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Analysis of The Influence of Management, Technical, and Digitalization Factors on Cost Performance through Green Shorebase Performance Based on Value Engineering

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ABSTRACT

The global maritime sector contributes around 2.5% of total CO^2 emissions, the majority of which originate from shipping and port operations. Shorebase is a port that plays an essential role in the oil and gas sector, but its logistical activities add significantly to overall port emissions. The implementation of green ports at shorebase is a method and resolve to emphasize the importance of a safe environment. This study analyzes the influence of management, technical, and digitalization factors on cost performance in a green shorebase project using Value Engineering (VE) and Life Cycle Cost Analysis (LCCA). Results show the technical aspect has the most significant impact at 58%, followed by management (20.6%) and digitalization (20%). Green shorebase performance contributes 97% to cost performance. VE implementation generated operational cost savings of IDR 1,135,948,542 or 7% of initial costs, exceeding efficiency benchmarks (Ekanayake et al., 2018). LCCA results indicate the project is feasible, with a Benefit Cost Ratio of 3.33, NPV of IDR 25,989,577,423, IRR of 49% (above the 20% discount factor), and a payback period of 3.93 years. These findings confirm that VE and LCCA are effective in optimizing costs and improving project feasibility. This research serves as a reference for applying green and smart port concepts in Indonesian shorebase projects.

1. Introduction

The global maritime sector contributes approximately 2.5% of total global CO_2 emissions, the majority of which originate from shipping activities and port operations. Consequently, emission reduction has become a critical target within this sector. The International Maritime Organization (IMO), as the international maritime policy-making body, has emphasized this issue in its routine agenda, the *IMO Strategy on Reduction of GHG Emissions from Ships*, in 2023. This strategy focuses on reducing carbon intensity in international shipping, aiming for an average reduction of 40% in CO_2 emissions by 2030. The 2023 IMO GHG Strategy also includes a new level of ambition concerning the adoption of technologies, fuels, and/or energy sources with zero or near-zero GHG emissions, targeting at least 5% adoption and striving for 10% in pursuit of net-zero emissions by 2050 [1].

The introduction of green shorebase serves as a means and resolution to highlight the importance of a safe and environmentally friendly infrastructure. IMO has started to implement such measures to protect both the environment and surrounding communities, as ports are also significant contributors to pollution.

However, the implementation of green concepts at ports and similar facilities in Indonesia remains limited. Previous research indicates that the level of green port implementation in Indonesia is relatively neutral, at 56.83% [2]. According to the Coordinating Ministry for Maritime Affairs and Investment (Kemenkomarves), there are currently only 13 ports and 1 shorebase in Indonesia that have adopted the green port concept. The ministry has set a target of 149 ports adopting this concept by 2024—an increase of tenfold compared to the achievements of the previous year [3].

One of the main challenges in adopting the green concept is cost. According to Kurniawan [4], green buildings typically

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experience a cost increase of approximately 4.5% to 7% compared to conventional designs. Other studies indicate a cost increase of around 5.92% from the initial estimate when the green concept is applied to terminals [5]. Meanwhile, Hwang et al. noted that the cost premium for green concepts ranges from 5% to 10%, depending on the type and size of the project [6].

Other challenges are believed to stem from several factors, including a lack of knowledge and socio-cognitive aspects, which play a significant role in implementation [7], as well as high initial investment costs in green technology. Additionally, the high cost of infrastructure and the demand for sustainable new technologies call for approaches that can reduce costs without compromising environmental and operational performance at ports.

Research on the implementation of the Green Shorebase concept in Indonesia has yet to be conducted. Shorebases themselves are significant sources of emissions, particularly from energy use and carbon emissions produced by heavy equipment and other operational activities. The application of the Green Shorebase concept has been proven to reduce greenhouse gas emissions by approximately 10% in major ports worldwide, such as the Port of Rotterdam [8]. In line with this, the application of the Green Shorebase concept should be accompanied by the implementation of Value Engineering and Life Cycle Cost Analysis (LCCA) to improve cost performance. Through the implementation of green concepts, it is expected that shorebases in Indonesia can operate more efficiently, be environmentally friendly and sustainable, and contribute to the achievement of the Sustainable Development Goals (SDGs) in the transportation and energy sectors.

Based on this background, this study aims to analyze the factors influencing the implementation of the Green Shorebase concept based on Value Engineering and LCCA to enhance cost performance. The study is expected to contribute to the development of the Green Shorebase concept in Indonesia and to provide strategic recommendations for effective implementation to improve cost efficiency.

2. Methods

This study observes the development of green concept implementation at shorebases. Figure 1 illustrates the research flow. There are six Research Questions (RQ) addressed in this study; 1) Do management aspects, technical aspects, and digitalization simultaneously influence cost performance in green shorebase projects?; 2) Which factor is the most dominant among management aspects, technical aspects, and digitalization in influencing cost performance in green shorebase projects?; 3) How is Value Engineering applied in green shorebase projects?; 4) How is Life Cycle Cost Analysis (LCCA) applied in green shorebase projects?; 5) What are the results of applying Value Engineering and LCCA in the implementation of the green shorebase concept?; 6) How do the results of this study compare to previous research?.

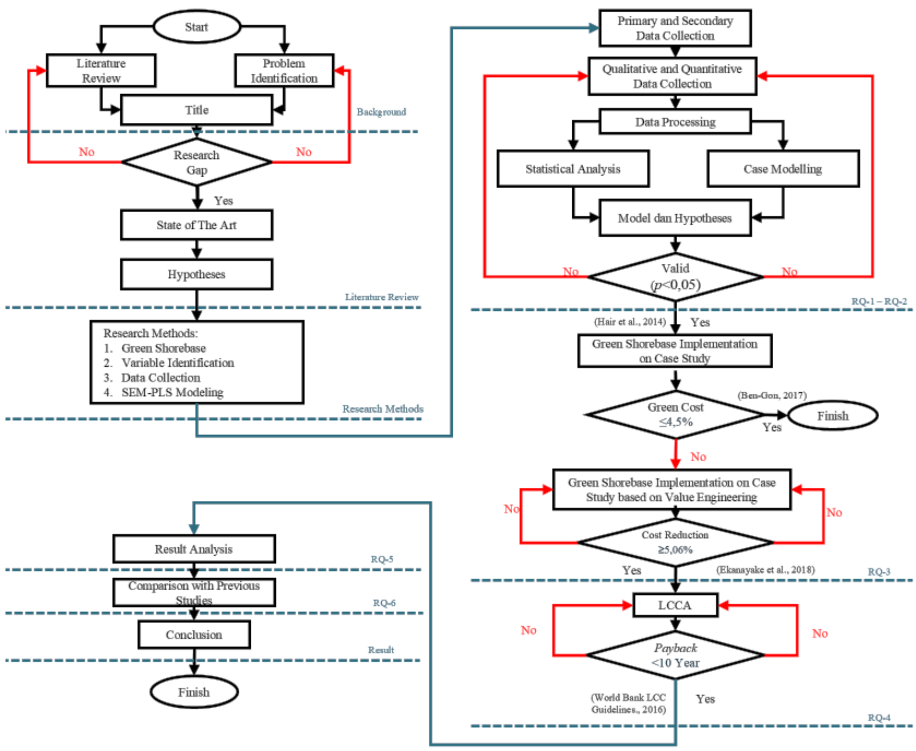

Figure 1. Research Flow Chart

The answers to RQ-1 and RQ-2 are obtained through questionnaire data, which are analyzed using a simulation tool, namely Structural Equation Modeling–Partial Least Squares (SEM-PLS). Subsequently, RQ-3 and RQ-4 are addressed through the direct application of the findings from RQ-1 and RQ-2, implemented in a predefined case study based on the research scope. The output of RQ-3 is the result of the Value Engineering application in the green shorebase project, while the output of RQ-4 is the result of the LCCA application in the green shorebase project.

The numerical results obtained from RQ-3 and RQ-4 serve as the basis for addressing Research Question RQ-5. This question is answered through a descriptive analysis of the Value Engineering (VE) and Life Cycle Cost Analysis (LCCA) outcomes in implementing the green shorebase concept, focusing on their impact on cost performance to test the study's hypotheses.

Research Question RQ-6 is addressed by comparing the findings of this study with previous research on the application of green concepts using VE and LCCA. This comparison aims to determine whether earlier findings support or contradict the results of the current study.

3. Result and Discussion

A total of 56 questionnaire sets were distributed, and 42 sets were returned and completed. According to Baley as cited in Mahmud, for research utilizing statistical data analysis, the minimum required sample size is 30 [9]. The sample size in this study was determined using the Slovin formula, as shown in Equation 1, resulting in the required sample size as follows:

$$n = \frac{N}{1+N\,(e)^2} \qquad (1)$$

With; n = sample; N = population size; e = margin of error (10%). So that the calculation obtains the Equation 2.

$$n = \frac{56}{1+56\,(0{,}1)^2} \qquad (2)$$

$n = 35{,}89$, rounded up to 36 samples.

The calculation results show that 42 data received have met the minimum standards based on the Slovin formula, which is greater than 36 samples.

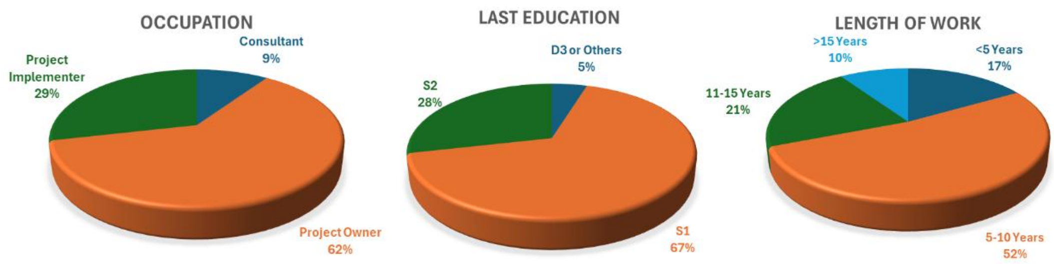

Figure 2. Respondent Data based on (a) Occupation, (b) Last Education, (c) Length of Work

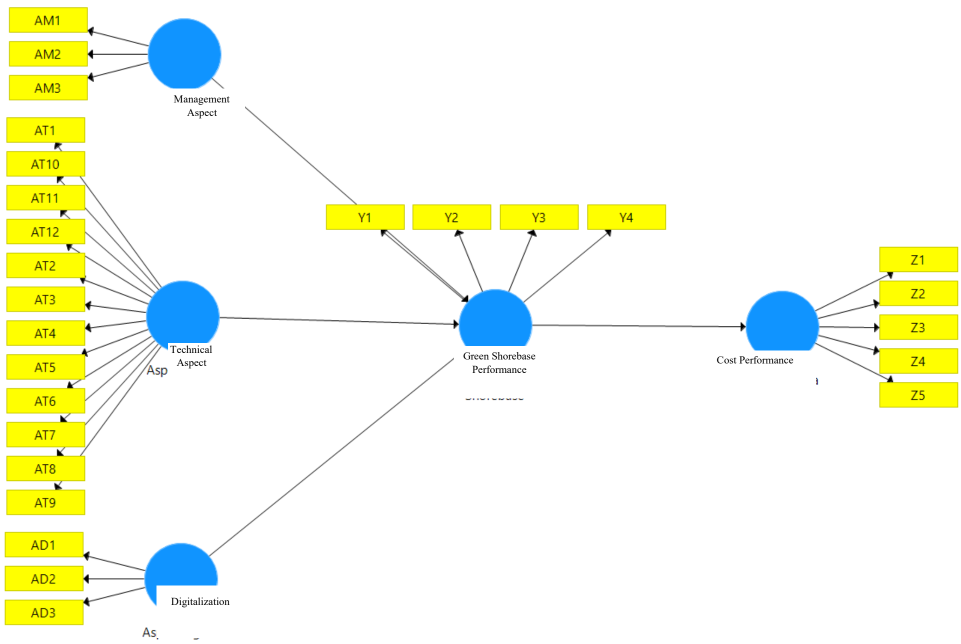

Figure 3. Research Model

Thus, the returned questionnaire data, as shown in Figure 2, can be further processed using statistical data analysis tools. Structural Equation Modeling - Partial Least Squares (SEM-PLS) was employed for statistical data analysis. SEM-PLS is a statistical technique capable of analyzing the relationships between latent variables and their indicators, between latent variables themselves, as well as directly accounting for measurement errors. This modeling technique allows for the simultaneous analysis of multiple dependent and independent variables.

The SEM-PLS application used in this study is Smart-PLS 3.0. The purpose of using this application is to estimate the relationships among the variables of management aspects, technical aspects, digitalization aspects, green shorebase performance, and cost performance. Smart-PLS 3.0 includes validation tests to assess whether the processed data meet the required criteria, which include; 1) Measurement Model, which evaluates convergent validity and discriminant validity; 2) Structural Model, which illustrates the hypothesized relationships among variables.

Before conducting the validity tests, the hypotheses constructed in the form of a relationship model, as illustrated in Figure 3 that presents the latent variables in blue and their indicators in yellow. All research variables are reflected by their respective indicators, with the following details; 1) Management Aspect (X1) is reflected by 3 indicators (AM1–AM3 or X.1.1–X.1.3); 2) Technical Aspect (X2) is reflected by 12 indicators (AT1–AT12 or X.2.1–X.2.12); 3) Digitalization Aspect (X3) is reflected by 3 indicators (AD1–AD3 or X.3.1–X.3.3); 4) Green Shorebase Performance (Y) is reflected by 4 indicators (Y1–Y4); 5) Cost Performance (Z) is reflected by 5 indicators (Z1–Z5).

Model evaluation in SEM-PLS is conducted through outer model and inner model assessments. The outer model evaluation involves testing four indicators: Convergent Validity, Discriminant Validity, Average Variance Extracted (AVE), and Composite Reliability. Each of these tests has specific criteria: the loading factor should be greater than 0.7; cross-loading values of a construct should be higher than those of other constructs; AVE should be greater than 0.5; and Composite Reliability should exceed 0.7.

Based on the results presented in Table 1 and Table 2, all indicators in the outer model meet these criteria, indicating that the measurement instruments exhibit good validity and reliability.

Table 1. Model validity test

Main Factor	Cronbach's Alpha	rho_A	CR	AVE	Result
Digitalization	0.837	0.843	0.903	0.756	Valid
Management Aspect	0.837	0.845	0.903	0.756	Valid
Technical Aspect	0.964	0.964	0.968	0.717	Valid
Cost Performance	0.922	0.922	0.941	0.762	Valid
Green Shorebase Performance	0.899	0.901	0.930	0.770	Valid

Table 2. Inner model validity test

Main Factor	R^2	Q^2	Result
Cost Performance	0.944	0.687	Valid
Green Shorebase Performance	0.971	0.712	Valid

Subsequently, the inner model is used to evaluate the relationships between constructs within the structural model, typically through tests such as R-square, path coefficients, and predictive relevance. An R-square value close to 0.67 is considered strong, 0.33 moderate, and 0.19 weak [9]. As shown in Table 2, the R-square values fall within the strong category, and the predictive relevance (Q^2) values are greater than zero, thereby meeting the evaluation criteria.

Therefore, the overall validity test results in Table 1 and Table 2 indicate that the data meet the required validity standards, and the dataset is deemed valid.

3.1. Research Question 1

The influence among variables can be observed from the research model processed using Smart-PLS 3.0 by executing the PLS Algorithm to obtain the Path Coefficients. The relationships between variables are interpreted based on the path coefficient (β) values for each independent variable (X), intervening variable (Y), and dependent variable (Z).

Table 3. Relationship between variables

Relationship	O	M	S	T	P
Digitalization (X3) -> Green Shorebase Performance (Y)	0.200	0.205	0.150	1.327	0.185
Management Aspect (X1) -> Green Shorebase Performance (Y)	0.206	0.176	0.150	1.376	0.170
Technical Aspect (X2) -> Green Shorebase Performance (Y)	0.588	0.613	0.169	3.472	0.001
Green Shorebase Performance (Y) -> Cost Performance (Z)	0.972	0.972	0.008	121.011	0.000

Whereas O as the original sample, M as the sample mean, S as the Standard Deviation, T as the T Statistics, and P as the P Values.

The calculation results in Table 3 indicate that the influence of management aspects (X1) and digitalization aspects (X3) on green shorebase performance (Y) is categorized as insignificant with a weak impact. In contrast, the influence of technical aspects (X2) on green shorebase performance (Y) is significant with a strong impact. This suggests that green shorebase performance is primarily influenced by technical aspects, which involve the governance of port areas towards sustainable green ports. These include environmental factors such as air and water quality management, waste management, and energy management.

3.2. Research Question 2

Theoretically, Kemenkomarves states that there are three aspects influencing green shorebase performance: management, technical, and digitalization aspects. All three aspects are believed to positively contribute to shorebases implementing the green concept.

The data analysis results in Table 3 show that the most dominant factor affecting green shorebase performance is the technical aspect (X2) with a contribution of 58%, followed by the management aspect (20.6%) and the digitalization aspect (20%). Additionally, statistical data processing indicates that green shorebase performance (Y) has a 97% influence on cost performance (Z).

These findings are supported by previous research, which found that the implementation of green ports positively affects operational cost efficiency [10]. In other words, shorebases that adopt the green concept tend to have more efficient operational costs compared to those that do not. This efficiency can be further optimized by focusing on the most dominant aspect influencing green shorebase performance.

3.3. Research Question 3

The case study in this research is conducted on a shorebase located in Tanjung Batu, Indonesia. The selected research object has undergone a pre-assessment for the application of the green concept to identify the largest GAP in achieving a green shorebase based on the evaluation criteria established by Kemenkomarves. The pre-assessment results indicate a score of 42% in the green port aspect and 88% in the smart port aspect. Based on the weighted scoring system, the total evaluation weight is 51%, with the lowest score found in the technical aspect category. Therefore, this becomes a focus area during the revitalization/renovation of the research object. The scope of the green shorebase project includes jetty repairs, building and non-building facility upgrades, electrical system improvements, and roof and warehouse structural enhancements.

Previous studies have applied Value Engineering (VE) to improve cost efficiency. VE focuses on function optimization at efficient costs without compromising quality. The application of VE is expected to identify or eliminate elements that do not add value and increase project costs. Past studies have shown that VE can reduce project costs by 20% to 30%, with additional savings of around 7% in energy consumption [11]. Therefore, through the VE approach, projects can reduce cost overruns while improving productivity and long-term operational sustainability. These outcomes also support the results of statistical data analysis, which confirm interrelationships among the aspects examined in this study.

VE consists of several stages; 1) Information Phase – to gather detailed project-related information; 2) Function Analysis Phase – to identify work elements with potentially high costs by performing a cost breakdown using the Pareto principle; 3) Creative Phase – to explore alternative materials or tasks that could deliver better cost-efficiency; 4) Evaluation Phase – to assess the proposed alternatives and narrow them down to the most feasible option; 5) Recommendation Phase – to present a final solution to the project owner that offers optimal value.

In the Information Phase, a general cost estimate was obtained, as shown in Table 4, which represents the initial revitalization cost without applying the green concept. After incorporating the green concept, with an emphasis on the energy component under the technical aspect, the total cost increased by 57% to approximately IDR 9.6 billion, as detailed in Table 5.

Table 4. Existing budget plan for shorebase revitalization project

Work Description	Budget
Jetty Repair	Rp2,720,000,000
Electrical System Repair	Rp1,800,000,000
Roof & Warehouse Structural Repair	Rp1,650,000,000
Total	Rp6,170,000,000

Table 5. Budget plan (RAB) for green shorebase revitalization project

Work Description	Budget
Jetty repair	Rp2,720,000,000
Building & non-building facilities upgrade	Rp3,397,000,000
Electrical system repair	Rp1,800,000,000
Roof & warehouse structural repair	Rp1,650,000,000
Total	Rp9,567,000,000

The data obtained during the information phase was subsequently processed in the function analysis phase. To determine the scope of work to be prioritized in the Value Engineering (VE) process, the Pareto analysis method was applied.

During the function analysis stage, identification of high-cost potential work elements was conducted by breaking down costs based on Pareto's Law [12]. This stage focuses on activities that have been identified as having a major impact on the project budget. Pareto analysis in Table 6 and Figure 4 illustrates the most dominant work components by observing their cumulative values. The analysis shows that the most dominant work components are building and non-building facility improvements (36%), jetty repairs (28%), and electrical works (19%). Therefore, these three work items must undergo further analysis, as they account for 80% of the total cost issues and should be prioritized for immediate attention.

The FAST (Function Analysis System Technique) diagram is a tool in Value Engineering used to understand, organize, and identify the relationships between functions within a system, product, or project. Based on analysis and discussions with relevant stakeholders, it was concluded that additional work items aligned with green concepts are needed to enhance functional value, with lower cost, environmental friendliness, and nearly zero energy use. Function additions are proposed as presented in Table 7.

In the function addition item, the the installation of a shore power connection was included, which is environmentally friendly and features low energy consumption. In the current condition, docked vessels still rely on auxiliary engines to power their onboard electrical systems. This practice leads to high energy consumption and increased costs due to the use of diesel fuel. Given the high fuel costs and energy consumption, there is a need for efficiency improvements through the implementation of shore power connections.

The logical "how-why" model is employed to identify, classify, develop, and select functions that can create greater value and benefits for project development [13]. As a result of the added function, the FAST (Function Analysis System Technique) diagram was modified as shown in Figure 5.

Table 6. Pareto analysis

Work description	Component cost (in million IDR)	Cumulative total component cost (in million IDR)	Component work percentage	Cumulative component work percentage
Jetty Repair	2.720	3.397	36%	36%
Building & non-building facilities upgrade	3.397	6.117	28%	64%
Electrical System Repair	1.800	7.917	19%	83%
Roof & Warehouse Structural Repair	1.650	9.567	17%	100%
Total	9.567		100%	

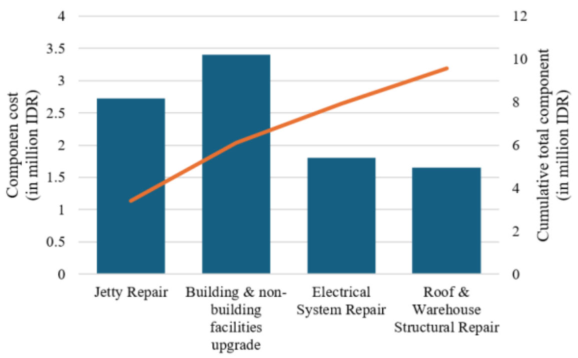

Figure 4. Pareto Chart

Table 7. Added function

Item	Function analysis
Installation of Green Concept Equipment	Shore power connection Maximization of natural lighting Energy efficiency Environmentally friendly

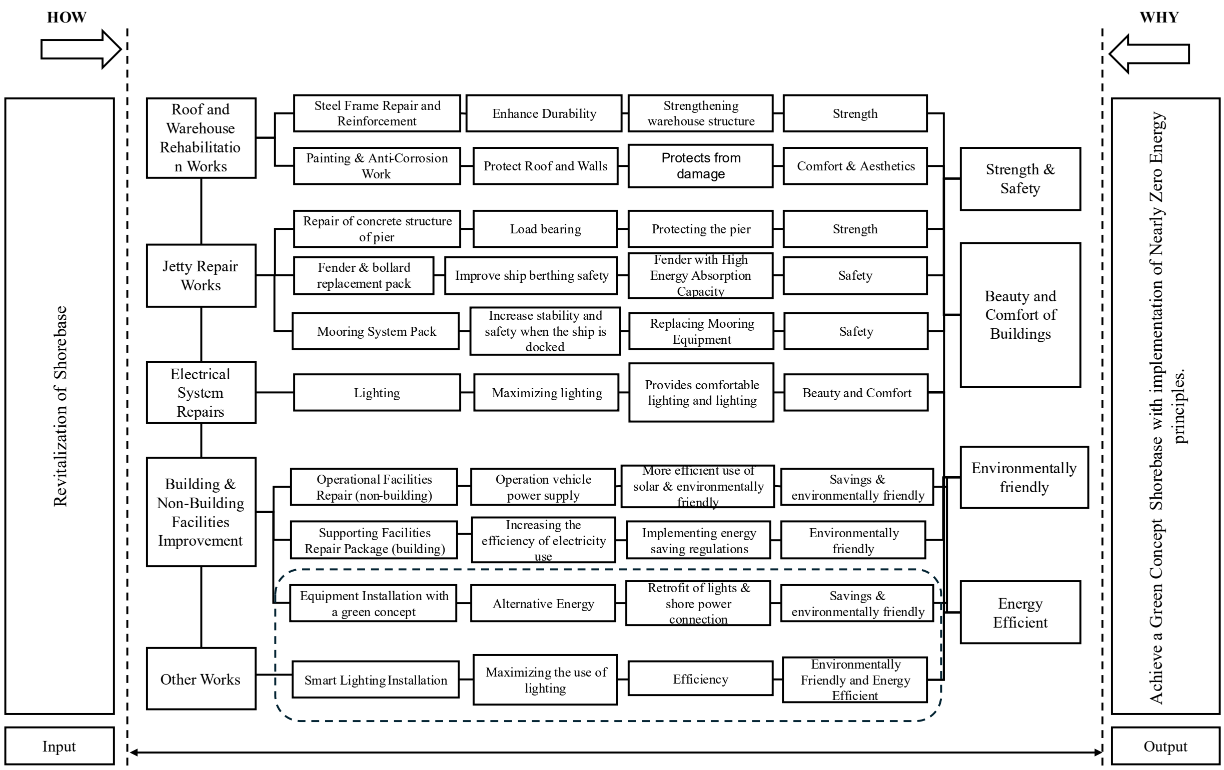

Figure 5. FAST Diagram with Added Function

Table 8. Creative Phase Discussion Results

Subject VE	Option 1 (Initial Condition)	Option 2 (Proposed Condition)
Electrical Power for Ship	Use of Auxiliary Engine on Ship	Use of Shore Power Connection
Vehicles for Port Operations	Low Vehicle	Electric Vehicle
Energy Monitoring System (EMIS)	EMIS	Cloud-based EMIS System
Air Conditioner (AC)	Conventional AC	Inverter AC
AC Temperature Setting (22-27°C)	No Spesific Regulation	Sett temperature at 22-27°C
Warehouse Lighting System	Standard LED Light	150 Watt UFO LED Light
Office Building Lighting Retrifit	T8 Fluorescent Tube (36W)	LED Tube (18W)

In the creative phase, alternative options are provided for key items of concern in the Value Engineering (VE) process. These alternatives are used to compare the initial planning of the green shorebase project with the cost estimates analyzed through VE. The goal of VE is not only to reduce costs but also to consider environmentally friendly energy aspects. Therefore, this study conducted discussions with stakeholders to evaluate feasible VE alternatives that can serve as references for selecting the best options, as described in Table 8.

Based on the results of the creative phase discussion, this study conducted a Value Engineering (VE) process focusing on the improvement of building and non-building facilities by implementing environmentally friendly and energy-efficient items. Accordingly, the overall outcome of the VE based on these improvement items is presented in Table 9.

The calculation results show that the estimated operational cost for Option 1 (before VE) is approximately Rp16 billion per year. However, after applying Value Engineering (VE) by introducing energy-efficient and environmentally friendly elements in the repair work for building and non-building facilities, annual operational cost savings of around Rp 1.1 billion (7%) were achieved, bringing the new operational cost to approximately Rp15 billion per year. According to Ekanayake et al. [14], if the percentage of cost reduction from VE analysis is ≥5.06%, the implementation of Value Engineering is considered feasible in terms of cost efficiency.

Table 9. Operational cost comparison between option 1 and option 2

Subject	Operational Cost/year (million IDR)		Operational Cost efficiency /year (million IDR)
	Option 1	Option 2	
Electrical Power for Ship	1.443	1.154	289
Vehicles for Port Operations	248	75	174
Energy Monitoring System (EMIS)	13.998	13.718	280
Air Conditioner (AC)	27	10	17
AC Temperature Setting (22-27°C)	3	0	3
Warehouse Lighting System	507	152	355
Office Building Lighting Retrifit	32	13	19
Sub Total	16.258	15.122	1.136
Annual Operating Cost Savings Percentage			7%

Table 10. Summary of LCCA Calculation Results

Item	Criteria	Result	Information
Benefit Cost Ratio	B/C>1	3.33>1	Fit
Net Present Value	NPV>0	26 M>0	Fit
Internal rate of return	IRR>DF	49%>20%	Fit
Payback Period	< Max Payback (10 year)	3 year 11 month	Fit

The operational cost comparison between a conventional shorebase and one implementing green concepts shows that the application of a green shorebase—emphasizing technical innovations and digitalization—can significantly reduce operational expenses. Initiatives such as the use of shore power connections (providing electricity to docked vessels), replacement of port operational vehicles with energy-efficient models, and the implementation of digital energy monitoring systems contributed to total operational savings of approximately Rp1.1 billion or 7% annually. Other technical initiatives, such as optimal AC temperature settings, retrofit of office lighting, and modernization of warehouse lighting systems, also played a role in reducing energy consumption and costs. For example, upgrading the warehouse lighting system alone saved up to Rp355 million per year. This data highlights that the integration of environmentally friendly technologies and energy digitalization not only reduces energy use and carbon emissions but also significantly improves cost efficiency in shorebase operations.Therefore, the implementation of a green shorebase, based on technological and energy management innovations, has proven to be effective in supporting more sustainable and economical operations.

3.4. Research Question 4

The Life-Cycle Cost Analysis (LCCA) method was used to evaluate the cost efficiency of different alternatives based on the Net Present Value (NPV) principle [15]. LCCA estimates the total cost over a project's life cycle—initial costs, replacement, operation and maintenance, residual value, and other relevant costs—converted to present value.

This study developed an economic evaluation model based on LCCA, incorporating environmental benefits. The analysis used three feasibility metrics: Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Internal Rate of Return (IRR) [16].

These results from Table 10 confirm that the green shorebase revitalization project is economically feasible, with a payback period of 3 years and 11 months.

3.5. Research Question 5

The research shows that the implementation of Value Engineering (VE) leads to operational cost savings of 7%, or approximately Rp1.1 billion per year. The LCCA analysis reveals that the return on investment (ROI) for green shorebase improvements in building and non-building facilities can be achieved within 3.926 years (≈ 3 years, 11 months, and 3 days), making the project economically viable.

3.6. Research Question 6

In general, this study aligns with previous research on green concept implementation in various projects—ports, schools, high-rise buildings, industrial facilities, and jetties. Although green concepts often involve higher initial investment, they consistently result in long-term operational savings and improved energy and environmental performance.

This study confirms that the integration of cost control methods such as VE and LCCA, along with policy support, technical factors, and digitalization, is crucial for successfully implementing green infrastructure. It reinforces the importance of synergy between management, technical, and digital aspects in enhancing cost efficiency in green shorebase projects.

4. Conclusions and Recommendations

Based on the findings from the green shorebase project in Tanjung Batu, it is concluded that management, technical, and digitalization factors significantly influence cost performance in Value Engineering (VE)-based projects. Statistically, the technical aspect had the most dominant influence at 58%, followed by management at 20.6%, and digitalization at 20%. The overall green shorebase performance contributed 97% to cost efficiency, indicating a strong link between operational efficiency and cost control. VE implementation successfully reduced operational costs by Rp1,135,948,542, or 7% of the total initial cost, exceeding the standard threshold for efficiency. Moreover, the LCCA analysis found the project to be financially feasible, with a BCR of 3.33, NPV of Rp25,989,577,423, IRR of 49%, and a payback period of 3.926 years, well within the expected lifecycle of the VE items. These findings reinforce that applying VE and LCCA can optimize costs and enhance the feasibility of revitalizing green shorebase projects.

This study can be further developed by applying the green shorebase concept to new shorebase construction projects, rather than just revitalization efforts. This would broaden the scope of green principles from renovation to comprehensive new development. Given the limited adoption of green port concepts in Indonesia, similar research should also be conducted on other types of ports to encourage broader implementation and awareness. Furthermore, the current cost optimization approach is limited to Value Engineering (VE) and Life-Cycle Cost Analysis (LCCA). It is therefore recommended to explore additional methods to enrich the perspective on cost efficiency and sustainability. The findings of this study can also serve as a reference for similar infrastructure projects, encouraging the adoption of VE and LCCA as strategic approaches in cost planning and control for environmentally friendly and sustainable project development.

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