Modeling and analysis of the solar photovoltaic levelized cost of electricity (LCoE) - case study in Kupang

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Abstract. This paper presents a modeling and analysis of the levelized cost of electricity (LCoE) related to solar Photovoltaic (PV) power plants. As the PV matures, the economic feasibility of PV projects is increasingly being evaluated using the LCoE. Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 19 the Year 2016 concerning the purchase of electricity from PV Power Plants by PT PLN (Persero) for On-Grid PV in East Nusa Tenggara with a purchase of 0.23 US$ / kWh, but the purchase price of electricity for Off-Grid PV system have not been determined. The aim of this study was to analyze LCoE for PV systems so that can help policymakers and PV investors to calculate the cost of providing PV systems for rural areas, especially in Kupang Regency. The research method uses an LCoE modeling approach. The results showed that LCoE PV On-Grid system at the level of 0.19-0.21 US$/kWh, and LPoE at the level of 0.21-0.23 US$/kWh, LCoE Off-Grid PV system at the level of 0.29-0.31 US$/kWh, and LPoE at the level of 0.31-0.33 US$/kW. The result from modeling PV On-Grid System, estimated by 2030, LPoE at the maximum level of 0.24 US$/kWh.

Keywords: Solar Photovoltaic, LCoE, Kupang, Off-Grid, On-Grid

1. Introduction

Electricity is required in almost every stage of economic activity from the upstream to the downstream of household appliances operation, information and communication equipment, education equipment, medical equipment, woodworking equipment, lighting, electrical machinery for driving such as water pumps, cooling machine, electric heating, and others [1]. Electricity will affect the development of the economy and society welfare. Until now, there are 7,245,728 of 66,489,400 million households in Indonesia having no access to Electricity Energy Source (EES) supplies with electrification ratio of 89.10% [2]. Meanwhile, Central Bureau of Statistics of Kupang Regency [3], noted that there are 29,542 out of 78,109 households in 29 of 177 villages in the Kupang Regency ENT Province have no access to EES supply (electrification ratio is 62%). On the other hand, in line with Paris agreement, Indonesia has expressed its commitment to reduce Greenhouse Gas (GHG) emissions by 29% on its own efforts, or 41% with International support, by the year 2030. [4]. If electricity production for
increasing the electrification ratio will be accomplished by using fossil energy sources, the commitment will be difficult to achieve. So that to achieve this commitment, a power plant from renewable energy is needed. Sinaga et.al [5] have conducted research on alternative solutions for electricity supply in Kupang Regency, finding that the PV most suitable renewable energy source in Kupang Regency.

Purchasing of electricity (PoE) from PV is the policy that regulates the purchase of electricity by the government of Indonesia from communities that produce electricity through PV. Levelized Cost of Electricity (LCoE) is the basis for calculating Levelized Purchasing of Electricity (LPoE) after adding profit margins. In this PoE policy is regulated to share matters related to buying and selling, including the purchase price of electricity and the duration of the contract so that the community or investors are encouraged to produce electricity by utilizing solar as the primary energy resource of PV, the electricity can be sold to the government through State Electricity Company (Perusahaan Listrik Negara/PLN).

Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 19 the Year 2016 concerning the purchase of electricity from PV Power Plants by PT PLN (Persero) for On-Grid PV in East Nusa Tenggara with a purchase of 0.23 US$ / kWh, but the purchase price of electricity for Off-Grid PV have not been determined. So that this research is important aiming to analyze the Level Cost of Electricity for PV and it could help policymakers and PV investors to calculate the cost of providing PV for rural areas, especially in Kupang Regency.

2. Methodology

The research method used a Levelized Cost of Electricity (LCoE) modeling approach. LCoE requires cost in a fixed currency per kWh which takes into account all the costs of a PV system, namely total life cycle costs, and total lifetime energy production. The life cycle costs of the system include initial investment costs, operational & maintenance costs, fuel costs, and other costs, however, PV didn't account fuel costs, for the reason PV system used a primary energy source from the solar is free. Lifetime energy production is the annual energy output by considering the capacity factor, decreased power and degradation factor. The LCoE formulation is presented in equation (1) [6, 7].

\[
LCoE = \frac{\text{Total Life Cycle Cost (US$)}}{\text{Total Lifetime Energy Production (kWh)}} \tag{1}
\]

Data for calculating the life cycle costs of PV systems got through market surveys from local vendors, interviews, and compilation of reports from the work of the company who have finished their contracts with PV customers. Data for calculating total lifetime energy production of PV system assumed lifetime PV panel 20 years, capacity factor 15%, decrease in power rate of 2% [8] and the degradation factor of 5% [6]. The research flowchart is presented in Figure 1.
Determine the PV system

Centralized Spread
On-Grid Off-Grid
Solar Home System Rooftop

Measure solar radiation and determine the solar irradiation times

Decreasing power and degradation rate

Technical and economic assumptions

Calculate Total Life Cycle Cost of Solar PV System

Total Life Cycle Cost

Levelized Cost of Electricity (LCoE)

Levelized Purchasing of Electricity (LPoE)

Market surveys, interviews and compilation of reports

Data prices solar PV System

Figure 1. Research flow chart

Cost calculation method used a spreadsheet-based cash flow model. The cash-flow model provides the annual estimation of all project expenses, revenues, tax obligations or benefits and payments to capital providers. The individual annual cash flows are discounted to a single Net Present Value (NPV). LCoE (US$/kWh) are calculated from the discounted cash flows and the discounted energy production. Unlike conventional cash-flow models, the model does not calculate the internal rate of return (IRR) of a project, but it calculates the LCoE as a function of the cash flows and a minimum required return on capital resulting in the IRR being equal to this required return on capital [9].

LCoE is the capital costs of electrical energy produced. Every investor who produces electricity through PV wants a reasonable profit in investing, so the capital price is added to a certain profit margin before being sold to PLN. The determination of profit margins is generally based on the interest rates of Indonesian bank deposits and or deposit rates on banks in the area. After capital costs and profit margins are obtained, LPoE can be calculated. PoE paid by the Government of Indonesia through PLN to PV investors who produce electrical energy is basically the sum of the capital price plus profit margin. The economic assumption to calculate the total lifecycle cost of PV used discounted rate of 7% [10] and profit margin to calculate LPoE of 8%.

On-Grid PV system designed to produce electrical energy directly connected to PLN network without using a battery, so that the PV system can only be used during the day to increase PLN’s electricity supply in the hope that electricity-powered fossil fuels can be used by PLN at night. The On-Grid PV system consists of PV panel, inverter, Balance of System (BOS), Operation & Maintenance (OM), Installation, and the other [11]. On-Grid PV system presented in Figure 2 [12]. Off-Grid PV system designed to produce electrical energy that can be stored in batteries so that stored energy can be used both at night and during the day. Off-Grid PV system did not connect to the electricity network PLN but is directly used by electricity consumers. Off-Grid PV system consists of PV panel, inverter, BOS, Battery with Solar Charge Controller, installation, OM, and the other. The type of PV used in this research is the polycrystalline type. Off-Grid PV system presented in Figure 3 [13].
LCoE PV system could be calculated using equation (2) [6, 7, 9, 14, 15, and 16]:

$$LCoE = \sum_{t=1}^{n} \frac{I_t + OM_t + F_t}{(1 + R)^t} \sum_{i=1}^{n} \frac{E_i}{(1 + R)^t}$$

Where $I_t$ is investment expenditure in the year $t$, $OM_t$ is operation and maintenance expenditures in the year $t$, $F_t$ is fuel expenditures in the year $t$, $R$ is the discount rate, $n$ is an economic life of the power plant, $E_t$ is the energy production of PV in the year $t$. $E_p = E_t (1 - d)^t$. $E_p$ is the effective energy production of PV in the year $t$, $d$ is a degradation factor.
Effective irradiation time every day is one of the most important variables in the analysis of the total lifetime energy production PV system, but previous studies using LCoE modeling approach haven’t shown the results of effective solar radiation measurement and LCoE modeling that has been done before, only show the results obtained from the software used. In this study shows the results of solar radiation measurements to get the effective working time of PV systems per day and LCoE modeling using dynamic systems with powersim software so that the system formulation can be seen in the stock and flow diagram components so that it could easy changes the variables.

3. Result and Discussion
The effective time interval for sun exposure in one day is needed to calculate the lifetime of PV energy production. The effective time data was obtained from measurements of solar radiation using solar power meters. The measurement results show that the effective time for sun irradiation was 6 hours, which starts from 9.00 WITA until 15:00 WITA. Under 9:00 WITA and above 15:00 WITA solar radiation is very small, averaging below 300 W/m$^2$. The result of measurements from 9.00 WITA until 15:00 WITA every half an hour in July, August, and September show an average solar radiation of 1.124 W/m$^2$. Graphs of measurement results are presented in Figure 4. Total lifetime energy production for 20 years with the average solar radiation 6 hours per day, capacity factor 15%, the decrease in power of 2% and the degradation factor of 5% is 19,395 kWh/Wp.

Data from market surveys indicated that there are price differences in each PV material provider so that the maximum prices and minimum prices can be determined. Recapitulation of data on equipment and PV material prices presented in Table 1. Results of calculation of LCoE PV On-Grid system at the level of 0.19-0.21 US $ / kWh, while LPoE PV On-Grid system at the level of 0.21-0.23 US $ / kW (Table 2). The maximum level of LPoE PV On-Grid system same as the regulation of Minister of Energy and Mineral Resources of the Republic of Indonesia Number 19 which is 0.23 US $ / kWh. The maximum LPoE which has been the same as the government regulation causing the investors reluctant to invest in the field of PV in Kupang Regency which probably caused by small profit margin. LCoE on Off-Grid PV systems, at the level of 0.29-0.31 US $ / kWh, while LPoE PV Off-Grid system at the level of 0.3-0.33 US $ / kW (Table 3). LPoE PV Off-Grid system needs to be determined by Minister of Energy and Mineral Resources of the Republic of Indonesia so that investors could invest currently, Off-Grid PV system actual needed by rural communities which have no access to electricity source from PLN.

![Figure 4. Results of measurement of solar radiation in Kupang Regency](image-url)
Table 1. Recapitulation of data on equipment and PV material prices

| Nr  | Description                        | Prices (US$/Wp) | Data Code |
|-----|------------------------------------|-----------------|-----------|
| 1   | PV Panel                           | 1.500           | LCVJ      |
|     |                                    | 1.464           | YSCVP     |
| 2   | Inverter On-Grid                   | 0.466           | IRS       |
|     |                                    | 0.651           | SRS       |
| 3   | Inverter Off-Grid                  | 0.558           | ORS       |
|     |                                    | 0.423           | PRS       |
| 4   | Battery                            | 1.957           | IRS       |
|     |                                    | 1.945           | NRS       |
| 5   | Balance of System                  | 0.726           | ORS       |
|     |                                    | 0.776           | CVGJ      |
| 6   | Instalation Cost                   | 0.469           | CVGJ      |
|     |                                    | 0.409           | CVJ       |
| 7   | O & M Cost                         | 0.490           | PASH      |
|     |                                    | 0.604           | CVGJ      |
| 8   | Land Cost & Site preparation       | 0.037           | CVGJ      |
|     |                                    | 0.038           | CVJ       |
| 9   | Permit                             | 0.013           | CVGJ      |
|     |                                    | 0.014           | CVJ       |
| 10  | Sales Tax                          | 0.093           | CVGJ      |
|     |                                    | 0.097           | CVJ       |
| 11  | Insurance                          | 0.021           | CVGJ      |

Table 2. LCoE and LPoE of On-Grid PV systems

| Nr. | Description                        | Prices | Data code | Unit   |
|-----|------------------------------------|--------|-----------|--------|
| A   | Lifetime Cycle Cost               |        |           |        |
| 1   | Initial investment cost:           |        |           |        |
| a   | PV Panel                          | 1.500  | LCVJ      | US$/Wp |
| b   | Inverter                          | 0.651  | SRS       | US$/Wp |
| c   | Battery                           |        |           |        |
| d   | Balance of system                 | 0.776  | ORS       | US$/Wp |
| e   | Installation Cost                 | 0.469  | CVGJ      | US$/Wp |
| Total Initial Investment Cost (a+b+c+d+e) | 3.396  | 3.065     | US$/Wp |
| 2   | Operation & Maintenance Cost      | 0.604  | CVGJ      | US$/Wp |
| 3   | Other cost:                       |        |           |        |
| a   | Land Cost & Site preparation      | 0.038  | CVJ       | US$/Wp |
| b   | Permit                            | 0.014  | CVGJ      | US$/Wp |
| c   | Sales Tax                         | 0.097  | CVJ       | US$/Wp |
| d   | Insurance                         | 0.021  | CVGJ      | US$/Wp |
| Total Other Cost (a+b+c+d) | 0.170  | 0.163     | US$/Wp |
| Total Lifetime Cycle Cost-NVP (1+2+3+4) | 4.170  | 3.718     | US$/Wp |
| Total Life Cycle Cost (R=0.07)    | 3.897  | 3.475     | US$/Wp |
| B   | Total Lifetime Energy Production  | 19.495 | 19.495    | kWh/Wp |
| Total Lifetime Energy Production (R=0.07) | 18.220 | 18.220    | kWh/Wp |
| C   | LCoE PV On-Grid                   | 0.21   | 0.19      | US$/kWh|
| D   | LPoE PV On-Grid                   | 0.23   | 0.21      | US$/kWh|
Table 3. LCoE and LPoE of Off-Grid PV systems

| Nr. | Description                              | Prices   | Data Code | Unit   |
|-----|------------------------------------------|----------|-----------|--------|
|     |                                          | Max      | Min       |        |
| A   | System Life Cycle Cost                   |          |           |        |
| 1   | Initial investment cost                  |          |           |        |
|     | a PV Panel                               | 1.500    | 1.464     | LCVJ   |
|     | b Inverter                               | 0.558    | 0.423     | ORS    |
|     | c Battery                                | 1.957    | 1.945     | IRS    |
|     | d Balance of system                      | 0.776    | 0.726     | CVGJ   |
|     | e Installation Cost                      | 0.469    | 0.409     | CVGJ   |
|     | Total Initial Investment Cost (a+b+c+d+e) | 5.260    | 4.967     | US$/Wp |
| 2   | Operation & Maintenance Cost             | 0.604    | 0.490     | CVGJ   |
| 3   | Other Cost                               |          |           |        |
|     | a Land cost & site preparation           | 0.038    | 0.037     | CVJ    |
|     | b Permit                                 | 0.014    | 0.013     | CVJ    |
|     | c Sales Tax                              | 0.097    | 0.093     | CVJ    |
|     | d Insurance                              | 0.021    | 0.020     | CVGJ   |
|     | Total Other Cost (a+b+c+d)               | 0.170    | 0.163     | US$/Wp |
|     | Total Life Cycle Cost-NVP (1+2+3+4)      | 6.034    | 5.620     | US$/Wp |
|     | Total Life Cycle Cost (R=0.07)           | 5.639    | 5.252     | US$/Wp |
| B   | Total Lifetime Energy Production         | 19.495   | 19.495    | kWh/Wp |
| C   | LCoE PV Off-Grid                         | 0.31     | 0.29      | US$/kWh|
| D   | LPoE PV Off-Grid                         | 0.33     | 0.31      | US$/kWh|

LCoE modeling is carried out with three scenarios, i.e. scenario 1 is an LCoE scenario taking into account inflation [3], scenario 2 is the LCoE scenario calculating the price of a decrease in PV [10]. Scenario 3 is a scenario that takes into account inflation and decreases in the price of PV. These three scenarios can be considered by the government or investors in policymaking. Figure 5 stock-flow diagram is deliberately displayed in this study so that any changes in LCoE variables can be dynamically implemented. For scenario 1, maximum LPoE PV ON-Grid system up to 2030 is estimated at 0.24 US $ / kWh, while the maximum LPoE Off-Grid PV system until 3030 is estimated at 0.34 US $ / kWh (Figure 6). PV On-Grid System, for the three modeling scenarios, it is estimated that by 2030, LPoE will still remain at the level of 0.22-0.24 US $ / kWh. The modeling results are presented in Figure 7.
Figure 5. Stock flow diagram of LCoE modeling

Figure 6. Results of LCoE-LPoE modeling with first scenarios
4. Conclusion

The effective time for sun irradiation to PV panel in Kupang Regency was 6 hours, starting from 9.00 WITA until 15:00 WITA and average solar radiation is 1.124 W/m². LCoE PV On-Grid system at the level of 0.19-0.21 US$/kWh, LPoE PV On-Grid system at the level of 0.21-0.23 US$/kWh. LCoE on Off-Grid PV systems, at the level of 0.29-0.31 US$/kWh, LPoE PV Off-Grid system at the level of 0.31-0.33 US$/kWh.

The result from modeling PV On-Grid system, estimated by 2030, LPoE at the maximum level of 0.24 US$/kWh. The technical assumption for the average solar radiation hour per day, capacity factor, the decrease in power, the degradation factor and economic assumption could be influential factors on LCoE and LPoE.

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