refer to equation (13) and (17)). The high initial investment mostly (>70% refer to Table 2) contributed by the high cost of purchasing lithium batteries (30%), solar panels (16%), LED lights (15%) and SCC (12%). The high price of lithium batteries, solar panels, LED lights and SCC arebecause the current production cost is still very high and most of them are imported from abroad (both raw materials or imported as finished goods) those subject to high value-added tax and import duty.

Table 3. Present Value Net Cash Flow Calculation Result

YEAR	CASH-IN: Electricity Cost Saving (000)	CASH-IN: Carbon Emission Reduction (000)	CASH-IN: Maintenance Cost (000)	CASH-OUT: Replacement Cost (000) Battery	CASH-OUT: Replacement Cost (000) LED Lamp	Net Cash Flow (NCF) (000)	DF (Discount Factor), i= 10.45%	PVNCFt= NCFt*DFt (000)	Cummulative , ∑NCFt*DFt (000)
0	-	-	-	-	-	-	1.0000	-	-
1	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.9054	297,693,781	297,693,781
2	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.8197	269,528,095	567,221,876
3	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.7422	244,027,248	811,249,124
4	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.6720	220,939,111	1,032,188,235
5	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.6084	200,035,410	1,232,223,645
6	369,487,802	101,204,224	141,889,245	4,197,708	-	-3,868,905,219	0.5508	-2,131,050,636	-898,826,991
7	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.4987	163,974,170	-734,852,821
8	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.4515	148,460,090	-586,392,731
9	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.4088	134,413,844	-451,978,887
10	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.3701	121,696,554	-330,282,333
11	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.3351	110,182,484	-220,099,849
12	369,487,802	101,204,224	141,889,245	4,197,708	2,129,900	-5,998,805,219	0.3034	-1,820,019,823	-2,040,119,671
13	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.2747	90,319,416	-1,949,800,256
14	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.2487	81,774,030	-1,868,026,226
15	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.2252	74,037,148	-1,793,989,078
16	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.2039	67,032,275	-1,726,956,803
17	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.1846	60,690,154	-1,666,266,649
18	369,487,802	101,204,224	141,889,245	4,197,708	-	-3,868,905,219	0.1671	-646,554,482	-2,312,821,131
19	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.1513	49,749,280	-2,263,071,851
20	369,487,802	101,204,224	141,889,245	-	-	328,802,781	0.1370	45,042,354	-2,218,029,498
							Cummulative ∑NCFt*DFt	-2,218,029,498	

The manufacturers and the government of Indonesia can work together to reduce the price of those products. Manufacturers are conducting R&D continuously to improve the efficiency and to lower production costs. In the last decade, production costs of lithium batteries, solar panels, LED lights and SCC are tendto decline in one hand and followed by the increasing energy density and life cycle base of batteries; increased efficiency of solar panels; increased efficacy (lm/watts) and life cycle of LED lights on the other hand.

While the Government of Indonesia may support it through fiscal policy, namely: (i) include LED lights, solar panels, lithium batteries and SCC as strategic products as stipulated in Government Regulation No: 31 Year 2007 on Reduction of Value Added Tax (VAT) for the Import and or Delivery of Certain Taxable Goods that are Strategic and (ii) include LED lights, Solar Panels, Lithium Batteries and SCC to obtain import duty reduction facilities as regulated by Regulation of the Minister of Finance No.: 154/PMK.011/2008 concerning the Exemption of Import Duty on the Import of Capital Goods in the Framework of Development and Development of Power Generating Industries for Public Interest [29]. So, that in the future, will enable SPL systems to be designed more efficiently, more compact and cheaper than per unit electrical cost of SPL is expected to be more competitive and finally, SPL investment is expected to become feasible.

4. Conclusion

According to technical analysis result, to fulfill requirement in providing average illumination ≥ 15-lux and uniformity > 0.3 on the Bali above seawater Toll-Road, the proposed SPL has to have the following specifications: every unit consists of 2 pieces of LED light 87-W,which are mounted on a 10-meter height-double arms octagonal pole with arm length and arm tilt angle 2.366-meter and 15° respectively. Each LED light is powered upbythe 260-Wp monocrystalline solar panel, 24V-180AH lithium battery, and 10-A MPPT solar charge controller. Every SPL unit should be installed on thetoll-road median with 22.5m pole spacing and required

361 units in total to illuminate throughout the toll-road length. The benefits of SPL Implementation are electricity saving 275.13MWh/year and carbon emission reduction 234.13T ones CO_2 per year those are worth IDR369,487,802.25 per year and IDR101,204,224.01 per year respectively.

However, based on the economic analysis, it is known that the per unit electrical cost of SPL is quite high, i.e., IDR6,695.25/kWhor approximately 3.9 times more expensive than conventional street lighting electricity tariff. While investment feasibility analysis isresulting NPV=-IDR16,406,953,998 (NPV<0) and PI:-0.156 (PI<1) those indicate that SPL investment of this project is not feasible.

The expensive of per unit electrical cost and unfeasibility of SPL investment are caused by high cost of initial investment which is more than 70% contributed by the price of batteries, solar panels, LED lights and SCC. Manufacturers of these products and the government can work together to reduce the price of these components. Manufacturers are continuously conducting R&D to improve efficiency and lowering production costs, while governments can support it with a series of fiscal policies such as lowering or even eliminating value-added taxes and import duties for such items that play a role in supporting energy conservation. Thus, in the future, the implementation of SPL will be more competitive and feasible.

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