Solar home & pumping system scheme for lighting & access to clean water in the 3T region

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Abstract. There are many regions in Indonesia where the electrification ratio is relatively low, even some still do not enjoy access to electricity. Low electrification is especially felt by Indonesians living in 3T areas (terdepan/frontier, terluar/outermost, and tertinggal/disadvantaged). On the other side, as archipelagic and tropical country, Indonesia has high potential in the development of renewable energy for electrical generation especially solar energy. This study aims to design a solar home & pumping system (SHPS) model and assess its feasibility. In this concept SHPS scheme is purposed to provide electricity access to 3T community for the needs of lighting and access to clean water. A total of 4 units of 3 watt LED lights integrated with batteries are used for lighting each household, while a 600 watt water pump can be used communally for 150 households. Both LED light and water pump are supplied with electrical energy from their respective solar panels. There are 3 scenarios in the implementation of SHPS for a total of 150 households with a discount rate for investments of 10%. Full grant by the government/private sector with a budget of Rp 480.5 million is the most recommended scenario. Another advantage of SHPS is environmentally friendly.

1. Introduction

Electricity development is prioritized using renewable energy resources, considering that fossil energy sources such as coal, fuel oil and gas have negative impacts on the environment, one of which is global warming. As mandated in the Paris Agreement that the increase in temperature due to the impact of global warming is limited to below 2°C, and to achieve it requires significant efforts to support the reduction of greenhouse gas emissions. Of the various types of renewable energy, solar energy has the greatest potential with the utilization of about 0.2% only so far [1] [2]. In addition, solar energy is evenly distributed throughout the archipelago, given its position around the equator. Therefore, the utilization of photovoltaic for electricity generation should be properly optimized.

Along with the huge potential of renewable energy, Indonesia also faces the problem of energy poverty. Energy poverty is closely related to economic poverty, especially for those who live in rural or 3T regions (terdepan/frontier, terluar/outermost, and tertinggal/disadvantaged). Most people in this region have low energy consumption and most still rely on human or animal labor for mechanical work. In general, electricity is needed to support basic household needs such as lighting at night and access to clean water facilities so that the electrical energy needed is still relatively small. On the one hand, the electrical energy needs are highly coveted by people living in the 3T area but on the other hand the residents generally have low purchasing power, therefore electricity facilities must be provided by the government or assisted by the private party. Meanwhile, the authority through the Decree of the Minister of Villages, Disadvantaged Regions, and Transmigration (Kemendesa PDTT) No. 126 of 2017, covers the 3T area as one of the villages that is included in the criteria for...
determining priority development villages. While in the Electricity Supply Business Plan (RUPTL) of PT. PLN (Persero) 2019-2028 mentioned the electrification strategy for areas that are still isolated and less likely the development of grid networks, including the 3T area, among others by developing power plants that take precedence over local renewable energy [3] [4].

Solar home & pumping system (SHPS) is an alternative solution for lighting and access to clean water by utilizing the potential of solar energy. Under the SHPS scheme, photovoltaic is a main source used to supply lighting needs and clean water for several households.

2. Methodology
In accordance with the research topic taken and the problem background as identified above, the authors formulized how to design the SHPS to fit community in 3T region by applying the concept of stand-alone generation for the purpose of lighting and providing clean water facilities utilizing solar energy. Furthermore, the concept was developed by modelling the load (LED lights and water pump) and photovoltaic source in SHPS. The lights are equipped with batteries to store electrical energy so that they can be operated at night, while the water pump in this study does not use batteries so they can only operate as long as they get enough energy from solar. SHPS scheme is illustrated in below.

![Solar Home & Pumping System (SHPS) Scheme](image)

Furthermore, two basic approaches are used in estimating the load, namely the Bottom-up approach and the Data-driven approach [5]. Through the Bottom-up approach, it is known several data such as type of consumer, type of load, power consumption, time and duration of load operation, and daily energy consumption. Daily energy consumption is assumed to be the same every day. While through a Data-driven approach, the SHPS component specifications, solar radiation data, and economic data are obtained.

Research on the application of SHPS begins with calculating the estimated load. There are 2 types of needs covered, i.e. the needs of home lighting with an electrical load in the form of 3 watt LED lights of 4 units per house and the needs for access to clean water with a 600 watt water pump load of 1 unit to serve 150 households. Then the total energy consumption is calculated for each need by first determining the operating duration of each load. LED lights can be lit for 6 hours, 12 hours, or 60 hours depending on the brightness level [6]. While the water pump operates for hours as long as getting sufficient solar radiation intensity. The total daily energy consumption is obtained from the total energy consumption of the two loads. Justification is carried out by applying a technical analysis to the specifications of the components making up the two systems and their operating capacity.

The next step is an economic analysis by calculating several parameters such as initial investment, NPC, energy costs, payback period, NPV, IRR, and profitability index. This parameter is then used as a tool to measure the feasibility of SHPS investment in the 3T region. In addition, a study was conducted on several scenarios that could be applied to this SHPS solution.
As a manifestation of the use of renewable energy, SHPS also has advantages from the environmental side, namely in the form of eliminating carbon emissions and other exhaust gases when electricity needs are met by using diesel-fueled generators. By knowing the properties of diesel fuel, the amount of exhaust emissions can be calculated and how much significance it has on the environmental impact.

3. Result and Discussion
In the SHPS scheme, the load data is determined in advance so that energy consumption can be calculated for a day or a year. Furthermore, battery and solar panel capacity required need to be obtained too. Finally, the total cost of the whole system as well as the feasibility can be measured, and the significance pollution can be avoided.

3.1. Load Data
There are three brightness mode of LED lights. The smaller the lumen produced, the longer the lamp will operate. For maximum brightness (240 lumens), the lamp can be lit for 6 hours with 3 watts of power, medium mode (120 lumens) for 12 hours with 1.5 watts of power, and dim mode (25 lumens) for 60 hours with 0.3 watts of power [6].

Meanwhile the need for access to clean water for the 3T community is provided from solar water pumps equipped with a water reservoir and radar sensor to regulate water levels, so that people can take water in a location close to where they live and save more time to be diverted to other productive activities. The capacity of solar water pumps can be adjusted according to the large number of people who want to be served. In this study, the authors used 150 household references for a village. If it is assumed that each household consists of 4 people and each person needs 30 liters of water [7] [8], then the total water requirements or minimum water debit required can be calculated according to the following Table 1.

| Description                  | Quantity                      |
|------------------------------|-------------------------------|
| Number of household          | 150 households                |
| Number of family members     | 4 people/household (assumption)|
| Water needs per capita       | 30 liter/capita per day (assumption)|
| Total water needs \((Q)\)    | \(150 \times 4 \times 30 = 18,000 \text{lt/day} = 18 \text{m}^3/\text{day}\) |

Furthermore, to determine the amount of pump power needed, first the design head of the pump must be calculated. The total surface height that must be pumped or the total dynamic head (TDH) is the sum of the ground water depth (aquifer) or called the dynamic water level (DWL), the water level in the reservoir or called the discharge head (DH), and the friction of water flow towards pipe or friction head or dynamic loss (DL). Meanwhile, DWL is the static ground level (SWL) by calculating the drawdown rate (DR) [7]. Thus, TDH can be calculated as written in the following Table 2.

The effective hours of pumping are taken from the minimum peak hours, i.e. the minimum duration of solar energy obtained so that the pump can work to draw water according to its capacity. In this study the shortest pumping duration was set to 4 hours [9] [10]. Based on Table 2, the required water pump capacity is 427 watts. Furthermore, the authors chose to use pump products that are available with a capacity of 600 watts. Table 3 shows a summary of the needs for lighting and access to clean water or SHPS according to the calculation above.
Table 2. Water Pump Heads and Power.

| Design Parameter       | Value                        |
|------------------------|------------------------------|
| Static water level/SWL | 15 meter                     |
| Drawdown rate/DR       | 2 meter (assumption)         |
| Discharge head/DH      | 2 meter                      |
| Dynamic loss/DL        | 10% x (SWL+DR+DH) = 10%*(15+2+2) = 1.9 m |
| Total dynamic head/TDH | TDH = (SWL+DR) + DH + DL     |
|                        | = (15+2)+2+1.9 = 20.9 meter ≈ 21 meter |
| Total hydrolic energy \((E_h)\) | \(E_h = \frac{Q \times TDH \times \rho \times g}{3,600,000}\) |
|                        | = \(\frac{18 \text{ m}^3/\text{day} \times 21 \text{ m} \times 1000 \text{ kg/m}^3 \times 9.8 \text{ m/s}^2}{3,600,000}\) |
|                        | = 1.02 kWh per day           |
| Pump efficiency \((\eta_p)\) | \(\eta_p = 60\%\)            |
| Electrical energy      | \(E = E_h / \eta_p\)         |
|                        | = 1.02 kWh / 60% per day = 1.7 kWh per day |
| Effective pump hours   | Minimum 4 hours per day      |
| Pump power             | \(\frac{1.7 \text{ kWh per day}}{4 \text{ jam per day}}\) |
|                        | = 427 watt                   |

Table 3. Load Data of Solar Home & Pumping System (SHPS).

| Load            | No. of Unit          | Nominal Power | Total Power |
|-----------------|----------------------|---------------|-------------|
| LED light       | 4 unit per household | 3 W           | 12 W        |
| Water pump      | 1 unit for 150 households | 600 W       | 600 W       |

3.2. Energy Consumption

In the previous calculation, power and the duration of each load have been obtained. Solar powered LED lights are able to work with 3 watts of power for 6 hours per day, so that with a simple calculation energy consumption is obtained for 4 units of LED lights of 72 Wh. Taking into account the number of households, the overall energy consumption is 72 Wh x 150 = 10,800 Wh or 10.8 kWh per day or 3942 kWh per year. While for solar water pumps, with 600 watts of power and peak hours are calculated for 4 hours per day, energy consumption is 2400 Wh per day or 876 kWh per year.

3.3. Main Components of SHPS

A battery used to supply electricity to an LED light is integrated with the lamp as shown in Figure 2 below [11]. The battery used is a type of lithium considering it has a high energy density so that it is more compact in terms of design, as well as minimum maintenance [12]. The required battery capacity can be calculated as follows.
Figure 2. Lighting Scheme on SHPS.

Table 4. Battery Capacity for Powering LED Light.

| Battery Parameter            | Value |
|-----------------------------|-------|
| Capacity of 1 unit LED light| 3 watt|
| Operating duration           | 6 hours|
| Energy consumption           | 3 watt x 6 jam = 18 Wh|
| DoD                          | 80%   |
| Autonomy day                 | 1 day  |
| Rated voltage                | 3.7 V  |
| Battery capacity             | \( C = \frac{18 \text{ Wh} \times 1 \text{ day}}{\text{80\%}} \text{ per day} = 22.5 \text{ Wh} = 22.5 \times 1000/3.7 \text{ mAh} = 6081 \text{ mAh} \) |

Meanwhile, the required solar panel capacity is used to charge the integrated batteries in each LED light. From Table 4, a battery with a capacity of up to 6081 Ah or 22.5 Wh is obtained. If the peak-hours reference is used for 4 hours and losses in the cable and a decrease in capacity due to the influence of temperature by 20%, then the capacity of the solar panel can be calculated as follow [13].

\[
\text{Solar panel capacity for lighting system} = \frac{4 \times 22.5 \text{ Wh}}{(100\%-80\%) \times 4 \text{ day}} = 28.125 \text{ Wp}
\]

For the purpose of solar water pump, solar panel capacity is calculated based on pump capacity by adjusting the efficiency factor of the sub-system due to power losses in the channel and controller. If the efficiency is determined at 77.4% [7], then the capacity of the solar panel can be determined as follow.

\[
\text{Solar panel capacity for pumping system} = \frac{600 \text{ W}}{77.4\%} = 775.2 \text{ Wp}
\]

3.4. Economic Analysis and Environmental Impact

There are 3 scenarios in assessing economics:

1) Scenario 1: Full investment of SHPS

2) Scenario 2: Grants or full subsidies by the government or private sector
3) Scenario 3: Government or private grants or subsidies for lighting systems, while investment schemes for water access systems

In terms of investment, an economic analysis is calculated based on an investment rate of 10% which was higher than the highest deposit rate [14]. The calculation results of the three scenarios above are shown in the following Table 5.

| Parameter | Scenario 1     | Scenario 2          | Scenario 3* |
|-----------|---------------|---------------------|-------------|
| NPC       | Rp 806 mil.   | Rp 480.5 mil.       | Rp 56 mil  |
| COE       | Rp 18,860/kWh | not assessed        | Rp 6,027/kWh|
| IRR       | 10.05065%     | not assessed        | 11.2108%   |
| UAW       | Rp 95 mil.    | not assessed        | Rp 23 mil. |
| PBP       | 9 years       | not assessed        | 3 years    |
| NPV       | Rp 2.8 mil.   | not assessed        | Rp 1.2 mil.|
| PI        | 1.00347       | not assessed        | 1.021      |
| IB        | Rp 52,800     | 0                   | Rp 13,000  |

*aScenario 3 only shows the investment portion

From the investment side, scenario 1 and scenario 3 have a positive NPV and an IRR of more than 10% so they can meet the eligibility criteria. On the other hand, based on the benefits felt by residents living in the 3T area, especially for disadvantaged citizens, the second scenario is certainly more expected than the other two scenarios. Whereas the third scenario can be applied to the community if it fulfills the ability to pay contributions of Rp 13,000 per month for the first 3 years. In terms of investment, the third scenario will attract more investors because besides fulfilling the eligibility criteria it also requires a relatively low initial investment compared to the first scenario. The return on investment only requires 3 years while the benefits of access to clean water can be enjoyed in the long run.

Another advantage obtained by installing solar powered lights and water pumps when compared to installing a generator is in terms of the impact on the environment. As it is known that when installing generators, in addition to the supply of fuel which is constrained by infrastructure access that is heavy enough for several regions, it also impacts the burning of the fuel itself for the environment. Emissions of substances that are not environmentally friendly such as carbon pollutants and sulfur can cause environmental pollution, the effects of greenhouse gases, or acid rain.

4. Conclusion

The design of the solar home & pumping system (SHPS) can help the 3T community in obtaining lighting and access to clean water through solar to electricity energy conversion. The SHPS scheme in this study can be applied to 150 households living in the 3T area. For more optimal calculations it is recommended to obtain more detailed data such as community data in a 3T village, geographical conditions, depth of ground water, solar radiation data, installation costs and supporting materials.

From an economic perspective, the scenario of grants or full subsidies by the government or private sector is more advisable considering that it does not burden the 3T people and also the relatively low cost. In addition, the SHPS scheme also has its own advantages considering the use of solar power that is environmentally friendly when compared to using diesel generators.

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