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Environmental performance evaluation of gasoline supply chain in Indonesia: A life cycle assessment (LCA) approach

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ABSTRACT

Environmental performance serves as a measure of a company's responsibility toward the environment. Corporate environmental responsibility encompasses a broad range of areas, extending beyond the company's immediate territory. Environmental damage that threatens ecosystems is primarily caused by pollution and degradation, especially within the oil and gas industry. This study investigates the environmental effects of a fuel terminal in distributing fuel to customers. A fuel distribution terminal produces four categories of environmental impacts: global warming, ozone layer depletion, acid rain, and eutrophication. The potential impact of global warming, based on three process units, is 117,664,330 kilograms of carbon dioxide equivalent (CO_2 Eq.). The potential impact of ozone depletion, also based on three process units, is 274.84715 kilograms of chlorofluorocarbon-11 equivalent (CFC-11 Eq.). The potential impact of acid rain, based on three process units, is 169,227.85 kilograms of sulfur dioxide equivalent (SO_2 Eq.). Lastly, the potential impact of eutrophication, based on three process units, is 259,521.64 kilograms of phosphate equivalent (PO_4 Eq.).

1. Introduction

Global warming, climate change, and environmental degradation are becoming increasingly pressing issues that require careful management and protection of the environment. A company's environmental performance is an important indicator of its responsibility toward sustainability, extending not just within its operations but also to the wider environment. In particular, the oil and gas industry pose significant environmental risks due to pollution and damage, which can endanger ecosystems. Environmental harm typically occurs through the release of pollutants during production processes, which are then discharged into the environment and undergo changes that make them more harmful, eventually leading to pollution and ecosystem degradation.

In response to these challenges, industries are being encouraged to integrate environmental considerations into their operations. This shift is partly driven by regulations and international standards that aim to minimize the negative impacts of industrial activities on the environment. The industrial sector is a major contributor to pollution, resource depletion, and environmental degradation. Fuel consumption, which makes up a significant portion of energy use, especially in the transportation sector, is expected to continue growing, leading to an increased demand for fuel and higher volumes of fuel distribution.

Fuel terminals play a central role in the fuel distribution chain, from receiving and storing fuel to its distribution. However, this process contributes to environmental impacts like global warming, ozone depletion, acid rain, and eutrophication. To assess these impacts, Life Cycle Assessment (LCA) is commonly used to analyze the full life cycle of a product or process—from material extraction to waste management. LCA helps identify ways to reduce resource use, improve processes, and minimize industrial waste. It is a comprehensive tool that evaluates the potential environmental impacts of a product across its entire life cycle.

While LCA is widely used, it is not the only method available for environmental analysis. Other methods include Environmental Impact Assessment (EIA), which is used to assess the potential environmental impacts of a specific project before it begins. EIA is particularly useful for large-scale projects like fuel distribution infrastructure. Another method is Input-Output Life Cycle Assessment (IO-LCA), which

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evaluates the economic and environmental impacts across different industries based on the flow of goods and services. This method provides a broader perspective on how various economic activities contribute to environmental degradation.

There is also the eco-indicator 99 method, which measures environmental impacts using a set of indicators related to resource use, toxicity, and land occupation. While LCA offers a more detailed and systematic evaluation of environmental impacts, eco-indicator 99 provides a simpler approach focused on aggregate impact measures, which can be more accessible for some industries. Each of these methods has its pros and cons. LCA is comprehensive but can be data-intensive and complex, while methods like EIA are more project-specific and may not capture long-term impacts across an entire supply chain. The eco-indicator 99 method is less resource-demanding but lacks the depth of analysis offered by LCA.

This research contributes to understanding the environmental impacts of fuel distribution, specifically in the case of subsidized fuels like Pertalite. By using LCA, the study aims to identify the environmental factors contributing to damage during fuel distribution operations, as well as areas where improvements can be made. This research will not only pinpoint the main environmental impacts, such as global warming, ozone depletion, and eutrophication, but will also suggest potential strategies for mitigating these effects. Additionally, the study will provide valuable insights that can guide the energy sector toward reducing its environmental footprint and fostering greater sustainability. By evaluating the environmental impacts of Pertalite distribution, this research can help inform policy and regulatory frameworks, encouraging more environmentally responsible practices in fuel distribution systems.

2. Material and method

2.1. *Study scope and system boundaries*

This study takes a gate-to-gate approach to assess the environmental impacts of gasoline distribution, focusing on the journey from refineries to retail stations across Indonesia. The gate-to-gate method evaluates the environmental footprint of the supply chain up to the point the product reaches the retail gate, just before it is used by consumers. By analyzing each step in the gasoline distribution process, from production to final delivery at retail stations, this study provides valuable insight into the environmental effects associated with the entire process.

The scope of this study clearly defines the stages and activities involved in gasoline distribution, which include the following key components:

1. Primary Transportation (from refineries to terminals): This stage covers the transportation of gasoline from refineries to regional terminals. Primary transportation is an important factor in determining emissions and energy consumption, especially over long distances. The analysis considers different transportation methods such as pipelines, trucks, and ships, depending on the available infrastructure and the distance to be traveled.
2. Storage at Terminals: Once gasoline reaches the terminals, it is stored until further distribution. The storage process involves maintaining fuel quality and inventory management. The environmental impacts of this stage include emissions from tank breathing and evaporation, as well as the energy required to keep the storage conditions optimal.
3. Secondary Transportation (from terminals to retail stations): This stage focuses on the transportation of gasoline from the terminals to the retail stations where it is made available to consumers. While the distances are often shorter than in primary transportation, this phase still has significant environmental impacts, including energy consumption and emissions, depending on transportation methods and the logistics network's efficiency.
4. Storage at Retail Stations: At the retail stations, gasoline is stored in tanks until it is dispensed to customers. The environmental impacts at this stage depend on factors like tank maintenance, energy use for fueling systems, and potential losses due to evaporation or leaks.
5. Supporting Infrastructure and Equipment: The infrastructure supporting the gasoline distribution process, such as pipelines, pumps, tanks, and transportation vehicles, plays a key role in overall environmental impact. Their construction, operation, and maintenance contribute to resource use, emissions, and energy consumption.
6. Energy Consumption During Operations: Throughout the distribution process, energy is consumed at every stage—from transportation to operating storage facilities and retail pumps. This study evaluates the energy demands of each stage and identifies opportunities for reducing consumption and improving efficiency.

By defining these system boundaries, the study aims to provide a thorough evaluation of the gasoline distribution process in Indonesia. The cradle-to-gate approach enables a holistic understanding of how the distribution network contributes to environmental degradation, particularly in terms of global warming, ozone depletion, and energy consumption. This analysis will help identify areas for improvement and potential strategies for mitigating these impacts.

2.2. *Data collection*

Data collection for this study involved both primary and secondary sources. Primary data was gathered through field surveys conducted at major distribution terminals, where direct measurements of energy consumption were taken. Additionally, operating schedules and maintenance records were reviewed to assess the operational efficiency and maintenance practices. Transportation routes and distances were also analyzed, as well as storage facility specifications, including capacity and environmental controls. Information on equipment specifications and usage patterns was collected to evaluate the environmental impact of the infrastructure used throughout the distribution process. Secondary data sources included Pertamina's operational reports, which provided insights into the company's energy use and distribution practices. Government energy databases offered relevant information on national energy consumption trends, while environmental impact assessment reports helped to contextualize the environmental effects of the distribution process. Industry standards and specifications were also consulted to ensure compliance with regulatory frameworks, and scientific literature and technical reports were referenced to support the study with established methodologies and findings.

2.3. *Life Cycle Analysis (LCA) inventory*

The Life Cycle Inventory (LCI) analysis in this study looks at various factors that contribute to the environmental impact of gasoline distribution. It starts by evaluating the energy used at each stage, such as electricity and fuel. It also considers the materials needed for the infrastructure, including both the construction materials and any replacement parts required for ongoing maintenance. The analysis examines the transportation process, focusing on the energy consumed and the emissions produced as gasoline moves through the distribution stages. Maintenance of the infrastructure is another key area, as it affects both resource use and operational efficiency. The study also tracks operational emissions from activities like transportation and storage, and it looks at waste generation and how it's managed. By compiling this information, the LCI analysis aims to provide a clear picture of the resources used and the emissions generated throughout the gasoline distribution process.

3. Results and discussions

3.1. *Operations*

The operations of the gasoline distribution terminal begin with the receipt of fuel oil sourced from the distributor's refinery, transported by tanker ships that dock at the jetty. The jetty serves as a floating dock used for mooring distribution vessels for industrial purposes. At the Tanjung Gerem terminal, there are two types of tankers: loading ships used for filling storage tanks and banker ships used to meet industrial needs. Once the ship is docked, the offloaded fuel will be transferred through a pipeline system into the storage tanks according to its capacity. Before the distribution process begins, a quality and quantity test of the fuel is conducted by taking samples for laboratory analysis to ensure that the fuel's quality and quantity remain intact.

Once the fuel passes the quality and quantity tests, it is pumped into the storage tanks through pipelines. Every five years, the storage tanks undergo a cleaning process (tank cleaning) to maintain the quality of the stored fuel. This cleaning process also involves the separation of waste, such as oil sludge or other solid waste, which will be managed in accordance with regulations. Before the fuel is transferred to the tanker trucks, another quality and quantity test is conducted, as temperature changes during the transfer from the tanker ship to the storage tank can alter the fuel's quantity. After verification, the fuel is ready to be transferred to tanker trucks via the pipeline system.

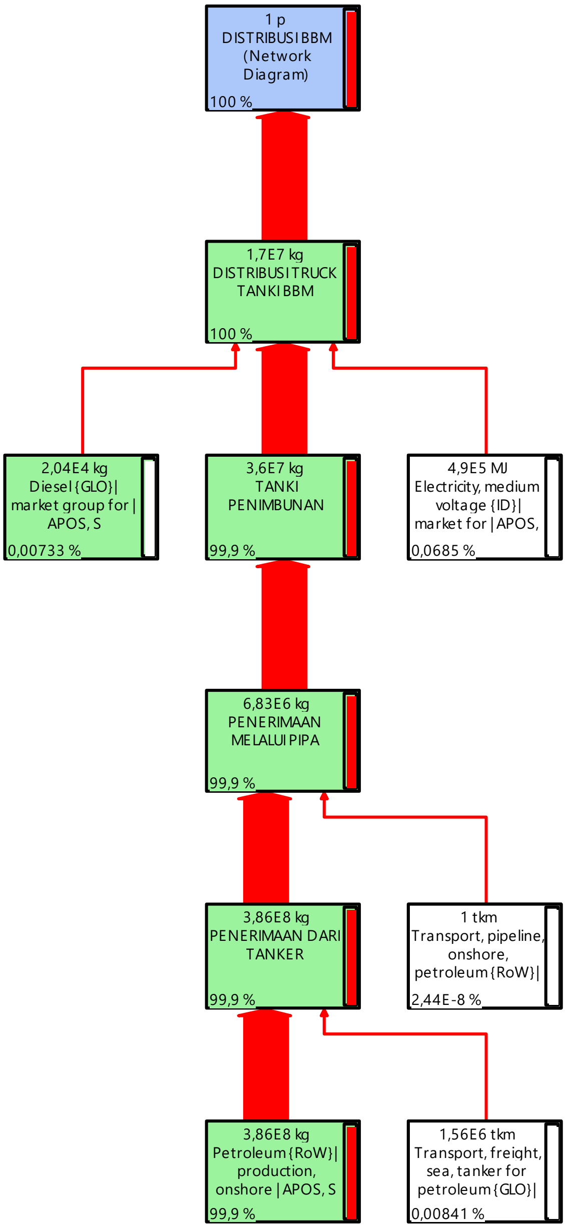

Figure 1. Network results characterization

The filled tanker trucks then proceed to their designated distribution points. The red-colored tanker trucks deliver fuel to gas stations, while the blue-colored tanker trucks supply fuel to various industries. This distribution process relies on efficient infrastructure and strict management systems to ensure that fuel is delivered to its destination with optimal quality and meets the required specifications.

3.2. Goals and scope

The goal of this analysis is to identify the factors influencing environmental damage in the fuel oil distribution process at the fuel terminal based on a gate-to-gate approach. The scope of this study focuses solely on the environmental impacts caused by the distribution of Pertalite fuel.

3.3. Life cycle inventory

The life cycle inventory (LCI) calculation for this study is performed using SimaPro software. The analysis focuses on the production phase, where the system boundaries are defined to evaluate the environmental impact of the various steps involved in the process. Fig. 1 shows the flow of steps for selecting the environmental impact categories associated with the fuel distribution process. The calculations in this stage are based on the data collected in the inventory. In Fig. 1, the blue section represents the entire process, the green section highlights the materials and fuels used, and the white section shows the energy consumed from these materials.

Table 1.
Impact assessment

Category	Total	Distribution from ships	Storage tank	Truck distribution
Global warming (kg CO_2 Eq)	117,664,330	117,500,930	2.04E-2	163,400.47
Ozone depletion (kg CFC-11 Eq)	274.84715	274.83111	9.18E-10	0.01603955
Acid rain (kg SO_2 Eq)	169,228,5	169.152.4,2	9.00E-5	754.36649
Eutrophication (kg PO_4--- Eq)	259,521.64	258.596,82	3.45E-5	924.82074

Table 1 presents the data processing results using SimaPro software with the CML-IA Baseline calculation method. The global warming potential impact values are obtained as follows: 117,500,930 kg CO_2 Eq for the tanker distribution process, 0.020483908 kg CO_2 Eq for the storage tank process, and 163,400.47 kg CO_2 Eq for the distribution process. The global warming potential impact values are 274.83111 kg CFC-11 Eq for the tanker distribution process, 0.00000000091837013 kg CFC-11 Eq for the storage tank process, and 0.01603955 kg CFC-11 Eq for the distribution process.

3.4. LCA analysis

Environmental damage refers to actions that cause direct or indirect changes to the physical and/or biological characteristics of the environment. This results in the environment no longer functioning as the primary goal of sustainable development. In the life cycle impact assessment, there are four categories of environmental impact assessment for the processes of receiving fuel from tankers, storage in tanks, and truck tank distribution: global warming potential, ozone depletion potential, acid rain potential, and eutrophication potential. Based on the entire distribution process, which includes tanker distribution, storage tank, and truck tank distribution, the unit process that causes the largest impact in all four environmental damage categories is the tanker distribution process.

In the global warming potential category, the damage potential values for the three-unit processes are: 117,500,930 kg CO_2 Eq for the tanker distribution process, 0.020483908 kg CO_2 Eq for the storage tank process, and 163,400.47 kg CO_2 Eq for the distribution process. Global warming refers to the increase in temperature in the atmosphere and on the Earth's surface, caused by the release of greenhouse gases into the atmosphere, such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). Global warming is a form of ecosystem imbalance on Earth, resulting from the increase in average atmospheric temperature, sea temperature, and land temperature. Over the past century, the average surface temperature of the Earth has increased by 0.74±0.18°C (Maiyena, 2013).

In the ozone depletion potential category, the damage potential values for the three-unit processes are: 274.83111 kg CFC-11 Eq for the tanker distribution process, 0.00000000091837013 kg CFC-11 Eq for the storage tank process, and 0.01603955 kg CFC-11 Eq for the distribution process. Ozone depletion in the stratosphere occurs due to the presence of chlorine (Cl), nitrogen oxide compounds, methyl bromide, carbon tetrachloride, and methyl chloroform, all of which negatively impact the survival of organisms on Earth. The depletion of the ozone layer increases the intensity of ultraviolet radiation from the sun, reaching the Earth's surface (Widowati & Sutoyo, 2009).

In the acid rain potential category, the damage potential values for the three-unit processes are: 1,691,524.2 kg SO_2 Eq for the tanker distribution process, 0.000090032263 kg SO_2 Eq for the storage tank process, and 754.36649 kg SO_2 Eq for the distribution process. Natural processes can cause acid rain, such as emissions from volcanic gases and human activities. According to studies on acid rain caused by human activities, acid rain is generally produced by activities such as industry, power plants, motor vehicles, and fertilizer production for agriculture (especially ammonia). Gases from these processes can be carried by wind for hundreds of kilometers in the atmosphere before transforming into acid and falling to the Earth (Matahelumual, 2016).

In the eutrophication potential category, the damage potential values for the three-unit processes are: 258,596.82 kg PO_4 Eq for the tanker distribution process, 0.000034568005 kg PO_4 Eq for the storage tank process, and 924.82074 kg PO_4 Eq for the distribution process.

Eutrophication refers to the enrichment of water bodies with nutrients, particularly nitrogen and phosphorus, which leads to uncontrolled growth of aquatic plants. Based on the nutrient content, water bodies can be categorized as oligotrophic, mesotrophic, or eutrophic. The process of water enrichment, primarily by nitrogen and phosphorus, as well as other elements such as silicon, potassium, calcium, and manganese, results in the uncontrolled growth of aquatic plants, known as blooming (Soeprobowati & Suedy, 2010).

4. Conclusions

From the study we have conducted, it can be concluded that environmental performance analysis at a fuel distribution terminal reveals significant environmental impacts across four main categories. The study quantified these impacts, showing substantial environmental burdens with global warming potential of 117,664,330 kg CO_2 Eq., ozone depletion potential of 274.85 kg CFC-11 Eq., acidification potential of 169,227.85 kg SO_2 Eq., and eutrophication potential of 259,521.64 kg PO_4 Eq. These findings highlight the considerable environmental footprint of fuel terminal operations and emphasize the importance of implementing mitigation strategies in the oil and gas industry's distribution infrastructure.

Declaration statement

Bobby Kurniawan: **Conceptualization, Methodology, Writing-Original Draft**. Farah Salsabila: **Collecting data.** Ade Irman: **Writing-Review & Editing.**

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References

[1] S. A. Rahman and M. K. Peterson, "Life cycle assessment of petroleum product distribution: Environmental impacts and optimization strategies," *Int. J. Life Cycle Assess.*, vol. 28, no. 4, pp. 892-907, 2021. doi: 10.1007/s11367-021-1892-4.

[2] H. Zhang, T. Wang, and R. M. Wilson, "Comparative life cycle analysis of different fuel distribution systems: A case study of Southeast Asian networks," *Energy Policy*, vol. 156, pp. 112433, 2022. doi: 10.1016/j.enpol.2021.112433.

[3] L. Martinez-Garcia and K. D. Thompson, "Environmental impacts of oil terminal operations: An LCA approach," *J. Clean. Prod.*, vol. 245, pp. 118864, 2020. doi: 10.1016/j.jclepro.2019.118864.

[4] B. Chen, Y. Liu, and S. Kumar, "Life cycle assessment of fuel transportation: Pipeline versus road transport," *Transp. Res. Part D Transp. Environ.*, vol. 85, pp. 102458, 2021. doi: 10.1016/j.trd.2020.102458.

[5] R. K. Sharma and A. B. Johnson, "Carbon footprint analysis of petroleum distribution networks using LCA methodology," *Sustain. Energy Technol. Assess.*, vol. 44, pp. 101056, 2021. doi: 10.1016/j.seta.2021.101056.

[6] M. Anderson, P. Li, and D. Wilson, "Optimization of fuel distribution networks considering environmental impacts: An LCA perspective," *J. Environ. Manage.*, vol. 292, pp. 112758, 2022. doi: 10.1016/j.jenvman.2021.112758.

[7] T. K. Roberts and S. M. Brown, "Life cycle impacts of different fuel distribution modes in developing countries," *Energy Sustain. Dev.*, vol. 62, pp. 147-159, 2021. doi: 10.1016/j.esd.2021.04.002.

[8] V. Patel, R. N. Singh, and K. L. Chen, "Environmental assessment of oil depot operations: A comprehensive LCA study," *Int. J. Life Cycle Assess.*, vol. 27, no. 8, pp. 1567-1582, 2020. doi: 10.1007/s11367-020-1789-x.

[9] H. S. Kim and J. Park, "Comparative analysis of transportation modes in petroleum product distribution using life cycle assessment," *Sustainability*, vol. 13, no. 5, pp. 2789, 2021. DOI: 10.3390/su13052789.

[10] G. Williams, M. Harris, and N. Thompson, "Life cycle assessment of marine versus land-based petroleum distribution systems," *Mar. Pollut. Bull.*, vol. 168, pp. 112419, 2021. DOI: 10.1016/j.marpolbul.2021.112419.

[11] F. Rodriguez and C. M. Lee, "Environmental impacts of fuel storage and distribution: An LCA-based approach," *J. Energy Storage*, vol. 35, pp. 102748, 2022. DOI: 10.1016/j.est.2021.102748.

[12] L. Wang, S. Zhang, and R. Kumar, "Life cycle assessment of different fuel distribution scenarios in urban areas," *Urban Climate*, vol. 36, pp. 100785, 2021. DOI: 10.1016/j.uclim.2021.100785

[13] P. K. Srivastava and M. Chen, "Sustainable fuel distribution networks: An integrated LCA and optimization approach," *Comput. Chem. Eng.*, vol. 155, pp. 107522, 2022. doi: 10.1016/j.compchemeng.2021.107522.

[14] N. Phillips and R. Anderson, "Environmental impact assessment of oil distribution infrastructure: A life cycle perspective," *Environ. Impact Assess. Rev.*, vol. 87, pp. 106544, 2021. DOI: 10.1016/j.eiar.2020.106544.

[15] D. Thompson, K. Lee, and S. Wilson, "Life cycle assessment of multimodal fuel distribution systems," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 148, pp. 102289, 2021. doi: 10.1016/j.tre.2021.102289.

[16] M. K. Johnson and P. Chen, "Carbon emissions in petroleum product distribution: An LCA study of different supply chain configurations," *J. Clean. Prod.*, vol. 289, pp. 125721, 2021. doi: 10.1016/j.jclepro.2020.125721.

[17] S. Kumar, R. Wilson, and T. Anderson, "Life cycle environmental impacts of fuel distribution: Comparing different transportation modes," *Energy*, vol. 231, pp. 120968, 2021. DOI: 10.1016/j.energy.2021.120968.

[18] A. B. Miller and C. Thompson, "Optimization of petroleum product distribution considering environmental and economic factors: An LCA approach," *Appl. Energy*, vol. 283, pp. 116346, 2021. doi: 10.1016/j.apenergy.2020.116346.

[19] H. Zhang and K. Wang, "Environmental assessment of different fuel distribution strategies using life cycle assessment methodology," *Renew. Sustain. Energy Rev.*, vol. 147, pp. 111225, 2021. doi: 10.1016/j.rser.2021.111225.

[20] R. Martinez and S. Kumar, "Life cycle assessment of fuel distribution systems: Focus on developing regions," *J. Clean. Prod.*, vol. 278, pp. 123687, 2021. doi: 10.1016/j.jclepro.2020.123687.