Vol 1 No 8 2024 || E-ISSN 2997-7258

The Journal of Academic Science

journal homepage:
https://thejoas.com/index.php/

Impact Analysis Study of Port Main Equipment Electrification Efforts on Emission Reduction at the Port: Case Study of Tanjung Priok Port

Nosep Kristoro[1], **Abdu Fadli Assomadi**[2*]
Institut Teknologi Sepuluh Nopember Surabaya[1,2]
Email: emailnosepkristoro@gmail.com[1], assomadi@its.ac.id[2*]

KEYWORDS
electrification, port main equipment, emission reduction

ABSTRACT
In order to decarbonize and support the achievement of emission reduction targets at Tanjung Priok Port, while mitigating the negative environmental impacts of port operations, the port has considered implementing the electrification of its main equipment. This study aims to analyze how the electrification of main equipment at Tanjung Priok Port can contribute to the reduction of greenhouse gas (GHG) emissions and air pollutants. The study involves measuring and analyzing emissions before and after electrification, conducting a technical analysis, and performing an economic/ financial analysis of the electrification implementation. The research methods include literature reviews, data collection on energy consumption at Tanjung Priok Port, and subsequent data analysis. The data analysis consists of emission calculations based on national emission inventory guidelines, a technical assessment of equipment eligible for electrification, and an economic/ financial analysis using the Cost-Benefit Analysis (CBA) method. The findings indicate the potential for significant reductions in GHG emissions, particularly CO_2, through the electrification of main equipment, including GLC, QCC, and RTG cranes at Tanjung Priok Port. Furthermore, the economic/financial analysis demonstrates that crane operational cost efficiency positively impacts the transition from fossil fuel energy sources to electricity. Therefore, this study underscores the potential of electrification as a strategic program for more effective environmental management within the maritime sector.

1. INTRODUCTION

Indonesia is increasingly committed to its climate ambitions in its decarbonization efforts, as reflected in National Contribution or Enhanced Nationally Determined Contribution (NDC) of 31.89% unconditional emission reduction by 2030 and its commitment to achieve zero emissions by 2060. These targets cannot be met without action. In the NDC there are 5 (five) sectors that contribute to reducing greenhouse gas emissions, namely the energy sector, waste, industrial processes and production use (IPPU), agriculture, and forestry. In the Regulation of the Minister of Environment and Forestry number 21 of 2022, for the energy sector it is divided into 3 sub-sectors, namely: power plant, transportation, and building (infrastructure) sub-sectors.

The transportation subsector covers all activities related to the movement of goods and people, including maritime transportation involving ships and port activities. Ports play a vital role in global and domestic logistics chains, where loading and unloading activities, ship operations, and land vehicles in port areas contribute to greenhouse gas emissions from the use of fossil fuels. The use of these fuels is a major source of greenhouse gas (GHG) emissions that have a negative impact on the environment.

The primary sources of greenhouse gas emissions at ports include the operation of diesel engines in cranes, trucks, and ships, as well as the combustion of fossil fuels in various industrial activities surrounding the port. Cranes and trucks powered by diesel engines contribute to CO_2, NOx, and particulate matter (PM) emissions, which have a direct impact on air quality. Additionally, ships at berth that rely on auxiliary engines during loading and unloading operations are also significant sources of greenhouse gas emissions. The use of electricity generated from fossil fuel-based energy sources for port operations contributes to an increase in CO_2 emissions (Smith et al., 2019).

The increased intensification of port equipment usage, where fuel combustion processes occur, generates carbon dioxide (CO_2) and sulfur dioxide (SOx) emissions, contributing to the decline in air quality around port areas (Moeis et al., 2020).

Tanjung Priok Port is the largest and busiest port in Indonesia, which plays a vital role in national and international trade among other ports managed by PT "X" as a Port Business Entity. Tanjung Priok Port handles around 37% of the total cargo volume in container flows handled by PT "X", the rest is spread across 70 (seventy) Port Branches of PT "X". This is a consideration of the focus of the study location where the use of energy used in handling the cargo volume is related to the emissions produced.

In the effort of decarbonization and supporting the achievement of emission reduction targets in the Port, this is done through standardization of port operations, electrification of port equipment, use of renewable energy, and implementation of environmentally friendly technology. The electrification of this equipment is to replace equipment energy sources from fossil fuels to using electrical energy. In addition to significantly reducing greenhouse gas emissions, the use of electrical energy can also increase operational efficiency and reduce fuel costs. However, the implementation of port equipment electrification requires large investments and significant infrastructure changes, so an in-depth study is needed on the impact of these electrification efforts. However, these electrification efforts have not been comprehensively analyzed regarding the impact of the amount of emissions reduced, including baseline emissions as part of the decarbonization roadmap at the Port, which has not been determined by PT "X".

Port equipment electrification refers to the process of replacing port equipment previously powered by fossil fuels with equipment that operates on electricity. This initiative is part of green efforts to reduce greenhouse gas emissions and enhance energy efficiency in port operations. Electrification encompasses various types of equipment, such as cranes, container trucks, and forklifts, which traditionally rely on diesel engines or other fuels that contribute to air pollution. Electrification is also regarded as one of the key strategies in ports' efforts toward environmental sustainability (Smith et al., 2019).

This study is important to measure the magnitude of the impact of emission reductions that can be achieved through the electrification of the main port equipment in Tanjung Priok. This study will analyze changes in emission levels before and after electrification, and evaluate its positive impacts on the environment. In addition, this study will also consider economic and technical aspects, such as investment costs, maintenance, and supporting infrastructure needs.

By conducting this study, it is expected to obtain a comprehensive picture of the benefits and challenges of port equipment electrification. The results of this study will be the basis for formulating more effective policies and strategies in environmental management at ports, as well as providing a positive contribution to achieving sustainable development targets in the maritime sector.

Previous studies by Yang & Chang (2013) reported that a comparative performance analysis between RTG and E-RTG demonstrated significant benefits from transitioning diesel-powered equipment to electric power, including energy savings of up to 86,60% and a reduction in CO_2 emissions by 67,79%. Another study revealed that replacing diesel engines in RTGs with diesel-electric systems at Nanjing Longtan successfully reduced CO_2 and NOx emissions by 68% (Zhang et al., 2017). Meanwhile, research by Geerlings & Van Duin (2011) in Rotterdam indicated that blending diesel with 30% biofuel could reduce CO_2 emissions by 26%.

Furthermore, a study on On-shore Power Supply or Shore-to-Ship connection (Wachjoe et al., 2020) at Tanjung Priok Port demonstrated that utilizing shore-side electrical power for berthed ships effectively reduces pollutant emissions significantly. NOx emissions decreased by 90%, VOC emissions by 87%, and PM emissions by 82% compared to conditions without shore power. Annually, NOx emissions were reduced from 166.8 tons to 9.2 tons, VOC from 5.67 tons to 0.51 tons, and PM from 4.25 tons to 0.59 tons. This approach plays a critical role in supporting green port technologies and environmental sustainability.

2. METHOD

This research framework is designed with the main objective to analyze the impact of electrification of main equipment at Tanjung Priok Port on reducing greenhouse gas (GHG) emissions and increasing operational efficiency. This research is necessary due to the high level of emissions from fossil fuel-powered equipment operating at the port, which significantly contributes to environmental degradation. With the national policy of the Republic of Indonesia through Enhanced Nationally Determined Contribution (NDC) set a 31,89% unconditional emission reduction by 2030 (enhanced nationally determined contribution republic of indonesia 2022, n.d.), electrification of equipment in the port sector can be potential contribution to emission reduction efforts .

The methods outline includes conducting an inventory of equipment at the port, collecting emission data both before and after electrification, and analyzing the data using standard methodologies. The data collection will encompass information related to equipment types, energy consumption, emissions, and cost efficiency, comparing the period before and after electrification.

This research framework explains the steps that will be taken to achieve the research objectives, including research ideas, problem formulation, literature study, data collection, data analysis, and conclusions.

Literature Study

This section includes a literature review on port equipment electrification and its impact on emission reduction. Relevant literature (both research journals, articles, final projects, theses, guidelines, national and international regulations, technical instructions and other sources) are analyzed to understand the theories underlying electrification and emission measurement methods. The literature study was conducted from the beginning of the research to analyzing and discussing the research results to reach conclusions.

The literature study in this research will cover several main topics that support the research:

1) Electrification of Port Equipment

This study will analyze the implementation of electrification in other ports as a benchmark, including the impact on emission reduction and operational efficiency improvement. Reference sources will include international journals, case study reports from other ports that have implemented electrification, and related technical guidelines.

2) Emission Measurement Methods

This review will discuss the emission measurement methodologies used in the study, such as the use of the IPCC Guidelines for GHG emission inventories. The literature used will include: relevant international guidelines, policy documents and technical reports.

3) A Cost-Benefit Analysis:

The research method for Cost Benefit Analysis (CBA) on the port equipment electrification program is carried out with several main stages to evaluate the balance between costs incurred and benefits obtained from the program. The first stage is the identification of costs and benefits, where all cost components related to electrification, such as initial investment for procurement of supporting electrification components, installation costs, operation and maintenance costs, and potential technology update costs, are identified and calculated. On the other hand, the benefits of the program are also calculated, including reduced fuel costs, savings in maintenance costs, potential reductions in greenhouse gas (GHG) emissions, and increased energy efficiency.

Data Collection

The data required for this study were collected through document analysis methods and reports related to the electrification program such as investment feasibility documents, equipment energy usage reports. The data collected include but are not limited to the type and number of equipment, energy consumption data, environmental monitoring reports of Tanjung Priok Port, and factors influencing the implementation of electrification.

The types of data that will be analyzed in this study include:

1) Emission Data

This data includes measurements of GHG emissions from port equipment that still uses fossil fuels before electrification, as well as after electrification. The target of the analysis is to measure how much emission reduction occurs. Emission data is obtained by calculating energy consumption and standard emission factors from national and global references.

Identification of GHG emissions at the Port:

a) Scope 1*:* Direct emissions from sources owned and controlled by the port, namely fuel burned from port equipment and vehicles owned by the port. Fugitive emissions such as refrigerants and others are not included in this scope. The data collected is in the form of fuel usage data from equipment, from the operational report of Tanjung Priok Port for the period 2023.

b) Scope 2*:* Indirect emissions from energy purchased for port-owned facilities and where the port purchases electricity. The data collected is electricity usage data from equipment and buildings, from the operational report of Tanjung Priok Port for the period 2023.

c) Scope 3*:* Indirect emissions from tenants, suppliers and other aspects of the port value chain. Scope 3 emission data is not included in this study considering *the obstacle* of data availability.

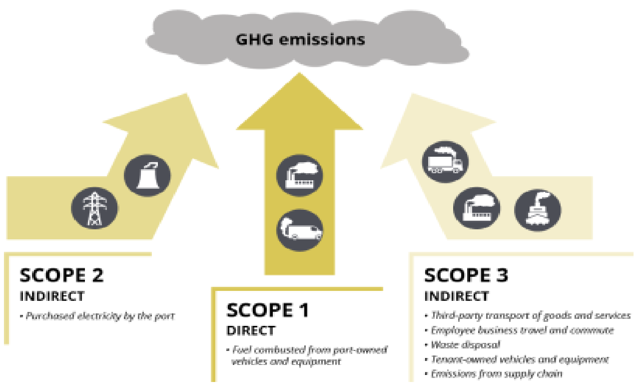

Image of Emission Source Scope at Port
Source: www.portvanusa.com

2) Technical Performance Data

Both fuel-based and electrical port equipment. The target of the analysis is to assess the technical performance of the same type of electrified equipment with similar equipment that still uses fuel. This data was collected from the technical report of Tanjung Priok Port.

3) Economic/ financial data

This data includes operating costs, and potential cost savings from replacing all fossil fuel energy sources with electricity. The target of the analysis is to assess the economic/ financial feasibility of electrification of port equipment. Data are obtained from financial reports or investment proposal documents.

Data Analysis

1) Technical Aspect

The technical aspects of this study will include the identification and classification of port equipment that significantly contributes to emissions. The required data will be prepared by referring to port operational standards and classified based on the type and fuel usage.

In emission calculations, the level of calculation accuracy is associated with the data and methods used, which correspond to Tier 1. This approach estimates emissions based on activity data and the default emission factors provided by the IPCC (as outlined in the National Greenhouse Gas Inventory Guidelines, Book II - Volume 1: Methodology for Calculating Greenhouse Gas Emission Levels for Energy Procurement and Usage Activities, Ministry of Environment, 2012).

2) Economic/ financial Aspect

Economic/financial aspects through cost-benefit analysis (CBA) encompassing operational and maintenance costs, as well as potential savings from emission reductions. CBA methodology for the electrification of port equipment:

a) Operational and Maintenance Costs: Comparing the operational and maintenance costs of electric equipment with those of fossil fuel-based equipment.

b) Potential Savings and Financial Benefits: Calculating savings from energy efficiency and reduced fuel consumption.

3. RESULT AND DISCUSSION

The research was conducted to analyze the impact of the electrification efforts of the main equipment at Tanjung Priok Port on reducing greenhouse gas emissions by analyzing the technical and economic/financial aspects related to the implementation of the electrification. This study consists of: identification /inventory of emission sources scope 1 and 2 at Tanjung Priok Port, emission calculations, technical analysis of electrification, analysis of economic/financial aspects using the *Cost Benefit Analysis method*.

Inventory and Classification of Port Equipment Data

a) Main Equipment: Equipment that is directly involved in the main operational activities at the port, such as loading and unloading goods, tugging ships, or piloting ships.
b) Support Equipment: Equipment used to support logistics and mobilization of goods in the port area, but is not part of the main operation.
c) Non-Equipment Facilities: Supporting facilities that are not directly involved in loading and unloading operations, but are essential to support the sustainability of port activities.

Identification/Inventory of *Scope* 1 and 2 Emissions

In the context of emission inventory, Tanjung Priok Port under the management of the port operator company is included in the energy sector (transportation/ infrastructure subsector) referring to the Guidelines for Implementing the National Greenhouse Gas Inventory, Book II - Volume 1 Methodology for Calculating Greenhouse Gas Emission Levels for Energy Procurement and Use Activities, Ministry of Environment 2012 ("MoE Guidelines, 2012").

Identification of Greenhouse Gas (GHG) emissions at Tanjung Priok Port:

a) Scope 1 (*Scope 1*)

Direct emissions from fuel combustion from port equipment and vehicles owned by Tanjung Priok Port, but this study does not include:

1) fugitive emissions in fuel production and supply activities;
2) emission from CO_2 transport and injection in CO_2 storage activities in geological formations.

The main source of GHG emissions from the energy sector is fuel combustion. Fugitive emissions from fuel production and distribution activities as a whole are much smaller than emissions from fuel combustion (KLH Guidelines, 2012).

b) Scope 2*:* Indirect emissions from energy purchased for facilities owned by the port and where the port purchases electricity.

Scope 1 emission sources at Tanjung Priok Port:

Table 1 Types of Equipment Based on Scope 1 Emissions at Tanjung Priok Port

No	TYPE OF EQUIPMENT	NUMBER OF EQUIPMENT	FUEL CONSUMPTION AMOUNT IN 2023 (LITER)
A	**MAIN EQUIPMENT**	**145**	**15,219,527.67**
1	Empty Container Handler	2	26,373.97
2	Gantry Luffing Crane (GLC)	2	45,500.00
3	Hybrid RTG	5	304,783.12
4	Pilot Ship	8	359,819.00

5	Tugboat	20	6,862,510.00
6	Quay Container Crane (QCC)	3	308,468.00
7	Rubber Tyre Gantry (RTG)	102	7,310,956.58
8	Tug Master	3	1,117.00
B	**SUPPORTING EQUIPMENT**	**276**	**4,313,293.50**
1	Diesel Prime Mover	44	777,403.03
2	Forklift	15	21,097.00
3	Ship	3	18,699.00
4	Garbage Cleaning Ship	6	12,000.00
5	Operation Car	1	149,163.50
6	Firefighters Car	4	79,470.00
7	Pallet Mover	4	-
8	Reach Stacker	14	182,958.02
9	Road Sweeper	3	39,057.00
10	Side Loader	9	77,405.04
11	Truck	170	2,955,872.91
12	Yard Sweeper	3	168.00
C	**NON-EQUIPMENT FACILITY**	**20**	**4177.00**
1	Generator	17	4047.00
2	Hydrant	1	0.00
3	Spitfire	2	130.00
	Grand Total (A+B+C)	**441**	**19,536,998.17**

Source: Tanjung Priok Port, 2024

The sources of scope 2 emissions at Tanjung Priok Port are :

Table 2 Types of Equipment Based on Scope 2 Emissions at Tanjung Priok Port

NO	TYPE OF EQUIPMENT	NUMBER OF EQUIPMENT	ELECTRICITY CONSUMPTION AMOUNT IN 2023 (KWH)
A	**MAIN EQUIPMENT**	**57**	**17,303,410.77**
1	Gantry Luffing Crane (GLC)	9	2,810,130.00
2	Quay Container Crane (QCC)	29	12,444,947.90
3	Rubber Tyre Gantry (RTG)	19	2,048,332.87
B	**SUPPORTING EQUIPMENT**	**23**	**248,378.30**
1	Vehicle	1	11,257.82
2	Forklift	10	12,380.48
3	Overhead crane	12	224,740.00
C	**NON-EQUIPMENT FACILITY**	**19**	**23,599,373.10**
1	Building	15	13,252,588.34
2	High Mast	1	92,930.25
3	Reefer Platforms/Sockets	1	2,668,147.51
4	Reefer Plug	1	6,807,900.00
5	Yard Lighting	1	777,807.00
	Grand Total (A+B+C)	**99**	**41,151,162.17**

Source: Tanjung Priok Port, 2024

Emission Calculation Results

In this section, the results of measuring GHG emissions produced by port equipment in Tanjung Priok are presented in the form of quantitative data. These measurements were carried out on the main equipment that uses fossil fuels (before electrification) and after the equipment switched to electric power.

In the calculation of emissions, the level of calculation accuracy related to the data and calculation methods used is Tier 1 method 1, namely emission estimates based on activity data and default emission factors of the Intergovernmental Panel on Climate Change (IPCC). The GHG emissions calculated due to fuel use are CO_2, CH_4, and N_2O (Guidelines for Calculation and Reporting of Greenhouse Gas Inventories, Ministry of Energy and Mineral Resources (2018)). The amount of emissions scope 1 and 2 for each type of equipment at Tanjung Priok Port is presented in table 3 and 4:

No	Type of Equipment	Number of Equipment	Fuel Consumption Amount in 2023 (Liters)	Emission CO_2 (ton)	Emission CH_4 (ton)	Emission N_2O (ton)
A	**MAIN EQUIPMENT**	**145**	**15,219,527.67**	**40,613,7091**	**0.001644280**	**0.000328856**
1	Empty Container Handler	2	26,373.97	70,3796	0.000002849	0.000000570
2	Gantry Luffing Crane (GLC)	2	45,500.00	121,4179	0.000004916	0.000000983
3	Hybrid RTG	5	304,783.12	813,3218	0.000032928	0.000006586
4	Pilot Ship	8	359,819.00	960,1864	0.000038874	0.000007775
5	Tugboat	20	6,862,510.00	18,312,7881	0.000741408	0.000148282
6	Quay Container Crane (QCC)	3	308,468.00	823,1550	0.000033326	0.000006665
7	Rubber Tyre Gantry (RTG)	102	7,310,956.58	19,509.4795	0.000789857	0.000157971
8	Tug Master	3	1,117.00	2,9807	0.000000121	0.000000024
B	**SUPPORTING EQUIPMENT**	**276**	**4,313,293.50**	**11,510,1369**	**0.000465997**	**0.000093199**
1	Diesel Prime Mover	44	777,403.03	2,074,5204	0.000083989	0.000016798
2	Forklift	15	21,097.00	56,2979	0.000002279	0.000000456
3	Ship	3	18,699.00	49,8988	0.000002020	0.000000404
4	Garbage Cleaning Ship	6	12,000.00	32,0223	0.000001296	0.000000259
5	Operation Car	1	149,163.50	398,0467	0.000016115	0.000003223
6	Firefighters Car	4	79,470.00	212,0678	0.000008586	0.000001717
7	Pallet Mover	4	-	-	-	-
8	Reach Stacker	14	182,958.02	488,2283	0.000019766	0.000003953
9	Road Sweeper	3	39,057.00	104,2246	0.000004220	0.000000844
10	Side Loader	9	77,405.04	206,5574	0.000008363	0.000001673
11	Truck	170	2,955,872.91	7,887.82	0.000319345	0.000063869
12	Yard Sweeper	3	168.00	0.4483	0.000000018	0.000000004
C	**NON-EQUIPMENT FACILITY**	**20**	**4,177.00**	**11,1464**	**0.000000451**	**0.000000090**
1	Generator	17	4,047.00	10,7995	0.000000437	0.000000087
2	Hydrant	1	-	-	-	-
3	Spitfire	2	130.00	0.3469	0.000000014	0.000000003
	Grand Total (A+B+C)	**441**	**19,536,998.17**	**52,134.9925**	**0.002110728**	**0.000422146**

Table 3 Scope 1 Emission Amount for Each Type of Equipment at Tanjung Priok Port

Table 4 Scope 2 Emission Amount for Each Type of Equipment at Tanjung Priok Port

NO	TYPE OF EQUIPMENT	NUMBER OF EQUIPMENT	ELECTRICITY CONSUMPTION AMOUNT IN 2023 (KWH)	Emission CO2 (ton)	Emission CH 4 (ton)	Emission N2O (ton)
A	**MAIN TOOLS**	**57**	**17,303,410.77**	**11,847,5411**	**0.2759**	**0.1517**
1	Gantry Luffing Crane (GLC)	9	2,810,130.00	1,924,0791	0.0448	0.0246
2	Quay Container Crane (QCC)	29	12,444,947.90	8,520,9809	0.1984	0.1091
3	Rubber Tyre Gantry (RTG)	19	2,048,332.87	1,402,4812	0.0327	0.0180
B	**SUPPORTING TOOLS**	**23**	**248,378.30**	**170,0631**	**0.0040**	**0.0022**
1	Vehicle	1	11,257.82	7,7082	0.0002	0.0001
2	Forklift	10	12,380.48	8,4768	0.0002	0.0001
3	Overhead crane	12	224,740.00	153,8781	0.0036	0.0020
C	**NON TOOL FAS**	**19**	**23,599,373.10**	**16,158,3486**	**0.3763**	**0.2069**
1	Building	15	13,252,588.34	9,073.9674	0.2113	0.1162
2	High Mast	1	92,930.25	63,6288	0.0015	0.0008
3	Reefer Platforms/Sockets	1	2,668,147.51	1,826.8645	0.0425	0.0234
4	REEFER PLUG	1	6,807,900.00	4,661,3281	0.1085	0.0597
5	Yard Lighting	1	777,807.00	532,5598	0.0124	0.0068
	Grand Total (A+B+C)	**99**	**41,151,162.17**	**28,175.9529**	**0.6561**	**0.3608**

Source: Tanjung Priok Port, 2024, processed.

Table 5 Recapitulation of Energy Consumption and Emissions at Tanjung Priok Port

No	Scope	Number of Tools	Amount of Energy Consumption	Unit	Emission CO2 (ton)	Emission CH 4 (ton)	Emission N2O (ton)
A	**Scope 1**	**441**	**19,536,998.17**	**Liter**	**52,134.9925**	**0.002110728**	**0.000422146**
B	**Scope 2**	**99**	**41,151,162.17**	**kWh**	**28,175.9529**	**0.6561**	**0.3608**

Emission Analysis and Electrification Techniques

In analyzing the impact of the electrification program on the main equipment (in this case cranes) at Tanjung Priok Port, with a review of how efficiently a port tool consumes energy in processing one container unit, the Energy per TEUS unit is used (with TEUS as an international standard that represents one 20-foot container). This compares the performance of different tools (especially cranes) or the technology used (fuel-based tools versus electric/electrified tools). A comparison of the amount of energy consumption per production, emissions and emission reductions for the main equipment of fuel-based cranes versus the main equipment of cranes that have been electrified (as in table 2), is presented in table 6.

Table 6 Comparison of Emission Reduction of Main Equipment (Crane) Based on Fuel and Electricity

No	Main Equipment Name	Energy consumption per Production (liters of fuel / TEUS)	Energy consumption per Production (kWh / TEUS)	CO_2 Emissions fuel ($kgCO_2$)	CO_2 Emissions Electricity ($kgCO_2$)	Emission Reduction (%)
A	Gantry Luffing Crane (GLC)	0.38	0.34	1,0146	0.232795952	77.06%
B	Quay Container Crane (QCC)	4.47	4.81	11,9349	3.293378029	72.41%
C	Rubber Tyre Gantry (RTG)	1.79	0.99	4,7793	0.677847037	85.82%

Source: Tanjung Priok Port, 2024, processed.
Remarks:
TEUS = 20 feet container unit
Fuel emissions = 2.67 $kgCO_2$ / liter of fuel
Electricity Emissions = 0.684693977 $kgCO_2$ /kWh (*Ecometrica (2011). Electricity-specific emission factors for grid electricity*)
Emission Reduction (%) = (Fuel Emission – Electricity Emission) / Fuel Emission x 100%

The analysis of the application of electrification to the main equipment at Tanjung Priok Port which is still fuel-based as in table 1 can be described in table 7:

Table 7 Summary of Electrification Potential for Various Types of Main Fuel-Based Equipment at Tanjung Priok Port

No	Main Equipment Type	Electrification Implementation Analysis	Current Operational Pattern & Energy Type	Compatibility for Electrification	Challenges & Success Potential	Operational Options	Success Indicators	Conclusion: Electrifiable or Not
1	Empty Container Handler	Can be electrified as electric motor technology is already available.	Uses diesel to handle empty containers	Compatible with electric motors	High initial costs, but great potential for emission and noise reduction	Full electric	Reduction in CO_2 emissions, noise, and cost efficiency	Can be electrified
2	Gantry Luffing Crane (GLC)	Can be converted from diesel to electric or hybrid power.	Uses diesel for container transfer	Compatible for electric or hybrid conversion	High investment costs and operator training challenges	Full electric or hybrid	Energy efficiency and reduced diesel consumption	Can be electrified
3	Harbour Mobile Crane (HMC)	Cannot be electrified. HMC is designed for high mobility in various locations, difficult to obtain stable electricity.	Uses diesel, high mobility	Not compatible with full electric	Supply stability issues and battery limitations	Diesel optimization	Fuel efficiency and reduced emissions per operational hour	Cannot be electrified
4	Pilot Boat	Full electrification is not possible due to high mobility and long-range travel.	Uses diesel for high mobility	Difficult for full electrification	Low battery capacity and high costs	Hybrid diesel-electric	Fuel efficiency and NOx emission reduction	Cannot be fully electrified
5	Tugboat	Full electrification is not possible, but hybrid technology is available.	Uses diesel to tow large ships	Limited due to high energy demands	High costs and low battery capacity	Hybrid diesel-electric	Emission reduction per ship towing operation	Cannot be fully electrified
6	QCC (Quay Container Crane)	Can be converted from diesel to electric.	Uses diesel or electricity	Compatible with full electric conversion	High initial costs and stable power supply challenges	Full electric	Reduction in operational costs and CO_2 emissions	Can be electrified
7	Rubber Tyred Gantry Crane (RTGC)	Can be electrified with direct power supply infrastructure (catenary or cable).	Uses hybrid diesel-electric power	Compatible for full electrification if new infrastructure is available	High initial costs and investment challenges	Hybrid diesel-electric / Full electric	Energy efficiency and reduction in VOC emissions	Can be electrified
8	Tug Master	Can be converted into electric or hybrid vehicles.	Uses diesel for internal port transportation	Compatible with full electric or hybrid conversion	Battery capacity and high cost challenges	Full electric or hybrid	Reduction in CO_2 emissions and noise	Can be electrified

In some cases, equipment that requires high mobility and large power, such as *Harbor Mobile Cranes*, pilot boats, and tugboats, have limitations in full electrification, but hybrid technology can reduce dependence on fossil fuels.

Financial Economic Analysis (Cost Benefit Analysis)

In the cost-benefit analysis of port crane equipment electrification, several key aspects are focused on due to their relevance to investment decisions and their long-term impacts. Pre-electrification costs, such as fuel consumption costs, provide a baseline of existing operational expenses. Post-electrification costs, which include the cost of electricity usage, need to be compared to evaluate potential efficiencies and savings. Cost reduction is an important indicator of the extent to which electrification is able to reduce port operational burdens. See table 8.

Electrification of port crane equipment, such as Gantry Luffing Crane (GLC), Quay Container Crane (QCC), and Rubber Tire Gantry (RTG), offers significant impacts both economically and environmentally. In terms of cost, electrification directly reduces dependence on fossil fuels that have high operational costs, such as fuel consumption per TEUS which previously could reach 4.47 liters at QCC. After electrification, energy consumption shifts to more efficient electricity with lower energy consumption costs.

4. CONCLUSION

The results of the study indicate that there are several main equipments at Tanjung Priok Port that have the potential for electrification, especially cranes (GLC, QCC and RTG), from being based on fossil fuels to electricity, also providing the potential for reducing GHG emissions, especially CO_2. The efficiency of operational costs on cranes (GLC, QCC and RTG) has a positive impact from the transition from fossil fuel energy sources to electricity. Thus, this study can contribute that electrification efforts are one of the strategic programs in efforts to manage the environment more effectively in the maritime sector.

Table 8 Comparison of Energy Efficiency of Main Equipment (Crane) Based on Fuel and Electricity

No	Main Tool Name	Fuel Consumption per Production (liters / TEUS)	Electricity consumption per Production (kWh / TEUS)	Fuel Consumption Cost (Rp)	Electricity Consumption Costs (Rp)	Energy Consumption Cost Efficiency (%)
A	Gantry Luffing Crane (GLC)	0,38	0,34	5.890	510	91,34%
B	Quay Container Crane (QCC)	4,47	4,81	69.285	7.215	89,59%
C	Rubber Tyre Gantry (RTG)	1,79	0,99	27.745	1.485	94,65%

Source: Tanjung Priok Port, 2024, processed.
Information:
TEUS = 20 feet container unit
Fuel rate = Rp15.500/liter Industrial Solar
Electricity Tariff = Rp1.500/kWh (assumption)
Cost Efficiency (%) = (Fuel Cost – Electricity Cost) / Fuel Cost x 100%

5. REFERENCES

Acciaro, M., Ghiara, H., Cusano, M.I., 2014a. Energy management in seaports: a new role for port authorities. Energy Policy 71, 4–12. https://doi.org/10.1016/j.enpol.2014. 04.013.

Acciaro, M., Vanelslander, T., Sys, C., Ferrari, C., Roumboutsos, A., Giuliano, G., Lam, J.S.L., Kapros, S., 2014b. Environmental sustainability in seaports: a framework for successful innovation. Marit. Policy Manag. 41, 480–500. https://doi.org/10.1080/ 03088839.2014.932926.

Acciaro, M., Wilmsmeier, G., 2015. Energy efficiency in maritime logistics chains. Res. Transp. Bus. Manag. 17, 1–7. https://doi.org/10.1016/j.rtbm.2015.11.002.

Brown, M. A. (2014). Enhancing efficiency and renewables with smart grid technologies and policies. Futures , 58 , 21–33. https://doi.org/10.1016/j.futures.2014.01.001

Brown, P. & Green, M., 2019. Types of Ports and Their Operations. Journal of Transport Geography, 58(4), pp. 76-84.

Christodoulou, A., Gonzalez-Aregall, M., Linde, T., Vierth, I., Cullinane, K., 2019. Targeting the reduction of shipping emissions to air: a global review and taxonomy of policies, incentives and measures. Marit. Bus. Rev. 4, 16–30. https://doi.org/10. 1108/mabr-08-2018-0030.

Coppola, T., Fantauzzi, M., Lauria, D., Pisani, C., Quaranta, F., 2016. A sustainable electrical interface to mitigate emissions due to power supply in ports. Renew. Sust. Energ. Rev. 54, 816–823. https://doi.org/10.1016/j.rser.2015.10.107.

Corbett, J.J. & Winebrake, J.J., 2008. The impacts of globalisation on international maritime transport activity: Past trends and future perspectives. OECD/ITF Joint Transport Research Centre Discussion Papers, pp. 2008- 2014.

Cullinane, K. & Bergqvist, R., 2014. Emission reduction strategies in the port sector. Maritime Policy & Management, 41(4), pp. 459-477.

Cullinane, K., Cullinane, S., 2019. Policy on reducing shipping emissions: implications for “Green Ports,”. In: Bergqvist, R., Monios, J. (Eds.), Green Ports. Elsevier, pp. 35–62. https://doi.org/10.1016/B978-0-12-814054-3.00003-7.

Dhupia, J., Adnanes, A.K., Lee, K.M., Kennedy, L., 2011. Electrification of port and port

operations. In: MTEC 2011, pp. 1–6 Singapore.
Díaz-Ruiz-Navamuel, E., Piris, A.O., Pérez-Labajos, C.A., 2018. Reduction in CO2 emissions in RoRo/Pax ports equipped with automatic mooring systems. Environ. Pollut. 241, 879–886. https://doi.org/10.1016/j.envpol.2018.06.014.
Enhanced Nationally Determined Contribution Republic Of Indonesia 2022 . (nd).
EPA, 2019. EPA's Regulatory Initiatives on Greenhouse Gas Emissions. [online] Available at: https://www.epa.gov/ghgemissions [Accessed 10 Aug. 2024].
Finnveden, G. et al., 2009. Recent developments in Life Cycle Assessment. Journal of Environmental Management, 91(1), pp. 1-21.
Geerlings, H., & Van Duin, R. (2011). A new method for assessing CO2-emissions from container terminals: A promising approach applied in Rotterdam. Journal of Cleaner Production , 19 (6–7), 657–666. https://doi.org/10.1016/j.jclepro.2010.10.012
Gibbs, D., Rigot-Muller, P., Mangan, J., Lalwani, C., 2014. The role of sea ports in end-toend maritime transport chain emissions. Energy Policy 64, 337–348. https://doi.org/10.1016/j.enpol.2013.09.024.
Guinée, J.B. et al., 2011. Life Cycle Assessment: Past, Present, and Future. Environmental Science & Technology, 45(1), pp. 90-96.
Hadi, A. S., 2019. Development and Modernization of Tanjung Priok Port. Indonesian Maritime Review, 27(3), pp. 56-70.
IMO, 2015. Study of Emission Control and Energy Efficiency Measures for Ships in the Port Area. International Maritime Organization, London: UK. https://doi.org/10.1017/CBO9781107415324.004.
IMO, 2018a. Port Emission Toolkit Guide No.1: Assessment of Port Emission. GloMeep project coordination unit and the International Maritime Organization, UK: London.
IMO, 2018b. Port Emission Toolkit Guide no.2: Development of Port Emission Reduction Strategies. GloMeep project coordination unit and the International Maritime Organization, London: UK.
IMO, 2018c. MEPC/72/17/ADD.1. Resolution MEPC.304(72): Initial IMO Strategy on Reduction of GHG Emissions from Ships. International Maritime Organization, London: UK.
IMO, 2019. MEPC/74/18/ADD.1. Resolution MEPC.323(74): Inivitation to Member States to Encourage Voluntary Cooperation between the Port and Shipping Sectors to Contribute to Reducing GHG Emissions from Ships. International Maritime Organization, London, UK.
Innes, A., Monios, J., 2018. Identifying the unique challenges of installing cold ironing at small and medium ports– the case of aberdeen. Transp. Res. Part D Transp. Environ. 62, 298–313. https://doi.org/10.1016/j.trd.2018.02.004.
IPCC, 2014. Climate Change 2014: Mitigation of Climate Change. [online] Available at: https://www.globalchange.gov/reports/ipcc-climate-change- 2014-mitigation-climate-change [Accessed 10 August 2024].
Iris, Ç., Lam, J.S.L., 2019. A review of energy efficiency in ports: operational strategies, technologies and energy management systems. Renew. Sust. Energ. Rev. 112, 170–182. https://doi.org/10.1016/j.rser.2019.04.06

9.
Jae Kim , Mansour Rahimi & Josh Newell (2012) Life-Cycle Emissions from Port Electrification: A Case Study of Cargo Handling Tractors at the Port of Los Angeles, International Journal of Sustainable Transportation, 6:6, 321-337, DOI: 10.1080/15568318.2011.606353
Johnson, D. J., & Asce, M. (2010). Process and Equipment Automation for Container Terminals.
Johnson, K., 2018. The Impact of Industrial Processes and Transport on Global Climate Change. Journal of Environmental Studies, 5(3), pp.123-145.
Johnson, L. H., 2021. Automation and Digitalization in Modern Ports. International Journal of Shipping and Logistics, 35(3), pp. 205-218.
Jonathan, Y.C., Kader, S.B., 2018. Prospect of emission reduction standard for sustainable port equipment electrification. Int. J. Eng. 31, 1347–1355. https://doi.org/10.5829/ ije.2018.31.08b.25.
Kementerian Lingkungan Hidup, Pedoman Perhitungan Penyelenggaraan Inventarisasi Gas Rumah Kaca Nasional, 2012.
Kim, J., Rahimi, M., Newell, J., 2012. Life-cycle emissions from port electrification: a case study of cargo handling tractors at the Port of Los Angeles. Int. J. Sustain. Transp. 6, 321–337. https://doi.org/10.1080/15568318.2011.606353.
Lee, M. K., 2020. Impact of Equipment Electrification on Carbon Emissions in Ports. Environmental Science and Policy, 39(1), pp. 83-95
Mishan, E. J., & Quah, E. (2020). Cost-Benefit Analysis (6th ed.). Routledge. https://doi.org/10.4324/9781351029780.
Moeis, AO, Desriani, F., Destyanto, AR, Zagloel, TY, Hidayatno, A., & Sutrisno, A. (2020). Sustainability assessment of the tanjung priok port cluster. International Journal of Technology , 11 (2), 353–363. https://doi.org/10.14716/ijtech.v11i2.3894
Smith, D., Graves, R., Ozpineci, B., Jones, P.T., Lustbader, J., Kelly, K., Walkowicz, K., Birky, A., Payne, G., Sigler, C., & Mosbacher, J. (2019). Medium- and Heavy-Duty Vehicle Electrification An Assessment of Technology and Knowledge Gaps .
Wachjoe, Ck, Zein, H., Supriyanti, Y., Gantina, Tm, Kurniasetiawati, A., & Marenshaputri, P. (2020). Air Pollution Reduction Based on Green Port Concept. ELKOMIKA: Journal of Electrical Energy Engineering, Telecommunication Engineering, & Electronic Engineering , 8 (2), 252. https://doi.org/10.26760/elkomika.v8i2.252
Yang, Y.C., & Chang, W.M. (2013). Impacts of electric rubber-tired gantries on green port performance. Research in Transportation Business and Management , 8 , 67–76. https://doi.org/10.1016/j.rtbm.2013.04.002
Zhang, Y., Peng, Y. Q., Wang, W., Gu, J., Wu, X. J., & Feng, X. J. (2017). Air emission inventory of container ports' cargo handling equipment with activity-based "bottom-up" method. Advances in Mechanical Engineering, 9 (7). https://doi.org/10.1177/168781401771138.