Technoeconomic analysis of a solar rooftop: a case study in Medan city, Indonesia

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Abstract. Indonesia has released its pledge on reduction Green House Gases (GHGs) emission. The mitigation action includes increasing the renewable energy utilizations. Solar rooftop is one of the potential mitigation actions to meet the GHG emission reduction and renewable energy target. In this work, techno and economic analysis on the solar rooftop presented. The analysis is made based on the solar irradiation in Medan city of Indonesia. The solar irradiations for several days are measured. The measured data and solar photovoltaic panel available in Indonesia market are used to perform technical analysis. Based on the technical analysis the economic analysis is carried out. The results are expected to supply the necessary information to build a city with low emission.

1. Introduction
Indonesia which is located on the equator and obtains sunlight for an average of 8 hours / day has a large enough solar energy potential. Great power of solar energy that can be generated about 100 watts per m\textsuperscript{2}, the solar cell efficiency by about 10\%. This solar energy is converted into electrical energy with the help of photovoltaic, so that it is an alternative power plant. As a result of greenhouse gas (GHG) emissions from fossil fuels and their potential impact on climate change, many countries are now reexamining their national energy policies with a view to shifting to low-carbon and renewable energy resources. Apart from being environmentally friendly, most renewable energy resources can be considered as local energy resources.

As for Chong Li, Dequn Zhou, Yuan Zheng conducted an evaluation and compared the performance of the economic technology of the photovoltaic (PV) power system connected to the network for building a rooftop solar PV containing 14 families in five climate zones in China. They get Radiation The average solar radiation in the normal years for Beijing (C), Harbin (SC), Shanghai (HC), Guangzhou (HW), and Kunming (M) is 4.32, 3.96, 3, 81, 3.69, and 4.75 kWh / m / day for each region [2]. Ihsan Ali, GM Sha fi ullah, and Tania Urmeethe conducted a feasibility study by calculating...
the available roof area of existing buildings and then carrying out a techno-economic analysis of the system proposed to identify potential PV roofs and battery storage for the Island in Maldives[3]. Nallapaneni Manoj Kumar, K. Sudhakar & Mahendra Samykano analyzed the feasibility of developing solar power plants on two different campuses from Universiti Malaysia Pahang (UMP) [4]. Piyush Sharma, Haranath Bojja, Pradeep Yemula In making a mathematical model that can do a techno-economic analysis of the roof solar system in India. This journal, although using a conservative model, is based on prevailing market conditions, making an interesting case for consumers who are switching from electricity to rooftop solar PV systems [5]. Nemanja Savi, Vladimir Kati, Dragan Milievi, Boris Dumni, Nenad Kati conducted a techno-economic analysis of rooftop PV power plants in the Republic of Serbia [6]. Yousef Gharbia and Mohammed Anany investigated the technical and economical feasibility of installing PV solar panels on the roof of a local gas station in Kuwait [7]. Imad Ibrik, Fadia Hashaika analyzes the impact of the techno-economic rooftop solar photovoltaic system that is connected to the network for schools in Palestine. The PV system performance applied shows that the average performance ratio (PR) is 78%, and the average annual energy produced by each system is 10,930 MWh / year [8]. Meheeb Alam conducted an economic analysis of rooftop solar system technology along with the potential and future prospects in India [9]. Kotub Uddin, Rebecca Gough, Jonathan Radli, e, James Marco, Paul Jennings conducted a techno-economic analysis of the viability of residential photovoltaics by using lithium-ion batteries for energy storage in the UK. Where a roof photovoltaic system integrated with lithium-ion battery storage is a promising route for decarbonization of the UK electricity sector [10]. Amin Lahnaoui, Peter Stenzel, Jochen Linssen conducted a techno-economic analysis investigating the impact of slope angles and orientations on roof solar generator production profiles and related performance of photovoltaic battery storage systems for family homes living in certain locations in Germany [11].

In this study, an analysis of economic characteristics on solar roofs was presented. The analysis was carried out by researchers based on solar irradiation in the Indonesian city of Medan. Solar irradiation for several days was measured. The measured data and solar photovoltaic panels available on the Indonesian market are used to carry out technical analysis and economic analysis. The results are expected to provide information on whether the installation of solar roof Photovoltaic has effective economic value and also to build a city of Medan with low emissions.

2. Method
2.1. Description of the PV
PV system The network-connected system considered in this study was installed on a flat part of a building in the city of Medan, Indonesia. The city of Medan is located at latitude 03° 35' LU and longitude 098° 40' BT, and is at an altitude of 2.5 - 37.5 meters above sea level. The PV system consists of eight modules with a peak power of 250 Wp for each module (eight of these modules have the same model namely Model No: AN Model No: AN-PSP-250W. The total installed capacity of the system is 2.0 kWp with a total area 13.01 m² the inverters are used for this study is Model: SCI02-3200 and has a capacity of 3.2 kW ratings.

As in this study the detailed performance measurements of PV system is based on satellite SOLARGIS to Medan, Indonesia. SOLARGIS referred to as system photovoltaic geographic information and is one of the most widely known tools for assessing the performance of solar power plants in most locations in the European, Asian and African regions. The European Commission developed it as a web application with an interface to geographical location for analysis related "geographic assessment sources solar power and performance of photovoltaic technology. "This tool is equipped with a package including a solar radiation database, pen Assessment of the performance of global horizontal irradiation methods and reference air temperature - climate, global irradiation in aircraft, PV electricity production at system start-ups and losses and performance ratios. The simulation results are visualized in various ways that may be in accordance with the user's requirements, namely, in the form of graphical representation, table columns, excel sheets, and in the
Measuring the PV system using the SOLARGIS web application for the city of Medan can be shown in Figure 1 below.

![Figure 1. Photo of SOLARGIS Medan City Web Application](image)

2.2. Economic analysis

The unit of energy costs generated by PV systems that are connected to the network depends on many factors. Accurate information about these factors is very important for the correct estimation of the cost of energy produced by the system. Some of these factors are:

- Location-specific weather (e.g., daily solar insulation and sunshine hours, ambient temperature);
- System components (e.g., PV modules, which in turn depend on module technology and efficiency, the cost of inverters, cables, and other electrical component costs);
- Location-specific economic parameters (e.g., interest and inflation rates as well as installation and operation and maintenance of costs);
- Electricity prices on location;
- Economic system life.

But if the PV system is optimally designed and the approved components are chosen appropriately, system costs can be expressed as costs per installed system capacity (cost / kW) or cost per unit of electricity generated by the system (cost / kWh) (i.e., leveling electricity costs, LCOE). LCOE is a measure of marginal electricity costs over a period of time and is usually used to compare the costs of electricity generation from various sources [12,13]. In addition, consumers, especially residential consumers, easily understand this approach since their electricity bills are usually reported in costs per kWh.

Therefore, in this study, the economic performance of the PV system was accessed using the LCOE Approach. Using the LCOE approach to determine energy unit costs involves three basic steps: (i) estimation of the total energy produced by the PV system during its economic life; (ii) calculation of investment costs including the costs of operating and maintaining projects; and (iii) dividing life cycle costs with energy yields by the system [14]. If it is assumed that the PV system generates the same amount of energy output ($E_A$) every year so long as it is useful for life, investment costs can be annualized using the capital recovery factor given as:

$$C_A = C_I \times CRF (i, n)$$  

where $C_A$ is the annual cost, $C_I$ is the investment cost, $i$ is the annual interest rate, $n$ is the economic life of the project (year) and CRF is the factor of capital recovery. CRF is given as:
In most cases, the energy tariff portion of the monthly electricity bill is charged at a constant level and this energy rate can vary from one month to another, therefore, it will be interesting to express Eq. (16) and (15) each on a monthly basis as follows:

$$CRF(i,n) = \frac{i \times (1+i)^n}{(1+i)^n - 1}$$ \hspace{1cm} (2)

$$CRF(Bulanan) = \frac{(1/12) \times (1+i)^{12n}}{(1 + (1/12))^{12n} - 1}$$ \hspace{1cm} (3)

$$C_m = C_t \times CRF \text{ (Monthly)}$$ \hspace{1cm} (4)

where \(C_m\) is a monthly fee and 12 is the number of months in a year. Annual and monthly LCOE can be estimated from:

$$LCOE_A = \frac{C_A \times C_{(O \& M),a}}{E_A}$$ \hspace{1cm} (5)

$$LCOE_m = \frac{C_m \times C_{(O \& M),m}}{E_m}$$ \hspace{1cm} (6)

where \(E_m\) is the monthly energy generated by the PV system, \(C_{(O \& M),a}\) is the annual operating and maintenance costs, and \(C_{(O \& M),m}\) is the operation and maintenance costs monthly. Because of the inflation rate, the nominal interest rate can be corrected to produce real interest rates \((r)\) using Fisher expressions as given in Eq. (7):

$$1 + r = \frac{(1 + i)}{(1 + \tau)}$$ \hspace{1cm} (7)

3. Results and Discussion

3.1. Results of SOLARGIS Web Application

By using the SOLARGIS web application, the visualization results for PV systems are obtained in Medan, Indonesia. The results of visualization can be seen from table 1 below.

Site: North Sumatra, Indonesia, lat / lon: 3.56534541055 ° / 98.6568160914 °

PV system: 2.0 kWp, crystalline silicon, fixed free, Azim. 180 ° (south), inclination 2 °

| Table 1. PV electricity production in the start-up |
|-----------------------------------------------|
| Month | Esm | Esd | Etm | Eshare | PR |
|-------|-----|-----|-----|--------|----|
| Jan   | 97  | 3:13| 194 | 7.8    | 76.7|
| February | 97.6| 3:49| 195.2| 7.8   | 76.2|
| March | 120.7| 3.89| 241.4| 9.6   | 76.1|
| April | 109.6| 3.65| 219.2| 8.8   | 76.2|
| May   | 110.6| 3.57| 221.2| 8.8   | 76.0|
| June  | 104.9| 3.50| 209.8| 8.4   | 75.9|
| July  | 106.8| 3.45| 213.6| 8.5   | 75.9|
| Aug   | 106.9| 3.45| 213.8| 8.5   | 75.8|
| September | 106.6| 3.55| 213.2| 8.5   | 76.2|
| Oct   | 104  | 3.35| 208  | 8.3   | 76.4|
| November | 96.3 | 3.21| 192.6| 7.7   | 76.7|
| Dec   | 90.6 | 2.92| 181.2| 7.2   | 76.8|
| Year  | 1251.6| 3.43| 2503.2| 100.0 | 76.2|
Long-term monthly averages:

- **Esm**: Prod. Monthly sum of specific electricity [kWh / kWp]
- **Esd**: Daily sum of specific electricity prod. [kWh / kWp]
- **Etm**: Monthly prod. [kWh]
- **Eshare**: Percentual prod. monthly share of electricity [%]
- **PR**: Performance ratio [%]

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**a. Investment costs for installing solar panels**

In this journal the researchers also calculated the investment costs of installing solar panels with a capacity of 2.0 kW. By calculating the investment costs of installing 2.0 kW solar panels, it is expected to provide information on whether the installation of solar roof photovoltaic has an effective economic value to build a city with a low emissions. The investment costs of installing 2.0 kW solar panels can be seen in Table 2 below.

| No | Name Item               | Specification                                                                 | Qty | Rate Unit | Rate Unit | Total Rate | Total Rate (Rp)       |
|----|-------------------------|-------------------------------------------------------------------------------|-----|------------|------------|-------------|-----------------------|
| 1  | Solar Panel Type: Polycrystalline Silicon PV Module Max Power: 330W Vmp: 35.5V, Imp: 8.21A Max: 1936mm x 96mm x 46mm 15 years power output guarantee | 6   | Peru       | $250.30    | -           | $1,500.24   | Rp2,169,862           |
| 2  | Grid-Tied Inverter Max DC Input Power: 375KW Max DC Input Voltage: 1000V DC Voltage Range: 400-1000V MPPT Voltage Range: 450-600V Max Input Current: 1270A Rated AC Output Power: 800VKA Rated AC Voltage: 400V Grid Voltage: 50~50Hz Max AC Output Voltage: 1000VAC Grid Frequency: 50~60 Hz Max Efficiency: 93.9% Size: 1000x1200x115mm Weight: 1600kg Warranty: 1 year | 1   | Pc         | $166.32    | -           | $166.32    | Rp2,278,376          |
| 3  | Kabel                   | Standar internacional, spesifikasi nominal panjang PV on grid 1500mm          | 20  | Mr         | $14.45     | -           | $297.00    | Rp4,247,100          |
| 4  | Kasiktor                | Diperlukan untuk koneksi antar panel                                          | 6   | Peru       | $7.55      | -           | $45.30     | Rp68,482             |
| 5  | Belon Dukungan Solar Panel | Rasi Sini                       | 5   | -          | -           | Rp250,000  | Rp1,250,000         |
| 6  | Karya dan Upah Rangka Dari Solar Panel | Rasio Sini (Rata-rata ukuran panel 1056 mm x 932 mm Luas satu unit panel sekitar 1.34 m², jumlah panel satu unit 5 pcs Selisih Total berasal dari insulasi panel) | 11.64 | L2         | Rp200.000  | -           | Rp2,320,000          |

**TOTAL INVESTASI PEMASANGAN SOLAR PANEL 2.0 kW** Rp35,271,986

Source: INTEGRATED SOLAR SOLAR PT., Email: Laurensius.aps@gmail.com; Website: www.estjakarta.com

**b. Results of economic analysis**

With the results of the visualization of the SOLARGIS web application, the value of electricity production from PV is obtained every month (kWh / kWp). So that from the monthly data on electricity production from PV (kWh / kWp) the value of the techno-economic analysis will be...
obtained from the installation of solar roofs in the city of Medan, Indonesia. The results of the techno-economic analysis can be seen from Figure 2 below.

![Electricity Vs Month](image)

**Figure 2.** Value of Money towards the production of electricity produced by PV.

Based on Figure 2 above, it is explained that the total electricity value annual obtained from each month of electricity production by the PV system of 2.0 kW for the city of Medan is Rp. 3,672,895.

4. **Conclusion**

With the techno-economic analysis of the PV system installed in the city of Medan, Indonesia using the SOLARGIS web application concluded obtained a:

- Economic analysis of the results of the power visualization produced by the PV system carried out for 1 year total value of IDR 3,672,895 for the city of Medan.
- With the investment costs of installing 2.0 kW solar roof panels of Rp. 33,271,986 compared to the total annual value of electricity obtained at Rp. 3,672,895, it was concluded that the capital for installation investment costs 2.0 kW solar roof panel can be returned after about 10 years of using solar panels.

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