

Techno-Economic Feasibility Assessment of Solar PV Water Pumping System In Dryland: Case Study In Madura

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ABSTRACT

Indonesia has enormous solar radiation potential, and it can be converted to electrical energy by utilizing solar PV systems. Mainly the irrigation of paddy rice fields in Indonesia dependent on a diesel-powered water pumping system. A solar PV system can replace this method, and it generates several benefits. The present study proposed the utilization of a solar PV system to drive the water pump based on a 100% renewable power supply. The technological and economic viability assessment of solar PV water pumping system to irrigate paddy rice filed at Telang village, Bangkalan, Indonesia, is investigated. The HOMER software has been used to generate the optimal configuration of a renewable system. Initial capital, net present cost, and cost of energy will evaluate as economic assessment criteria. The solar PV and diesel generator water pumping system also compared. The results showed that for water pumping systems, a solar PV system is more cost-effective than a diesel generator. It has lower annual operational and maintenance costs, 100% renewable energy penetration, and free energy cost

Keywords : Solar PV, water pumping system, Solar Energy, HOMER software

INTRODUCTION

Water pumping for paddy rice fields in Indonesia's rural area is generally dependent on diesel-generated electricity. It is due to has low annual precipitation and unavailability of the electricity grid. In most regions with low rainfall, irrigation is the primary water source, especially in Madura. In Madura, The diesel generator-based water pumping system supply the irrigation to watering the paddy rice fields. The diesel generator-based water pumping system generates noise, air, and environmental pollution (Julian *et al.*, 2020) (Ezani *et al.*, 2018).

Renewable based power system used to drive water pump reduces the dependence on diesel generator-based electricity. It leads to a reduction in the negative environmental impact. Solar photovoltaic (PV) water pumping system gains much attention due to has no fuel cost, and environmental friendly (Meah *et al.*, 2008). Most regions in Indonesia have a tremendous solar radiation potential of more than 4.5 kWh/m²/day (Handayani & Ariyanti, 2012). This energy can be

converted to electricity through solar PV technology. The proper configuration of a solar PV system will reduce the system's reliance on solar radiation and increase its reliability. The uses of solar PV water pumping systems for irrigation have been reported by several works of literature (Mokeddem *et al.*, 2011; Pande *et al.*, 2003; Kolhe *et al.*, 2004; Benghanem *et al.*, 2013).

Mokeddem *et al.*, (2011) conducted an empirical investigation on the performance of solar PV based water pumping system. The components consist of 1,5 kWp solar PV panel and centrifugal pump coupled with dc motor afterwards tested over 4 months under varying climatic condition and solar irradiance. The study concluded that the system is applicable for water pumping system. Benghanem *et al.*, (2013) determined an optimum solar PV configuration to drive the water pumping system in the remote area of the Madina site. The solar PV water pumping system uses to supply water in the semi-arid areas for domestic and livestock usage.

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The result shows that the solar PV water system is suitable for delivering water and supplies the water needs in a remote area. (Chueco-Fernández & Bayod-Rújula, 2010) analyzed the comparison of using solar PV system, diesel generator and electricity grid in remote areas of Chile. The study considering the length to the power grid, the electricity and gasoline fuel cost, and vital investment to the analyzation. Solar PV systems are more cost-effective than diesel generators or electrical grids for driving water pumping systems in small and medium demands.

Sahin & Rehman (2012) studied the techno-economic viability of solar PV water pumping systems in several regions of Saudi Arabia. The study investigated the potential of using solar PV systems in Riyadh, Nejran, Guriat, Jeddah, and Dhahran regions to drive the water pumping system. The result found that the Nejran region is the most economical to use solar PV water pumping system. Mahmoud & el Nather (2003) did a feasibility study using a solar PV water pumping system to deliver water for irrigation systems in remote areas. The study also compares a solar PV system with a diesel generator system to drive a water pump. The study reported that using a solar PV system for water pumping is more economical than using a diesel generator system.

Several authors also use the modeling approach to improve and optimize the solar PV water pumping system (Nasir, 2019; Rao *et al.*, 2015; Taufik *et al.*, 2009; Odeh *et al.*, 2006). Al-Badi *et al.*, (2018) used MATLAB simulation model to determine the required size of the solar PV system to drive water pump for an existing farm in the Sultanate of Oman. The system built from several components such as solar PV arrays, inverter, electrical motor, water well and water tank. The simulation model is validated with the experimental work at a laboratory-scale. The study demonstrates that using solar PV water pumping system is cost-effective application in remote areas and also has positive impact to the environment. Raghuwanshi & Khare (2018) developed a simulation model to determine the size of the solar PV and water pumping system for irrigation purposes. The system is proposed to supply 35.000 L/day of water in remote areas. The study shows that the solar PV water pumping system is viable for providing irrigation and drinking water. The study also recommends using an automatic control system to

improve reliability and efficiency. Biswas & Iqbal (2018) developed dynamic modeling of a solar PV system to drive the groundwater pumping for irrigation in remote areas of Bangladesh. The components such as solar PV panels, inverter, electrical AC motor, and pump is used to provide the irrigation with 1.930 m³/day of water. To increase the system performance, the energy storage system is performed using MATLAB simulation in terms of battery bank for an electrical energy and water storage tank for stored water. This study found that the solar PV water pumping system is applicable for irrigation systems in remote areas of Bangladesh. This system can be used for a long period solution with indicates positive economic results.

The solar PV water pumping system is more economical than a diesel generator water pumping system for 25 years of operation. Saving energy in battery storage and the water tank is gaining much benefit for irrigation systems during the dry season. Based on the literature review, a solar PV water pumping system is a feasible and cost-effective solution to support irrigation systems in areas where the lack of water and an electricity grid. In this study, Hybrid Optimization Models for Energy Resources (HOMER) software is used to find the optimum configuration of solar PV water pumping system in the proposed study site. The objective of the present study is to determine the technological and economic viability of a solar PV water pumping system in Madura.

This study uses solar energy to drive the water pump and eliminates the dependence on diesel generators. First, the water required to support the irrigation system on site is established. Then the utilization of a solar PV water pumping system to irrigate the paddy rice field is presented. The benefit of using a solar PV water pumping system compared to a diesel generator is also discussed. This study can enlighten the government on the viability of the solar PV water pumping system in Madura

RESEARCH METHODS

Study Area

The study was carried out in the dry land area located in Telang village, Bangkalan, Indonesia, at an altitude of 5 m above sea level. The location found in the global positioning system coordinates at latitude 7° 7' 13.2348" S and longitude 112° 44'

1.0536" E. The annual average temperature, humidity, precipitation, and sunshine duration are 29°C, 76.8%, 20.57 mm, and 6.24 hours, respectively (Badan Pusat Statistik Kabupaten Bangkalan, n.d.). This study area is selected because of water scarcity and quite difficulty getting groundwater resources. Only one groundwater well available in that area and use as a water source for irrigation, as shown in Figure 1a. The groundwater well of 25 m in depth was drilled and using an 8-inch polyvinyl chloride pipe as well casing. Based on an interview with the local farmer, the groundwater source will never get dried and always available even in the dry season.



Figure 1. (a) Water Irrigation System Available In The Site; (b) Groundwater Pump Powered By Diesel Generator

A heavy-duty high flow centrifugal pump uses to watering the paddy rice farm. The groundwater pump is powered by a diesel generator because no electricity from the grid reaches the site. The diesel generator uses to drive the groundwater pump is shown in Figure 1b. The diesel generator uses both in the dry and rainy seasons due to low annual precipitation. Paddy rice grows throughout the year, and it is harvested three times a year, including pre and post-harvest treatment. The paddy rice field in the study area is shown in Figure 2. The water irrigation is supplied by groundwater well (April – September) and combines between groundwater well and rain (October – March).



Figure 2. Paddy Rice Farm in The Study Area

Solar Energy Resources

Site weather data such as daily global horizontal irradiance (GHI) and clearness index are imported using the National Aeronautics and Space Administration (NASA) surface meteorology database (*NASA POWER | Prediction Of Worldwide Energy Resources*, n.d.). The monthly average daily GHI and clearness index are shown in Figure 3. The highest and lowest daily solar radiation are September (6.05 kWh/m²/day) and January (4.7 kWh/m²/day), respectively. It corresponds to the peak of the dry and rainy season in the site. The annual average daily solar radiation in the study area is 5.17 kWh/m²/day. The annual average clearness index is 0.52 in the study area. The Study area has significant solar potential and the ability to produce electricity using a solar PV panels.

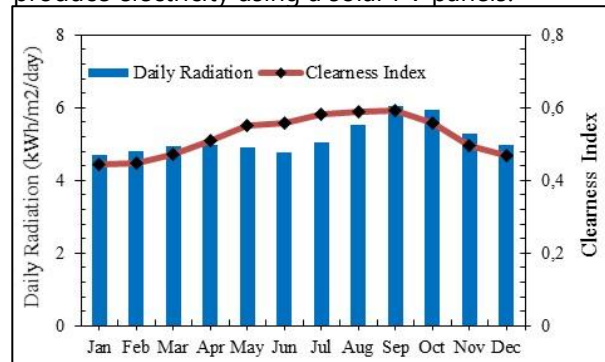


Figure 3. Daily GHI and Clearness Index of Telang Village, Bangkalan Regency, East Java Province, Indonesia

Estimation of Water Requirement

In this study, the water need can be evaluated from the total size of the agricultural land and the amount of water needed for paddy rice during the growing period. A 26 ha paddy rice field will be watering from an irrigation system. Paddy rice consumes water, typically ranges from 450 - 700 mm from the total growing period (*CHAPTER 2: CROP WATER NEEDS*, n.d.). This water required for transpiration and evaporation thus called evapotranspiration. Local farmers also confirm these numbers of water needs during the oral interview on-site conducted by the author.

Load Profile

A heavy-duty high-flow centrifugal pump uses to irrigate a 26-hectare paddy rice field. The specification of the pump equipment is listed in Table 1. The power consumed by the pump represented 100% of the total daily load. The load demand is starting from 9 a.m. to 6 p.m. and around ten hours per day to supply the water to the paddy

rice field through the irrigation system. The pump consumes 150 kWh of electrical energy to produce 2000 m³ of water every day. At the moment, the power supply is currently provided by a stand-alone 35 HP diesel generator.

Components Description

The schematic illustration showing the solar PV system used to drive a water pump for irrigation of a paddy rice field is presented in Figure 4. The schematic diagram shows the whole system that consists of a combination of water pumping and renewable power generation system. The water pumping system consists of the centrifugal pump, water pipe, and irrigation system. These components stream water from the groundwater well to the paddy rice field through the irrigation system. The renewable power generation system consists of a solar PV array, inverter, and a storage battery system. These components generate the electrical energy to drive the water pump and storing the excess energy in the storage battery. The primary purpose of the renewable power generation components is to replace the diesel

generator used in the paddy rice farm to drive the water pump.

Simulation Methods

The technological and economic viability assessment simulated and optimized using HOMER Pro software. First, an initial assessment is performed to evaluate the renewable energy resources, load demand, and component cost based on the actual data on-site. The data daily GHI, clearness index, and daily load profile are inputted on the HOMER Pro software input box interface. The component properties and cost for solar PV panels, inverter, and storage battery are generated from the local distributors. Thus, the valid data is entered into the HOMER Pro software. Detailed values of the solar PV panels, inverter, and storage battery properties and cost are presented in table 2. Second, the proper technology configuration is selected, simulated, and optimized in HOMER Pro software. The techno-economic analysis executes to find the optimized results in terms of technical configuration and economics. Initial capital, net

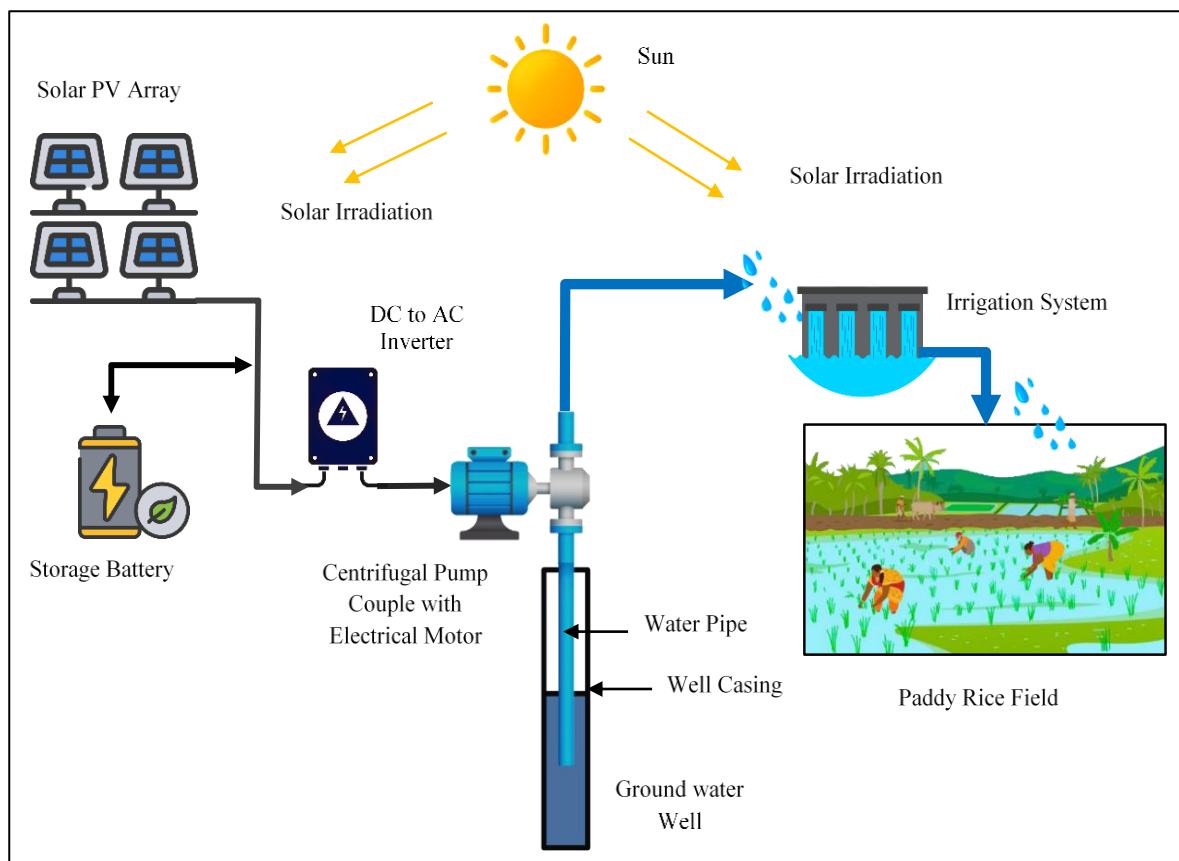


Figure 4. Diagrammatic representation of solar PV powered water pumping system

present cost (NPC), and cost of energy (COE) will evaluate as economic assessment criteria.

Table 1. Specification of centrifugal pump

Parameters	Unit	Value
Required power	kW	15
Flow rate	m ³ /hour	200
Head	m	30
Suction pipe diameter	m	0.152
Discharge pipe diameter	m	0.127
Max water temperature	°C	80
Synchronous speeds	rpm	1450

RESULTS AND DISCUSSION

The solar PV system has a 100% renewable fraction, zero gas emissions, and zero adverse effects on the environment. Based on the oral interview conducted by the local farmer on-site, the oil and fuel spill from the diesel generator has damaged the paddy crop. Furthermore, the on-site distribution of oil and fuel consumes a lot of time and cost, which drives up production costs. HOMER Pro software simulated and optimized the input data, then get the optimal solar PV system to drive the water pump. The solar PV system consists of 60 kW solar PV panels, 78 batteries, and a 24 kW inverter. The cost of energy of solar PV system was \$0.519/kWh with 100% renewable energy penetration.

Developing the solar PV system on-site required initial capital of \$220,853. The system has a high life cycle cost represented with higher NPC (\$277,833). The high number of batteries dominates 77.3% of the total system capital. Compare with the diesel generator system, solar PV lower in operating cost (\$5,822/year) than diesel generator (\$25,905/year). The initial capital of a diesel generator (\$1,700) is lower than a solar PV system due to using an unreliable diesel engine. The existing diesel generator cost is lower more than ten times than another reliable diesel generator. The COE and NPC of diesel generator are \$0.49/kWh and \$216,074, respectively, and it is little bit lower than the solar PV system. This study also compared to this literature (Gao & Liu, 2016). The initial capital is almost the same for both studies, \$1,929 / ha (present study) and \$1,981/ha (Gao & Liu, 2016) when developing a solar PV system for water pumping at a paddy rice field without a battery. The

difference is, this study used a battery to drive the water pump when the solar radiation not available in the afternoon. Then the initial capital is higher due to the utilization of the battery. This study's solar PV system power is higher than the compared paper (Gao & Liu, 2016) reported value then correspond to the higher energy production. This study produces 12,538 m³ of water per ha, while another study (Gao & Liu, 2016) produces 5,520 m³ water per ha during the whole growth period.

Table 2. Component properties and cost

Description	Unit	Value
Solar PV Array		
Rated power	W	250
Capital cost	\$/kW	650
Replacement cost	\$/kW	450
Operation and Maintenance cost	\$/year	10
Lifetime	years	25
Derating factor	%	88
Storage Battery		
Capital cost	\$/unit	300
Replacement cost	\$/unit	150
Operation and Maintenance cost	\$/year	10
Nominal capacity	kWh	1
Maximum capacity	Ah	83.4
Nominal voltage	V	12
Lifetime	years	15
DC to AC inverter		
Capital cost	\$/kW	300
Replacement cost	\$/kW	122
Lifetime	years	15
Efficiency	%	99

CONCLUSIONS

Supplying water for paddy rice fields using a solar PV water pumping system improves national food security. The techno-economic viability of a solar PV water pumping system to irrigate the paddy rice field has been presented. Based on the present studies, the finding can be concluded as follows :

- i. The 2000 m³ of water is required to irrigate 26 ha paddy rice field in Madura per day

- ii. A total electrical energy requirement of 150 kWh/day is required to generate water for the paddy rice field in Madura
- iii. The optimal configuration of solar PV water pumping system consists of 60 kW solar PV panels, 78 batteries, and a 24 kW inverter
- iv. The initial capital developing the solar PV water pumping system in Madura is \$8,495 per ha with a COE of \$0.519/kWh.
- v. The solar PV system is more cost-effective than a diesel generator for driving water pumping systems due to low operation and maintenance costs per year, 100% renewable energy penetration, and free energy cost.

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