



Electrical Power and Energy

## Analysis of an Off-grid PV System for Disaster Mitigation Scheme in Remote Areas

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### ABSTRACT

The main objective of this paper is to present the techno-economic analysis of an off-grid Photovoltaic system, which prepared to support disaster mitigation scheme in remote areas. As a case study, a regency in Mentawai Island, Sumatera Barat is chosen to represent a remote area in a disaster-prone location. The proposed system capacity is 20 kWp PV system as a single electricity source for medical facility in the island. As a tool in this study, RETScreen software was used to analyze the technical, environmental, and economical feasibility analysis. As a base case scenario, the medical facility was supported by a diesel-fueled generator and the PV system can deliver 10.14 MWh of electricity to load annually. Net annual GHG emission reduction of the system is 19.4 ton of CO<sub>2</sub> equivalent. With the total initial cost for the whole PV system at USD 41,380, RETScreen simulation result showed that the equity payback of the project is 6.0 years with IRR of 11.9% hence the project is financially viable.

### INTRODUCTION

Indonesia is the fourth most densely populated country in the world. The population of Indonesia in 2019 reached 273 million or grow with an average of 1.01% annually since 2010 [1]. At this time approximately 45% of the population lives in rural areas [2]. Gross domestic product (GDP) of Indonesia reached USD 1.12 trillion with GDP growth rate averaged over the last 20 years around 5% [3], [4]. The increasing economic and population has resulted in increasing electricity demand and supply in Indonesia. Moreover, electricity as one of the final energy forms plays an important role in supporting various economic activities to increase people's welfare. In shorts, the electricity supply supports economic prosperity.

As one of the developing countries, Indonesia is facing the problems of electricity supply. The electrification ratio which is supplied by PLN (state-owned utility company) and Independent Power Producer (IPP) in 2017 was 95.35% [5]. The remaining 5% which not yet electrified are scattered in many remote areas across the country. In terms of electricity production, fossil fuel such as coal, oil, and natural gas was the majority of all fuels. Until 2017, the share of new and renewable energy (EBT) in national electricity mix of Indonesia is only 12.4% [6].

In addition to electricity scarcity condition in remote areas in Indonesia, the country is also located in the ring-of-fire and

surrounded by massive subduction plates. This condition made Indonesia highly prone to disasters, such as earthquake, tsunami, and volcano eruption. Considering this condition, the government of Indonesia have prepared disaster mitigation schemes, including the electricity supply during emergency case. An off-grid renewable energy system such as solar PV could be one of the application to support disaster mitigation in a remote island - which relatively vulnerable- as well as to increase the electrification ratio in the area.

This study objective is to conduct a feasibility study of a solar PV system in Mentawai Island as the power supply for medical facility and to support disaster mitigation scheme. As a tool in this study, RETScreen software was used to analyze the techno-economic analysis as well as the emission reduction analysis of the project.

RETScreen had been used by several researchers in order to study the feasibility of the renewable energy systems, and to evaluate the systems performance. Studies in Pakistan [7] and Iran [8] were using RETScreen to analyze the economic viability of PV system for a city. A feasibility analysis on distributed energy system was also conducted in China [9] using RETScreen. Several specific cases have also applied using RETScreen, such as feasibility study of solar power plants in Iran [10], grid-connected PV system for residential in Indonesia [11], solar PV water pump for agriculture in Pakistan [12], and swimming pools in Greece [13]. On the other way, this study was using RETScreen

to analyze the technical, environmental, and economic feasibility of a PV system application for medical facility to support disaster mitigation scheme in remote areas.

## DATA AND RESOURCES

Kabupaten Kepulauan Mentawai consists of more than 90 small islands in West Sumatra Province. There are four main islands in Mentawai, namely: Siberut, Sipora, Pagai Utara, and Pagai Selatan. Geographical condition of Kabupaten Kepulauan Mentawai is vary between plain, river, and hills. Tuapejat, the capital city of Kepulauan Mentawai is located in Sipora island. This city can be reached from Padang by around 10 hours using ferry or around 4 hours using a speed boat [14].

Geologically, Kabupaten Kepulauan Mentawai is located in the middle of two great subduction/tectonics plate, namely Indo-Australia plate and Sunda plate [15]. This condition makes Mentawai as one of the most disaster-prone location in Indonesia, especially in terms of earthquake and tsunami. The biggest earthquake ever recorded in Mentawai was in 1833 [16] while the latest disaster occurs in 2010 and followed by a tsunami. Figure 1 below shows the Mentawai plate.

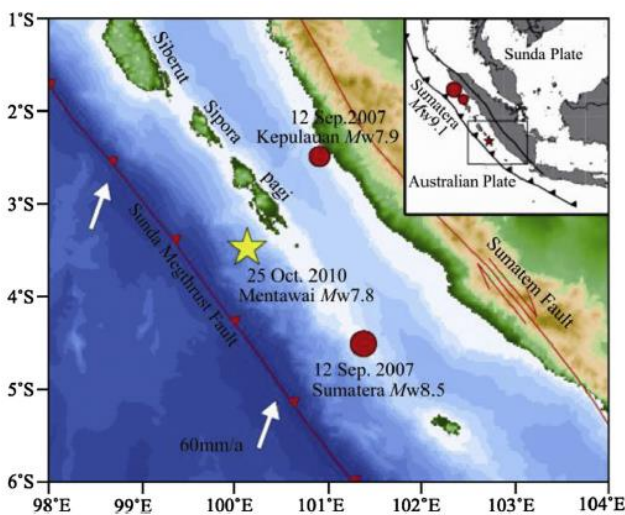


Figure 1. Mentawai Plate

In 2019, population of Kabupaten Kepulauan Mentawai was 92,021 people. Population density of Mentawai in 2019 was around 15 people per km<sup>2</sup>. The highest population density was in Sikakap with almost 38 people per km<sup>2</sup>, while the lowest density was in Siberut Barat with only 7 people per km<sup>2</sup>. The majority of the people in Mentawai is working on agriculture, forestry, and fishery sectors [14].

According to PLN, in 2019, number of electricity customer in Mentawai has reached 13,088 customers. This number almost doubled the electricity customers in 2016 with 7,170 customers. However, the current electrification ratio of Mentawai is only 61%, far below the electrification ratio of West Sumatra Province at around 98% [14]. In most areas, the electricity in Mentawai was supplied by operating a diesel-fueled power plant. Therefore, an off-grid renewable energy system such as solar PV and micro hydro is suitable for Mentawai to increase the electrification ratio

as well as to reduce the consumption of fossil fuel for generating electricity.

The data for this study came from various sources. The macro level energy data for Mentawai is mainly from PLN [17] and from Ministry of Energy and Mineral Resources [18]. All economic data such as Gross Domestic Product (GDP) and population data with its growth level were referring to data from BPS-Statistics Indonesia [19].

## METHOD

### RETScreen Software

RETScreen is a decision support tool jointly developed by the Government, Industry and Academia by Natural Resources Canada in 1996 for evaluating both financial and environmental costs and benefits [20]. It is freely available for download from the website of RETScreen International. The program is accessible in more than 30 languages and has two separate versions: RETScreen 4 and RETScreen Plus.

RETScreen4 is a Microsoft excel based energy project analysis software tool which can determine the technical and financial viability of renewable energy, energy efficiency and cogeneration projects. There are a number of worksheets for performing detailed project analysis including Energy Modeling, Cost Analysis, Emission Analysis, Financial Analysis and Sensitivity and Risk Analyses sheets. RETScreen is used for the analysis of different types of energy efficient and renewable technologies covering mainly energy production, life-cycle costs and greenhouse gas emission reduction. RETScreen Plus is a Windows-based energy management software tool to study the energy performance.

RETScreen was first released for on-grid applications. RETScreen PV model can also covers off-grid applications and include stand-alone, hybrid, and water pumping applications. Furthermore, RETScreen also supports a number of combined heat and power (CHP) and trigeneration technologies such as absorption chillers, gas turbines, reciprocating engines and fuel cells. RETScreen is able to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for both isolated and grid-connected cogeneration projects. In terms of scale, this tool has the capabilities to analyze a variety of projects ranging in size, as for instance natural gas-fired gas turbine connected to district energy networks, biomass-fired distributed energy systems providing cooling, heating and power to institutional and commercial buildings and industrial facilities or small-scale remote reciprocating engine CHP systems.

RETScreen could performs comparisons between the conventional case and an alternate “clean energy” one, aided by economic indicators such as the NPV and IRR of the investment. The output of this simple approach is that in the end the investment costs are optimized very quickly, also because RETScreen uses monthly time steps. Some advantages of this model are that it allows for a multiple number of generators, its ease of use and user-friendly interface. One limitation which is known from the model is its inability to model any storage systems but batteries. RETScreen has been mainly used for two

particular kinds of applications [21]: 1) Various scale renewable energy project analysis and 2) large capacity plant design.

**Energy Model**

Considering the climate data, mainly the solar radiation, the PV module and the inverter efficiency, in the energy model, RETScreen estimates the energy production from the GSR of each geographical location using the Duffie & Beckman equations [22] for the annual average solar radiation on a tilted surface ( $H_t$ ), where the total energy that can be converted in a year at full load is shown in Eq. (1).

$$E_p = S\bar{H}_t \tag{1}$$

where  $S$  is the total area of the array. The average energy converted by the system in a year can be obtained from Eq. (2).

$$\bar{E} = S\bar{H}_t\eta_p\lambda_p \tag{2}$$

where  $\eta_p$  is the efficiency of the PV system and  $\lambda_p$  is the miscellaneous losses of the system.

The model calculates the efficiency of the plant through the Capacity Factor (CF) of the PV system that represents the ratio of the average energy converted by the system for a year ( $\bar{E}$ ) over the energy that can be converted during the year at full load ( $E_p$ ), as shown in Eq. (3).

$$CF = \frac{\bar{E}}{E_p} \tag{3}$$

**Financial Model**

The financial indicators used for the assessment correspond to NPV and IRR as shown in Eq. (4) and Eq. (5) respectively. These indicators are widely used for profitability analysis of this type of project.

$$NPV = \sum_{n=0}^N \frac{C_n}{(1+r)^n} \tag{4}$$

$$0 = \sum_{n=0}^N \frac{C_n}{(1+IRR)^n} \tag{5}$$

$$C_n = C_{ener}(1+r_e)^n - (C_{O\&M}(1+r_i)^n + D) \tag{6}$$

In Eq. (6),  $C_n$  are the net flows produced as a result of the difference between the revenue from the energy converted and the operational costs of the plant.  $C_n$  also includes the inflation rate, the escalation rate of the electricity converted per year and

the income tax. It is important to note that amortization was considered in this model whereas other fiscal measures were not included because there is no policy in Indonesia for this type of technologies. Finally, the discount rate  $r$  includes the risk and opportunity cost of the investor.

**Emission Model**

The potential of GHG mitigations with the implementation of this PV system can be evaluated with the RETScreen emissions model. It calculates the GHG emission profile and compares it with a base case system using fossil fuel based generator such as diesel generator.

The RETScreen emissions model can determine the amount that can be mitigated with the implementation of this PV system. This model incorporates the factor of GHG with the index  $e$  ( $tCO_2e$ , which is the equivalent tons of  $CO_2$ ), which is evaluated by Eq. (7).

$$e = (e_{CO_2}GWP_{CO_2} + e_{CH_4}GWP_{CH_4} + e_{N_2O}GWP_{N_2O}) \frac{1}{\eta} \frac{1}{1-\lambda} \tag{7}$$

where, each  $e_i$  corresponds to an emission factor associated with each element in the combustion products.  $GWP_i$  is the equivalent factor, and  $\eta$  and  $\lambda$  are the efficiency of conversion and the loss on transmission and distribution, respectively.

**RESULTS AND DISCUSSION**

**Solar Energy Potential**

The site location is at 2° 2' 48" South and 99° 6' 00" East. Monthly climatology data at the site location is shown in table 1 below.

Table 1. Climatology Data at Location

Month	Air Temperature (°C)	Solar Radiation (kWh/m <sup>2</sup> /day)	Wind Speed (m/s)
January	26.6	4.74	3.8
February	26.8	5.16	3.5
March	26.8	5.19	2.9
April	26.8	5.05	2.6
May	27.1	5.05	2.8
June	27.0	4.90	3.0
July	26.8	4.78	3.4
August	26.7	4.78	3.7
September	26.4	4.62	3.5
October	26.2	4.69	3.0
November	26.1	4.39	2.9
December	26.1	4.56	3.4
Annual	26.6	4.82	3.2

**Load Characteristics**

The PV system in this study is planned to support medical facility under the disaster mitigation scheme. Classification of the healthcare facilities are referring to [23], where hospital definition is infrastructures in terms of patient capacity over 120 beds and range of services. The hospital must have full-time doctors, nurses, and obstetricians as well as technical staff for the operating and maintenance of the hospital. In terms of services, hospital offers various services such as first aid, surgery, and intensive care. Several facilities that available are medical laboratories, diagnostic equipment, and storage facilities for blood and vaccines. Hospitals’ daily average power consumption ranges from 15-35 kWh [24]. Typical daily power consumption based on hospital’s equipment [23] is shown in table 2.

Table 2. List of Equipment and Power Consumption

Equipment	Power (W)	Hours used per day (h)
Lights	11	6
Mobile phone charger	5-20	8
Ceiling fan	30-100	10
Water pump	100	6
Computer	15-200	4
Portable heater	1,000	4
Radio	2-30	8
Printer	65-1,000	4
Small waste autoclave	600	1
Sterilizer (steam)	500-1,560	2
Suction	24	10
Pulse oximetry	24	2
Water purifier	260-570	8
Dental X-ray machine	200	0.5
X-ray machine	3,000-50,000	0.5
Newborn incubator	420	24
Mechanical ventilator	200	10
Ultrasound scanner	75	2-3
Electrocardiogram	50-80	0.5
Nebulizer	180	3-5
Vaccine refrigerator	40-500	4
Microscopes	30	2
Centrifuge	600	2
Spectrophotometer	63	1
Blood chemistry analyser	45	2
Haematology analyser	230	2
Arterial blood gas analyser	250	0.5

**Off-grid PV System**

The off-grid PV System in this study consists of a 20 kWp photovoltaics, inverter, and battery system. Figure 2 shows the system analyzed in this study.

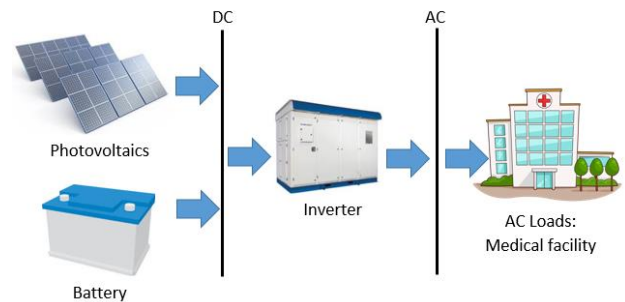


Figure 2. Schematic of PV System

Detailed specification of PV system in this simulation using RETScreen are as follow:

- Type : Polycrystalline
- Quantity : 100 unit @200 Wp
- Temp. coeff. : 0.40 %/°C
- PV area : 146.5 m<sup>2</sup>
- Capacity factor : 16.7 %
- Annual production : 10.14 MWh

**Financial Analysis**

The inflation rate of Indonesia for 2020 is at 2.07%. Using the assumption of debt interest rate for the whole off-grid PV system at 9.2% and with 10 years debt term, the initial cost needed to install the system is USD 41,380 (1 USD = IDR 14,500). RETScreen calculation is shown in figure 3 and the financial parameters are as follows:

- IRR : 11.9 %
- Equity payback : 12.7 years

The results proved that the off-grid PV system is financially viable for medical facility in Mentawai. However, considering a high initial cost and the urgency of this facility for the people, local government might need to consider some options for private sector involvement in realizing this system.

**Emission Reduction**

RETScreen calculates the emission reduction as the amount of emission that could be mitigated by implementing the system, compared to a diesel-based system. Based on the calculation, this PV system is able to reduce GHG emission by around 19.4 ton of CO<sub>2</sub> equivalent per year.

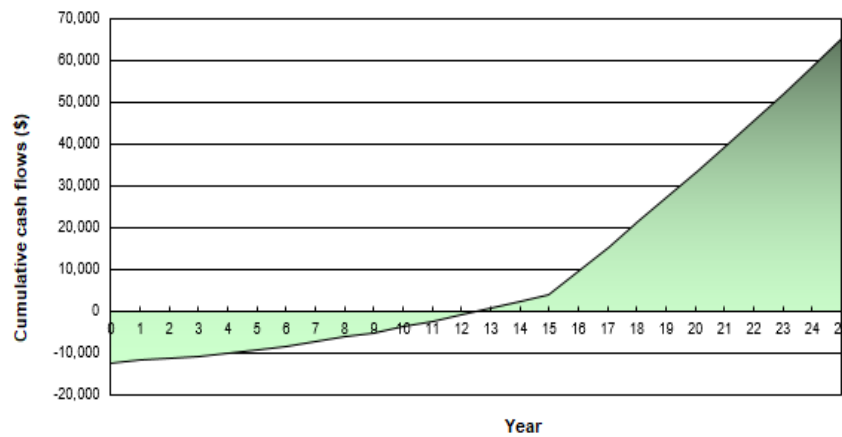


Figure 3. Cumulative Cash Flow

## CONCLUSIONS

Technically, this 20 kWp PV system is able to produce 10.14 MWh of electricity annually or sufficient for a medical facility unit such as hospital with 120 beds. Economically, this infrastructure will need initial investment at USD 41,380. By IRR at 11.9% and equity payback 12.7 years, this project is financially viable. In addition, this off-grid PV system can reduce CO<sub>2</sub> emission by around 19.4 tons annually compared to using a diesel generator. These results will hopefully bring the initiatives from stakeholders to provide the facilities since it is very important for remote areas which are disaster-prone such as in Mentawai islands.

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## NOMENCLATURE

$E_p$	total energy of PV
$S$	total area of PV array
$H_t$	annual average solar radiation on a tilted surface
$E$	annual energy of PV
$\eta_p$	efficiency of PV system
$\lambda_p$	losses of PV system
CF	capacity factor
NPV	net present value
$C_n$	net flows, including inflation rate and escalation rate of electricity converted annually

IRR	internal rate of return
D	discount rate
e	emission factor
GWP	equivalent factor of GHG emission

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