Energy analysis of solar farm planning in Weh Island, Aceh, Indonesia

S Rahmawati¹, M Iqbal² and I D Sara³

¹Megister of Industrial Engineering Program, Syiah Kuala University, Banda Aceh, Indonesia
²Department of Mechanical and Industrial Engineering, Syiah Kuala University, Banda Aceh, Indonesia
³Department of Electrical Engineering, Syiah Kuala University, Banda Aceh, Indonesia

Email: mohd.iqbal@unsyiah.ac.id

Abstract. The paper discusses the simulation study and analysis of output energy produced by 5MW solar farm located in Weh Island, Aceh Province, Indonesia. Weh Island is a tourist area. Currently, a diesel power plant supplies all of its electricity requirement. Most of the user were household, hotels and public facilities. Weh Island consists of 8,858 family houses, 124 medium and small hotels. 48 educational facilities (formal schools and traditional Islamic schools) 48 healthcare facilities (consisting of 2 hospitals, 6 public healthcare centre, and 23 public healthcare service units). The daily peak load of electricity usage occurred at two points; 03.00 pm and 08.00 pm, with the peak load reaches 4,667 kW and 5,009 kW respectively. The solar farm was designed based on the peak electrical load (5MWp) using grid-connected system to ensure continuous availability in the area, as solar farms are only able to operate during the day. The system used 300 Wp Monocrystalline technology panels with 16.4% efficiency and inverter with 20Kw capacity and 98.8% efficiency. Each of the inverter was designed to serve 66 to 67 solar panels. Therefore, in order to produce 5MW of electricity, the solar farm was developed with 16,668 solar panels and 250 inverters on 32,309 m² of land space area. The simulation model of the solar farm was developed using PVsyst simulation software. The simulation study was conducted based on monthly solar radiation, temperature and daily radiation time of the Weh Island during one year. The result of the study showed that the system produced sum annual energy of 7991 MWh/year and the solar panel obtained the average radiation of 5.2 kWh/m²/day. The highest energy output was 792.4 MWh which was produced in January, and the lowest energy output was 603.3 MWh which was produced in September. Furthermore, when the usage time distribution of the electricity was formulated into the model, the simulation result showed that the solar farm system were able to accommodate the electricity requirement in Weh Island.

1. Background

The general energy crisis, including electrical energy, is now a major issue in the world. So far the main source of electrical energy used by the world comes from fossils that are known to be environmentally unfriendly and have limited capacity [1]. In fact, the need for electrical energy consumption continues to increase every year [2]. This limitation makes the number of proposals to process electrical energy from renewable resources such as solar, water, wind, geothermal, wave currents, biomass and hybrid systems as the latest alternative.

Aceh, until 2016 has a peak load requirement of 325 megawatts (MW) derived from fossil, such as Gas Power Plant (PLTG), Steam Power Plant (PLTU) and Diesel power plant (PLTD). The availability of electricity in Aceh should reach 50% of the peak load requirement or should be available around 500 MW, but up to now only 340 MW is available [3], so there is a need for...
additional power supply, one of them is with a friendly energy proposal environment and renewable (ET).

One of the easiest ET to apply and minimal maintenance cost is Solar Farm. The main component used in solar farm system is a solar module which is strung by photovoltaics (PV) cells. Solar modules today can be found easily in the market, although in Indonesia the price of solar panels are relatively expensive.

1.1. Solar Radiation Potential in Research Location

Data from NASA (National Aeronautics and Space Administration - NASA) that has been recorded for 20 years from 1983-2005 explains that the potential of solar radiation in some areas in Aceh is different. The highest solar radiation of 5.1 Kwh / m2 / day occurred in areas such as Weh Island, Nasi Island, Banda Aceh and Aceh Besar. For more detailed explanation of the potential solar radiation in Pulau Weh as the study location are described in Table 1. The highest solar radiation on Weh Island occurs in February-April. Where the sun radiation is in the order of 5.75 - 5.79 - 5.64 kWh / m2 / day. The lowest radiation occurred in October and November, where the radiation is at the number 4.66 - 4.67 kWh / m2 / day.

1.2. Electricity load in Weh Island

The electricity in Pulau Weh is still supplied with diesel power plants (PLTD), and several renewable energy (ET) are being developed. It is planned to support the existing electricity in Weh Island also in the hope of replacing the working hours of the power plant with all aspects of ET surplus and also as support to achieve 23% of ET target in Indonesia [4]. The peak of the electrical load on Weh Island occurs at 15.00 p.m and 20.00 p.m. with average power consumption usage, reaching about 4,667 to 5.009 kW as described in figure 3. The basic production cost (BPP) for this electricity is Rp.2.500, - / kWh and the selling price to the public is Rp.900 / kWh [5].

| Solar Radiation In Weh Island | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Average |
|------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| Monthly Radiation (kWh/m2/mnth) | 167.1 | 161 | 179.5 | 169.2 | 155.3 | 149.7 | 151.9 | 149.1 | 142.2 | 144.8 | 139.8 | 151.3 | 155.1 |
| Daily Radiation (kWh/m2/day)   | 5.39 | 5.75 | 5.79 | 5.64 | 5.01 | 4.99 | 4.9 | 4.81 | 4.74 | 4.67 | 4.66 | 4.88 | 5.1 |

Source: Surface Meteorology and Solar Energy (National Aeronautics and Space Administration – NASA)

![Figure 1](image_url)

**Figure 1.** Graph of monthly average data solar radiation in Weh Island (Aceh-Indonesia) in kWh / m2 / day year (NASA 1983-2005)
The price of BPP in Weh Island is currently more expensive than the Decree of the Minister of ESDM No.1404 Year 2017 for Weh Island area where Rp 1,733 / kWh [6]. One solution offered to lower BPP is to replace the operating hours of the diesel with EBT in the form of Solar Farm. Application of solar farm has started to be done in the region of ASIA although with relatively high investment value.

Research on feasibility studies of solar farm investments conducted in Perlis-Malaysia was investigated by M. Pauzi M. Kassim, et al. (2015) mentions the 5 MW solar farm performance with an investment of RM 41,579,448.10 can produce 1358.11 kWh / kwp of solar energy with a return on investment capital for 11 years. The return on investment capital is closely related to the output of the energy output produced.

The research on energy output performance has been studied by Manoj Kumar et al. (2017) using a 100 Wp Poly-si with a grid-connected system in India. The resultant performance is 161.6 MWh / year, with the specification of energy that can be injected into the grid of 1,616 kWh / kWp / year. The highest energy production is 15,800 kWh / month and the lowest is 11,060 kWh. The overall performance of the Poly-100 kwp is 80%.

With the potential of solar radiation at Pulau Weh averaging at 5.1 kWh / m2 / day, the analysis of energy output from solar farm planning in Pulau Weh is considered important. It aims to see the potential output to be generated as well as the influence of energy output from other environmental variables in Pulau Weh. To meet the needs of the weh island electricity, the solar farm planning on this research is designed based on the daily peak electricity required in Weh Island of 5009 kW, or designed for 5 MWp. The planning in this Solar Farm research, conducted with a grid connected system to ensure continuous availability of electricity in the research area. The solar farm system to be planned is full photovoltaics on-grid system.

1.3. Temperature
Unlike the radiation cases, higher temperatures will actually decrease the power produced by Photovoltaic (PV), this is because the rise in temperature can decrease the voltage on the PV and affect the electrical power generated in PV [7] [8]. Ideally, solar panels work on standard test conditions (STC) with 1000 w / m2 radiation at standard temperature of 25°C, where for every 1°C rise in temperature in PV will reduce the working efficiency of solar panels. This decrease depends on the character of each PV, called Temperature coefficient factor (TCF). The decrease in PV efficiency ranges from 0.4 to 0.6 for every 1°C increase [9]. The average temperature in Indonesia is about 25-35°C, so it needs to be considered in the construction of solar panels to provide sufficient space under it, so that the air flow can lower the panel temperature [10]. Temperature data obtained from the results of BMKG Weh Island and also available from NASA recorded for 20 years. As shown in table 2.

![Figure 2. Average daily load curve in Weh Island for the past year (April 2017-March 2018) [5]
Source: PLN Data Centre and PLN Rayon Weh Island- Aceh.](image)
Table 2. Temperature data in Weh Island from BMKG and NASA

| Month | Data BMKG | Data NASA | Month | Data BMKG | Data NASA |
|-------|-----------|-----------|-------|-----------|-----------|
| Jan   | 26.75     | 26.4      | July  | 27.65     | 27.8      |
| Feb   | 26.9      | 26.9      | Aug   | 27.35     | 27.4      |
| March | 27.8      | 27.5      | Sept  | 27.1      | 27.1      |
| Apr   | 27.9      | 27.9      | Oct   | 26.6      | 26.8      |
| May   | 28.3      | 28.1      | Nov   | 26.4      | 26.5      |
| Jun   | 28.1      | 28.2      | Dec   | 26.4      | 26.3      |
| **Average** | **27.27** | **27.24** |       |           |           |

Source: Secondary data from BMKG Indrapuri, Sabang (Year 2015-2017) and NASA

Figure 3. Graph of temperature data in Weh Island

Source: Secondary Data from BMKG Indrapuri and Sabang (Year 2015-2017)

Figure 3. Describes the average temperature as well as the maximum and minimum temperatures that occurred over a year. From the graph it is known that the highest temperature occurred in June at point 34°C and the lowest temperature at Weh Island was in January at 20.5°C.

2. Methodology

2.1. General Information About the research location

The location studied is the Islands of Aceh, namely Pulau Weh, where this island is one of the islands that have the potential of solar radiation is quite good. Based on the geographic map of google earth, Weh Island is located at the coordinate point 5.84° N 95.28° East. Data related to general information about the condition of Weh Island was obtained from the Central Bureau of Statistics (BPS) of Weh-Aceh Island as shown in table 3. From BPS data it is known that, the population of the island is recorded with the number of existing household heads, which is as many as 8,858 heads of households. Since it is a tourist area, the island consists of about 124 hotels. On this island there are 48 educational facilities in the form of schools, foundations and boarding school, 48 units of worship facilities such as mosques and prayer rooms, as well as the number of public health facilities consisting of 2 hospitals, 6 public healthcare centre and 23 public healthcare service unit. All general information shown in table 3.
### Table 3. General Information of Weh Island Condition

| General Information of Weh Island – Aceh (2018) |
|------------------------------------------------|
| **Research Location**                           |
| (5,84°LU 95,28°BT)                              |
| **Number of heads of households (2018)**        |
| 8,858                                           |
| **Number of hotels**                            |
| 124                                             |
| **Number of educational facilities**            |
| 48                                              |
| **Number of facilities of worship**             |
| 48                                              |
| **Number of facilities:**                       |
| Hospital                                        |
| 2                                               |
| Public healthcare center                        |
| 6                                               |
| Public healthcare service units                 |
| 23                                              |

Source: Google earth and BPS data in 2018

2.2. **Pvsyst software**

PVSyst (Photovoltaics System) is one of the software used to study the size (sizing) and analyze data of PV system which is complete enough. Available simulation systems consist of grid-connected, stand-alone, pumping and public transportation / DC connected systems [11]. The PVsyst simulation process takes into account the behavior of all system characters and all interruptions for every hour of system operation. The energy generated depends on the meteorological data of site installation by analyzing the data of energy resources, energy production, system configuration and system losses to install the system [12].

Some of the input data on the software, described in figure 4 to 5, consists of meteor data (global radiation, diffuse radiation and temperature), optimal slope of panel construction, the main data product specification, ie solar panel si-monocrystalline 300 Wp and inverter 20 KW.

2.3. **Tilt**

In this study the tilt/slope with optimum loss of 0% is determined by 10° west direction. Determination of the slope is based on the latitude of the research location where it is 5,84° and the position of the module buffer installation is 10°. As illustrated in figure 5(b). The slope of the solar panel installment affects the amount of solar radiation received and the temperature. The temperature affected by the slope distance between the panels is ambient temperature. This ambient temperature, a benchmark of the amount of energy generated by the panel based on the influence of temperature in the research location.
2.4. Manufacturer Specification components
(Solar panel Si-mono crystalline 300 Wp and Inverter 20 kW)

The standard of sunlight that Earth receives on the right conditions above the head is 1000 W/m². T_{Ref} standard working conditions of solar panels at panel temperature of 25°C. Manual input of product specifications with selected product specifications are described in the table 4 (a) specification of panel module and (b) specification of the inverter.

Table 4. (a) Manufacturer specification of module Si-Monocrystalline 300 Wp (b) Manufacturer specification of Inverter

| Specification                  | Product Ability | Symbol | Specification                  | Product Ability | Symbol |
|--------------------------------|-----------------|--------|--------------------------------|-----------------|--------|
| Capacity                       | 300             | W      | Capacity                       | 20000           | W      |
| Max. Power Voltage (Vmp)       | 37.70           | V      | MPPT Efficiency                | 99.9            | %      |
| Max. Power Current (Imp)       | 8.40            | A      | Maximum Efficiency             | > 98.2          | %      |
| Open circuit Voltage (Voc)     | 45.60           | V      | Input Range                    | 400-850         | Vdc    |
| Short Circuit Current (Ics)    | 8.80            | A      | Output                         | 230/400 50/60 Hz | VAC    |

(a) (b)
2.5. PVsys simulation Software

![Table Image](image)

**Table 1.** Geographical Coordinates

| Site       | Pulau Weh (Indonesia) |
|------------|-----------------------|
| Data source| NASA-SSE satellite data, 1983-2005 |

| Date       | Global Irrad. | Diffuse | Temp. |
|------------|---------------|---------|-------|
|            | kWh/m²·mth    | kWh/m²·mth | °C    |
| January    | 167.1         | 54.3    | 26.4  |
| February   | 161.0         | 53.5    | 26.9  |
| March      | 179.5         | 65.7    | 27.5  |
| April      | 169.2         | 65.1    | 27.9  |
| May        | 155.3         | 66.3    | 28.1  |
| June       | 149.7         | 61.5    | 28.2  |
| July       | 151.9         | 64.3    | 27.8  |
| August     | 149.1         | 60.5    | 27.4  |
| September  | 142.2         | 68.7    | 27.1  |
| October    | 144.8         | 66.7    | 26.8  |
| November   | 139.8         | 59.1    | 26.5  |
| December   | 151.3         | 56.1    | 26.3  |
| Year       | 1850.9        | 759.9   | 27.2  |

![Figure 4](image)

**Figure 4.** (a) Input data parameters that affect the output on the solar farm system in PVsys software
(b) Optimization of tilt determination at study Location (Weh Island)

![Figure 5](image)

**Figure 5.** Input data specification of (a) module and (b) inverter

### 3. Result and discussion

The results of the 5 MWp solar farm planning on Weh Island using Si-Mono (Crystalline) 300Wp technology with manual data input on PVsys software shown in table. For the 5 MWp solar farm planning, the system requires as many as 16,667 solar panels with 250 inverters with a capacity of 20 kW. The configuration consists of 18 modules in series with 926 strings, where one inverter will serve 66-67 solar panels.
3.1. Balances and main results of simulation
From the results of the study as shown in table 6, it was known that the average of solar radiation at the horizon line (Horizontal Global Irradiation) was 155.07 kWh / m\(^2\) or the sums radiation per year is 1860.9 kWh / m\(^2\). The average Ambient temperature of 26.49 °C, utilizing 300 Wp solar panel by 16,667 panels with an efficiency of 16.4% will produce sums an annual energy of 8173.6 MWh / year (noted as EArray in table 6).

| Table 5. Results of Simulation Sizing Solar Farm with PVsyst software |
|---------------------------------------------------------------|
| **Sizing Simulation** | **5000 MW** |
| Number of Modul | 16.668 |
| Number of inverter (20kW) | 250 |
| Configuration | 18 modules in series with |
| | 926 string |
| The area of land required by the panel | 32.309 m\(^2\) |

The energy output generated by the panels is not only influenced by global radiation on the horizon surface, but is also influenced by the global incident in collector plane of the 10°C panel slope design effect. Global incident in collector plane generated an average of 5.2 kWh / m\(^2\) / day or by the sums of 1877.8 kW/m\(^2\) (as noted in GlobInc in table 6). The highest solar radiation potential occurred in January in DC from was 792.4 MWh (as noted by E Array in table 6). This energy then distributed to the inverter to be converted into electrical energy in the form of AC which will occur energy reduction due to the conversion process, so the monthly hourly sums for output generated by inverter in the form of AC energy in January is 775.7 MWh (Noted as E_gri in table 6). The lowest output will occur in September as 603.3 MWh. For more details the data of DC-AC energy conversion can be seen in table 6 (Noted by EArray-E_Grid).

3.2. Performance Ratio
The performance ratio of 5MW solar farm with monocrystalline technology for one year was described as PR in Table 6. The average performance of solar farm was 8.51%. The highest performance occurred in August of 8.55% and the lowest performance ratio occurred in March and May of 8.47%.
3.3. Loss diagram

The various energy losses incurred in the system are described in the diagram above at figure 7. From the PVsyst simulation results, the Global irradiance value on the horizon field occurring in Pulau Weh is 1861 kWh / m², while the effective irradiance on collector is worth 1817 kWh / m². The energy conversion that falls on the array with efficiency under standardized test conditions (STC) of 16.38%, yields 9617 MWh of energy in the form of DC. Various losses at this stage occur for -15.4%. The energy generated from the array of virtual energy in MPP is 8174 MWh. The energy then distributed to the Inverter to be converted into AC with a total energy loss of -2.2%. The energy generated by an AC inverter of 7991 MWh / year is the energy that can be channeled to the Grid for distribution to the end-user / load.

### Table 6. Balances and Main results of simulation from Pvsyst

|       | GlobHor | DifHor | T Amb  | GlobInc | GlobEff | EArray | E_Grid | PR  |
|-------|---------|--------|--------|---------|---------|--------|--------|-----|
| January | 167.1   | 54.90  | 26.19  | 181.8   | 176.4   | 792.4  | 775.7  | 0.853 |
| February| 161.0   | 53.50  | 26.19  | 159.7   | 164.9   | 736.6  | 720.3  | 0.845 |
| March  | 173.5   | 65.70  | 26.30  | 192.3   | 177.0   | 783.1  | 772.1  | 0.847 |
| April  | 163.2   | 65.10  | 26.58  | 155.1   | 159.9   | 717.1  | 701.4  | 0.850 |
| May    | 153.3   | 66.30  | 27.10  | 145.9   | 141.6   | 639.3  | 622.2  | 0.847 |
| June   | 143.7   | 61.50  | 27.20  | 139.6   | 134.5   | 608.5  | 584.3  | 0.851 |
| July   | 151.9   | 64.80  | 27.03  | 142.7   | 137.6   | 622.2  | 607.4  | 0.851 |
| August | 143.1   | 58.50  | 26.73  | 143.0   | 136.9   | 623.3  | 514.6  | 0.655 |
| September | 142.2  | 58.70  | 26.44  | 141.6   | 136.9   | 617.5  | 503.3  | 0.852 |
| October | 144.8   | 56.50  | 26.13  | 143.7   | 144.9   | 654.4  | 539.6  | 0.654 |
| November| 130.9   | 53.10  | 25.00  | 149.2   | 144.6   | 640.5  | 604.0  | 0.650 |
| December| 151.3   | 56.10  | 26.05  | 165.3   | 160.2   | 721.1  | 706.5  | 0.854 |
| Year   | 1360.9  | 750.80 | 26.49  | 1877.8  | 1817.4  | 9173.8 | 7590.9 | 0.851 |

### Table 7. The hourly maximum value for E_grid from PVsyst

|       | 01H | 02H | 03H | 04H | 05H | 06H | 07H | 08H | 09H | 10H | 11H | 12H | 13H | 14H | 15H | 16H | 17H | 18H | 19H | 20H | 21H | 22H | 23H | 24H |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| January | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 2   | 3   | 4   | 4   | 4   | 4   | 4   | 4   | 3   | 3   | 1   | 0   | 0   | 0   | 0   | 0   | 0   |
| February| 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 2   | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 0   | 0   | 0   |
| March   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 2   | 3   | 4   | 4   | 4   | 4   | 4   | 3   | 3   | 2   | 1   | 0   | 0   | 0   |
| April   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 2   | 3   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 3   | 3   | 3   | 2   | 1   | 0   | 0   |
| May     | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 2   | 3   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 3   | 2   | 1   | 0   |
| June    | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 1   | 2   | 3   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 3   | 2   |
| July    | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 1   | 1   | 2   | 3   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 3   |
| August  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 1   | 1   | 1   | 2   | 3   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   |
| September | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 1   | 1   | 1   | 1   | 2   | 3   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   |
| October | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 2   | 3   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   |
| November| 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 1   | 2   | 3   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   |
| December| 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 1   | 1   | 1   | 1   | 2   | 3   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   |
| Year    | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 1   | 2   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   |
4. Conclusion
From the simulation results using PVsyst software, 5 MWp solar farm planning in Weh Island, Aceh-Indonesia with crystalline technology (monocrystalline) can be concluded the solar-powered Energy will follow the normal solar graph. At the peak of solar radiation, ie during the day, a 5 MWP solar farm is capable of producing an average of hourly electricity of 3-5 MW. In the morning and afternoon, solar farm capable of producing electricity with an average of 1-2 MW. The total conversion in monthly hourly sums (E_Grid) of solar radiation into electrical energy from solar farm can be
delivered to the grid by 7991 MWh per year. The energy losses occurring in the solar conversion process were 17.6%. Although the highest solar radiation occurred in March but in the conversion process from solar farm affected by other variables showed that the highest production occurred in January at 792.4 MWh / m². The lowest electricity production occurred in September as 603.3 MWh.

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