

Determination of desalination system pricing in Penjaringan Utara subdistrict, North Jakarta using HOMER simulation

H. A. Danang Rimbawa¹, Gabriel Winandika Saragih², M. Irsyaad Nurrahman³

¹Military Electrical Engineering Study Program, Faculty of Defense Engineering and Technology, Republic of Indonesia Defense University, Bogor, Indonesia

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ABSTRACT

The coastal area of Muara Angke in North Jakarta grapples with significant challenges regarding access to clean water, compounded by limited energy availability. In 2024, a desalination project utilizing reverse osmosis (RO) technology was launched to address this issue, with a capacity to produce 320 liters of clean water per hour. A key feature of this initiative is its reliance on solar energy, which offers a sustainable solution to the region's energy constraints. However, to ensure the project's long-term viability, it is essential to conduct an economic evaluation, particularly focusing on the cost of producing the desalinated water. This cost is intricately linked to the energy required to power the reverse osmosis (RO) system. Specifically, the Cost of Energy (CoE) plays a crucial role in determining the price of the desalinated water. To assess the economic feasibility of the solar-powered desalination system, HOMER simulation software was used to model the performance of the solar power system, considering factors such as solar energy potential, system capacity, and the financial costs of the solar infrastructure, including the solar panels, inverters, and battery storage. The simulation results reveal an annual energy production of 58,900 kWh and a CoE of Rp 575.55 per kWh, which directly influences the cost of water production, resulting in a price of Rp 17.27 per liter for the desalinated water. This study highlights the essential role of renewable energy sources in ensuring the sustainability of desalination systems and emphasizes the importance of accurate cost analysis to make such systems economically viable in coastal communities like Muara Angke. By integrating RO technology with solar energy, this initiative offers a promising approach to addressing water scarcity while reducing reliance on non-renewable energy sources, ultimately providing a long-term solution to clean water access.

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Corresponding Author:

H. A. Danang Rimbawa,
Military Electrical Engineering,
Republic of Indonesia Defense University,
Kawasan IPSC Sentul, Sukahati, Kec. Citeureup, Bogor, Jawa Barat, 16810, Indonesia.
Email: hadr71@gmail.com

1. INTRODUCTION

Facing recurring clean water access issues, a common plight for coastal and island populations in the region (Mycoo & Roopnarine, 2024; Pandey & Asif, 2022), This research fills the gap in existing studies by taking a more integrated approach, combining solar-powered desalination technology with in-depth economic analysis for application in urban environments, specifically in Muara Angke, North Jakarta. While previous studies have addressed the application of solar desalination systems in rural or remote areas, this research focuses on the urban context, which presents different challenges and opportunities, such as higher energy demands, a more diverse population, and more complex

infrastructure. Furthermore, this research not only assesses the technical feasibility of the solar desalination system but also explores the economic aspects in detail by calculating the cost per liter of water produced, along with operational and maintenance costs over the long term, which have often been overlooked or oversimplified in many studies. Muara Angke's geographical advantage, offering ample sunlight, presents a significant opportunity to harness solar energy for converting seawater into a reliable source of drinking water.

According to the Indonesian Minister of Health Regulation No. 32 of 2017, the standards for acceptable drinking water quality within Indonesia are rigorously defined by a set of key physical characteristics. These water quality standards, designed to protect public health and ensure the potability of water sources, encompass several crucial parameters. Specifically, they include the regulation of turbidity, which refers to the cloudiness or haziness of the water; color, ensuring the absence of discoloration that might indicate contamination; the concentration of total dissolved solids (TDS), to limit the presence of minerals and salts; temperature, to maintain a palatable and safe range; and the absence of any objectionable taste and odor, both of which are critical indicators of water purity (Tsaridou & Karabelas, 2021). Thus, this project's focus on water quality directly addresses the urgent need to fulfill the basic needs of the local community for clean and safe water, while simultaneously offering a sustainable and environmentally friendly water resource management concept. Seeking to resolve the clean water shortage in Muara Angke, North Jakarta, a viable strategy involves employing desalination technology to convert seawater into a source of drinkable water. Based on research conducted (Kalogirou, 2005), thermal desalination utilizes heat energy, which is often waste from power plants. Meanwhile, membrane desalination, such as reverse osmosis, only requires electrical energy to operate pumps (Kamel et al., 2019).

Research relevant to seawater desalination technology, while seawater desalination offers a potential solution, in addition to exploring the technical feasibility of solar desalination, this study takes a significant step forward by incorporating an in-depth economic analysis, which has often been overlooked in prior works. Previous research often focused primarily on the engineering aspects of desalination systems; its widespread adoption is hindered by high economic and energy costs associated with major desalination technologies. Forward osmosis (FO) is emerging as a potentially more energy-efficient alternative, but it faces challenges related to draw solutes, their recovery, and other operational complexities, prompting ongoing research into both conventional desalination methods and the viability of FO (Aende et al., 2020; Al-Obaidi et al., 2022) who developed a solar-powered seawater desalination process using reverse osmosis, capable of filtering various large molecules and ions from a solution by applying pressure to the solution when it is on one side of a selective membrane (Al-Hotmani et al., 2020). Advances in reverse osmosis desalination technology, characterized by reduced operational costs, improved membrane quality, and better energy efficiency, provide positive prospects for its implementation in Muara Angke.

Through addressing these gaps, this research presents an innovative solution to the pressing issue of clean water scarcity in urban coastal areas. By demonstrating the potential of solar-powered desalination systems to provide an environmentally sustainable and economically viable source of drinking water, the findings of this study contribute valuable insights for policymakers, engineers, and researchers involved in urban water management. The approach also sets the stage for future research on integrating solar desalination in various urban settings, particularly in countries with similar geographical and socio-economic conditions (Cohen et al., 2017; Liponi et al., 2020) needs in Muara Angke Village. The application of Solar Power Energy in reverse osmosis clean water treatment systems is considered very suitable for application in border and outermost areas, as well as in drought-stricken areas as a solution to meet water and electricity needs.

Indonesia, located along the equator, has significant potential for solar energy utilization. This energy can be converted into electricity through photovoltaic (PV) technology. This technology uses semiconductor materials, generally silicon, modified with additional elements to create solar cells. When sunlight hits these cells, electrons in the silicon are released and move, creating an electric current and generating electricity. The output of photovoltaic cells depends on sunlight intensity; with lower intensity, less power is generated, while higher intensity means more power can be generated. With an average daily insolation rate of 4.5 kWh/m² per day to 4.8 kWh/m² per day, the potential for solar energy development in Indonesia is very significant (Al-Ezzi & Ansari, 2022; Widyawati Putri et al., 2022).

2. RESEARCH METHOD

The developed analytical model for predicting electricity generation in a Photovoltaic Power Station (PVS) demonstrates strong potential for optimizing energy supply to reverse osmosis-based water desalination systems, particularly in solar-powered applications (Alhousni et al., 2023).

In this research method, the analytical approach begins by gathering critical data on the solar energy availability specific to the location, the energy consumption of the desalination system, and the technical specifications and associated costs of the solar power components. The first step involves collecting data on the local solar energy potential, which is essential for determining how much solar energy can be harnessed. The electrical load data, which indicates the power consumption patterns of the desalination system, is crucial for understanding the energy needs of each component involved in the desalination process. Furthermore, it is important to gather information about the solar power components, such as their capacity, purchase cost, expected operational lifespan, and ongoing operational and maintenance costs (Sonong et al., 2024). The next stage is to develop a Solar Power Energy simulation model using HOMER software. The data collected is input into the model to simulate how the Solar Power Energy system performs under different operational conditions. The simulation involves evaluating the daily solar energy potential, ensuring the solar panel and energy storage capacities are appropriately matched to the desalination system's energy requirements, and calculating the associated energy costs.

Once the simulation is completed, the results are used to calculate the Cost of Energy (CoE) generated by the solar power system. The CoE is a critical economic indicator that reflects the cost of producing one kilowatt-hour (kWh) of electricity from the solar power system. The formula used to calculate the CoE includes several key components: the initial capital investment, replacement costs for solar power system components (such as solar panels and inverters), operational and maintenance costs, and the expected lifespan of the equipment. The fuel cost for solar power is considered zero since it relies on renewable energy. The remaining value of the system at the end of its operational life is also taken into account in the CoE calculation, ensuring that all factors influencing the system's financial sustainability are included.

Subsequently, the cost of producing desalinated water is determined by dividing the total monthly operational costs by the total monthly volume of clean water produced. This figure provides a clear economic assessment of how much it costs to produce each liter of clean water using the solar-powered desalination system. The final step involves analyzing the results to evaluate the feasibility of the solar-powered desalination system in the given location. This analysis includes an assessment of whether the system can deliver a cost-effective and sustainable solution for providing clean water, taking into account the environmental benefits of using renewable solar energy. The cost of water production (Rp/liter) is calculated by dividing the total monthly operational costs of the system by the monthly volume of clean water produced. The results are then analyzed to draw conclusions about the feasibility of this solar-powered desalination innovation.

3. RESULTS AND DISCUSSIONS

In 2024, a water desalination facility project was inaugurated in RW 17, Penjaringan, North Jakarta, Special capital Region of Jakarta, Java, 14430, Indonesia. This project is part of a Community Service initiative by the Indonesian Defense University. It involves a water filtration facility utilizing Reverse Osmosis (RO) membrane technology, capable of producing 320 liters of water per hour. Emphasizing sustainability, the system is powered by solar energy, showcasing the university's dedication to efficient and environmentally conscious technological solutions for local communities. The utilization of solar energy as a resource for this desalination system requires the collection of specific data, such as electrical energy consumption per liter of water produced, which is essential for managers in determining the price of clean water per liter (Kalogirou, 2005). To ensure the desalination system runs smoothly long-term, it's important to do an economic study. This study will figure out how much consumers should pay for the desalinated water, taking into account both the initial setup costs and the ongoing expenses for operation and upkeep.

3.1 Location of Solar Power Desalination System

The Solar Power Energy in the water desalination facility is located at 06° 06' 32.80" LS 106° 47' 55.07" BT. The location of the Solar Power Energy can be seen in Figure 3.1

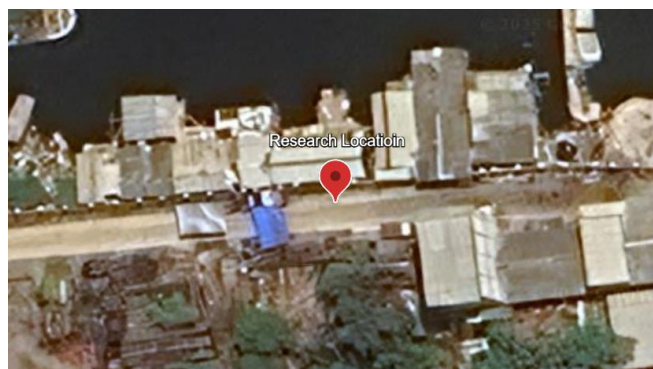


Fig. 1 Location of Solar Power Desalination System

3.2 Electric Load of Desalination System

The electrical load of a reverse osmosis (RO) desalination system can vary due to several factors, including pressure, temperature, salinity, flow rate, equipment age, and the energy source used. Higher pressure is required for desalination of water with higher salinity, leading to increased energy consumption, while lower salinity results in reduced energy needs. Temperature also impacts the system, with warmer water requiring less energy for desalination due to faster membrane permeability, whereas colder water increases viscosity, raising energy consumption. Variations in flow rate can alter the electrical load, with higher flow rates demanding more power to maintain pressure. The age of the equipment, particularly the membranes and pumps, can also influence energy usage, as wear and fouling lead to increased power consumption. For solar-powered systems, energy availability fluctuates with solar irradiance, causing energy needs to rise during cloudy periods or at night when relying on battery storage or grid electricity. By understanding and managing these variables, the system's efficiency can be optimized to reduce costs while maintaining the desired water output by using reverse osmosis system (Wang et al., 2021), which has a production capacity of 320 liters of desalinated water per hour. The components, including different types of pumps, have a total maximum power requirement of 9.8 kilowatts. The specifics of the electrical usage for each component are provided in the table below:

Table 1 Reverse Osmosis Desalination System Component Details

No	Unit Machine	Amount	Power (Watt)	Ampere
1	Muara Intake Pump	1	1300	5,8
2	FRP Pre Treatment Pump	1	550	3,8
3	Feeder Pump	2	1500	8,2
4	RO Booster Feeder Pump	2	4400	20,0
5	Clean Water Distribution Pump	2	750	4,2
6	Reject Water Distribution Pump	1	750	4,2
7	Distribution Backup Pump	1	550	3,8

3.3 Solar Power Energy Components

The Solar Power Energy system is an eco-friendly technology that captures solar energy to produce electricity. This process is enabled by solar panels made up of photovoltaic cells, which are thin layers of pure silicon or other semiconductor materials. These cells function by absorbing photons from sunlight, which causes electrons to excite to higher energy levels, creating free electrons that generate direct current (DC) electricity. There are three critical components that define the operational core of a Solar Power Energy: solar modules, controllers, and storage batteries (Obaideen et al., 2023).

The solar panel for the Solar Power Energy system in the desalination system consists of 14 panels, each with a capacity of 550 Wp, accumulating a total capacity of 7.7 kWp. The input parameters for the PV module in the Homer simulation software reflect the actual conditions at the location, with an emphasis on the system capacity of 7.7 kWp. The procurement cost of these PV modules is 23,800,000 Rupiah with an estimated lifespan of 25 years. The replacement cost during this period

remains constant at 23,800,000 Rupiah. The annual operational and maintenance costs are calculated at 10% of the initial procurement cost, which is 2,338,000 Rupiah.

Complementing the PV components, the system also includes a hybrid inverter, which is an intelligent device that combines the functions of a standard inverter with a charge controller, using technologies such as Maximum Power Point Tracking (MPPT) for better efficiency (Hawsawi et al., 2023; Wang et al., 2021). The specific parameters of the hybrid inverter used in the Homer simulation include an MPPT capacity of 10 kW. The initial investment for the MPPT is 24,000,000 Rupiah with an estimated lifespan of 15 years and a replacement cost identical to the initial cost. The operational and maintenance costs of the MPPT system are also estimated at 10% of the initial cost, totaling 2,400,000 Rupiah per year.

Batteries, as another main component in the Solar Power Energy desalination system, function to store electrical energy and provide it as needed and its also make the system efficiently manages energy conversion and distribution, offering a promising solution for powering energy-intensive processes such as reverse osmosis in variable environmental conditions (Gajewski, 2021; Powar & Singh, 2021). The battery parameters in the Homer simulation indicate a capacity of 3.2 kWh, with an initial procurement cost of 90,000,000 Rupiah, an equal replacement cost, and annual operational and maintenance costs of 9,000,000 Rupiah.

The economic viability and performance efficiency of these Solar Power Energy components are essential for their use in the desalination system (Ghazi et al., 2022). It combined functionality not only demonstrates an integrated approach to sustainable energy production but also highlights the potential for scalable renewable energy solutions. The table below will display the parameters of the PV modules, Hybrid Inverter, and batteries used in the simulation, outlining operational details and financial considerations. (de Oliveira Azevêdo et al., 2021)

Table 2 Solar Power Energy Simulation Parameter

Parameter	Amount
PV Capacity	7.7 kWp
PV Procurement Cost	Rp28.300.000
PV Replacement Cost	Rp28.300.000
PV Operational and Maintenance Cost	Rp 2.830.000/year
PV Lifetime	25 year
Hybrid Inverter Capacity	10 kW
Hybrid Inverter Replacement Cost	Rp24.000.000
Hybrid Inverter Operational and Maintenance Cost	Rp 2.400.000/year
Hybrid Inverter Lifetime	15 year
Battery Capacity	3,2 kWh
Battery Procurement Cost	Rp90.000.000
Battery Replacement Cost	Rp90.000.000
Battery Operational and Maintenance Cost	Rp 9.000.000/year
Battery Lifetime	15 year

3.4 System Schematic and Simulation of Solar Power Energy

To model the system, the arrangement of the Solar Power Energy components and the desalination load is depicted in a schematic diagram using HOMER software. Figure 3.2 presents the system scheme consisting of solar panels (PV), a hybrid inverter (with MPPT), a battery bank, and the electrical load of the desalination installation. This schematic diagram shows the flow of energy and the interactions between the components, making it easier to understand how electricity generated by the PV system is stored in the batteries and then directed to the RO load. Each component is connected in a way that optimizes the use of available solar energy.

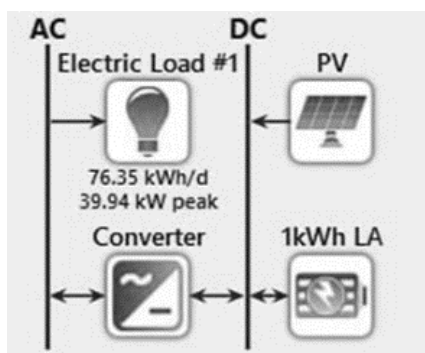


Fig. 2 Simulation Schematic Solar Power Energy with HOMER

3.5 Results of Solar Power Plant Performance and Cost Simulation

Solar energy is an extraordinary natural resource, as you know global fossil fuel reserves are declining due to differential uses, especially for power generation where heat energy from the sun is converted through various media into different forms of energy (Abdullah-Al-Mahbub et al., 2022), which can be utilized for various purposes. Specifically, in RW 17, Penjaringan, North Jakarta, Special capital Region of Jakarta, a study of solar energy potential has been conducted as an initial step in simulating the construction of a Solar Power Energy. (Icaza et al., 2020; Marzouk, 2024) The data used in this analysis was obtained from the NASA Surface Meteorology and Solar Energy dataset, which offers detailed information on solar energy potential. To provide a clearer picture of this potential, a graph illustrating the solar energy potential in the Muara Angke area over a one-year period is presented visually in Figure 3.3.

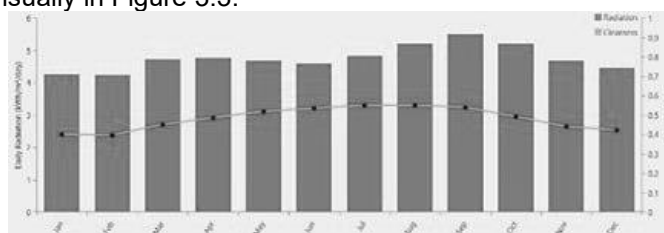


Fig 3 Solar Energy Potential in Muara Angke

Table 3 Solar Power Energy Parameters from HOMER Simulation Results

Parameter	Amount
Energy Production PV/year (kWh/year)	58,900 kWh/year
Renewable Fraction (%)	100%
Net Present Cost (NPC)	Rp384.050.000
Cost of Energy (CoE)	Rp 575,55/kWh

The simulations conducted revealed that over a year, the Solar Power Energy system successfully produced 58.9 kWh of energy. This result is considered favorable, especially considering the system exclusively relies on energy from sustainable sources, with a 100% commitment to renewable energy.

A comprehensive Net Present Cost (NPC) calculation, which includes the total cost of construction or initial investment and system operation, reached a total of Rp 384,050,000. This NPC calculation is based on the following equation:

$$NPC = CC + RC + O\&M\ cost + FC - S \tag{1}$$

Which: CC (Capital Cost), RC (Replacement Cost), O&M cost (Operational and Management Cost), FC (Fuel Cost), S (Residual Cost of the Component)

Subsequently, further analysis was performed to determine that the Cost of Energy (CoE), the cost to produce each kWh of energy, is Rp 575.55, based on the following equation:

$$CoE = \frac{Tac}{E_{total\ served}} \quad (2)$$

Which: T_{ac} (Total Annualized Cost), $E_{total\ served}$ (total annual cost of the power energy), Based on this CoE value, we can estimate the monthly raw water production cost of the desalination system using the following equation:

$$CoE \times Monthly\ Cost \quad (3)$$

Where the daily electrical consumption of the desalination system is 235.2 kWh and the monthly consumption is 7,056 kWh, resulting in a monthly cost of approximately Rp 4,061,080. To determine the cost per liter, we can use the following equation:

$$\frac{Monthly\ Cost}{Monthly\ Raw\ Water\ Volume} \quad (4)$$

By dividing the monthly cost of Rp 4,061,080 by the raw water production volume of 235,200 liters, the cost required to produce each liter of raw water from the desalination system is found to be Rp 17.27 for each liter. This analysis not only presents a thorough overview of the cost efficiency of a solar-powered desalination system but also underscores the significance of utilizing clean energy for sustainable raw water production. It provides valuable insight into the cost-effectiveness and sustainability of solar-powered desalination systems, showing how the use of eco-friendly energy can both support sustainable water production and ensure cost efficiency. At the end, it highlights the crucial economic impact of incorporating green technologies into the management of natural resources. (Chen et al., 2021), At the end, we can produce clean water or raw water from desalination system is found at be Rp 17.27 for each liter.

4. CONCLUSION

ased on the comprehensive analysis of the solar-powered desalination system in Muara Angke, it can be concluded that the integration of reverse osmosis (RO) desalination technology with solar energy offers a robust, sustainable, and economically viable solution to the persistent clean water scarcity challenges that coastal communities face. The results of this pilot project underscore the technical feasibility of such systems, evidenced by a Net Present Cost (NPC) of approximately Rp 384 million and a Cost of Energy (CoE) of Rp 575.55 per kWh, which signifies the efficiency of solar power in operating desalination systems. The production cost of clean water, calculated at approximately Rp 17 per liter, reinforces the system's affordability and highlights solar energy's potential as a reliable and low-cost electricity source for desalination, especially in regions where traditional freshwater resources are limited or nonexistent. By utilizing renewable energy, this solution not only meets critical water demands but also minimizes reliance on fossil fuels, contributing to a reduction in carbon emissions and positioning solar-powered desalination as a key player in sustainable water resource management. This research also reveals that the successful application of solar-powered reverse osmosis (RO) technology in Muara Angke could serve as a replicable model for other coastal and island communities across Indonesia, many of which face similar water scarcity challenges. The Indonesian Defense University's pilot project sets a new benchmark for innovation in desalination technologies powered by renewable energy, presenting a scalable and environmentally responsible approach to water provision. Moving forward, additional research is warranted to optimize system performance in diverse geographical locations with varying solar potential, explore hybrid energy systems that combine solar with other renewable sources, and evaluate the long-term economic and environmental impacts of large-scale implementation. Moreover, advancements in reverse osmosis membrane technology and energy storage systems could further enhance the system's operational efficiency and cost-effectiveness. Ultimately, this research reaffirms that solar-powered desalination systems, when strategically designed and integrated, represent a promising and scalable solution for addressing water scarcity in coastal regions, aligning with global sustainability goals and climate change mitigation efforts.

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