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Solar Irrigation System in Indonesia: Practical Assessment and Evaluation for Converting Fossil Fuels with Solar Energy

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Abstract. This study proposes a sustainable solar-powered irrigation system (SPIS) for a 75-hectares rice farm in Krandegan Village, Purworejo Regency, Indonesia. The existing water pumping system uses diesel engines which costs around Rp. 200 million per year that cannot be provided by the farmers. The SPIS was designed based on water requirements calculated according to the Food and Agriculture Organization (FAO). The technical design of SPIS used Lorentz Compass considering local solar energy sources and the availability of SPIS components in the local markets. The entire farm in Krandegan requires 11 SPISs with a total capacity of solar panel is 20.8 kWp. Also, the SPISs use 11 centrifugal DC pumps; 10 surface and 1 submersible type. The SPIS in Krandegan would require a total cost of Rp. 1.29 billion. Without the financial support of the capital costs from other parties, the simple payback time (SPT) would be around 6.5 years, which is good for a solar photovoltaic (PV) project. SPIS not only a viable solution to replace diesel engines in supplying water to the rice farm in Krandegan, but is also in line with the seventh target of Indonesia's Village sustainable development goals (SDGs).

1. Introduction

Krandegan Village in Purworejo Regency has 75 hectares of wet rice farm. The water requirement of the rice farm in Krandegan is supplied through a free irrigation program. The free irrigation program uses water pumps driven by diesel-fueled engines that increase the rice production to three times a year from only one harvest per year when it was a rainfed rice farm. The program is named 'free' irrigation because the cost of purchasing engines and pumps as well as the fuel cost is provided by other parties so that it is free for the farmers.

However, after about three years in operation, the use of fossil fuels under the free irrigation program in Krandegan is starting to raise problems. The main problem is due to the high cost of fuel. Every year, the donor provides cash of around Rp. 200 million[1]. The fuel costs have become increasingly expensive since early 2021 due to the government's restriction to Premium fuel production, so farmers are switching to Pertalite or diesel fuels which are more expensive. In addition, the availability of Pertalite and diesel fuels cannot be guaranteed because the priority of sales at gas stations is given to vehicles.

[1] US$ 1 approximately equals to Rp. 14,500.

Thus, the free irrigation program in Krandegan cannot be continued. Also, the program is not in line with the sustainable development goals (SDGs) [1] because the burning of fossil fuels produces carbon dioxide (CO_2), carbon monoxide (CO), and other greenhouse gases. The use of oil and lubricants in the machines can also pollute the environment.

The signal to stop the fuel donation by the donor could reduce the number of harvests from three times to once per year because the farm would again depend on rainwater following the seasons. Krandegan village demands innovation to anticipate this big problem. The high solar radiation in Krandegan can provide solutions through a sustainable solar-powered irrigation system (SPIS) which is cheaper than a diesel irrigation system [2]. SPIS is also clean and silent and has low operational and maintenance costs [3].

The method will describe the steps taken in designing an SPIS in Krandegan. The results of the technical design and cost analysis are shown in the results and discussion. The conclusion will present the important findings of this study and recommendations.

2. Method

2.1 Mapping the Study Location

The rice farm in Krandegan takes an area of 75 hectares consisting of six blocks of different areas (Figure 1). The blocks are marked with B1 to B6. It is assumed that adjacent blocks would be connected with waterways so that four locations, L1 to L4, are obtained.

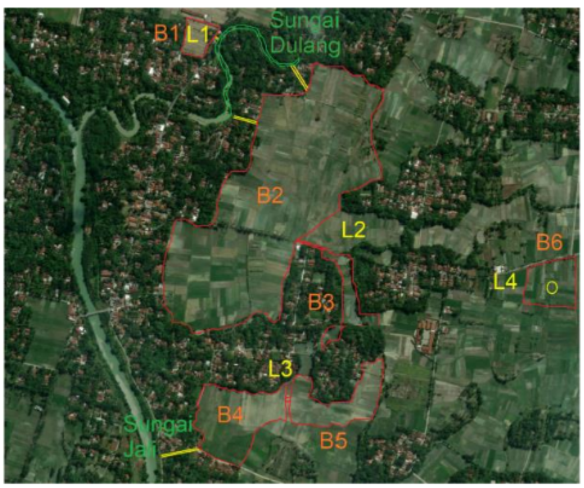


Figure 1. Four locations of rice farm in Krandegan consisting of six blocks.

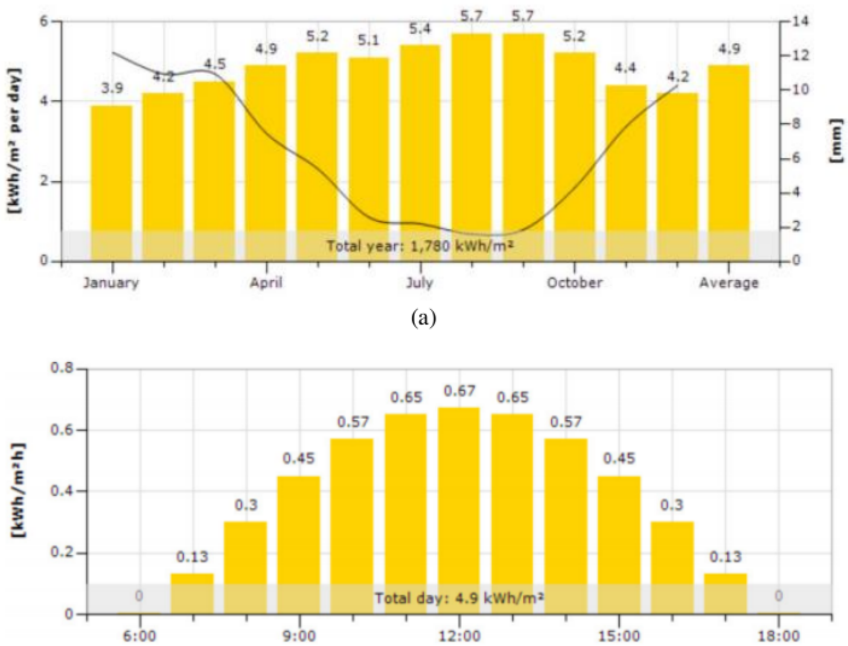
Table 1 shows the area and water source of each location. It can be seen that L2 is a combination of blocks B2 and B3. L2 has the largest area with a total of 62 hectares. The water source of L2 is the Dulang River. L3 covers an area of 5 hectares with water coming from the Jali River. L1 is the smallest location with an area of 3 hectares with a water source from the Dulang River. L4 is the farthest location from the river, so the water source comes from a borehole at that location. The area of L4 is 5 hectares.

Table 1. The location areas of rice farm in Krandegan

Location	Block	Area (hectares)	Water source
L1	B1	3	Dulang River
L2	B2+B3	60 + 2 = 62	Dulang River
L3	B4+B5	3.5 + 1.5 = 5	Jali River
L4	B6	5	Borehole
Total area		75	

2.2 Getting Climate Data

Krandegan village is located close to the South coast of Java Island where solar radiation is quite high. Figure 2a shows that on average the radiation on a horizontal plane is 4.9 kWh/m^2 per day [4], ranging from the lowest radiation in January to the highest in August to October, respectively at 3.9 kWh/m^2 to 5.7 kWh/m^2 per day. The total radiation is 1780 kWh/m^2 per year. The seasonal profile of solar radiation is the opposite of the rainfall profile; radiation is lower in periods of high rainfall and vice versa, as shown in Figure 2b.



(b)

Figure 2. Solar energy source in Krandegan: (a) monthly-averaged radiation, (b) hourly-averaged radiation. Data obtained from POWER NASA *Langley Research Center* (LaRC) Project funded by NASA *Earth Science/Applied Science Program*.

2.3 Planning the SPIS

Technically, the SPIS in Krandegan was planned through the following eight steps:

a. Calculate water requirements and determine the design month,
b. Calculate the total dynamic head and select the pump,
c. Calculate solar panel size, configuration, inverter/controller selection, and solar panel direction,
d. Determine the location of the main components,
e. Minimum balance of system (BoS) requirements.

2.4 Calculating Water Demand

Water requirements are expressed in cubic meters (m^3) and are calculated according to the method from the Food and Agriculture Organization (FAO) [5] that can be used manually or using CROPWAT [6]. The steps for manual calculating of water requirements are shown below:

1. Determine the reference plant evapotranspiration (ETo),
2. Determine the plant factor (Kc),

3. Calculate the crop water requirements (ET plant = ETo × Kc),
4. Determine the amount of water needed to saturate the soil for land preparation with inundation (SAT),
5. Determine the amount of percolation and seepage loss (PERC),
6. Determine the amount of water needed to form a water layer (WL),
7. Determine the effective rainfall (Pe), and
8. Calculate irrigation water needs (IN = ET plants + SAT + PERC + WL – Pe).

Using the above method by applying the annual average, rice farm in Krandegan requires water about 30 m^3/hectare per day.

2.5 Design Information

The design was implemented using Lorentz Compass [7]. Table 2 summarizes the results of the design steps described above. The parameters are named referring to Figure 3. The water requirements at each location and the parameters/assumptions used are also shown in the table. Specifically for the location L2, there are eight SPIS units (sub-systems) due to the large area of the field.

Table 2. Design information of SPIS in Krandegan

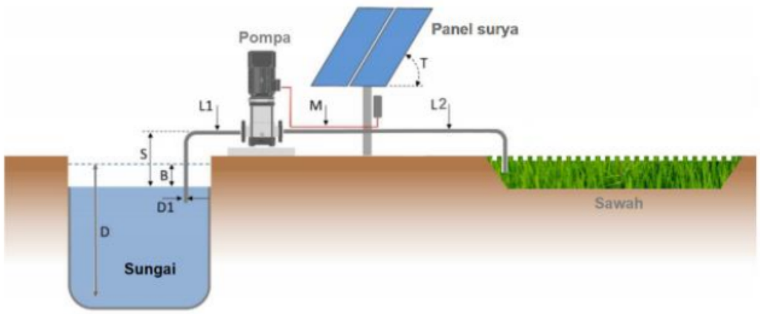
Parameters/Assumptions	Location			
	L1	L2	L3	L4
Location (Latitude; Longitude)	7.75 LS; 109.93 BT			
Area (hectare)*	3	62	5	5
Total water requirement per day (m^3)	90	1860	150	150
Number of pumps (units)	1	8	1	1
Water requirement per pump per day (m^3/day)	90	233	150	150
Bore well water production (m^3/hour)*	>100	>100	>100	>100
Groundwater temperature (°C)	30	30	30	25
Depth of well/river, D (m)*	3	3	5	12
Static water level, S (m)*	5	3	3	7
Dynamic water level, B (m)*	1	1	1	12
Rice field height (m)*	0.5	0.5	0.5	0.5
Cable length, M (m)*	10	55	8	20
Pipe length (pump to rice farm), L2 (m)*	20	80	200	20
Pipe diameter (inch)*	2	4	2	2

**Based on data supplied by Krandegan Village officials.*

3. Results and Discussion

3.1 Technical Design

For the design of an SPIS, the main focus of the designers is not on the pump, but on the water requirement. An undersized system may be cheaper, but will not meet the water needs, while an oversized system will provide the water needs throughout the year but the capital costs are high. The design is based on the volume of water pumped per day (during sun hours). SPIS consists of several main components, namely solar panel generators, pumps, and several control equipments for optimization, control, and balance of system (BoS). For simplicity, this section only shows the components of solar panels and pumps as the main components. In the implementation of SPIS, other components are also required such as control and safety equipment (pump controller, PV disconnect, lightning surge protector, water filter, grounding, and floating switch), cables (motor cables, module cables), and pipes (suction pipes, delivery pipes). In this study, all solar panels are installed with a tilt angle of 15 ° and azimuth angle of 180 °.



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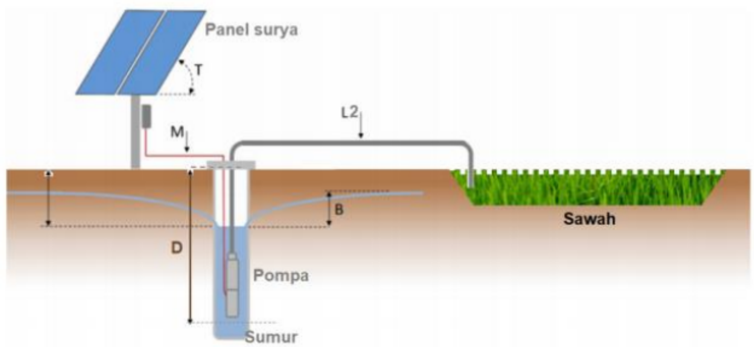


(b)

Figure 3. Illustration of SPIS layout in Krandegan: (a) Location L1, L2, and L3 with water source from Dulang River and Jali River, and (b) Location L4 with water source from a borehole. Legend: M = cable length, D = Depth of well/river.

To illustrate the design results, the SPIS at location L1 is shown (Figure 4). It consists of 4 pieces of 200 Wp solar modules with 4 parallel string configurations (Figure 5). The total capacity of the solar panels is 800 Wp. The solar panels drive a 1 DC centrifugal pump of 1.8 kW mounted above the water surface.

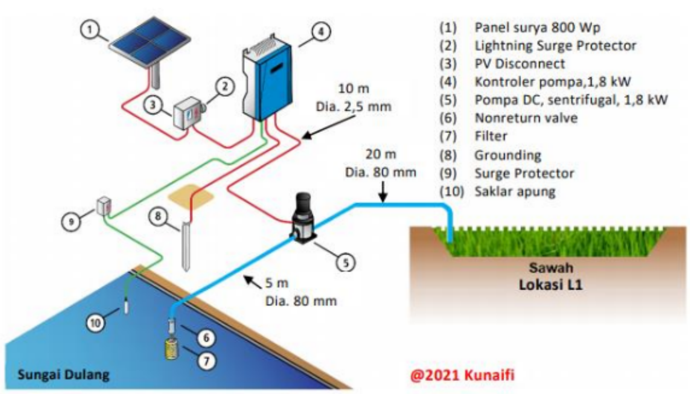


Figure 4. SPIS Design for location L1.

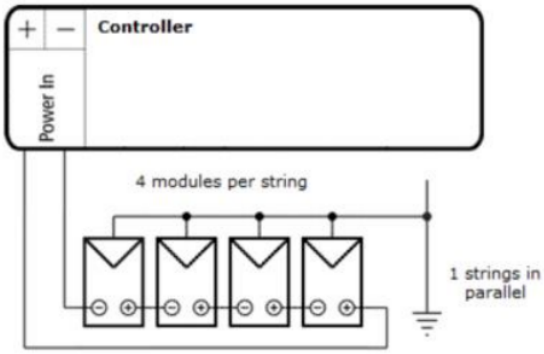
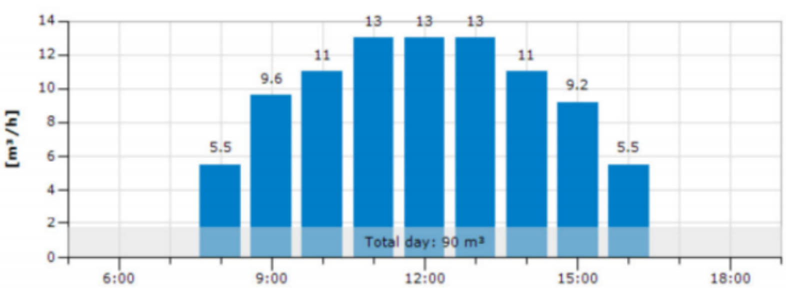


Figure 5. Solar panel wiring diagram for SPIS at location L1.

The design objective of SPIS at Location L1 is to provide 90 m^3 of water per day to a 3-hectare rice farm. Assuming an operating period of 7 hours a day, the pump must be able to draw an average of 13 m^3 of water per hour. The SPIS design at location L1 shown above could pump water around 110 m^3/day, which is higher than the daily water requirement. Figure 6a shows the daily profile of water production in January, the month with the lowest water production. It is seen that the production of a small amount of water, around 5.5 m^3/hour starts at around 8 am, increases to 13 m^3/hour at around noon, and drops to 5.5 m^3/hour at around 4 pm. The total water production per year is 33,000 m^3, or 0.5% higher than the volume of water needed for one year (Figure 6b). The smallest daily volume pumped is around 90 m^3 per day during the rainy season in January. The highest water production occurs at the peak of summer in July-August, amounting to 127 m^3 per day. Thus, SPIS could meet the water needs of location L1 throughout the year.



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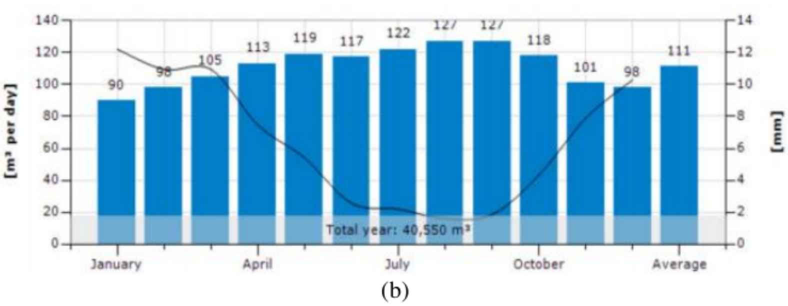

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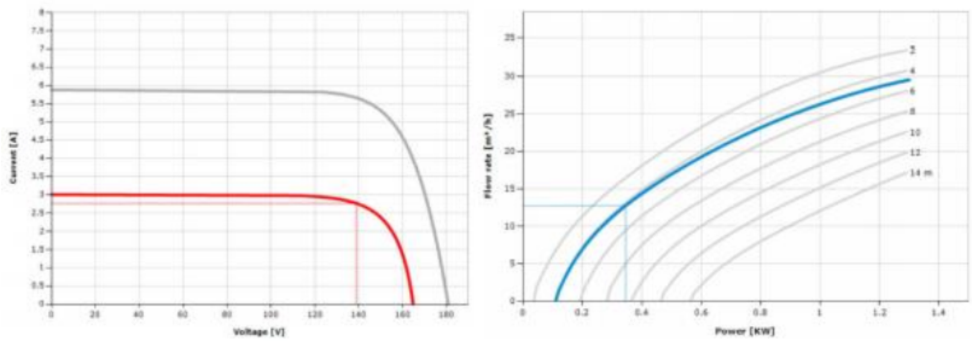
Figure 6. The volume of water pumped by SPIS at Location L1.

Figure 7 shows the performance of solar panels and pumps of SPIS at location L1 when the radiation is 535 Watt/m^2 or 80% of the highest radiation at the location and the temperature is around 35 °C. This analysis is provided to estimate pump performance when radiation is lower than expected, for example during rain or cloudy days. It can be seen that the output voltage decreases by 11% due to the panel temperature rising to 52 °C. Of the total installed PV panel of 800 Wp, under these conditions, the panel produces 361 Watts so it can still rotate the pump fast enough to pull and push water. However, the pump which has a maximum speed of 2605 rotation per minute (rpm) under these conditions only rotates 1665 rpm (81%), pumping 13 m^3 of water per hour with a pump efficiency of 42%. Thus, in the light cloudy days that often occur in Krandegan, SPIS still works quite well.



(a) (b)

Figure 7. The performance of SPIS at location L1 when the radiation is 535 Watt/m^2 (80% of highest radiation at the site) and ambient temperature is 35 °C: (a) solar panel characteristic, (b) pump characteristic.

Table 3 shows the design results of SPIS for the entire rice field in Krandegan.

3.2 Economic analysis

The total cost needed to provide water for the 75 hectares of rice fields using SPIS in Krandegan is Rp. 1.29 billion. The costs of suction and delivery pipes are not calculated. The existing pumping system within the free irrigation program costs an average of Rp. 200 million per year. Thus the simple payback time (SPT) [8] is around 6.5 years, which is quite good for a solar PV project. SPT will be shorter if the capital cost of the free irrigation system were taken into account and the increase in fuel prices during the coming years is considered. Also, if some of the initial costs of the SPIS are provided by third parties (such as government, private companies, and donors), the SPT will be shorter.

4. Conclusion

It is feasible to implement a solar-powered irrigation system (SPIS) in Krandegan Village by considering the water needs, rainfall, solar radiation at the location, and the costs. SPIS can prevent farmers from re-applying rainfed rice fields practice so that harvests can be maintained three times a year. In addition, the Green Village program is one aspect of the Village's sustainable development goals (SDGs) [9]. The seventh target of the Village SDGs is a Clean and Renewable Energy Village. Krandegan Village is a progressive village, so it has a great potential to achieve the status of a Clean and Renewable Energy Village in the coming years. The benefits from the SPIS program in Krandegan could also be extended to other villages because rice field irrigation and SPIS are naturally in harmony.

Table 3. The design results of SPIS for the entire rice field in Krandegan

Parameters/Components	**Location**			
	L1	**L2*** **	**L3**	**L4**
Area (hectare)*	3	62	5	5
Total water requirement (m^3/day)	90	1860	150	150
Number of pumps/sub-systems	1	8	1	1
Water must be supplied by each pump (m^3/day)	90	233	150	150
Design month**	Worst	Average	Worst	Worst
Pump				
▪ Installation of the DC centrifugal pumps		Surface		Submerged
▪ Minimum capacity (kW)	1,8	8 x 1,8	1,8	1,8
PV generator				
▪ PV panel capacity (Wp)	4x200	8 x 8 x 260	8x205	5x260
▪ PV panel configuration per system (sub-system for L2)				
○ Number of parallel string	1	2	2	1
○ Number of modules per string	4	4	4	5
Motor cable				
▪ Minimal length (m)	10	8 x 55	8	8
▪ Minimal diameter (mm^2)	2,5	8	2,5	2,5
Piping				
▪ Suction pipes, length (m)	5	8 x 5	5	-
▪ Suction pipes, minimum diameter (mm / inch)	80/3,1	50/2	80/3,1	-
▪ Delivery pipes, panjang (m)	20	8 x 80	200	20
▪ Delivery pipes, minimum diameter (mm / inci)	80/3,1	100/3,9	80/3,1	100/3,9
Result estimation (water pumped)				
▪ Total volume (m^3/year)	33.000	85.000	63.400	66800
▪ Average volume (m^3/day)	110	233	174	153
▪ Demand met (%)	100,05	99,95	116	122

* Based on data provided by Krandegan Village officials.
** The design in the worst month results in sufficient water supplied on the month with the lowest solar radiation, while in the other 11 months the water supply will be excessive. The design in an average month uses the annual average radiation, so that in the months with low radiation the water supply will not be sufficient, but in other months the water supply will be excessive. SPIS costs with designs using the worst month are more expensive than the designs that use the average month.
** Design at location L2 was carried out for each sub-system. There are eight sub-systems at location L2.

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