Techno-Economic Analysis of Small-Scale Reverse Osmosis Desalination for Likupang Tourism Area

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Abstract— **Likupang, a Super Priority Tourism Destination in Indonesia, faces significant challenges in securing a reliable and affordable fresh water supply, currently depending on expensive trucked-in water. This study evaluates the techno-economic feasibility of a small-scale Reverse Osmosis (RO) desalination system to address this issue. Using DuPont's WAVE Water Treatment Design software, three distinct operational scenarios (A = 50, B = 80, and C = 90 m³/day capacities) were designed and simulated to accommodate the fluctuating water demand characteristic of a tourism area. The technical analysis identified the 80 m³/day demand-responsive scenario as the most energy-efficient, with a Specific Energy Consumption (SEC) of 3.73 kWh/m³. Meanwhile, the economic evaluation, based on the Levelized Cost of Water (LCOW), determined that the most cost-effective strategy is Scenario A with an LCOW of 60,766 IDR/m³. This cost is significantly lower than the current market price of trucked-in water, demonstrating that small-scale RO desalination is a viable and economically competitive solution to support sustainable tourism development in Likupang.**

Keywords—Desalination, Fresh Water, Reverse Osmosis, Techno-Economic, Tourism Area

I. INTRODUCTION

The Indonesian government has designated five Super Priority Tourism Destinations (DPSP) to drive the development of the national tourism sector, one of which is Likupang in North Sulawesi [1]. As a coastal area renowned for its marine beauty, Likupang is projected to attract significant investment and a large number of tourists. However, despite its coastal location, it faces a critical challenge in securing a sustainable and reliable supply of fresh water [2], [3]. At key tourist spots like Paal and Pulisan Beaches, local businesses and communities rely on water transported by trucks from neighbouring villages [4], [5]. This practice leads to supply uncertainty, as water availability depends on external factors. This situation fails to meet the infrastructure standards required for a Super Priority Tourism Destination. Therefore, establishing an independent and reliable water source is crucial for ensuring the long-term sustainability of investments and tourism in the area.

Small-scale desalination has been identified as a highly suitable solution for supplying fresh water in remote coastal areas due to its flexibility and ease of operation [6], [7]. Among the various available technologies, Reverse Osmosis (RO) stands out as the most appropriate choice. Previous studies have confirmed the technical feasibility and advantages of RO for small-scale applications. Song et al. [8] and Alqaed et al. [9] highlight the scalability and capability of RO in providing high-quality water in coastal areas. From an economic perspective, Kyriakarakos and Papadakis [10] demonstrate the cost-effectiveness of RO systems in remote areas, while Wang et al. [11] emphasize the importance of energy-efficient design to reduce operational costs.

Although the feasibility of small-scale RO has been widely demonstrated, the majority of studies focus on meeting the needs of residential communities with relatively stable demand, which limits their applicability to tourism-driven systems. In general, three design approaches dominate the literature. Many studies adopt representative or average water demand assumptions when evaluating small-scale RO systems, effectively treating system utilization as quasi-steady over the year [10]. Other studies design desalination systems to satisfy peak demand conditions to ensure supply reliability, which often leads to prolonged periods of under-utilization and increased unit water costs, particularly in systems with variable demand [12]. In addition, economic indicators such as levelized cost of water (LCOW) are frequently calculated on an annual basis using fixed production volumes, which provides a convenient comparison metric but may obscure temporal mismatches between installed capacity and actual system loading [13]. As a result, the trade-off between RO capacity selection, utilization factor, and LCOW under fluctuating demand conditions remains insufficiently explored, particularly for coastal tourism regions where water use can vary sharply between weekdays, weekends, and peak seasons.

As a Super Priority Tourism Destination, Likupang represents a relevant case of this challenge. The area experiences short-term and seasonal variability in water consumption driven by tourism activity, while infrastructure investment decisions must be made on the basis of long-term financial viability. Under such conditions, RO system design cannot be reduced to a single nominal capacity without considering how different operating regimes influence both energy consumption and cost of water. A demand-responsive design framework is therefore required to evaluate how alternative capacity and operating strategies perform under realistic demand patterns.

To address this gap, this study aims to analyse the techno-economic feasibility of a small-scale RO desalination system to meet the water needs of Likupang using an operational scenario approach that explicitly links demand variability to RO capacity, utilization, and cost. By utilizing local seawater quality data and water consumption patterns, this study conducts a technical evaluation through process simulation and scenario analysis. The resulting system performance is evaluated using specific energy consumption (SEC). Subsequently, the economic feasibility is assessed using the primary metric of Levelized Cost of Water (LCOW) to determine the cost-competitiveness of the desalination system

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compared to current water supply practices. Finally, this study provides a framework that is transferable to other tourism-driven coastal regions facing similar water-supply challenges, by embedding temporal demand variability into the capacity selection and economic assessment.

II. METHODS

This study was conducted in three main stages: a field survey and water analysis, a technical process simulation which included a scenario analysis, and an economic feasibility analysis focused on the Levelized Cost of Water (LCOW).

A. Field Survey and Seawater Analysis

A field survey was conducted between June−August 2025 in the Likupang tourism area, focusing on Paal Beach and Pulisan Beach. The primary goal of the survey was to analyse the estimated water consumption patterns and requirements to inform the system's design capacity. This was achieved through site surveys and interviews with local tourism business owners. The semi-structured interviews were done with two key local business owners. The primary informant was a shop owner with the most frequent operating hours, complemented by a second shop owner located at a peripheral zone to provide comparative insight. Based on the survey and interview results, the total water demand in the study area was estimated to be approximately 350 m³/week. Due to the absence of formal water consumption records and the irregular operating schedules of tourism-related businesses, this estimated demand represents a planning-level, order-of-magnitude value rather than a precise statistical estimate and is subject to substantial short-term and weekly variability. To account for this inherent uncertainty, the analysis employs a scenario-based approach by evaluating multiple RO capacity options, thereby ensuring that system performance and economic indicators remain robust under fluctuating demand conditions.

The technical data used as input for the Reverse Osmosis system modelling is primary data, obtained from laboratory analysis of seawater samples collected directly from the Likupang study site. The analysis was performed by the Industrial Standardization and Testing Centre (BSPJI) of Manado. A comprehensive set of parameters was measured, including general properties (pH, Turbidity, Total Suspended Solids/TSS, Total Dissolved Solids/TDS, Salinity, and Alkalinity) as well as major ion concentrations (SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}).

B. RO System Design and Process Simulation

Based on the field survey water demand analysis, the proposed Reverse Osmosis (RO) system was designed to meet a weekly demand of 350 m³. The general process flow diagram (PFD) outlining the main components and flow paths of the system is presented in Figure 1. To add a practical dimension to the analysis and ensure accurate system design [14], the detailed simulation was performed using WAVE (Water Application Value Engine) software by DuPont Water Solutions, with the simulation utilizing the specific raw water quality data from the Likupang site.

To comprehensively evaluate the system's viability in a tourism area with unique, fluctuating needs, a scenario-based analysis was adopted. This approach was necessary to model different operational strategies capable of handling the significant variation in water demand between weekdays and weekends. Three scenarios were defined: Scenario A represents the baseline capacity of 50 m³/day, which is directly derived from the estimated weekly demand of approximately 350 m³, assuming continuous operation over seven days. Scenario B represents a demand-responsive operating strategy, in which a higher installed capacity of 80 m³/day is used to accommodate increased weekend demand, while production is reduced to approximately 27.5 m³/day during weekdays by adjusting operating hours, resulting in the same total weekly water production. Finally, Scenario C evaluates a system with a larger installed capacity of 90 m³/day that is operated at reduced hours to meet the same weekly demand, allowing an assessment of the trade-off between higher initial capital investment and potential operational flexibility.

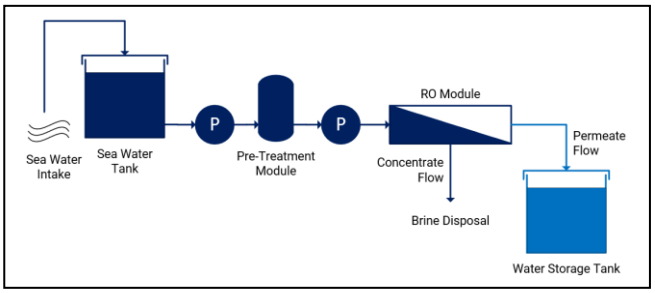

Fig. 1. RO System Process Flow Diagram

To establish a robust and efficient technical basis for each of these scenarios, an iterative optimization process was conducted within WAVE software for each required production capacity. The process involved systematically varying key design parameters – specifically the recovery rate, which is typically between 35–45% [15] and the number of elements per vessel – while keeping others fixed to find a hydraulically stable design. The parameters used in this optimization are summarized in Table I.

TABLE I. SIMULATION PARAMETERS FOR SYSTEM OPTIMIZATION IN WAVE

Parameter Type	Parameter	Value/Range	Source
Fixed	Seawater Characteristics	As per lab analysis result	User-defined (input)
	RO Membrane Element	DuPont SW30HR-380	User-selected (WAVE library)
	Number of Stages	1	User-defined
	Flow Factor	0.85	Default (WAVE)
	Design Temperature	30°C	User-defined
Varied	System Recovery Rate	35 - 45%	User-defined (constraint)
	Elements per Vessel	4, 5, and 6	User-defined

The optimal configuration for each production capacity was then selected from the simulation results through a hierarchical evaluation process. First, the design had to be free of any software-generated RO Design Warnings. Next, the permeate quality was required to have a TDS below the 300 mg/L target to comply with hygiene and sanitation standards (Permenkes No 2 Tahun 2023) [16]. Furthermore, for design reliability, the calculated design flux needed to fall within the conservative range of 12–19 L/m²·h, as recommended by the membrane manufacturer [17], to ensure long-term operational reliability. From the configurations meeting these initial criteria, the design with the highest possible recovery rate was then selected to maximize water production efficiency. Finally, among those, the design exhibiting the lowest Specific Energy Consumption (SEC) was chosen as the final optimal configuration.

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C. Economic Feasibility Study

The economic feasibility of the proposed SWRO system was evaluated to determine its long-term cost-effectiveness. The primary metric for this evaluation was the Levelized Cost of Water (LCOW), which represents the average production cost per cubic meter (m^3) of water. The methodology follows the simplified approach used by Ayou et al. [18] in their techno-economic study of a similar small-scale RO plant in Indonesia.

The analysis began by identifying all project-related costs, which were categorized into two main groups: Capital Expenditure (CAPEX) and Operational and Maintenance Expenditure (OPEX). The main components considered for CAPEX include the RO system with auxiliary components, supporting systems (seawater intake, pre-treatment, brine disposal), civil works (building and site preparation), and indirect costs (engineering, developer, contingencies, and financing costs), while OPEX consists of routine annual costs such as energy, chemicals, system maintenance, membrane element replacement, labour, brine disposal, environmental and performance monitoring, and other operating-related costs. The specific cost assumptions and data sources for each of these components are detailed in Table II. All cost values are presented in Indonesian Rupiah (IDR) to reflect the local economic context. The adopted cost correlations are used to obtain consistent, order-of-magnitude estimates suitable for comparative scenario analysis rather than detailed project-level cost prediction.

TABLE II. CAPITAL AND OPERATIONAL COST ASSUMPTIONS OF THE ECONOMIC ANALYSIS

Description	Correlation/Value	Ref.
Direct Capital Cost		
Seawater Intake	$CC_{SWI}\,(IDR) = 9{,}986{,}600 \times \left(Q_{F,daily}/0.9\right)^{0.78}$	[19]
Pre-Treatment	$CC_{PT}\,(IDR) = 8{,}147{,}930 \times \left(Q_{F,daily}/0.9\right)^{0.78}$	
RO Plant	$CC_{RO}\,(IDR) = CC_{ROPV} + CC_{ROE} + CC_{ROHPP} + CC_{ROWS}$	
RO Pressure Vessel (8040 type)	$CC_{ROPV}\,(IDR) = 19{,}800{,}000/unit$	[20]
RO Element (DuPont SW30HR-380)	$CC_{ROE}\,(IDR) = 21{,}977{,}033/unit$	[21]
HP Pump	$CC_{ROHPP}\,(IDR) = 868{,}400 \times Q_{F,daily} \times \Delta P_{HP}$	[22]
Water Storage	$CC_{ROWS}\,(IDR) = 107{,}010 + 3{,}291.76 \times V_T$	[23]
Auxiliary Components	$CC_{Aux}\,(IDR) = 1.5\% \times CC_{RO}$	[18]
Building for RO Unit	$CC_{Building}\,(IDR) = 3.5\% \times CC_{RO}$	[18]
Site Preparation	$CC_{Site}\,(IDR) = 1.5\% \times CC_{RO}$	[18]
Brine Disposal	$CC_{Brine}\,(IDR) = 15\% \times CC_{RO}$	[24]
$Q_{F,daily}$ = Feed flow rate per day (m^3/day); ΔP_{HP} = High pressure pump difference (bar); V_T = Tank volume (L)		
Indirect Capital Cost		
Engineering, Developer, Contingencies, and Financing Cost	15%, 9%, 15%, and 10% of Direct Capital Cost respectively	[18]
Operational Cost		
Energy of Intake Pump	$OC_{SWI}\,(IDR/hr) = 0.028 \times Q_{F,daily} \times C_{Electricity} \times L_f/(\eta_{IP} \times 24)$	[19]
Energy of Pre-Treatment Pump	$OC_{PT}\,(IDR/hr) = 0.028 \times Q_{F,daily} \times C_{Electricity} \times L_f/(\eta_{IP} \times 24)$	[19]
Energy of HPP Pump	$OC_{HPP}\,(IDR/m^3) = SEC \times C_{Electricity}$	
Chemical for Pre-Treatment	$OC_{Chem}\,(IDR/m^3) = 10{,}855$	[18]
RO System Maintenance	$OC_{Main}(IDR) = 15\% \times CC_{RO}$	[18]
RO Membrane Replacement	Every 5 years	
Brine Disposal	$OC_{Main}(IDR) = 5\% \times CC_{Brine}$	[18]
Operation Labor	$OC_{OL}(IDR/month) = 3{,}775{,}425$	[25]
Environmental and Performance Monitoring	5% of Total Operational Cost	[18]
Other Indirect O&M Cost	12% of Total Operational Cost	[18]
$C_{Electricity}$ = Cost of electricity (kWh/IDR) = 1,445; L_f = Load factor = 0.9; η_{IP}= pump efficiency = 0.7		

The LCOW was estimated using the following formula:

$$LCOW = \frac{(CC \times \alpha) + OC}{Q_{P,annual}} \quad (1)$$

The capital amortization factor (α) is calculated as:

$$\alpha = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (2)$$

The variables for the formula are defined as follows, where CC is the initial capital investment (Total CAPEX), OC is the annual cost of operation (Total OPEX), $Q_{P,annual}$ is the amount of water produced per year, α is the capital amortization factor, i is the annual discount rate, and n is the operational life of the project in years.

To determine the parameters for the LCOW calculation, the analysis was based on several key assumptions. The project was assumed to have an operational life of 10 years (n), which was selected as a conservative value to reflect practical considerations for small-scale RO installations, including financing horizons, component replacement cycles, and operational uncertainty in an emerging tourism area. A discount rate of 6.5% was applied, and the system was assumed to operate for 330 days per year to calculate the annual water production $Q_{P,annual}$. Furthermore, RO membranes were assumed to be replaced every 5 years (accounted for in OPEX), and the inflation rate was ignored to simplify the calculations. The target amount of water produced for each scenario was the same, namely 16,500 m^3 per year. This normalization was applied to ensure a consistent basis for LCOW comparison across scenarios, although it does not fully capture differences in operational flexibility.

III. DISCUSSION

This section presents the results of the technical simulation and economic feasibility analysis for the proposed small-scale SWRO plant in Likupang.

A. Technical Performance Analysis

The technical performance of the three operational scenarios was evaluated using simulations based on the actual seawater characteristics at the study site. The results of the laboratory analysis of the raw seawater, which served as the

primary input for the WAVE software, are presented in Table III.

TABLE III. SEAWATER QUALITY CHARACTERISTICS IN LIKUPANG

Parameter	Average Value	Unit
Salinity	31.0	‰
pH	7.6	-
Cations		
Potassium (K)	385.4	mg/L
Calcium (Ca)	284.8	mg/L
Magnesium (Mg)	676.8	mg/L
Sodium (Na)	402.0[a]	mg/L
Anions		
Total Alkalinity[b]	512.0	mg/L
Sulfate	3624.5	mg/L

[a]Sodium (Na) concentration was software-adjusted to match the measured total salinity (TDS), a standard practice for RO simulation.
[b]Added as HCO_3

Using this input data, the iterative optimization process described in the Methods section was performed to find a stable and efficient configuration for each required production capacity. The process successfully yielded warning-free designs that met all technical constraints for the 50, 80, and 90 m³/day systems. The key design and performance parameters of these final optimized configurations are summarized in Table IV.

TABLE IV. OPTIMIZED DESIGN AND PERFORMANCE PARAMETERS FOR EACH SYSTEM CAPACITY

Parameter	Scenario A	Scenario B	Scenario C
Elements per Vessel	4	6	6
Recovery Rate (%)	36	45	45
Flux (LMH)	14.8	15.7	17.7
Feed Flow (m³/hr)	5.62	7.40	8.33
Product/Permeate Flow (m³/hr)	2.08	3.33	3.75
Reject/Concentrate Flow (m³/hr)	3.54	4.06	4.58
Product/Permeate TDS (mg/L)	245.3	254.1	226.2
Operating Pressure (bar)	43.3	48.2	50.1
SEC (kWh/m³)	4.19	3.73	3.88

The analysis of the technical results in Table IV reveals a key finding regarding energy efficiency. Scenario B proves to be the most efficient design, exhibiting the lowest Specific Energy Consumption (SEC) at 3.73 kWh/m³. Conversely, Scenario A, despite operating at the lowest pressure, is the least energy-efficient due to its significantly lower recovery rate. These results indicate a clear trade-off between recovery and operating pressure. From a membrane transport perspective, operating at a moderate recovery limits the increase in osmotic pressure along the membrane, allowing the desired permeate flux to be achieved at a lower operating pressure, which in turn reduces specific energy consumption [26]. This mechanism explains why Scenario B, which balances a relatively high recovery with moderate operating pressure under demand-responsive operation, achieves the lowest SEC. In contrast, Scenario C has the highest production per hour, but it also uses more energy than Scenario B. This means that running the system at maximum capacity is technically possible, but it is less efficient. For this reason, Scenario B shows a good balance between a high recovery rate and a moderate operating pressure. These results are also consistent with the SEC values obtained with baseline seawater RO performance reported in the literature. For instance, Al-Hathal and Alanezi (2020) [27] reported specific energy consumption values in a similar range under comparable seawater conditions, with minimum energy consumption occurring at moderate recovery ratios. The validated SEC values from each scenario are important inputs for the economic analysis in the next section.

B. Economic Analysis

The economic feasibility of the proposed scenarios was evaluated against the current water supply costs in Likupang. A key finding from the field survey indicated that the primary water source for tourism activities is trucked-in water, with a price of approximately 100,000 IDR/m³ [4], [5]. The trucked water price used represents an average market price during active tourism periods in the study area. While trucked water prices are known to fluctuate depending on demand and availability, the selected value reflects typical conditions encountered by local businesses rather than extreme peak or subsidized rates.

Based on the technical parameters from the optimized designs and the economic assumptions outlined in the methodology, the Capital Expenditure (CAPEX), annual Operational Expenditure (OPEX), and the resulting Levelized Cost of Water (LCOW) for each scenario were calculated. A summary of the economic results is presented in Table V. The economic analysis reveals that all three proposed desalination scenarios offer a significantly lower cost of water compared to the existing supply from water trucks. Among the scenarios, Scenario A emerges as the most cost-effective option with the lowest LCOW. The detailed interpretation and discussion of these findings are presented in the next section.

TABLE V. COMPARISON OF ECONOMIC RESULT BETWEEN SCENARIOS

Parameter	A	B	C
CAPEX (IDR)	2,658,361,353	2,790,840,256	2,895,728,625
OPEX (IDR)	632,856,393	636,917,698	652,786,501
LCOW (IDR/m³)	60,766	62,129	63,976

IV. DISCUSSION

This techno-economic analysis provides important findings on the feasibility of using small-scale RO desalination in a tourism area like Likupang. While all three operational scenarios are technically viable, the economic results show that Scenario A is the most cost-effective option, with the lowest Levelized Cost of Water (LCOW). However, the other scenarios are very close in cost, meaning the difference between the cheapest and most expensive option is around 5%. This highlights a clear trade-off between initial investment (CAPEX) and energy efficiency (SEC). Scenario B, which is the most energy-efficient, requires a higher CAPEX. The analysis shows that the savings from its better energy efficiency were not enough to fully offset its higher initial cost, which is why its LCOW is slightly higher than in Scenario A. Because the final costs are so similar, the choice becomes a strategic one for stakeholders: prioritizing the lowest initial investment with Scenario A, or gaining better energy efficiency and operational flexibility with Scenario B for a small extra cost per cubic meter. The cost-competitiveness of this solution is clear when compared to the current water supply in Likupang. The lowest LCOW found in this study is approximately 39% cheaper than the average price of trucked-in water. This shows that RO desalination not only provides a reliable and independent water source but also offers a substantial cost saving for the local tourism industry.

To compare our findings with other studies, we looked at a recent review by Alzahrani et al. (2024) [28] on small-scale RO systems. Their review reported a wide LCOW range from $0.54/m³ to $9.00/m³, depending on the plant's location and energy source. The LCOW of $3.64/m³ (60,766 IDR/m³) from our study is well within this range. Our result is much cheaper than the higher end of the range, which is typically for systems using off-grid solar panels. However, our cost is higher than some of the most optimized grid-powered systems in the

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review (around $1.60-$1.80/m³). This difference is expected and can be attributed to several interrelated factors. First, due to simplicity, this study's design does not include an Energy Recovery Device (ERD). While ERDs are a standard component in highly optimized and larger-scale SWRO systems and can significantly reduce specific energy consumption, their economic and operational benefits are strongly scale-dependent [12]. Previous studies on small-scale and decentralized RO systems have shown that configurations without ERDs remain viable, particularly in contexts where capital cost, system simplicity, and operational robustness are prioritized [29]. Moreover, the integration of ERDs in small-scale installations may introduce additional capital cost and operational complexity, which can be less attractive in emerging or informal tourism settings [12], [29].

Second, while the principle of 'economy of scale' generally applies, its effect is more complex in the small-scale range. The reviewed data by Alzahrani et al. (2024) shows that micro-scale plants (<10 m³/day) indeed have a much higher LCOW (up to $9.00/m³). However, the relationship is not strictly linear, as other factors like feedwater salinity or the level of technical optimization can become more dominant. This explains why some smaller but highly optimized systems in the literature report a lower LCOW than the one found in this study. Third, regional factors in Indonesia, such as equipment import costs and specific electricity tariffs, contribute to the overall cost difference when compared to studies conducted in other geographical contexts. Finally, operational assumptions related to membrane lifetime and system robustness also influence cost estimates. In this study, a conservative membrane replacement interval was adopted to reflect practical operation under site-specific seawater conditions. In systems with higher fouling control or more advanced pretreatment, longer membrane lifetimes may be achievable, potentially resulting in lower operating costs. As such, differences in fouling management strategies represent another contributing factor to variations in LCOW reported across the literature.

Beyond the specific numerical results discussed above, the findings of this study also have broader implications. While the numerical results are dependent on local demand, electricity tariffs, and cost structures in Likupang, several qualitative insights are transferable to other tourism-driven coastal regions. In particular, the scenario-based framework linking RO capacity, utilization patterns, and levelized cost of water is generally applicable to areas with fluctuating tourism demand, whereas absolute LCOW values should be interpreted within the local context due to their strong dependence on site-specific economic conditions. In this context, the economic analysis is necessarily based on point estimates for key parameters, including electricity price, discount rate, and capital cost. Among those parameters, variations in electricity price are expected to exert a strong influence on LCOW through their direct and linear contribution to operating costs, given the energy-intensive nature of seawater RO desalination. Meanwhile, capital cost assumptions primarily affect the amortized investment component and variations in discount rate influence LCOW to a lesser extent through capital recovery. Although a full quantitative sensitivity analysis is beyond the scope of this study, these qualitative considerations suggest that the relative ranking of the evaluated scenarios remains robust within realistic parameter ranges.

Beyond the core technical and economic findings, the following discussion is presented as an implementation consideration to illustrate how the proposed system could be practically managed and financed in the local context, specifically through a Village-Owned Enterprise (BUMDes) management model. For an initial phase with limited capital, Scenario A is recommended as the most cost-effective entry point due to its significantly lower initial investment. As demand grows and revenue is generated, the BUMDes could then reinvest to scale up the system, potentially towards a more energy-efficient model like Scenario B. To address the challenge of the initial investment for the BUMDes, several financing models can be pursued. A portion of the annual Village Fund Allocation (Dana Desa) can be allocated as initial capital for the BUMDes to kickstart the desalination project, an example that has been successfully implemented by other villages in Indonesia for providing clean water supply [30], [31]. This practice aligns with the fund's purpose for community economic development. Additionally, given Likupang's status as a Super Priority Tourism Destination (DPSP), the BUMDes, supported by the local government, can actively seek grants from relevant ministries aimed at developing essential infrastructure in priority areas. Finally, the BUMDes could form a partnership with the private sector, where an investor provides the capital in exchange for a long-term water supply contract, while the BUMDes remains the operator.

Overall, this study provides a foundational techno-economic analysis for a grid-powered RO system, which opens several opportunities for future research. Future studies could build upon this work by incorporating an Energy Recovery Device (ERD) into the design to quantify its potential for further reducing the SEC and LCOW. Another valuable direction would be to explore a hybrid power model, combining grid electricity with solar PV, to assess the trade-offs between higher capital costs and long-term energy savings. To expand upon the cost-effectiveness demonstrated here, a subsequent study could perform a comprehensive investment analysis by calculating profitability metrics such as Net Present Value (NPV) and Internal Rate of Return (IRR) to evaluate the project as a commercial venture.

V. Conclusion

This study evaluated the techno-economic feasibility of a small-scale, grid-powered reverse osmosis (RO) desalination system to provide a reliable water source for the tourism area of Likupang. From a technical perspective, the analysis of three different operational scenarios (50, 80, and 90 m³/day capacities) confirmed that all proposed designs are technically viable, producing high-quality water that meets sanitation and hygiene standards.

From an economic perspective, the results indicate that the baseline 50 m³/day system (Scenario A) is the most cost-effective option, with a Levelized Cost of Water (LCOW) of 60,766 IDR/m³. This cost is approximately 39% lower than the current market price of trucked-in water (100,000 IDR/m³). While the more energy-efficient scenarios had a slightly higher LCOW, the costs for all three were very close (within a 5% range). This presents a strategic choice for investors between the lowest initial investment (Scenario A) and better long-term efficiency for a small premium (Scenario B).

From a policy and implementation perspective, these findings demonstrate that small-scale RO desalination is a highly viable and economically competitive solution to address water scarcity in Likupang. The evaluated scenarios provide practical options for local stakeholders to secure a reliable and affordable water supply, thereby supporting the long-term development of this Super Priority Tourism Destination.

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