

Water Treatment Plant Operational Costs Efficiency Strategy with Green Concept and Value Engineering

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| Submitted: December 22, 2025 | Revised: January 05, 2026 | Accepted: August 27, 2026 |

| Published: September 16, 2026 |

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 encompasses 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.

Keywords: efficiency, green concept, IPA, value engineering, life cycle cost analysis.

INTRODUCTION

Water is an essential resource for human survival, underpinning health and daily life. 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 [1]. The Drinking Water Supply System (SPAM) is a critical infrastructure for fulfilling the public's right to clean water. The Drinking Water Supply System (SPAM) is one of the uses of water resources and sanitation management as a form of protection and preservation that needs to be carried out by the government [2].

Water treatment plants are integral to this system, playing a pivotal role in ensuring water security. 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 [3]. The environmental impacts of processing are divided into three broad categories: human health, ecosystem quality, and resources. Electricity use indirectly impacts natural resource depletion (fossil fuels) and human health (climate change) due to CO₂ combustion [4]. The pursuit of Sustainable Development Goals (SDGs) has highlighted the need for integrating economic, environmental, and social considerations to prevent environmental degradation [5]. This has led to growing interest in applying green concepts to various sectors, including water treatment facilities [6]. The importance of the green concept in all aspects of life today is based on global warming, namely increased development, which is followed by economic development which leads to increased national energy needs [7]. 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 [8] 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 [9]. 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. [10].

RESEARCH METHODS

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:

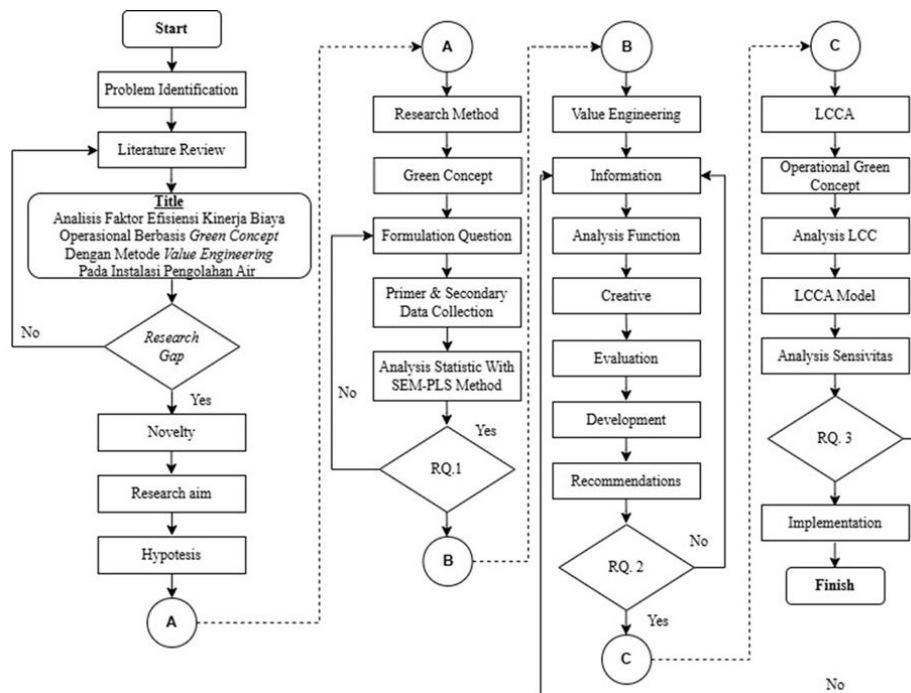


Figure 1. Research Flowchart

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 [11]. 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.

RESULTS 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 <i>recycle</i> [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			

Evaluation Criteria	A	B	C	D	E	DxExA	DxExB	DxExC
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 (Hypothesis)	0,864	0,864	0,864	0,864				
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 [8]. 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

Table 3. Ranging 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 [12] (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.

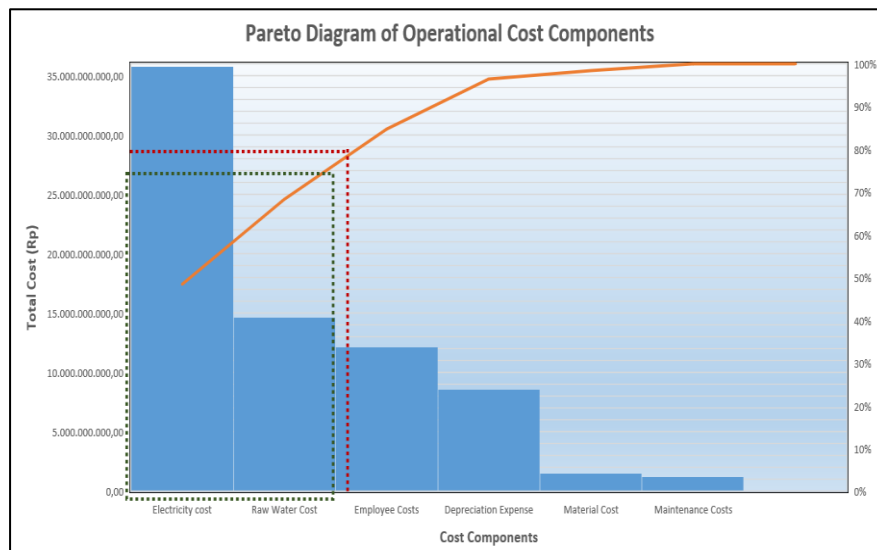


Figure 3. Pareto Diagram

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 etc	Operating	Light	B	21.873.737.010	21.873.737.010
	- 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.

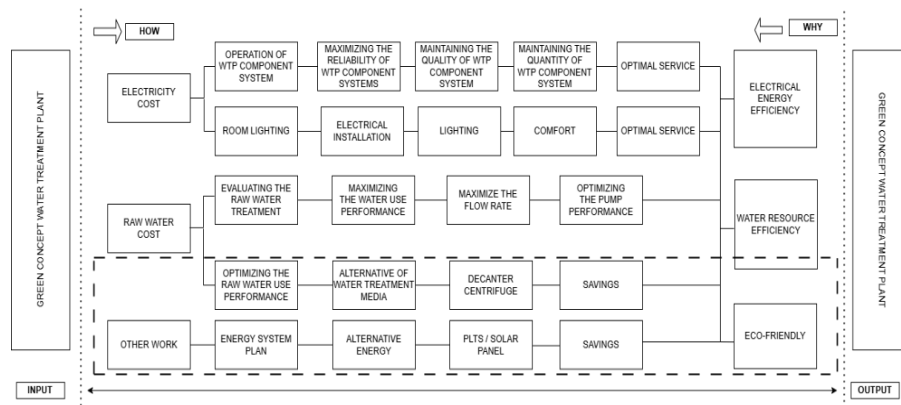


Figure 4. Fast Diagram of Activities Related to WTP Operational Cost Components

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.[13]. 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
Pemanfaatan Kembali Limbah	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 [14]. 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:

R_t = 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:

$$MARR = \text{Safe Rate} \pm (\text{Risiko} \times \text{Rata-Rata Suku Bunga Deposito}) \quad (2)$$

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% [15].

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:

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

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

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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