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Technoeconomic and environment assessment of rural electrification using solar photovoltaic (Case study in Parang Island, Indonesia)

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Abstract

This study evaluates technoeconomic and environment assessment of solar photovoltaic (PV) system in Parang Island, Indonesia. Up to 2014, electricity in Parang Island was generated from diesel generator. Supply for diesel fuel is prone to scarcity, especially when the supply from Java stopped during high waves. Installation solar PV for electricity improves energy access in Parang Island, as well as reducing carbon dioxide (CO_2) emission from fossil-based fuel. However, performance of the system should be evaluated by conducting assessment using sustainability indicators. The assessment analyzed technoeconomic and environment indicators, i.e. capacity factor, daily service operation, levelized cost of electricity (LCOE), payback period, internal rate of return (IRR), and carbon dioxide (CO_2) emission saving. The system shows good performance in technical and environment aspect with 25.76% capacity factor, 12 hours a day daily operation, and 4.81ton CO_2 emission savings annually. In economic assessment, it shows the LCOE is at USD 0.11 per kWh which is higher than retail electricity price (USD 0.09/kWh). With 20 years of lifetime, the system indicates unattractive investment with having minus IRR and failure to achieve payback. Sensitivity analysis is done to check the effect of assumption in the result. In this study, sensitivity analysis shows that energy production affect LCOE the most compare to capital cost, Operation and Maintenance Cost, Panel and Battery Size. This assessment only considered six indicators due to limited data available in field.

Keywords: rural electrification, sustainability assessment, photovoltaic

1. Introduction

Deployment of renewable energy in Indonesia is keep increasing due to supporting policy enforcement, such as Government Regulation No 79 2014. Government Regulation No 79 2014 aims 100% electrification ratio throughout Indonesia by 2020. This regulation also imposed renewable energy share should be 31% from Total Primary Energy Supply (TPES) by 2050.

Electrification ratio in Indonesia is moving progressively from 88.30% in 2015 to 91.16% in 2016 [1]. However, the dispersed location of archipelago makes the distribution of electricity access become uneven, especially for small island likes Parang Island.

Parang Island is located in Karimunjawa District, in the north of Java Island, the most populated Island in Indonesia. Despite the location near Java, electricity access is still limited. Up to 2014, electricity is generated only from diesel generator between 6 PM until 12 AM. This generator is run by local district government [2]. Yet, diesel supply for the generator is scarce especially during high waves.

To help give more electricity access to people in Parang Island, several solar photovoltaic (PV) systems are built. Parang Island has one solar PV system with 75 kWp and 0.5 kWp capacity, respectively [3]. Since June 2016, 0.5 kWp system is not being used due to technical problem on its inverter.

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Projects like solar PV system in Parang Island could boost installed capacity of renewable energy and delivering novel technology to rural community [4]. Yet it failed to incorporate sustainability of the system. Some indications of unsustainability in renewable energy project are low acceptance of the users, unresponsive policy measure [5], and dependence of project to subsidy over its lifetime [4]. Thus, assessment of renewable energy project is important to ensure its sustainability performance.

Indicators to analyze sustainability performance of renewable energy project are varied, depends on data availability and local context. The most common indicators to be assessed are indicators in environment, economic and social; or so-called Triple Bottom Line (TBL) [6]. Onat and Bayar [7] proposed sustainability analysis of energy system using seven indicators, which are unit energy cost, carbon dioxide emission, availability, efficiency, fresh water consumption, land use, and social affects. In addition, Ilskog [7] developed indicators for assessment of rural electrification, which can be divided into five dimensions, i.e. technical, economic, environment, social, and institutional. Yet, there are no standard on how many indicators and dimensions that should be evaluated [8]. Considering the data availability, there are three dimensions that will be assessed in this study, i.e. technical, economic, and environment. These dimensions are divided into several indicators, i.e capacity factor, daily operation, levelized cost of energy (LCOE), payback period, internal rate of return (IRR), and carbon dioxide (CO2) emission saving.

Some studies for sustainability assessment using various frameworks had been done using Indonesia as study case. Purwanto and Afifah [9] examined technoeconomic and social dimensions using indicators in Ilskog [7] to evaluate impacts of micro-hydro projects in West Bandung and Pekalongan, Indonesia. While Budiarto et al [10] assessed many renewable energy plants in Yogyakarta Province, including 20 solar home systems. Solar PV in Yogyakarta had technical problem such as in wiring, inverter and light ballast. There was lack of proper maintenance from local community as well. Nevertheless, assessment using sustainability indicators for solar PV system in Indonesia have not been known to date. This study will explore indicators that leading and lagging in sustainability performance of a renewable energy project.

The rest of this paper is divided into four sections. The next section explains about method of this research, derives equation for capacity factor, LCOE, Net Present Value (NPV), and CO2 emission savings, as well as a brief description on Parang Island. Then, result and discussion of this assessment is presented in Section 3. Last, conclusion for this study is enclosed in Section 4.

2. Method

This study analyzed performance of solar PV system in Parang Island. Indicators to be assessed are presented in Table 1. The indicators are selected from previous literatures while taking into consideration data availability and its compatibility with local context. This study focused more on quantitative data which collected from site visit in March - April 2017, project feasibility report, and literature review. Detail on method to calculate the result are written in the following section.

Table 1. Indicators of assessment.

Dimensions	Indicators	Units	References
Technical	Capacity Factor	%	[7], [9]
	Daily Operation	Hours per day	[7], [9]
Economic	Levelized Cost of Energy	USD/kWh	[11]–[13]
	Discounted payback period	Year	[14]
	Internal Rate of Return (IRR)	%	
Environment	CO_2 emission saving	tonCO_2/year	[7], [9]
	Increase of renewable energy fraction in Total Primary Energy Supply (TPES)	%	[7], [9]

Parang Island is located at 5.7429 ° South and 110.2445 ° East. Administratively, the Island belongs to Karimunjawa district, along with Karimunjawa, Kemujan, and Nyamuk village. By 2014, there was 1,153 people lived in this island, or equals to 11.5% of total population in the district. Diesel generator from local government is the only electricity source until 2014. Currently, there are 338 household which connected with 75 kWp solar PV system. By using solar electricity, each household is able to enjoy reliable lighting (LED Lamps) and sometimes, entertainment from LCD TV. Due to limited capacity, solar electricity only able to be utilized in the morning, while diesel electricity will be utilized from 5 pm onwards.

2.1. Technical dimension

Capacity factor represents ratio of gross electricity production and total installed capacity that should be delivered to local community. Gross electricity, $E_{annual.gross}$, measured from energy monitoring on site location (kWh/year) from 17 May until 13 July 2017. It is assumed that technical losses, e.g. cabling and mechanical losses, equals to 20%. Meanwhile, total installed capacity calculated by multiplying nameplate capacity, *kW*, with annual working hour (8760 hours/year). Capacity factor, CF, also can be expressed as follows:

$$CF = \frac{E_{annual.gross}}{kW \times 8760\, hours/year} \times 100\% \tag{1}$$

Solar electricity is utilized by local community from morning until 5 pm, while they will use diesel electricity after that. However, solar electricity sometimes faced failure due to weather condition or technical trip. Thus, average daily operation service required to be monitored to ensure sustainability of the system. Data for daily operation service is gathered from recorded data from field visit.

2.2. Economic dimension

In this study, viability of solar PV project is analyzed through three indicators, i.e. levelized cost of energy (LCOE), payback period, and profitability. The LCOE represents cost that should be paid so that the project will be break even in the end of its lifetime [15]. The LCOE formula is written as:

$$LCOE = \frac{\sum_t (I_t + OM_t + A_t + C_t + D_t) \times (1+r)^{-t}}{\sum_t (E_t \times (1+r)^{-t})} \tag{2}$$

where I_t is capital cost at year t, OM_t is operation and maintenance cost at year t [16]. A_t represents production cost of solar electricity, which in this study equals to zero since solar energy is free. C_t is carbon credit revenue at year t and D_t is demolition cost at the end of lifetime. Indonesia does not have carbon credit for small scale solar PV system so Ct for this project is zero. D_t is assumed to be zero since there are no reliable data regarding demolition cost of solar PV project.

Discounted payback period is time when all cost of investment will be break even. Discounted payback period considers time value for money by putting interest rate, i, in the calculation. Discounted payback period is time t when NPV is zero Equation 3.

$$NPV = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} \tag{3}$$

where R_t is net cash flow in year t (USD) and N is project lifetime (years) [17].

Internal Rate of Return (IRR) is calculated by solving interest rate, i, when Net Present Value (NPV) equals to zero. IRR deliver the profitability of investment in percentage, which presents amount of profits over project lifetime. Zero IRR represent that the project is breakeven. On the other hand, economically feasibility project will result in positive IRR.

2.3. Environment dimension

One of benefit from renewable energy deployment is reduction of carbon dioxide (CO_2) emission.

Emission savings in this study is calculated from fuel shift by using electricity from solar PV rather than using electricity from former fuel generator, which is oil-based-generator. CO_2 emission saving by using solar PV system is 0.6-1.0 $kgCO_2$/kWh [18]. Hence, the savings can be formulated as follows:

$$GHG_{savings} = E_{annual.gross} \times F_{emission.saving} \tag{4}$$

where $E_{annual.gross}$ is electricity annual gross production (kWh) and $F_{emission.saving}$ is emission saving factor by implementing renewable energy plant.

Renewable energy fraction (%) is increase share of renewable energy in total primary energy supply (TPES) after the project being implemented. This calculated using equation below:

$$RE.fraction = \frac{kW}{TPES} \times 100\% \tag{5}$$

where kW is installed capacity from solar PV and TPES is total primary energy supply nationally.

3. Result and Discussion

3.1. Technical dimension

Installation of 75 kWp solar PV in Parang Island is able to electrify households and government building in the area. The system potentially able to generates up to 661 MWh of electricity every year. There is 338 households and one government building that are connected to the system. Each household utilizes 260 Watt-peak of power. Total energy consumption in Parang Island is around 170.338 MWh annually. Thus, the capacity factor of the system is 25.76%, as shown in Table 2. This capacity factor is slightly above typical capacity factor in Asia because it is assumed that the technical losses of solar PV installation is 20%.

Table 2. Result of assessment.

Dimensions	Indicators	Units	Result Value
Technical	Capacity Factor	%	25.76%
	Daily Operation	Hours per day	12
Economic	Levelized Cost of Energy (LCOE)	USD/kWh	USD 0.11
	Payback period	Year	*Failed to payback*
	IRR	%	-
Environment	CO_2 emission saving	tonCO_2/year	4.81

The system operates 12 hours a day. However, grid installation is usually got trouble if a lightning strikes grid connection. Thus, the availability of the system is less than 100%. Considering this factor, the grid installation needs to be improved so that it can be safer and compatible with future grid system. Compatibility of grid with the future system will become added value for solar PV technically and economically [9].

3.2. Economic dimension

Solar PV system in Parang Island was built in 2014, with USD 243,019.85 capital cost. 70% of the capital cost is price of batteries, while solar panels only accounts for 22% of the cost. To help balancing the costs, local community pay electricity bill as much as IDR 10,000 or USD 0.73 monthly. Another economic benefit of using solar PV is fuel shift from diesel generator to solar electricity. Diesel price in Parang Island is USD 0.56 per litre. In total, benefit of fuel shifting is USD 34,121.12 annually.

The economic calculation shows that LCOE of solar PV in Parang Island equals to 0.11 USD/kWh, as shown in Table 3. This value is higher than retail electricity price in Central Java, which is 0.09 USD/kWh. Price of grid electricity in Java Island is relatively cheap because it mostly uses fossil-based fuel. The absence of carbon credit for power generation limit deployment of renewable-based electricity.

Table 3. Result of economic analysis.

Indicators	Value
Capital Cost	USD 243,019.85
Interest rate	10%
Maintenance Cost	USD 15,266.78
Net Present Value	USD 80,788.24
LCOE	USD 0.11/kWh
IRR	-

The investment failed to achieve payback. Moreover, IRR calculation could not be run because the result produces minus IRR. It implies that investment for solar PV is not attractive. This might be caused by high investment cost and low economic benefit.

Regular retribution that paid by local people is not enough to balance cost of investment. Monthly payment as much as USD 0.73 equals to USD 0.01/kWh, which is below LCOE. Due to economic condition of people in Parang Island, additional economic benefit, such as subsidy for renewable energy, feed in tariff and incentive are valuable to help improve economic performance of renewable project.

3.3. Environment dimension

One of benefit to use renewable energy is lower CO_2 emission compares to fossil-based energy. Using average value of emission factor from solar based electricity, Parang Island could reduce CO_2 emission up to 4.81 tonCO_2 per year. Assuming average grid emission in Indonesia is 0.76 tonCO_{2eq}/MWh [19], annual emission of solar PV in Parang Island equals to emission of 6.33 MWh of electricity from conventional power plant. Additionally, installation of solar PV in Parang Island is the same with 0.00001% of national TPES.

3.4. Sensitivity analysis

Sensitivity analysis is done to explore how much one parameter affecting a result. It also can be utilized to investigate potential change in assumption and parameters (Pannell, 1997). In this study, LCOE is set as the evaluated result, while the changing parameters are annual electricity production, capital cost, operation and maintenance cost, battery price and panel price.

Result of sensitivity analysis presents in Fig. 1. Base value in the analysis is at 100%. Then, all parameters are lowered at 80%, 60% and 40%. It also varied at 120% until 160% to see LCOE response to the changes of parameters.

Among all evaluated parameters, change in annual electricity production affects LCOE the most. Reduction or increase of annual energy production changes LCOE steeper than other parameters. When other technical parameters, i.e. effective daylight and capacity factor, are taken into account, it results same pattern as annual electrical production.

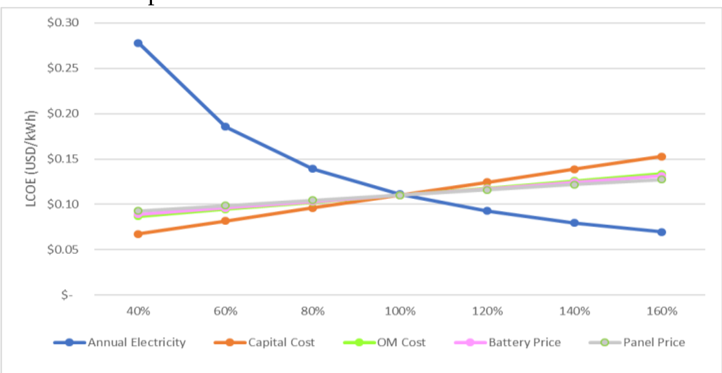

Fig. 1. Sensitivity Analysis on Levelized Cost of Electricity (LCOE)

The second parameter that influence LCOE the most is capital cost. Capital cost changes drive changes in LCOE more abrupt than other economic indicators. If the capital cost reduces up to 40%, LCOE of solar PV becomes 0.07 USD/kWh. This equals to 60% raise of annual energy production. Additionally, increase of annual electricity production is proportional to increase of economic saving by shifting from fossil-based electricity to renewable-based one.

Changes of operation and maintenance cost drives steeper LCOE changes than ones created by battery and panel price. At 60% of normal battery or panel price, LCOE becomes 0.10 USD/kWh. While at the same reduction rate, Operation and Maintenance Cost can reduce LCOE to 0.09 USD/kWh. However, at 40% of normal value, those three parameters push LCOE at 0.09 USD/kWh. At increasing 40% of its normal value, Battery and Panel Price increase LCOE to 0.12 USD/kWh; while Operation and Maintenance Cost increase LCOE at 0.13 USD/kWh.

From this analysis, it is known how much improvement should be targeted to make LCOE at least as attractive as grid electricity price (0.09 USD/kWh). For example, LCOE from solar PV will be at 0.09 USD/kWh if the annual electricity production increase 20% or if the operation and maintenance cost reduce as much as 40%. However, combination of several attempts should be better than only one action done, e.g. increasing capacity factor while giving advance training for local community to reduce operation and maintenance cost.

Sensitivity analysis is a useful tool to explore influence of several parameters and predict if several assumptions change in the future. Yet, this study is applied for quantitative data. Sensitivity analysis for qualitative data requires application of other

4. Conclusion

This study examined sustainability performance of solar PV installation in Parang Island, Karimunjawa, Indonesia. The installation aims to improve energy access for people in the area. In technical and environment dimension, solar PV installation is able to show good performance with high capacity factor 25.76%, 12 hours of service and 4.81 tonCO_{2eq} per year CO_2 emission saving. However, profitability of this installation is unattractive which is indicated by minus IRR and failure to achieve payback. This caused by low retribution to balance the investment. Considering economic condition of the local people, aids like subsidy, feed in tariff and incentive, are valuable to improve sustainability level of the system.

This study only considers three dimensions of sustainable development (technical, economic and environment) with six indicators. This selection is due to limitation of data available in field. Data monitoring and recording is not implemented fully in the area. More recorded data will result in better assessment for future research.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Dintani Y N Naimah conducted the research on evaluation of photovoltaic implementation in Parang Island, Karimunjawa; Dwi Novitasari, Ellena Wulandari did technical data collection and analysis; Yuli Setyo Indartono supervised technical aspect of the; all authors had approved the final version.

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