

Optimizing the Application of Conventional RTG Electrification to Increase Efficiency with the Cost Benefit Analysis (CBA) Method

Melky Gloria Samosir ^{1✉}, Marcus Tukan ², Marcy L. Pattiapon ³
(1,2,3) Industrial Engineering Department, Universitas Pattimura, Ambon, Indonesia

Abstract: The operation of diesel-powered Rubber Tyred Gantry (RTG) cranes at PT Pelindo Terminal Petikemas Ambon is associated with several challenges, including high fuel consumption, substantial maintenance costs, and frequent engine failures that disrupt container handling activities. To address these issues, the company plans to convert the conventional RTG into an Electric Rubber Tyred Gantry (E-RTG). This study aimed to evaluate the investment feasibility of the RTG electrification project using the Cost Benefit Analysis method. A quantitative approach was employed using primary data collected through field observations, interviews, and company documentation. The analysis included the identification of investment costs, operating costs, maintenance costs, and economic benefits resulting from the electrification project. Investment feasibility was evaluated using the Net Present Value, Internal Rate of Return, Payback Period, and Cost Benefit Analysis ratio. The results indicate that the electrification project can generate annual operational cost savings of IDR 1,229,334,168, consisting of fuel cost savings of IDR 1,032,486,918 and maintenance cost savings of IDR 196,847,250. The financial evaluation produced a Net Present Value of IDR 1,320,903,256, an Internal Rate of Return of 7.89%, a Payback Period of 5.74 years, and a Cost Benefit Analysis ratio of 1.159 (>1). These findings demonstrate that the RTG electrification project is financially feasible and can significantly improve operational efficiency at the container terminal.

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INTRODUCTION

Container ports play a strategic role in supporting national logistics systems and global supply chains. The operational performance of a container terminal is highly dependent on the reliability of its cargo-handling equipment, as such equipment directly affects productivity, vessel turnaround time, and operational efficiency (Cholidis et al., 2026). One of the primary handling equipment used in container terminals is the Rubber Tyred Gantry (RTG), which is responsible for lifting, transporting, and stacking containers within the container yard. According RTGs play a crucial role in improving loading and unloading efficiency, thereby significantly influencing the overall logistics performance of port operations (Kersey et al., 2022). However, conventional diesel-powered RTGs continue to face several operational challenges, including high fuel consumption, increasing maintenance costs, and frequent engine failures. Similar conditions are observed at PT Pelindo Terminal Petikemas Ambon, where operational records indicate that engine-related failures constitute the most dominant type of equipment breakdown, resulting in increased operational costs and reduced efficiency in container handling activities (Rania et al., 2025).

Several previous studies have investigated the implementation of RTG electrification as an approach to improving port operational efficiency (Temesgen & Bekele, 2025). Dewi et al., (2023) reported that the implementation of Electric Rubber Tyred Gantry (E-RTG) systems reduced operating costs by up to 80.66% compared with conventional diesel-powered RTGs. Shofi'i et al. (2024) demonstrated that the use of electrical power reduced energy costs by approximately 66% and maintenance expenses by 77.67%. In another study, Shofi'i et al., (2024) employed ETAP simulation to evaluate the electrification of container cranes and reported a potential operational cost reduction of 48%. Ramadhana et al., (2025) found that E-RTG implementation not only improved energy efficiency but also significantly reduced carbon emissions while providing a relatively short investment payback period (Setiawan & Prenata, 2024). Despite these findings, most previous studies primarily focused on technical performance, electrical system simulation, or operational cost savings (Alginat Romadhon, 2024). Comprehensive research evaluating the economic feasibility of RTG electrification using a Cost Benefit Analysis (CBA) approach, particularly in container terminals located in Eastern Indonesia such as PT Pelindo Terminal Petikemas Ambon, remains limited. Therefore, further research is required to comprehensively assess the economic viability of RTG electrification as a basis for investment decision-making.

To address these operational challenges, PT Pelindo Terminal Petikemas Ambon plans to implement the electrification of one conventional RTG by replacing its diesel-powered engine with an electrical power system (Achmadi & Khaqiqi, 2020). This initiative is expected to reduce fuel consumption, lower maintenance costs, and improve operational efficiency without compromising equipment reliability, as the RTG is capable of automatically switching back to diesel operation in the event of power interruptions or instability in the electrical supply (Pratama, 2021). Nevertheless, the electrification project requires a substantial initial capital investment, making a comprehensive economic feasibility assessment essential before implementation (Khaqiqi et al., 2024). In this study, the Cost Benefit Analysis (CBA) method is employed using the indicators of Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP) to evaluate whether the anticipated economic benefits outweigh the investment costs throughout the project life cycle (Putra et al., 2025).

The novelty of this study lies in the integration of operational cost comparison and investment feasibility analysis to evaluate the electrification of a conventional RTG at PT Pelindo Terminal Petikemas Ambon. Unlike previous studies that primarily focused on technical performance, electrical system simulation, energy efficiency, or operational cost reduction, this study combines actual operational data of RTGC-03, including diesel fuel consumption, operating hours, container throughput, and maintenance costs, with the estimated electricity consumption, maintenance requirements, and initial investment costs of the proposed E-RTG. These components are integrated into a Cost Benefit Analysis (CBA) framework using Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PP), and CBA ratio to determine whether the operational savings are sufficient to justify the required capital investment. Therefore, the contribution of this study is not only to quantify the potential cost savings from RTG electrification but also to provide an investment-oriented evaluation that can support managerial decision-making for port electrification, particularly in an Eastern Indonesian container terminal context. The findings provide a more comprehensive economic perspective on RTG electrification by linking operational efficiency improvements with long-term investment feasibility (An-Nisa Addawiyah & Suroso, 2025).

RESEARCH METHOD

This study employed a quantitative case study approach to evaluate the economic feasibility of electrifying a conventional Rubber Tyred Gantry (RTG) at PT Pelindo Terminal Petikemas Ambon. The research was conducted from January to April 2026 at PT Pelindo Terminal Petikemas Ambon, located on Yos Sudarso Street No. 1, Ambon, Indonesia. The study focused on a single RTG unit, RTGC-03, planned for electrification by replacing its diesel-powered system with an electric power system. The research was designed to compare the operational costs of the conventional diesel-powered RTG and the proposed electrically powered RTG using the Cost Benefit Analysis (CBA) approach.

Data Sources and Data Collection

Primary and secondary data were collected throughout the study (Dibaba et al., 2022). Primary data were obtained through direct observation and structured interviews with personnel from the Engineering Department of PT Pelindo Terminal Petikemas Ambon. The interviews were conducted to obtain information regarding RTG operating conditions, diesel fuel consumption, operating hours, maintenance activities, electricity requirements, and the planned electrification project. Information regarding the estimated investment and maintenance requirements of the proposed E-RTG was also obtained through discussions with the relevant engineering personnel (Prasetyo et al., 2025).

Secondary data were obtained from company records and technical documents relevant to the operation and electrification of the RTG. These data included monthly and annual maintenance reports, diesel fuel consumption and purchasing records, RTG operational records, and technical documentation related to the proposed electrification of the container handling equipment (Rigsun, 2021). The collected data were reviewed and classified according to their respective analytical purposes, including operational data, energy consumption data, investment cost data, and maintenance cost data.

The operational data consisted of historical diesel fuel consumption, operating hours, and container throughput of RTGC-03. These data were used to establish the operating profile of the conventional RTG and as the basis for estimating the equivalent electricity consumption of the proposed E-RTG. Maintenance records were used to identify the maintenance requirements and costs associated with the conventional RTG, while technical and project documentation was used to identify the equipment and infrastructure required for the proposed electrification system.

Research Variables and Assumptions

The research variables consisted of cost and benefit components. Cost variables included investment costs, project-related costs, operating costs, and maintenance costs associated with the RTG electrification project (Ankel-Peters et al., 2025). Benefit variables represented the economic advantages expected from the implementation of the E-RTG, particularly reductions in energy and maintenance costs. These variables were subsequently used to construct the annual cash flows for the investment feasibility analysis (Dwisetiono & Irianto, 2022).

Several assumptions were established as the basis for the economic feasibility analysis. The diesel fuel price used in the analysis was based on the applicable fuel price during the study period and was used to determine the fuel cost of the conventional RTG. The electricity cost was estimated using the applicable industrial electricity tariff (I-3/TM). The tariff was used as the basis for estimating the operating cost of the proposed E-RTG.

The electricity consumption of the E-RTG was estimated by converting the historical diesel fuel consumption of the conventional RTG into equivalent electrical energy. A conversion factor of 3.68 kWh per liter of diesel was applied to establish the equivalent electrical energy consumption. The estimated electricity consumption was subsequently used to determine the electricity operating cost of the E-RTG.

The investment evaluation was conducted over an assumed project lifetime of 10 years. A discount rate of 4.75% was established as the primary discount rate for the investment feasibility analysis. An additional discount rate scenario was considered to assess the sensitivity of project feasibility to changes in the discount rate. The assumptions were applied consistently throughout the economic evaluation.

Determination of E-RTG Investment Cost

The initial investment cost was determined based on the costs required to implement the proposed RTG electrification system. The investment cost estimation considered the equipment, electrical infrastructure, supporting facilities, installation, and other project-related components required for the conversion from the conventional diesel-powered RTG to the proposed E-RTG system.

The investment cost data were obtained from the available project cost information and technical specifications provided during the data collection process. Each investment component was identified and classified according to its function in the electrification system. The cost of each component was then aggregated to determine the total initial investment required for the project. The resulting total investment cost was subsequently used as the initial capital expenditure in the NPV, IRR, PP, and CBA calculations.

Determination of E-RTG Maintenance Cost

The estimated maintenance cost of the proposed E-RTG was determined based on the maintenance requirements of the electrical equipment and supporting infrastructure included in the electrification system. The maintenance estimation considered the type of equipment, unit maintenance cost, required quantity, and estimated maintenance frequency of each component.

The maintenance components considered in the estimation included the transformer, cable reel and plug, power house, medium-voltage cubicle, and unscheduled maintenance requirements. The maintenance cost for each component was determined based on the available technical and cost information obtained during the data collection process. The annual maintenance cost was then estimated by aggregating the maintenance costs of the individual components according to their respective quantities and maintenance requirements.

The calculation of the estimated maintenance cost can be expressed as:

$$\text{Annual Maintenance Cost} = \sum (\text{Unit Maintenance Cost} \times \text{Quantity} \times \text{Maintenance Frequency}) \quad (1)$$

This approach was used to establish a comparable maintenance cost between the conventional RTG and the proposed E-RTG system.

Data Analysis and Investment Feasibility

Before performing the economic evaluation, the adequacy and consistency of the historical operational and cost data were reviewed to ensure that sufficient information was available for analysis. The collected data were then processed to estimate conventional RTG operating costs, E-RTG electricity costs, maintenance costs, and the economic benefits associated with the electrification project.

The investment feasibility was evaluated using three engineering economic indicators: Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). NPV was used to determine the present value of future project cash flows relative to the initial investment. IRR was used to determine the discount rate at which the NPV of the project becomes zero, while PP was used to determine the period required to recover the initial investment. A project was considered economically feasible when the NPV was greater than zero, the IRR exceeded the applicable discount rate, and the payback period remained within the assumed investment horizon (Pratiwi et al., 2026).

Finally, the overall economic feasibility of the electrification project was assessed using the Cost Benefit Analysis ratio, expressed as:

$$\text{CBA Ratio} = \text{Present Value of Benefits} / \text{Present Value of Costs} \quad (2)$$

A CBA ratio greater than one indicates that the present value of the economic benefits exceeds the present value of the project costs, indicating economic feasibility (Irawan, 2022).

The overall research procedure consisted of identifying the operational problem, collecting operational, technical, and financial data, establishing the research assumptions, estimating the investment and maintenance costs of the proposed E-RTG, estimating the associated operating costs and economic benefits, performing investment feasibility analysis using NPV, IRR, and PP, calculating the CBA ratio, and interpreting the results to support investment decision-making for RTG electrification at PT Pelindo Terminal Petikemas Ambon (Pratama, 2021).

RESULTS AND DISCUSSION

Average fuel consumption of RTGC

The initial stage of the Cost Benefit Analysis (CBA) involved identifying all cost components associated with both the conventional diesel-powered RTG and the planned electric RTG (E-RTG). This analysis was conducted to establish the baseline operating costs before estimating the economic benefits generated by the electrification project. The primary cost components analyzed included diesel fuel consumption, operational hours, and equipment productivity. These variables were subsequently used to estimate potential energy cost savings after the implementation of the electrification system.

Table 1 presents the historical diesel fuel consumption of RTGC-03 during 2025. Fuel purchases were recorded in two procurement periods each month, reflecting fluctuations in diesel prices throughout the year. Consequently, the annual operating cost was influenced not only by the amount of fuel consumed but also by variations in fuel prices.

Table 1. Average Diesel Fuel Consumption of RTGC-03 in 2025

Month	Period 1			Period 2			Total Volume (L)	Total Cost (Rp)
	Volume (L)	Price/L (IDR)	Fuel Cost (IDR)	Volume (L)	Price/L (IDR)	Fuel Cost (IDR)		
January	2.842	19.103	54.290.726	4.150	19.000	78.850.000	6.992	133.140.726
February	2.669	19.470	51.965.430	3.202	19.229	61.571.258	5.871	113.536.688
March	2.325	19.430	45.174.750	2.674	19.269	51.525.306	4.999	96.700.056
April	2.171	19.187	41.654.977	3.773	19.229	72.551.017	5.944	114.205.994
May	3.437	18.651	64.103.487	2.268	18.400	41.731.200	5.705	105.834.687
June	2.381	17.457	41.565.117	2.757	17.399	47.969.043	5.138	89.534.160
July	2.842	17.631	50.107.302	3.206	18.651	59.795.106	6.048	109.902.408
August	2.656	17.825	47.343.200	3.146	17.787	55.957.902	5.802	103.301.102
September	2.625	17.709	46.486.125	3.726	17.864	66.561.264	6.351	113.047.389
October	3.347	17.709	59.272.023	3.682	19.942	73.426.444	7.029	132.698.467
November	2.947	17.787	52.418.289	3.870	17.942	69.435.540	6.817	121.853.829
December	2.515	17.903	45.026.045	2.789	17.593	49.066.877	5.304	94.092.922
Average							6.000	110.654.036
Total							72.000	1.327.848.428

Based on Table 1, the RTGC-03 consumed a total of 72,000 liters of diesel fuel during 2025, resulting in an annual fuel expenditure of IDR 1,327,848,428, with an average monthly operating cost of approximately IDR 110,654,036. The highest fuel expenditure occurred in January, while the lowest was recorded in June, indicating variations in equipment utilization and fuel prices throughout the year. These findings demonstrate that fuel consumption constitutes one of the largest operational cost components of the conventional RTG system. Therefore, replacing diesel with electricity has the potential to significantly reduce operating expenses and improve the economic performance of container handling operations.

To further evaluate the operational efficiency of the RTG, fuel consumption was analyzed in relation to operating hours and container handling productivity. This comparison provides a more representative measure of equipment performance because it considers the intensity of RTG utilization rather than only the total monthly fuel consumption.

Table 2. Average Operating Hours and Fuel Consumption of RTGC-03 in 2025

Month	Operating Hours/Month	Total Fuel Volume (L)	Fuel Consumption (L/Hour)	Fuel Price/L (IDR)	Fuel Cost/Hour (IDR)	Container Throughput (Boxes)	Fuel Consumption (L/Box)
January	483	6992	14,47619048	19.000	275.047,619	3.772	1,853658537
February	458,5	5871	12,80479826	19.229	246.223,4656	4.227	1,388928318
March	379	4999	13,18997361	19.269	254.157,6016	4.082	1,224644782
April	411	5944	14,4622871	19.229	278.095,3187	3.723	1,596561912
May	426	5705	13,39201878	18.400	246.413,1455	4.500	1,267777778
June	376,5	5138	13,64674635	17.399	237.439,7397	4.276	1,201590271
July	475,5	6048	12,7192429	18.651	237.226,5994	5.687	1,063478108
August	468,5	5802	12,38420491	17.787	220.277,8527	5.644	1,02799433
September	468,5	6351	13,55602988	17.864	242.164,9178	5.644	1,125265769
October	456,5	7029	15,39759036	19.942	307.058,747	5.727	1,227344159
November	507,5	6817	13,43251232	17.942	241.006,136	6.697	1,017918471
December	384	5304	13,8125	17.593	243.003,3125	4.587	1,156311315

Average	441,2083333	6000	13,60617458	252.342,8713	4.881	1
Total	5.294,5				58.566	

As shown in Table 2, the RTGC-03 operated for a total of 5,294.5 hours during 2025, with an average monthly operating time of 441.21 hours. The equipment consumed an average of 13.61 liters of diesel per operating hour, corresponding to an average fuel cost of approximately IDR 252,342.87 per hour. During the same period, the RTG handled 58,566 containers, averaging 4,881 containers per month. The analysis also indicates that approximately one liter of diesel fuel was required to handle one container, highlighting the strong relationship between fuel consumption and equipment productivity.

These results indicate that fuel expenses represent a significant proportion of RTG operating costs. Since fuel consumption increases proportionally with operating hours and container throughput, improvements in energy efficiency can directly reduce operating expenditures. Consequently, the electrification of the RTG is expected to generate substantial economic benefits through lower energy costs while maintaining the same level of operational productivity. The quantified fuel consumption presented in this section serves as the baseline for estimating the cost savings and investment feasibility discussed in the subsequent sections.

Maintenance Cost Analysis of the Conventional RTG

Maintenance costs constitute one of the major operational expenditures of conventional diesel-powered RTGs because the equipment requires periodic servicing to maintain reliability and prevent unexpected failures during container handling operations. At PT Pelindo Terminal Petikemas Ambon, RTGC-03 was maintained through preventive, predictive, corrective, and breakdown maintenance strategies, with preventive maintenance being performed routinely according to predefined operating-hour intervals. Each maintenance interval involved different replacement activities depending on component service life, making maintenance scheduling an important factor in determining the overall operating cost of the RTG.

Table 3. Preventive Maintenance Schedule of RTGC-03

No	Material	Quantity	50 Hrs	250 Hrs	500 Hrs	1000 Hrs	2000 Hrs	6000 Hrs
1	Engine Oil Filter	2	R	R	R	R	R	R
2	Oil Filter By Pass	1	R	R	R	R	R	R
3	Water Separator	1	Drain	R	R	R	R	R
4	Fuel Filter	1		R	R	R	R	R
5	Brake Oil Filter	1			R	R	R	R
6	Servo Filter	1			R	R	R	R
7	Fine Filter Hydraulic	1	R		R	R	R	R
8	Transmisi Filter	2	R			R	R	R
9	Coolant Filter	1				R	R	R
10	Breather Brake Filter	1					R	R
11	Breather Hyd. Filter	1				R	R	R
12	Hydraulic Oil Filter	2				R	R	R
13	Return Filter Hydraulic	2				R	R	R
14	O-Ring Return Filter	2				R	R	R
15	Air Filter Outer	1				R	R	R

16	Air Filter Inner	1		R	R
17	Fresh Filter AC	1	R	R	R
18	Gasket Baut Tap	1	R	R	R

Table 3 shows that preventive maintenance was divided into six operating-hour intervals (50, 250, 500, 1,000, 2,000, and 6,000 hours), with the scope of maintenance becoming increasingly comprehensive as equipment operating hours increased. Early maintenance intervals mainly focused on lubrication and fuel filtration systems, whereas higher intervals included hydraulic, cooling, transmission, and air filtration components. At the 2,000-hour and 6,000-hour intervals, nearly all critical components required replacement to maintain equipment reliability and minimize the risk of operational breakdowns, indicating that maintenance requirements and associated costs increase as equipment utilization accumulates.

Routine maintenance costs were subsequently estimated based on the replacement frequency of consumable materials and spare parts specified in the preventive maintenance schedule. This calculation provides an estimate of the annual maintenance expenditure required to maintain RTGC-03 under normal operating conditions and serves as one of the principal cost components considered in the Cost Benefit Analysis.

Table 4. Routine Preventive Maintenance Cost of RTGC-03

Maintenance Item	Specification	Unit	Quantity	Equipment Unit	Frequency	Total Quantity	Unit Price (IDR)	Total Cost (IDR)
Engine Oil	Rimula R4 14W-40 / Meditran SX	L	40	1	36	1,440	33,455	48,175,200
Engine Oil Filter	LF9009	pcs	1	1	36	36	720,720	25,945,920
Fuel Filter	FS1212	pcs	2	1	36	72	232,947	16,772,184
Fuel Water Separator Filter	Racor PN2020	pcs	1	1	36	36	238,095	8,571,420
Air Filter (Outer)	891 MA (Outer)	pcs	1	1	4	4	1,930,500	7,722,000
Air Filter (Inner)	892 MA (Inner)	pcs	1	1	4	4	1,930,500	7,722,000
Grease	Gadus S2OG 200 / Grease WR-NR	kg	30	1	3	90	82,727	7,445,430
V-Belt	PN178691	pcs	1	1	3	3	1,500,000	4,500,000
Total							6.668.944	126.854.154

Based on Table 4, the estimated annual routine maintenance cost reached IDR 126,854,154, with engine oil representing the largest expenditure due to its high consumption and replacement frequency, followed by engine oil filters and fuel filtration components. These findings indicate that routine maintenance contributes substantially to the operating cost of the conventional RTG, primarily because numerous engine-related components require periodic replacement throughout the equipment's service life.

To determine the actual maintenance expenditure incurred during the study period, maintenance costs were calculated using the recorded operating hours of RTGC-03 throughout 2025. This analysis

combines labor costs and spare-part replacement costs to provide a more realistic representation of the annual maintenance expenses associated with conventional RTG operations.

Table 5. Annual Maintenance Cost of RTGC-03 in 2025

Month	Jasa (Rp)	Hourmeter (Hour)	Spare Part	Total (Rp)
January	26.921.000	483	-	26.921.000
February	26.921.000	458,5	-	26.921.000
March	26.921.000	379	3.198.250	30.119.250
April	26.921.000	411	3.143.500	30.064.500
May	26.921.000	426	12.034.000	38.955.000
June	26.921.000	376,5	3.508.500	30.429.500
July	26.921.000	475,5	3.068.500	29.989.500
August	26.921.000	468,5	3.068.500	29.989.500
September	26.921.000	468,5	3.068.500	29.989.500
October	26.921.000	456,5	3.068.500	29.989.500
November	26.921.000	507,5	3.068.500	29.989.500
December	26.921.000	384	3.068.500	29.989.500
Total	323.052.000	5.294,5		363.347.250

Table 5 indicates that RTGC-03 accumulated 5,294.5 operating hours during 2025, resulting in a total annual maintenance cost of IDR 363,347,250. Monthly maintenance expenditures varied depending on the scheduled maintenance interval and the corresponding spare-part replacement requirements, while labor costs remained relatively constant throughout the year. These results confirm that maintenance represents a significant component of total RTG operating costs and provide a baseline for quantifying the maintenance cost savings expected from the proposed RTG electrification project.

Initial Investment Cost Estimation for RTG Electrification

The implementation of RTG electrification required a substantial initial investment covering project preparation, electrical infrastructure, electrification components, and engineering consultancy services. These investment costs were estimated based on the technical specifications and implementation plan provided by PT Pelindo Terminal Petikemas Ambon. Estimating the initial investment was essential because it represents the largest capital expenditure in the Cost Benefit Analysis (CBA) and directly influences the project's economic feasibility.

Table 6. Initial Investment Cost for RTG Electrification

No.	Work Item	Qty.	Unit	Unit Price (IDR)	Total Cost (IDR)
1	Administration and Documentation	1	LS	20.863.964	20.863.964
	Site Office Provision	1	LS	42.500.000	42.500.000
	Water and Electricity Supply	1	LS	7.875.000	7.875.000
	Occupational Safety Equipment	1	LS	14.515.000	14.515.000
	All-Risk Insurance	1	LS	52.500.000	52.500.000
2	Procurement and Installation of Cable Track				
	Facilities, Power Station, and Electrical				
	Distribution Network				
	Civil Works	1	LS	650.000.000	650.000.000
	40-Foot Power House Complete with In-Out	1	UN	1.087.500.000	1.087.500.000
	Cubicle and Transformers				

	20-Foot Power House (220 V) Complete with Transformers	1	UN	750.000.000	750.000.000
	Main Power Distribution Cable	820	M	550.000	451.000.000
	Junction Box Distribution Cable	290	M	550.000	159.500.000
	Cubicle System Including ATS	1	UN	550.000.000	550.000.000
	CRS Cable	300	Meter	800.000	240.000.000
	Anchor Drum	1	UN	65.000.000	65.000.000
	Electrical Installation Network	1	LS	175.000.000	175.000.000
3.	Procurement and Installation of Electrification Components				
	Gantry Cable Reel System				
	Motor Gear				
	Drum				
	Control Panel and Inverter				
	Plug	1	Set	2.371.246.036	2.371.246.036
	Installation				
	Bracket				
	Auto Gantry Steering System (AGSS) D-GPS Module				
4	Consulting Services				
	Engineering Design Consultant			287.500.000	762.500.000
	Supervision Consultant			475.000.000	
	Subtotal				7.400.000.000
	Value Added Tax (VAT) 12%				888.000.000
	Total Investment Cost				8.288.000.000

As shown in Table 6, the estimated investment cost for electrifying RTGC-03 amounted to IDR 7,400,000,000, excluding value-added tax (VAT). After including the 12% VAT, the total project investment increased to IDR 8,288,000,000. The largest investment component was the procurement and installation of the electrification system, particularly the gantry cable reel system and supporting electrical infrastructure, including power houses, transformers, distribution cables, and automatic transfer equipment. These components accounted for the majority of the capital expenditure because they constitute the primary infrastructure required to replace the conventional diesel-powered system with an electric power supply. This initial investment served as the basis for evaluating the project's financial feasibility using NPV, IRR, PP, and the Cost Benefit Analysis ratio.

Estimated Electricity Consumption of the Electric RTG (E-RTG)

Following the estimation of the initial investment cost, the operational electricity consumption of the Electric RTG (E-RTG) was estimated to determine the expected annual energy expenditure after electrification. The calculation was performed by converting historical diesel fuel consumption into equivalent electrical energy using a conversion factor of 3.68 kWh per liter of diesel fuel. Electricity costs were then estimated using the PLN industrial electricity tariff (I-3/TM), enabling a direct comparison between diesel fuel costs and electricity costs under equivalent operating conditions.

Table 7. Estimated Annual Electricity Cost of E-RTG

Month	Total Fuel Volume (L)	Conversion Factor (kWh/L)	Total Energy (kWh)	Container Throughput (Boxes)	Tarif/kWh (I-3/TM) (IDR/kWh)	Total Cost (IDR)	Energy Consumption per Box (kWh/Box)
January	6.992	3,68	25.730,56	3.772	1.114,74	28.682.884,45	6,821463415
February	5.871	3,68	21.605,28	4.227	1.114,74	24.084.269,83	5,11125621
March	4.999	3,68	18.396,32	4.082	1.114,74	20.507.113,76	4,506692798
April	5.944	3,68	21.873,92	3.723	1.114,74	24.383.733,58	5,875347838
May	5.705	3,68	20.994,4	4.500	1.114,74	23.403.297,46	4,665422222
June	5.138	3,68	18.907,84	4.276	1.114,74	21.077.325,56	4,421852198
July	6.048	3,68	22.256,64	5.687	1.114,74	24.810.366,87	3,913599437
August	5.802	3,68	21.351,36	5.644	1.114,74	23.801.215,05	3,783019135
September	6.351	3,68	23.371,68	5.644	1.114,74	26.053.346,56	4,14097803
October	7.029	3,68	25.866,72	5.727	1.114,74	28.834.667,45	4,516626506
November	6.817	3,68	25.086,56	6.697	1.114,74	27.964.991,89	3,745939973
December	5.304	3,68	19.518,72	4.587	1.114,74	21.758.297,93	4,255225638
Average			22.080				4,64645195
Total						295.361.510,4	

Table 7 indicates that the estimated annual electricity consumption of the E-RTG reached 22,080 kWh per month on average, with an annual electricity expenditure of approximately IDR 295,361,510.40 based on the industrial electricity tariff of IDR 1,114.74 per kWh. Compared with the annual diesel fuel expenditure of the conventional RTG, the projected electricity cost is substantially lower, indicating considerable potential for reducing operational energy expenses. These results demonstrate that electrification can significantly improve energy efficiency while maintaining the same operational capacity, making electricity cost savings one of the primary economic benefits considered in the investment feasibility analysis.

Estimated Maintenance Cost of the Electric RTG (E-RTG)

In addition to reducing energy costs, RTG electrification is expected to decrease maintenance expenses because electric drive systems require fewer mechanical and engine-related components than conventional diesel-powered RTGs. The estimated maintenance cost was therefore calculated by considering the routine maintenance requirements of the electrical infrastructure and supporting equipment, including transformers, cable reels, power houses, distribution cubicles, and contingency maintenance.

Table 8. Estimated Annual Maintenance Cost of the Electric RTG

Maintenance Item	Unit Cost (IDR)	Quantity	Total Cost (IDR)
Transformer	75,000,000	1	75,000,000
Cable Reel & Plug	25,000,000	1	25,000,000
Power House	32,500,000	1	32,500,000
MV Cubicle (Distribution Room)	2,000,000	1	2,000,000
MV Cubicle (RTG)	2,000,000	1	2,000,000
Unscheduled Maintenance Cost	2,500,000	12	30,000,000
TOTAL			166.500.000

Based on Table 8, the estimated annual maintenance cost of the Electric RTG was IDR 166,500,000, which mainly consisted of transformer maintenance, cable reel and plug inspection,

power house maintenance, medium-voltage cubicle servicing, and contingency maintenance. Compared with the maintenance cost of the conventional RTG, the electrified system requires significantly lower maintenance expenditure because it eliminates many engine-related components that require periodic servicing and replacement. This reduction in maintenance requirements represents an additional economic benefit of the electrification project and contributes to improving the overall financial feasibility evaluated through the Cost Benefit Analysis.

Benefit Identification

Following the estimation of the operating costs for both the conventional RTG and the Electric RTG (E-RTG), the economic benefits resulting from the electrification project were identified and quantified. The benefits were calculated by comparing the annual operating expenses of the diesel-powered RTG with those of the electrified system. The analysis focused on two primary benefit components, namely energy cost savings and maintenance cost savings, which represent the direct operational advantages expected after the implementation of RTG electrification.

Table 9. Identification of Economic Benefits from RTG Electrification

Benefit Identification	Amount (IDR)	Percentage (%)
Fuel Cost Savings (Diesel vs. Electricity)	1,032,486,918	77.76%
Maintenance Cost Savings (Conventional RTG vs. E-RTG)	196,847,250	54.18%
Total Operational Benefits	1,229,334,168	-

Table 9 shows that the implementation of RTG electrification is expected to generate total annual operational benefits of IDR 1,229,334,168. The largest contribution originated from energy cost savings, amounting to IDR 1,032,486,918, representing an efficiency improvement of 77.76% compared with the annual diesel fuel expenditure. In addition, maintenance costs were projected to decrease by IDR 196,847,250, equivalent to a 54.18% reduction relative to the conventional RTG. These findings indicate that energy savings constitute the primary economic benefit of the electrification project, while the reduction in maintenance costs provides additional long-term financial advantages. The quantified benefits presented in this section were subsequently used as the annual cash inflows in the investment feasibility analysis using the Cost Benefit Analysis (CBA), Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP) methods.

Investment Feasibility Analysis

The economic feasibility of the RTG electrification project was evaluated using three investment appraisal indicators, namely Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). These indicators were selected because they comprehensively assess the project's profitability, investment return, and capital recovery period. The analysis was performed using the estimated initial investment cost and the annual operational benefits obtained from fuel and maintenance cost savings.

Net Present Value (NPV)

The Net Present Value was calculated using the following equation:

$$NPV = \sum_{t=1}^n \frac{Benefit}{(1+i)^t} - Investasi\ Awal$$

where i represents the discount rate and t denotes the project year. The analysis assumed an initial investment of IDR 8,288,000,000 and an annual net cash inflow of IDR 1,229,334,168, consisting of fuel cost savings and maintenance cost savings. Two discount rate scenarios were evaluated to assess the project's financial robustness.

Table 10. Net Present Value Using a 4.75% Discount Rate

Year	$(1 + i)^t$	Annual Benefit (IDR)	Present Value (IDR)
Year 1	1,0475	1.229.334.168	1.173.588.705
Year 2	1,09725625	1.229.334.168	1.120.371.078
Year 3	1,149375922	1.229.334.168	1.069.566.662
Year 4	1,203971278	1.229.334.168	1.021.066.026
Year 5	1,261159914	1.229.334.168	974.764.702,3
Year 6	1,32106501	1.229.334.168	930.562.961,6
Year 7	1,383815598	1.229.334.168	888.365.595,8
Year 8	1,449546839	1.229.334.168	848.081.714,4
Year 9	1,518400313	1.229.334.168	809.624.548,3
Year 10	1,590524328	1.229.334.168	772.911.263,3
TOTAL			9.608.903.256

Based on Table 10, the total present value of the projected benefits over the ten-year project life reached IDR 9,608,903,256, resulting in an NPV of IDR 1,320,903,256. Since the NPV is positive, the projected benefits exceed the initial investment, indicating that the RTG electrification project is economically feasible under the 4.75% discount rate. This result suggests that the investment is capable of generating additional economic value beyond the required capital expenditure.

To evaluate the project's sensitivity to a higher financing cost, a second NPV analysis was conducted using a 12% discount rate, which incorporated the prevailing interest rate, administrative costs, project implementation risk, and depreciation considerations.

Table 11. Net Present Value Using a 12% Discount Rate

Year	$(1 + i)^t$	Annual Benefit (IDR)	Present Value (IDR)
Year 1	1,12	1.229.334.168	1.097.619.793
Year 2	1,2544	1.229.334.168	980.017.672,2
Year 3	1,404928	1.229.334.168	875.015.778,7
Year 4	1,57351936	1.229.334.168	781.264.088,2
Year 5	1,762341683	1.229.334.168	697.557.221,6
Year 6	1,973822685	1.229.334.168	622.818.947,8
Year 7	2,210681407	1.229.334.168	556.088.346,3
Year 8	2,475963176	1.229.334.168	496.507.452
Year 9	2,773078757	1.229.334.168	443.310.225
Year 10	3,105848208	1.229.334.168	395.812.700,9
TOTAL			6.946.012.226

The results in Table 11 show that the present value of future cash inflows decreased substantially as the discount rate increased. This finding demonstrates that the project's economic value is highly influenced by the cost of capital, emphasizing the importance of selecting an appropriate financing strategy when implementing large-scale infrastructure investments.

To determine the break-even discount rate, an additional NPV analysis was conducted by adjusting the discount rate until the NPV approached zero.

Table 12. NPV at the Break-Even Discount Rate

Year	$(1 + i)^t$	Annual Benefit (IDR)	Present Value (IDR)
Year 1	1,07895	1.229.334.168	1.139.380.108
Year 2	1,164133103	1.229.334.168	1.056.008.257
Year 3	1,256041411	1.229.334.168	978.736.972,6
Year 4	1,35520588	1.229.334.168	907.119.859,7
Year 5	1,462199385	1.229.334.168	840.743.185,2
Year 6	1,577640026	1.229.334.168	779.223.490,6
Year 7	1,702194706	1.229.334.168	722.205.376,2
Year 8	1,836582978	1.229.334.168	669.359.447,8
Year 9	1,981581204	1.229.334.168	620.380.414,1
Year 10	2,13802704	1.229.334.168	574.985.322,8
Total			8.288.142.434
NPV			142.434

As shown in Table 12, the project generated an NPV of approximately IDR 142,434 at a discount rate of 7.895%, indicating that the investment reached its financial break-even point while still maintaining a slightly positive economic value. This result implies that the RTG electrification project remains financially acceptable as long as the applicable discount rate does not exceed approximately 7.9%, providing an indication of the project's financial resilience under changing economic conditions.

Internal Rate of Return (IRR)

The Internal Rate of Return was calculated using the following equation:

$$IRR = I_1 \frac{NPV^{(+)} }{NPV^{(+)} - NPV^{(-)}} (I_2 - I_1) \quad (3)$$

where I_1 and I_2 represent the lower and upper discount rates used in the interpolation process. The IRR analysis was performed using the positive NPV obtained at the 4.75% discount rate and the negative NPV generated at the 12% discount rate.

The calculation produced an Internal Rate of Return (IRR) of approximately 7.89%, indicating that the project is capable of generating an annual return exceeding the applicable discount rate of 4.75%. The IRR is consistent with the break-even discount rate of approximately 7.89%, at which the NPV approaches zero. Since the IRR exceeds the benchmark discount rate, the RTG electrification project can be considered financially feasible. Since the IRR is higher than the benchmark discount rate used for investment evaluation, the electrification project can be considered financially feasible. Furthermore, the obtained IRR demonstrates that the investment has sufficient profitability to recover the initial capital while generating additional economic returns throughout the project lifetime.

Payback Period (PP)

The Payback Period was calculated using the following equation:

$$PP = \frac{\text{Investasi awal}}{\text{Arus kas tahunan}} \quad (4)$$

The payback analysis was conducted to estimate the amount of time required for the cumulative project benefits to recover the initial investment cost.

Table 13. Payback Period Analysis

Year	Investment Balance (IDR)	Annual Cash Flow (IDR)	Cumulative Balance (IDR)
Year 0	-8.288.000.000	0	-8.288.000.000
Year 1	-7.058.665.832	1.229.334.168	-5.829.331.664
Year 2	-5.829.331.664	1.229.334.168	-4.599.997.496
Year 3	-4.599.997.496	1.229.334.168	-3.370.663.328
Year 4	-3.370.663.328	1.229.334.168	-2.141.329.160
Year 5	-2.141.329.160	1.229.334.168	-911.994.992
Year 6	-911.994.992	1.229.334.168	317.339.176
Year 7	317.339.176	1.229.334.168	1.546.673.344

The results indicate that the RTG electrification project requires approximately 5.74 years to recover the initial investment, equivalent to approximately 5 years and 9 months. The cumulative balance becomes positive during the sixth year, confirming that the initial investment is recovered between the fifth and sixth years. After the payback period is reached, the project is expected to generate a positive annual cash inflow of approximately IDR 1,229,334,168, contributing to long-term operational cost reduction.

Cost-Benefit Analysis (CBA)

The final stage of this study involved evaluating the overall economic feasibility of the RTG electrification project using the Cost-Benefit Analysis (CBA) approach. This analysis integrates the investment cost, project lifetime, discount rate, and the investment appraisal indicators obtained from the previous analyses, namely Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). The objective of the CBA was to determine whether the cumulative economic benefits generated throughout the project life exceeded the total investment cost.

Table 14. Investment Parameters Used in the Cost-Benefit Analysis

Investment Parameter	Value
Initial Investment	IDR 8,288,000,000
Discount Rate	4.75%
Project Lifetime	10 Years

Table 15. Summary of Investment Feasibility Analysis

CBA Analysis Parameter	Result
Net Present Value (NPV)	IDR 1,320,903,256
Internal Rate of Return (IRR)	7.89%
Payback Period (PP)	5.74 Years

The Cost-Benefit Analysis (CBA) ratio was calculated using the following equation:

CBA = Benefit / Cost

CBA = 9,608,903,256 / 8,288,000,000 = 1.159

Based on Tables 14 and 15, the RTG electrification project generated an estimated annual operational benefit of IDR 1,229,334,168, primarily derived from reductions in diesel fuel consumption and maintenance costs. Over the assumed 10-year project lifetime, the cumulative present value of these benefits reached IDR 9,608,903,256, while the total initial investment amounted to IDR 8,288,000,000. Consequently, the project produced a Cost-Benefit Analysis ratio of 1.159, indicating that every IDR 1.00 invested is expected to generate approximately IDR 1.16 in economic benefits over the project life. The project also produced a positive NPV of IDR 1,320,903,256, an IRR of approximately 7.89%, and a Payback Period of approximately 5.74 years. Since the CBA ratio is greater than one, the project can be considered economically feasible.

Discussion

The economic benefits identified in this study indicate that energy cost reduction is the primary financial driver of RTG electrification at PT Pelindo Terminal Petikemas Ambon. The estimated annual fuel cost savings of IDR 1,032,486,918 are substantially higher than the maintenance cost savings of IDR 196,847,250, indicating that the transition from diesel fuel to electricity provides the largest direct contribution to the project's economic benefits. This finding is consistent with Dewi et al. (2023), who reported that E-RTG implementation can substantially reduce operating costs compared with conventional diesel-powered RTGs. It is also in line with Shofi'i et al. (2024), who found that electrical operation can reduce energy and maintenance costs. However, the present study extends these findings by translating the identified operational savings into an investment feasibility assessment rather than evaluating cost reduction alone. The result therefore suggests that the economic advantage of electrification is not merely associated with lower day-to-day operating expenses but also has a direct effect on the project's ability to recover its initial capital investment.

The investment feasibility results provide an important indication of the financial attractiveness of the proposed electrification project. The positive NPV of IDR 1,320,903,256 indicates that the present value of the expected project benefits exceeds the initial investment of IDR 8,288,000,000 when evaluated at a 4.75% discount rate. Meanwhile, the IRR of 7.89% is higher than the benchmark discount rate, indicating that the project generates a return above the minimum rate used in the feasibility assessment. The Payback Period of 5.74 years also indicates that the initial capital expenditure can be recovered before the end of the assumed 10-year project lifetime. More importantly, the CBA ratio of 1.159 indicates that the present value of benefits is approximately 1.16 times the investment cost. Taken together, these indicators show that the electrification project is not only capable of reducing operating costs but also has sufficient economic benefits to justify the required capital expenditure. This finding strengthens the investment case for E-RTG implementation because the decision is supported simultaneously by profitability, capital recovery, and benefit-to-cost considerations.

Compared with previous studies, the findings of this research confirm that RTG electrification can provide substantial operational and economic benefits. Dewi et al. (2023) reported an operating cost reduction of up to 80.66% following E-RTG implementation, while Shofi'i et al. (2024) reported reductions in energy costs and maintenance expenses of approximately 66% and 77.67%, respectively. The present study similarly demonstrates substantial savings, with fuel costs decreasing by IDR 1,032,486,918 annually and maintenance costs decreasing by IDR 196,847,250. Although the magnitude of savings cannot be directly compared because the operating conditions, electricity tariffs,

equipment characteristics, and cost structures differ between studies, the overall direction of the findings is consistent with previous research. The main difference is that the present study goes beyond operational efficiency evaluation by integrating the savings into a comprehensive investment feasibility framework using NPV, IRR, Payback Period, and CBA. This approach provides a stronger basis for investment decision-making because it evaluates not only whether electrification reduces operating costs, but also whether the resulting economic benefits are sufficient to justify the initial investment over the project lifetime.

The contribution of this study is therefore reflected in the integration of operational evidence and investment analysis within a single evaluation framework. Previous research has demonstrated the technical and operational advantages of RTG electrification, whereas this study connects these operational improvements with the financial consequences of a real investment decision at a container terminal in Eastern Indonesia. The results indicate that the feasibility of E-RTG implementation is primarily driven by the substantial reduction in energy expenditure, while lower maintenance requirements provide an additional financial benefit. From a managerial perspective, this finding suggests that electrification should be evaluated not only as an equipment modernization initiative but also as a long-term capital investment whose feasibility depends on the relationship between initial investment, recurring savings, and project lifetime. Therefore, the proposed CBA framework can serve as a practical basis for evaluating similar RTG electrification projects before wider implementation.

CONCLUSION

This study demonstrates that converting the conventional diesel-powered RTG at PT Pelindo Terminal Petikemas Ambon into an Electric Rubber Tyred Gantry (E-RTG) is economically feasible. The electrification is estimated to generate annual operational benefits of IDR 1,229,334,168, mainly from reductions in fuel and maintenance costs. The investment analysis resulted in a positive NPV of IDR 1,320,903,256, an IRR of 7.89%, a Payback Period of 5.74 years, and a CBA ratio of 1.159, indicating that the project can recover its initial investment within the 10-year project lifetime and generate additional economic value.

These findings indicate that RTG electrification can improve operational cost efficiency while providing a financially viable investment option for port operations. The results therefore provide a quantitative basis for PT Pelindo Terminal Petikemas Ambon to consider RTG electrification as a long-term investment decision. However, the findings are based on a single RTG unit and relatively stable operational and economic assumptions; therefore, further evaluation involving multiple RTG units and varying energy and fuel price conditions is recommended.

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