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# Strategies for Enhancing Operational Cost Efficiency in Water Treatment Plants through the Integration of Green Concepts and Value Engineering

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Efficiency, Green Concept, IPA, Value Engineering, Life Cycle Cost Analysist

**ABSTRACT**

The government prioritizes targets 100% access to drinking water through Vision 2030, with a service coverage target of 94.61% in Tangerang Regency by 2030. Water Treatment Plants (WTPs) are a crucial component of clean water supply systems, yet their operation poses environmental impacts. This research analyzes the operational cost efficiency of WTPs by integrating green concepts and Value Engineering (VE) methods. The aim is to identify economical and environmentally friendly solutions without compromising water quality and quantity, by pinpointing key factors influencing operational cost efficiency. The methodology encompassed literature review, hypothesis formulation, and data collection via questionnaires, analyzed using Structural Equation Modeling (SEM) and VE studies. Results indicate that Sustainable Technology with Renewable Energy Use and Innovation Implementation are the most influential variables. A case study at PERUMDAM TKR WTP applies VE and Life Cycle Cost Analysis (LCCA) for green concept operational cost analysis. VE results in an 8.97% cost increase, amounting to IDR 1,717,378,957. LCCA shows green concept investment in WTPs is viable with NPV > 0 (IDR 14,076,121,227.33), IRR of 16.42%, and a Payback Period of 8.60 years.

## INTRODUCTION

Water is an essential resource for human survival, underpinning health and daily life (Gupta & Orbán, 2018; Musie & Gonfa, 2023; Stewart-Koster et al., 2024; Tahir, Batool, & Ghani, 2026). Ensuring access to quality and sustainable drinking water remains a significant challenge globally, including in Indonesia. Effective water resource management and clean water supply have become pressing concerns, exacerbated by population growth and climate change. The Indonesian Ministry of Public Works and Housing (PUPR) has set a target of 100% access to drinking water by 2030 under Vision 2030 with a specific goal of achieving 94.61% service coverage in Tangerang Regency (Perpres No. 122 Tahun 2016, 2017). The Drinking Water Supply System (SPAM) is a critical infrastructure for fulfilling the public's right to clean water.

Water treatment plants are integral to this system, playing a pivotal role in ensuring water security (Adesina, William, & Oke, 2024; Arora & Mishra, 2022; Dada et al., 2024; Hussain et al., 2025; Tripathy, Kar, & Pradhan, 2025). As demand for clean water escalates, managing water resources in an efficient, effective, and sustainable manner has become increasingly challenging. Infrastructure development often has both positive and negative environmental impacts, necessitating strategies to mitigate adverse effects and promote green infrastructure (Heryana & Firmansyah, 2024). The pursuit of Sustainable Development Goals (SDGs) has highlighted the need for integrating economic, environmental, and social considerations to prevent environmental degradation (Jain & Jain, 2020). This has led to growing interest in applying green concepts to various sectors, including water treatment facilities (Biekša et al., 2022). PERUMDAM Tirta Kerta Raharja, the SPAM operator in Tangerang Regency, aims to harmonize its operations with environmental sustainability. However, the implementation of green concepts poses operational cost challenges. Environmentally friendly technologies typically require substantial initial investments and higher operational costs compared to conventional systems. Empirical data indicates that 30% of green construction projects experience rework (Hwang et al., 2016), 50% encounter delays, and 90% incur cost premiums of up to 21%. In water supply systems, these costs influence consumer tariffs and overall operational sustainability (Bon-Gang, 2018). Value Engineering (VE) offers a solution to reduce green concept costs without compromising quality or function. In the context of water treatment plants, VE involves evaluating and identifying high-cost, ineffective components, enabling their redesign or replacement with cost-efficient alternatives. This research applies VE to analyze operational cost factors in green concept water treatment plants, providing comprehensive guidance on enhancing cost efficiency and identifying variables for optimization (Rani, 2022).

The urgency of this research is underscored by several critical factors. First, Indonesia's Vision 2030 drinking water access target requires rapid expansion and optimization of existing WTP infrastructure, making operational efficiency a national priority. Second, climate change and water scarcity concerns demand that water utilities adopt sustainable practices to reduce their environmental footprint. Third, the high operational costs of WTPs directly impact consumer water tariffs, affecting affordability for low-income communities in Tangerang Regency. Fourth, without systematic cost efficiency strategies, PERUMDAM TKR faces potential financial sustainability challenges that could compromise service quality and coverage expansion. Fifth, empirical data shows that 90% of green projects experience cost premiums up to 21% (Hwang et al., 2016), making it essential to identify strategies that minimize these premiums while maximizing long-term savings. This research provides timely evidence to support decision-making for green investments in water infrastructure.

The novelty of this research lies in five key areas. First, it integrates green concepts, Value Engineering, SEM-PLS analysis, and Life Cycle Cost Analysis in a single comprehensive framework for water treatment plant operational cost optimization, which has not been previously attempted. Second, it employs SEM-PLS to identify the most influential variables affecting cost performance, revealing that Sustainable Technology with Renewable Energy Use and Innovation Implementation are the dominant factors—a finding that provides quantitative guidance for investment prioritization. Third, it applies Value Engineering to three specific green concept alternatives (SCADA automation, solar cell integration, sludge recirculation with decanter systems) at a large-scale WTP serving over 1.3 million people, providing empirical evidence from a real operational context. Fourth, it conducts comprehensive Life Cycle Cost Analysis over a 20-year period, including sensitivity analysis to assess investment risk under changing cost and revenue conditions. Fifth, it provides a replicable methodology for other PERUMDAM and water utilities across Indonesia seeking to optimize operational costs while meeting sustainability targets.

The objectives of this research are: (1) to identify the key variables influencing operational cost efficiency in WTPs through SEM-PLS analysis of survey data; (2) to analyze the most influential factors affecting cost performance, particularly Sustainable Technology and Innovation Implementation; (3) to apply Value Engineering to evaluate green concept alternatives (SCADA automation, solar power, sludge recirculation) for WTP operations; (4) to conduct Life Cycle Cost Analysis including NPV, IRR, Payback Period, and sensitivity analysis to assess financial viability; and (5) to formulate evidence-based recommendations for enhancing operational cost efficiency through green concept integration. The contributions of this research are both theoretical and practical. Theoretically, it advances the literature on green infrastructure by applying SEM-PLS to identify key cost drivers in WTPs, extends Value Engineering applications to water treatment facilities, and provides empirical evidence on the financial viability of green investments in this sector. Practically, it offers PERUMDAM TKR and other water utilities: (1) a validated methodology for identifying cost-saving opportunities; (2) specific green concept alternatives with quantified cost implications (8.97% initial increase, 8.60 year payback); (3) financial feasibility evidence (NPV IDR 14.08 billion, IRR 16.42%); (4) risk assessment through sensitivity analysis; and (5) a replicable framework for future green infrastructure investments. The benefits include reduced operational costs, improved environmental performance, enhanced service reliability, and support for achieving national drinking water access targets.

## METHOD

### Research Flowchart

To analyze the implementation of green concepts in water treatment plant operations and their impact on operational costs, a research instrument was developed comprising variables formulated into a questionnaire. A case study was subsequently conducted. The research flowchart is presented in the following diagram:

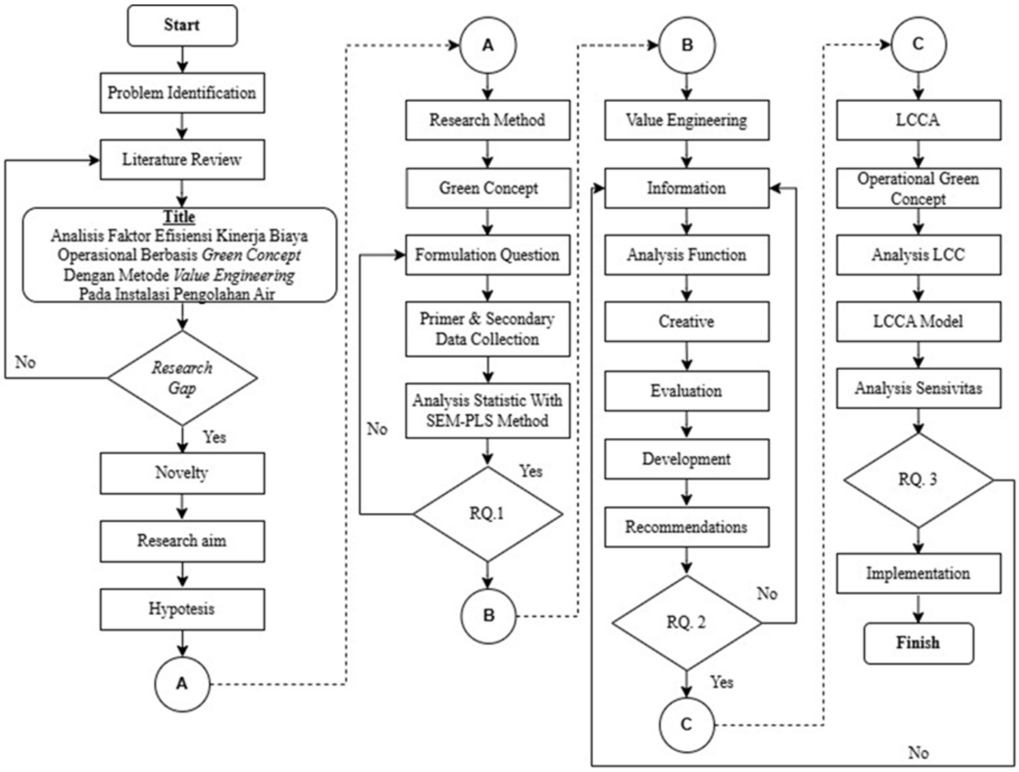


**Figure 1. Research Flowchart**

## Research Design

Primary data collection was facilitated through a research instrument, specifically a close-ended questionnaire designed to enable respondents to provide answers efficiently and effectively, aligned with the research objectives. The research instruments employed for qualitative data analysis were Microsoft Excel and Structural Equation Modeling (SEM-PLS). SEM, being covariance-based, yields more accurate covariance matrices compared to linear regression analysis (Husin & Kurniawan, 2023). The data analyzed was obtained from a questionnaire with a number that had been calculated using the Slovin formula which was used to represent the research results and the calculation did not require a sample number table.

The data analyzed were obtained from a calculated sample size using the Slovin formula, ensuring representativeness without requiring sample size tables. To identify additional functions as innovations in green concept design development for water treatment plants, and to evaluate operational costs, the Value Engineering method was applied. Subsequent research stages involved Life Cycle Cost Analysis to assess the life cycle costs throughout the recommended usage period.

## Research Location

The research was conducted at a Water Treatment Plant (WTP) owned by PERUMDAM Tirta Kerta Raharja in Tangerang Regency. This location was selected due to its capacity of 1,575 L/s and its service area encompassing Tangerang, Jatiuwung, Kalideres, Cibodas, Kutabumi, Kelapa Dua, Pasar Kemis, and other areas within Tangerang Regency. Furthermore, according to the water system classification by the United States Environmental Protection Agency (EPA), the PERUMDAM TKR WTP falls under the "very large water systems" category, serving a population of 1,360,800 to 2,268,000 people.

## RESULT AND DISCUSSION

### SEM PLS Analysis Results

The variables and main factors in this study can be seen in Table 1.

**Table 1. Research Variables and Main Factors**

| Variabel | Main Factor |
|---|---|
| Operation and maintenance WTP [A] | Equipment condition [A1] Maintenance frequency [A2] |
| Sustainable Technology [B] | Energy Efficiency [B1] Sustainable materials (Sustainable Material) [B2] |
| Environmental Conservation [C] | Protection of water source areas [C1] Use of materials reuse *recycle* [C2] |
| Operation Maintenance WTP [D] | Technological Innovation [D1] Consumption of production materials [D2] |
| Cost Performance [E] | Electricity costs [E1] Chemical costs [E2] Maintenance costs [E3] Waste management costs [E4] |

Table 1 presents the research variables used in this study. The dependent variable, Cost Performance [E] analyzes the efficiency factor of operational cost components by considering the factors of Electrical Energy Cost [E1], Chemical Cost [E2], Maintenance Cost [E3] and Waste Management Cost [E4]. The independent variable consists of IPA Operation and Maintenance [A] which evaluates system performance and measurement efficiency against Equipment Condition [A1] and Maintenance Frequency [A2]. Sustainable Technology [B] creates technology that reduces energy and material consumption by analyzing Energy Efficiency [B1] and Sustainable Material [B2] factors. Environmental Conservation [C] maintains and preserves the quality and sustainability of natural resources and ecosystems by protecting water source areas [C1] and using reused and recycled materials [C2]. IPA Operational Design [D] increases efficiency and sustainability in the design and management of water treatment systems, with Technological Updates [D1] and managing Production Material Consumption [D2] in a more economical and environmentally friendly manner. The purpose of using SmartPLS 4.0 is to estimate the relationship between the independent variables, namely Operation and Maintenance of WTP, Sustainable Technology, and Environmental Conservation, to the dependent variable Cost Performance, with the moderator variable, namely Operational Design of WTP. The results of the analysis value summary are presented in Table 2.

**Table 2. Summary of SEM-PLS Analysis Results**

| Evaluation Criteria | A | B | C | D | E | DxExA | DxExB | DxExC |
|---|---|---|---|---|---|---|---|---|
| **Reflective Measurement** | | | | | | | | |
| **Loading Factor** | >0,7 | >0,7 | >0,7 | >0,7 | >0,7 | | | |
| **Composite Reliability** | 0,961 | 0,914 | 0,939 | 0,901 | 0,947 | | | |
| **(AVE)** | 0,841 | 0,774 | 0,845 | 0,646 | 0,610 | | | |
| **Discriminant Validity** | AVE > Latent | AVE > Latent | AVE > Latent | AVE > Latent | AVE > Latent | | | |
| **Cross loading** | 0,917 | 0,880 | 0,919 | 0,781 | 0,804 | | | |
| **Formative Measurement** | | | | | | | | |
| **t-statistic > 1.96** | 3,744 | 6,533 | 2,780 | 2,483 | | 3,083 | 6,364 | 2,379 |
| **(VIF) < 0.05** | 1,205 | 1,188 | 1,204 | 1,183 | | 1,193 | 1,299 | 1,386 |
| **Structural Model** | | | | | | | | |
| **R square** | 0,864 | 0,864 | 0,864 | 0,864 | | | | |
| **(Hypothesis) P-values < 0.05** | $2x10^{-4}$ | $1x10^{-10}$ | 0,005 | 0,013 | | 0,002 | $1x10^{-11}$ | 0,017 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **f square** | 0,356 | 1,366 | 0,163 | 0,298 | | 0,251 | 1,755 | 0,139 |
| **Information** | Valid | Valid | Valid | Valid | | Valid | Valid | Valid |

Table 2 presents the SEM-PLS test results, indicating that the variables of WTP Operation and Maintenance [A], Sustainable Technology [B], Environmental Conservation [C], and WTP Operational Design [D] significantly influence Cost Performance [E], as evidenced by P-values < 0.05 (Husin & Kurniawan, 2023). WTP Operational Design [D] moderates the effects of WTP Operation and Maintenance [A], Sustainable Technology [B], and Environmental Conservation [C] on Cost Performance [E]. The average values of each construct's indicators provide insights into the green infrastructure of the Drinking Water Supply System (SPAM). By calculating the average values, the top five indicators are presented in Table 3

**Tabel 3. Ranking Sample Mean**

| Rank | Name | Mean |
|---|---|---|
| **1** | B.8 Use of renewable energy and application of innovation | 0,950 |
| **2** | C.2 Waste Management | 0,941 |
| **3** | A.1 Tool Reliability and Tool Performance | 0,940 |
| **4** | A.2 Repair and Maintenance Costs | 0,935 |
| **5** | C.1 Monitoring the Quality and Quantity of Water Sources | 0,933 |

Table 3 presents the ranked sample mean indicators analyzed using SEM-PLS. The results indicate that the Sustainable Technology variable, specifically indicators B.8 (Renewable Energy Use) and Innovation Implementation, exhibits the highest ranking. Considering the Outer Model, p-values, T-statistics, Mean Ranking, and Green Building Performance Assessment Parameters (Permen PUPR No. 21 Tahun 2021, 2021) (energy efficiency, water efficiency, and wastewater management), the Sustainable Technology variable is identified as the most influential, with Renewable Energy Use and Innovation Implementation being the most impactful indicators.

### Value Engineering

Value Engineering analysis was conducted at a Water Treatment Plant (WTP) owned by Perumdam Tirta Kerta Raharja in Tangerang Regency, with a capacity of 1,575 L/s, as depicted in Figure 2.


**Figure 2. Research Location**

**Information Phase**

This phase is crucial as sufficient information enables the design of targeted solutions to enhance value or efficiency through specific methods. The initial step involves identifying high-cost work items by developing a comprehensive cost breakdown of the project and its components. The cost model analysis begins with a Pareto Analysis to pinpoint high-cost items with potential for Value Engineering. Based on the Pareto principle, 80% of total costs typically originate from 20% of components. The operational cost components of the WTP are presented in Table 4.

**Table 4. IPA Operational Cost Components**

| No. | Cost Components | Total cost (Rp) | Percentage (%) | Cumulative (%) |
|---|---|---|---|---|
| **1** | Electricity cost | 35.761.824.000 | 48,38 | 48,38 |
| **2** | Raw Water Cost | 14.628.821.130 | 19,79 | 68,17 |
| **3** | Employee Costs | 12.180.000.000 | 16,48 | 84,65 |
| **4** | Depreciation Expense | 8.610.000.000 | 11,65 | 96,29 |
| **5** | Material Cost | 1.500.573.160 | 2,03 | 98,32 |
| **6** | Maintenance Costs | 1.239.000.000 | 1,68 | 100 |
| | **Total cost** | 73.920.218.290 | 100 | |

Based on Table 4, the Pareto principle is applied to identify cost components contributing over 20% to the total cost, which are prioritized for Value Engineering analysis. The Pareto diagram illustrating the operational cost components of Perumdam Tirta Kerta Raharja WTP is presented in Figure 3.

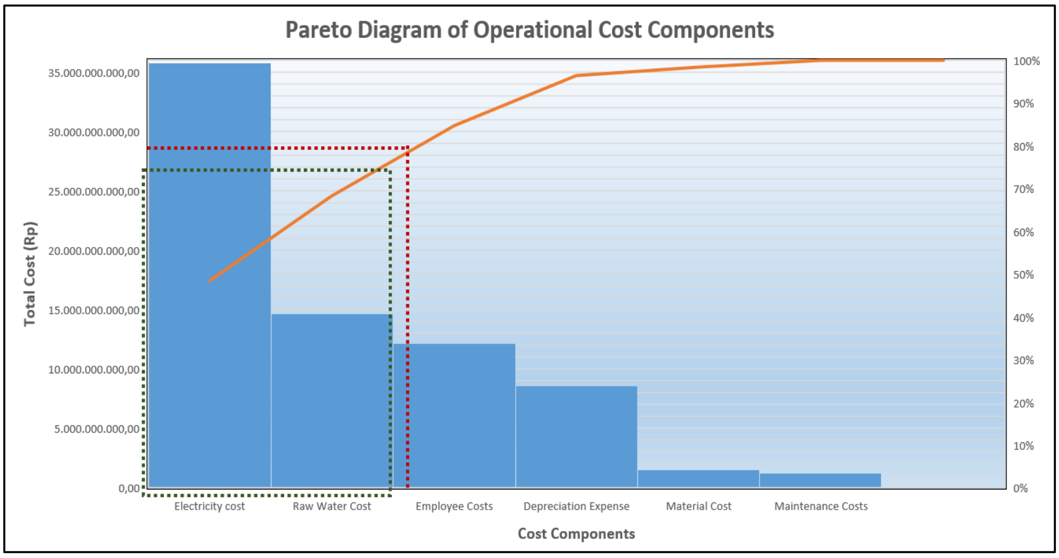


**Figure 3. Pareto Diagram**

The initial operational cost of the WTP is IDR 73,920,218,290, with Electricity Costs accounting for 48.38% and Raw Water Costs constituting 19.79%. These components, particularly Electricity Costs and water usage efficiency, warrant evaluation as they significantly impact overall operational expenses.

## Function Analysis

The final result of the functional analysis will yield cost and worth values, which will be compared to the requirement that a value greater than 1 be greater than 1 to meet the value engineering feasibility requirements. The results of the functional analysis can be seen in Table 5. Table 5. Analysis of Activity Functions Related to IPA Operational

**Table 5. Analysis of Activity Functions Related to IPA Operational Cost Components**

| No | Activities Related to Cost Components | Function | | Type | Cost | Worth |
|---|---|---|---|---|---|---|
| | | Verb | Noun | | | |
| 1 | Electricity cost | | | | | |
| | - Pumping | Operating | Pump | S | 13.888.086.990 | |
| | - Lighting and | Operating | Light | B | 21.873.737.010 | 21.873.737.010 |
| | etc | | | | | |
| | - Raw Water Cost | Used | Raw Water | B | 14.628.821.130 | 14.628.821.130 |
| | **Total Cost** | | | | 50.390.645.130 | 36.502.558.140 |
| | | **C/W** | **1,38** | **>** **1** | ***Worthy of Value Engineering*** | |

The next step in Cost/Worth analysis is to create a Fast diagram, which includes activities related to cost components that can be value engineered without compromising functionality, at a lower cost and in an environmentally friendly manner. Using a Fast Diagram, VE analysis focuses not only on cost reduction but also on evaluating the basic functions that serve as a reference in selecting alternative designs. The Fast Diagram in this study can be seen in Figure 4.

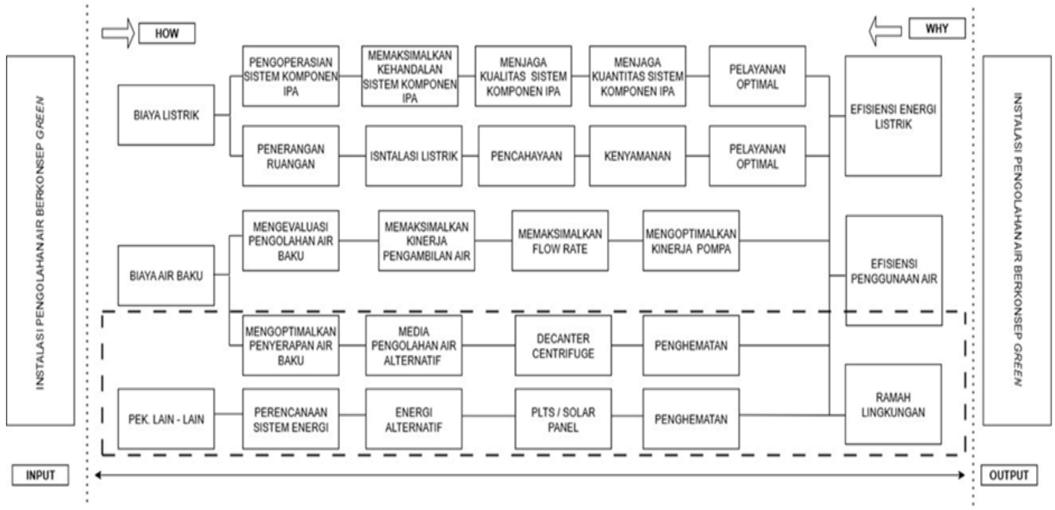


**Figure 4.** Fast Diagram of Activities Related to IPA Operational Cost Components

The FAST diagram illustrates the technical process and strategy for implementing a green concept in water treatment plants, aiming to optimize energy and water efficiency. The primary focus is on achieving optimal service while maintaining system quality and quantity, lighting comfort, and energy and water efficiency to support environmentally friendly practices.

### *Creative Phase*

In the creative phase, alternatives are generated by comparing initial operational plans with new green concept-based operational strategies, incorporating value engineering analysis. The initial conditions and alternatives are presented in Table 6.

**Table 6. Initial and Alternative Conditions**

| No. | Description | Initial Conditions | Alternative |
|---|---|---|---|
| 1 | System Operation Water Treatment | Scada Manual | System Automation Scada |
| 2 | Electric Power Usage | All Equipment Using PLN Electricity | Using Solar Cells |
| 3 | Exhaust System Mud | Drainage and Sludge Retention Pond | System Creation Recirculation and Decanter |

Table 6 outlines several operational cost optimization strategies incorporating green concepts to achieve efficient and energy-saving operations. The Perumdam Tirta Kerta Raharja WTP currently employs a Manual SCADA system, where SCADA is used solely for monitoring, and operations remain manual. The system relies on PLN electricity, and sludge disposal utilizes drainage channels and settling ponds, with periodic dredging required.

Based on green building performance parameters, including energy efficiency and wastewater management, alternative design optimizations are proposed: upgrading to an Automated SCADA system, transitioning specific areas to solar power, and implementing sludge recirculation and decanter systems. A Multi-Criteria Decision Analysis (MCDA) evaluation is then conducted to score each scenario, facilitating complex decision-making with multiple criteria.(Abdulah Shrrat Omar, 2023) The results of the MCDA evaluation can be seen in Table 7.

**Table 7. Multi Criteria Decision Analysis**

| Criteria | Weight (%) | Initial Conditions | | | Alternative | | |
|---|---|---|---|---|---|---|---|
| | | A1 | A2 | A3 | B1 | B2 | B3 |
| **Initial Investment, Operational, and Maintenance Costs** | 20 | 4 | 5 | 4 | 2 | 3 | 2 |
| **Efficiency & Productivity** | 15 | 1 | 3 | 1 | 5 | 5 | 5 |
| **Data Accuracy, Monitoring, and Response Speed** | 10 | 2 | - | - | 5 | - | - |
| **Security and Integration with Other Systems** | 10 | 1 | - | - | 4 | - | - |
| **Environmental Impact** | 15 | - | 2 | 2 | - | 5 | 5 |
| **Reliability and Energy Supply Independence** | 10 | - | 4 | - | - | 3 | - |
| **Regulatory Compliance** | 10 | - | 3 | 2 | - | 5 | 5 |
| **Repurposing of Waste** | 10 | - | - | 2 | - | - | 4 |
| | 100 | 1,25 | 2,45 | 1,65 | 2,05 | 2,90 | 2,80 |

Based on Table 7, the MCDA results indicate that upgrading SCADA to automation, implementing solar power, and adopting sludge recirculation and decanter systems score higher than the existing conditions. Thus, the alternative scenario is selected as the optimal operational strategy.

### *Evaluation Phase*

In the evaluation phase, the alternatives SCADA automation, solar power integration, and sludge processing upgrades are assessed. The green cost calculations for these implementations are presented in Table 8

**Table 8. Green Cost Calculation**

| Job Description | Before VE (Rp.) | After VE (Rp.) | % |
|---|---|---|---|
| **Design, Preparation and Other Work on Buildings** | 1.779.875.000 | 1.779.875.000 | 00..00 |
| **and Mechanical and Electrical Water Treatment** | 4.356.909.421 | 4.859.037.878 | 11,52 |
| **Supplementary Facilities** | 13.012.711.482 | 14.227.961.982 | 9,34 |
| **Total Cost** | 19.149.495.903 | 20.866.874.860 | |
| **Cost After VE – Cost Before VE** | | 1.717.378.957 | 8,97 |

Table 8 indicates that implementing green concept designs increases the initial investment by IDR 20,866,874,860. Compared to the original investment plan of IDR 19,149,495,903, this represents a cost increase of IDR 1,717,378,957 or 8.97%. This green cost calculation exceeds the 7% threshold.

### *Development Phase*

Life Cycle Cost Analysis (LCCA) estimates the total cost of an asset up to the nth year in present value. Cash flow is a report detailing the flow of incoming (revenue) and outgoing (expense) cash flow of an entity during a certain period (Imron & Husin, 2024). Cash flow indicates the financial health of company, where positive cash flow means income is greater than expenses, and negative cash flow means the opposite. Cash flow in this study can be seen in Table 9.

**Table 9. Net Cash Flow**

| Year - | Expenditure (Rp.) | Income (Rp.) | Net Cash Flow |
|---|---|---|---|
| **Investment** | 20.866.874.860,00 | - | - 20.866.874.860,00 |
| **1** | 87.404.862.555,72 | 89.549.168.150,61 | -18.722.569.265,11 |
| **2** | 86.204.056.655,14 | 89.457.637.252,16 | 3.253.580.597,01 |
| **3** | 86.298.083.222,99 | 89.555.212.643,90 | 3.257.129.420,92 |
| **4** | 86.264.799.482,16 | 89.520.672.682,22 | 3.255.873.200,07 |
| **5** | 86.255.646.453,43 | 89.511.174.192,76 | 3.255.527.739,33 |

Net Present Value helps in evaluating projects holistically and provides more accurate information about the potential profit or loss of an investment. NPV can be calculated using the following formula:

$$NPV = \frac{R_t}{(1+i)^t} \quad (1)$$

Dimana:

Rt = Net Cash Flow at time t

i = Discount Rate

t = Cash Flow Period

To calculate NPV, the Minimum Attractive Rate of Return (MARR) is required. This is the minimum rate of return deemed appropriate by management or investors to initiate a project, taking into account the risks and opportunity costs of other investment alternatives. MARR is calculated using the formula:

*MARR=Safe Rate ±(Risk x Average Deposit Interest Rate)* *(2)*

The Minimum Acceptable Rate of Return (MARR) is determined using a risk-adjusted approach, calculated as the product of the average deposit interest rate (2.80% based on January 2025 data from five major Indonesian banks) and a risk factor of 1.5, yielding a MARR of 6.95% (Idawicaksakti, 2022).

The Net Present Value (NPV) and Internal Rate of Return (IRR) are presented in Table 10. The NPV is IDR 14,076,121,227.33, indicating a viable investment (NPV > 0). The IRR is 16.42%, exceeding the MARR of 6.95%, confirming the investment's feasibility.

The Payback Period (PP) analysis assesses the time required to recover the investment, using the formula:

$$\textit{Payback Period} = n + \frac{a-b}{c-b} \quad (3)$$

Description:

n = The last year in which the cumulative cash flow is insufficient to cover the initial investment

a = Initial investment value

b = Cumulative NPV up to year n

c = Cumulative NPV in year (n+1)

From the calculation results, the Payback Period value or the time period required to return the investment value according to the cost analysis of implementing the green concept that has been spent for 8.60 years is obtained.

**Table 10. Net Present Value (NPV) 20 Year Period**

| Year To | Cost Increase (%) | Net Cash Flow (Rp.) | Discount Factor | NPV (Rp.) | IRR (%) |
|---|---|---|---|---|---|
| **0** | | 20.866.874.860,00 | | | |
| **2025** | 3,705 | (18.722.569.265,11) | 0,935 | (17.505.908.616,28) | |
| **2026** | 3,599 | 3.253.580.597,01 | 0,874 | 2.844.461.052,69 | |
| **2027** | 3,712 | 3.257.129.420,92 | 0,817 | 2.662.518.589,86 | |
| **2028** | 3,672 | 3.255.873.200,07 | 0,764 | 2.488.538.289,44 | |
| **2029** | 3,661 | 3.255.527.739,33 | 0,715 | 2.326.577.135,02 | |
| **2030** | 3,681 | 3.256.155.849,76 | 0,668 | 2.175.807.402,42 | |
| **2031** | 3,671 | 3.255.841.794,55 | 0,625 | 2.034.219.304,79 | |
| **2032** | 3,671 | 3.255.841.794,55 | 0,584 | 1.902.028.335,48 | |
| **2033** | 3,675 | 3.255.967.416,63 | 0,546 | 1.778.496.234,29 | |
| **2034** | 3,673 | 3.255.904.605,59 | 0,511 | 1.662.891.000,67 | |
| **2035** | 3,673 | 3.255.904.605,59 | 0,478 | 1.554.830.295,16 | |
| **2036** | 3,673 | 3.255.904.605,59 | 0,447 | 1.453.791.767,33 | |
| **2037** | 3,673 | 3.255.904.605,59 | 0,417 | 1.359.319.090,54 | |
| **2038** | 3,673 | 3.255.904.605,59 | 0,390 | 1.270.985.591,90 | |
| **2039** | 3,673 | 3.255.904.605,59 | 0,365 | 1.188.392.325,29 | |
| **2040** | 3,673 | 3.255.904.605,59 | 0,341 | 1.111.166.269,56 | |
| **2041** | 3,673 | 3.255.904.605,59 | 0,319 | 1.038.958.643,81 | |
| **2042** | 3,673 | 3.255.904.605,59 | 0,298 | 971.443.332,22 | |
| **2043** | 3,673 | 3.255.904.605,59 | 0,279 | 908.315.411,15 | |
| **2044** | 3,673 | 3.255.904.605,59 | 0,261 | 849.289.771,99 | |
| **Total** | | 36.626.552.809,04 | | 14.076.121.227,33 | 16.42 |

Sensitivity analysis is performed to assess the level of investment risk in response to changes in costs and revenues, using data that is based on assumptions and estimates, resulting in considerable uncertainty. The sensitivity analysis is performed by increasing total costs by 10% and decreasing total revenue by 10%. The results of the sensitivity test are shown in Table 11.

**Tabel 11. Sensitivities Analysis**

| Percobaan | | ***Total Cost* Naik** | | | | |
|---|---|---|---|---|---|---|
| | | **10%** | **20%** | **30%** | **40%** | **50%** |
| ***Total Revenue* Turun** | 10% | 21.914.763.338,74 | 16.362.142.134,85 | 14.411.055.191,42 | 12.459.968.247,99 | 10.508.881.304,56 |
| | 20% | - 47.473.925.603,72 | - 49.425.012.547,15 | - 51.376.099.490,59 | - 53.327.186.434,02 | - 55.278.273.377,45 |
| | 30% | - 116.862.614.546,19 | - 118.813.701.489,62 | - 120.764.788.433,05 | - 122.715.875.376,48 | - 124.666.962.319,91 |

From the calculation results in Table 11, the sensitivity analysis shows that if the total cost changes by 10% and the total revenue decreases by 20%, it is said to be not feasible because the NPV < 0, namely Rp - 47,473,925,603.72.

### *Recommendation Phase*

Based on the preceding analysis, it is recommended that implementing SCADA automation, solar-powered panel systems, and sludge recirculation with decanter technology at the Water Treatment Plant is viable, with a payback period of 8.60 years. This relatively short recovery time supports the adoption of green concepts as an effective strategy for optimizing operational costs at water treatment facilities.

## CONCLUSION

The SEM-PLS analysis and outer model evaluation identified Sustainable Technology as the most influential variable, with Renewable Energy Use and Innovation Implementation as key indicators. This highlights the critical role of technological innovation in driving cost savings. The Value Engineering approach, incorporating SCADA automation, solar power, and sludge recirculation with decanter systems, resulted in an 8.97% (IDR 1,717,378,957) initial cost increase. However, this is considered manageable and aligns with green concept objectives without compromising functionality or financial viability. Life cycle cost analysis confirms the investment's feasibility Net Present Value: IDR 14,076,121,227.33 (NPV > 0), indicating long-term profitability. Internal Rate of Return: 16.42%, exceeding the 6.95% MARR, affirming investment attractiveness. Payback Period: 8.60 years, demonstrating efficient cost recovery and supporting green concepts as a viable operational cost optimization strategy.

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