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Circular Economy Potential of Fuel Oil Distribution Activities Based on the Results of the Life Cycle Assessment (LCA) Study

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ABSTRACT:
Fuel Oil (BBM) distribution activities are crucial components of the global energy supply chain, resulting in significant environmental impacts. Therefore, it is important to understand and quantify these impacts through Life Cycle Assessment (LCA). This study uses the ReCipe 2016 method with a gate-to-gate approach, integrating midpoints and endpoints for a comprehensive evaluation. The LCA results show environmental impacts in several categories, including global warming: 0.1453 kg CO2eq, stratospheric ozone depletion: 0.0000000000724 kg CFC11eq, ozone formation affecting human health: 0.00004768 kg NOxeq, fine particulate matter formation: 0.0000010919 kg PM2.5eq, ozone formation affecting terrestrial ecosystems: 0.000031904 kg NOxeq, terrestrial acidification: 0.000007825 kg SO2eq, and water consumption: 0.000657 m3. Endpoint impacts include human health: 0.000000136 daily, and ecosystems: 0.0000000000412 species.yr. The hotspot process unit in fuel distribution activities is the elmot pump. Based on the Analytical Hierarchy Process (AHP), the priority improvement program is the Variable Speed Drive (VSD) program with a weight value of 0.572 or 57.2%. The VSD program is prioritized due to its significant impact on environmental, financial, and technical aspects. The circular economy analysis of the VSD program indicates that it aligns with circular economy principles 1 and 2, leading to reduced electrical energy consumption and decreased GWP emissions from electricity use. In conclusion, this study highlights the importance of targeted improvement programs to mitigate environmental impacts and enhance the sustainability of fuel oil distribution activities.
Keywords: Analytical Hierarchy Process (AHP), Fuel Distribution, Circular Economy, Life Cycle Assessment (LCA), SimaPro.

INTRODUCTION

Meeting energy needs while mitigating environmental impacts is a dual challenge that demands immediate and innovative solutions. Fuel oil distribution plays a crucial role in the global energy supply chain, influencing various sectors of the economy and daily life. Currently, fuel oil accounts for approximately 31.8% of the world's total energy consumption (Dudley, 2019), and its use is projected to continue until 2050 (Setyono & Kiono, 2021). The Agency for the Assessment and Application of Technology (BPPT) estimates that demand for fuel oil in the transportation sector will grow by 3.2% per year, which underscores the importance of enhancing the efficiency and sustainability of the fuel oil distribution process to address environmental concerns (Kholil et al., 2022).

In the life cycle of petroleum production, the production process and use of fuel oil products, from distribution to use by consumers, results in more than 40% environmental impact (Liu et al., 2020). To analyze the environmental impact of the fuel oil distribution process, the Life Cycle Assessment (LCA) method can be used (Gupta et al., 2022). LCA is an efficient method for measuring the environmental impact of any particular stage of a product, process or activity, and has been widely used in a variety of fields (Saputra et al., 2023). LCA has many benefits that can be used by companies and governments (Ahmadi et al., 2021). This LCA follows the Indonesian National Standard (SNI) ISO 14040:2016 and ISO 14044:2017 reference framework.

This environmental impact category is selected based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 1 of 2021 concerning the Company Performance Rating Assessment Program in Environmental Management (MoEF, 2021). A Life Cycle Impact Assessment (LCIA) is carried out based on the environmental impact category. LCIA can be done using the ReCiPe 2016 method, which provides a cause-and-effect implementation to calculate the characterization of the process by endpoint and midpoint (Huijbregts et al., 2019). Based on the ReCiPe 2016 method, it focuses on human health, ecosystems, and resources (Pré Sustainability, 2020).

Efforts to improve the fuel oil distribution process are urgently needed to reduce the environmental impacts identified through Life Cycle Assessment (LCA). This research is particularly important now due to the escalating climate crisis and the pressing need for sustainable resource management. These improvement efforts must be holistic, integrating business, environmental, and social performance to avoid the pitfalls of greenwashing (van Stijn et al., 2021). These improvement efforts must be holistic, integrating business, environmental, and social performance to avoid the pitfalls of greenwashing. Greenwashing, as defined by Elkington (2020), involves initiatives that appear to address environmental issues but lack substantive value. By genuinely addressing these issues, we can unlock the potential of the circular economy (Peña et al., 2021). The circular economy is a transformative concept where waste from one system can serve as an input to another, enhancing resource efficiency and minimizing environmental burdens (Dwiningsih & Ha, 2022).

This research diverges from existing research by specifically focusing on the fuel oil distribution process through the lens of LCA, whereas previous studies have often generalized across multiple industries. The primary objective of this research is to identify and implement strategies that enhance the sustainability of the fuel oil distribution process, thereby contributing to the circular economy. The benefit of this research extends beyond environmental impact reduction; it aims to provide a replicable model for other industries seeking to integrate circular economy principles with LCA, ultimately fostering a more sustainable and resilient global economy.

RESEARCH METHODS

Life Cycle Assessment (LCA)

1. **Goals and Scope**

   The initial stage in the LCA study is to determine the goals and scope. Goals are the creation of statements related to the goals to be achieved and to whom the results of the LCA will be communicated. Scope is the determination of things that need to be detailed in the research, including:
   - The functional unit used is 1 kL of fuel;
   - The system product is the flow of the fuel distribution process at the study site; and
   - System boundaries are the limits of the scope of study used, namely gate to gate, including: Fuel Oil Receipt, Fuel Storage Tank, Elmot Pump, Filling Shed (Tank Car and Rail Tank Wagon).
2. **Life Cycle Inventory (LCI)**

   Life Cycle Inventory (LCI) is a stage for the inventory of data used in the LCA study as well as inputs and outputs in SimaPro software. Inventory data in the form of raw material inputs, energy consumption data, clean water consumption data and output data in the form of emissions from each process unit ((Budiono, 2023).
3. **Life Cycle Impact Assessment (LCIA)**

   The Life Cycle Impact Assessment (LCIA) stage is the stage of selecting the impact category and determining the impact analysis method. The impact analysis method used is the ReCipe 2016 midpont H and H/H endpoint (Sonderegger & Stoikou, 2022).
4. **Characterization**

   All elementary flows from LCI are assessed according to their contribution factor to an impact, which is multiplied by the characterization factor according to the LCIA method (Yilmaz, 2023).
5. **Normalization**

   Normalization is an optional stage in the LCIA. It is the result of characterization divided by normalization factors according to the ReCiPe 2016 (H) method. Normalization equalizes the units of impact to make it easier to compare between impact categories (Nadhifatin, 2019).
6. **Data Interpretation**

   Interpretation is the stage of presenting the study's results, which includes identifying important issues using hotspot analysis.

Analysis of Improvement Efforts

Environmental program recommendations are obtained from a significant reduction in the impact of implementing each environmental program's LCA. Thus, the environmental program that provides the greatest impact reduction will be selected as the most optimal environmental program. The programs to be implemented were selected using the AHP approach and Expert Choice software (Vantil, 2023). The AHP is carried out to determine the priority scale of impacts based on environmental, technical, and financial aspects. The environmental aspect includes the selection of programs based on the analysis of impact hotspots. Technical aspects include ease of operation, availability of human resources, and availability of materials or materials. The financial aspect discusses the estimated investment costs and savings obtained from the implementation of the repair program. This alternative program was determined through a questionnaire given to respondents, which was also divided into two elements, namely the company and the practitioner. The selected elements are personnel with expertise in their respective fields so they can support program selection. In this AHP method, more emphasis is placed on the ability of respondents to answer questions (Ratnawati et al., 2023). The number of respondents for each element is three personnel. The criteria for each element of the respondent are as follows: Respondents from the company have ≥ 3 years of experience, occupy a supervisor/management position in a division directly related to the company's operations; and Respondents from practitioners have experience related to LCA and net production ≥ 3 years.

The Potential of the Circular Economy

Environmental program recommendations that have been implemented using AHP are then identified to determine the potential of the circular economy. Determination of circular economy value based on Operational Principles of Circular Economy for Sustainable Development: Linking Theory and Practice (Suárez-Eiroa et al., 2019). There are seven principles of circular economy potential, including adjusting inputs to the system equivalent to the level of regenerative ability, adjusting the output of the system to the level of absorption ability, closed systems, maintaining the value of resources in the system, reducing the size of the system, designing a circular economy, and circular economy education (Tóth Szita, 2017).

RESULTS AND DISCUSSION

Life Cycle Assessment (LCA) Study

In this study, the goals carried out are to identify the amount of environmental impact caused by the fuel distribution process with a case study on one of the fuel terminal units and evaluate the management program that has been carried out as an effort to reduce the resulting environmental impact (Alfonso, 2023). The scope used in this study is a gate-to-gate process. The gate-to-gate process in the study area starts from fuel receipts, fuel storage tanks, elmot pumps, and filling sheds (tank cars and rail tank wagons). The functional unit used in this study is 1 kL of fuel. The data used is secondary data for a period of one year in 2023, including fuel inputs, water use, energy use, and outputs in the form of products and emissions resulting from fuel distribution activities. The method used in analyzing the impact is ReCiPe 2016 (Midpoint H). The system boundary can be seen in Figure 1.

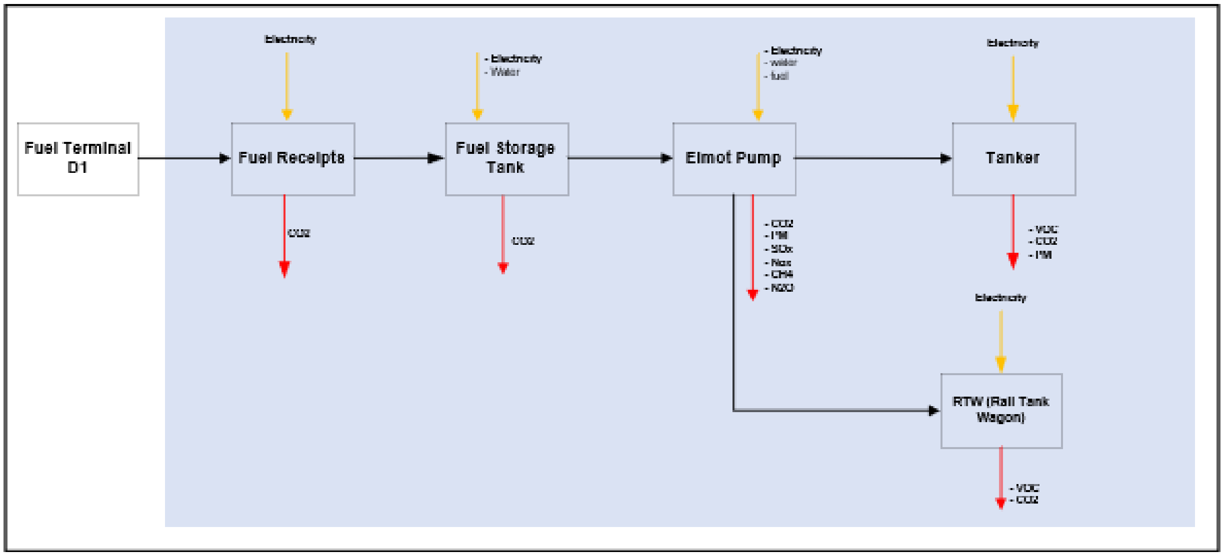


Figure 1. Fuel Distribution System Boundary

Source: Research Results, 2024

The life cycle inventory based on the goals and scope that have been determined can be seen in Table 1.

Table 1. Fuel Distribution Process Inventory

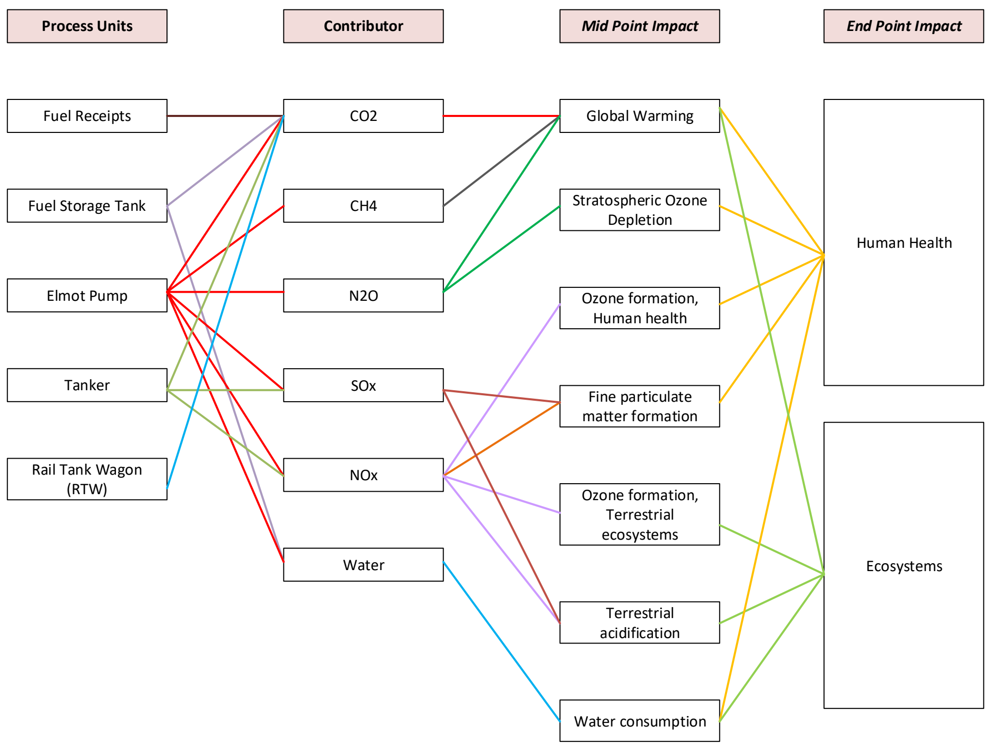
Process Unit	Input / Output	Data Categories	Unit	Number in 2023	Amount Per Product (Per kL of Fuel)
Fuel Receipts	Input	FUEL	Kl	1.486.780	1
		PLN Electricity	Kwh	1.874,27	0,00126
	Output	CO2 Electricity	Ton	1,649	0,00000111
		FUEL	Kl	1.486.780	1
Fuel Storage Tank	Input	FUEL	Kl	1.486.780	1
		PLN Electricity	Kwh	8.400,49	0,00565
		Electric Generator	Kwh	33,73	0,0000227
		Water	m3	946,68	0,000636732
	Output	CO2 Electricity	Ton	7,422	0,00000499
		FUEL	Kl	1.486.780	1
Elmot Pump	Input	FUEL	Kl	1.486.780	1
		PLN Electricity	Kwh	110.139,79	0,0741

Process Unit	Input / Output	Data Categories	Unit	Number in 2023	Amount Per Product (Per kL of Fuel)
		Solar	Litre	697	0,0004688
		Electric Generator	Kwh	442,328	0,000298
		Water	m3	30,85	0,00002074954
		CO2	Ton	99,171	0,000066751
	Output	FUEL	Kl	1.486.780	1
		PM10	Ton	0,0033443	0,00000000225
		Sox	Ton	0,0031285	0,00000000210
		Nox	Ton	0,0475734	0,00000003200
		Q4	Ton	0,0000753	0,0000000000506
		N2O	Ton	0,0000979	0,0000000000658
Tanker	Input	FUEL	Kl	947.100	0,637
		PLN Electricity	Kwh	72.514,984	0,049
		CO2 Electricity	Ton	63,813	0,0000429
	Output	FUEL	Kl	947.100	0,637
		PM10	Ton	0,0458867	0,00000003086
RTW (Rail Tank Wagon)	Input	FUEL	Kl	539.680	0,363
		PLN Electricity	Kwh	21.037,101	0,0141
		VOC	Ton	32,7300000	0,00002201402
	Output	CO2 Electricity	Ton	18,512	0,0000125
		FUEL	Kl	539.680	0,363

Source: Fuel Distribution Process Inventory Data, 2023

The fuel received at the receiving unit comes from the supply from the fuel terminal. Previously, the fuel was flowed to the fuel storage tank to be stored or stockpiled for the next process. Fuel storage tanks use the main energy source, namely PLN electricity and backup energy sources from generators. Thus, it causes emissions from the electricity consumption used. Fuel products in the fuel storage tank are then distributed to the tank car and RTW uses the help of an elmote pump. The elmot pump uses the main energy source, namely PLN electricity and additional electrical energy using a generator. In running the elmot pump unit, diesel is needed to power the generator, thus causing emissions from the use of diesel. Water is needed as a coolant for an elmot pump. Furthermore, the product is distributed to tank cars to be distributed to consumers. In distributing products to tank cars, electricity is required for lighting installations and activities on fuel filling in tank cars, thus causing emissions from the use of electricity. Fuel is also distributed using RTW in addition to tank cars. In the process of distributing fuel from the elmot pump to RTW, electricity is needed for operations and to support activities at RTW. In the implementation of this study, it is only limited to these activities. It does not calculate the impact of fuel distribution to consumers.

The LCIA stage aims to make the results of LCI analysis easier to understand and relate to the environmental impacts that occur. The impact category, indicators, and characterization model selected are the ReCiPe 2016 (H) Method. In the ReCiPe 2016 method, indicators are divided into two levels, namely 7 (seven) midpoint indicators and 2 (two) endpoint indicators.



Source: Observation Results, 2024

Figure 2. Classification of Fuel Terminal Fuel Distribution Process

The classification of the fuel distribution process data inventory is seen in Figure 4.3. In the process of receiving fuel, it produces the impact of CO_2 from the use of electrical energy. Fuel storage tanks provide CO2 contributors to electricity use, and water use in these activities. In the process of the elmot pump, it produces the contribution of CO_2, CH4, N2O,$_{SOx}$, and NOx from the emission of diesel use, as well as the use of water in the cooling of the generator set. In the process of tank cars causing CO2,$_{SOx}$, and NOx emissions. As well as the RTW process produces CO2 emissions. Contributors to$_{CO2}$, CH4, and N2O cause the impact of global warming. N$_{2O\ also}$ causes stratospheric ozone depletion impacts. SO_x causes the impact of fine particulate matter formation and terrestrial acidification. NO_x causes the impact of ozone formation, human health, terrestrial ecosystems, and terrestrial acidification. Also, water causes the impact of water consumption in the midpoint impact. In the impact of endpoints, what causes human health is the impact of global warming, stratospheric ozone depletion, ozone formation, human health, fine particulate matter formation, and water consumption. The endpoint impacts that cause ecosystem impacts are global warming, ozone formation, terrestrial ecosystems, terrestrial acidification, and water consumption.

Based on the results of LCI in the fuel distribution process, the characterization factor will be carried out in the impact category. All LCIs are classified in a specific impact category which is then multiplied by the characterization factor and summed up all relevant interventions resulting in an impact score in a specific impact category. The characterization of fuel distribution using SimaPro with the ReCiPe 2016 analysis method can be seen in Table 2.

Table 2. Results of Characterization of the Fuel Distribution Process

Impact category	Unit	Total
Midpoint		
Global Warming	kg CO2 eq	0,1453
Stratospheric Ozone Depletion	kg CFC11 eq	0,000000000724
Ozone Formation, Human Health	kg NOx eq	0,00004768
Fine Particulate Matter Formation	kg PM2.5 eq	0,0000010919
Ozone Formation, Terrestrial Ecosystems	kg NOx eq	0,000031904
Terrestrial Acidification	kg SO2 eq	0,000007825
Water Consumption	m3	0,000657
Endpoint		
Human Health	DAILY	0,000000136
Ecosystems	Species.yr	0,000000000412

Source: SimaPro Analysis Results, 2024

The impact resulting from the distribution of fuel for 1 kL of fuel causes 7 (seven) midpoint impacts and 2 (two) endpoint impacts. The midpoint impact in the Global Warming category is 0.1453 kg $CO_{2eq.}$ Impact categories Stratospheric Ozone Depletion produces as much as 0,000000000724 kg CFC11eq. Impact categories Ozone Formation, Human Health produces an impact of 0,00004768 kg NO_{Xeq}. Impact categories Fine Particulate Matter Formation produces an impact of 0,0000010919 kg PM2.5eq. Impact categories Ozone Formation, Terrestrial Ecosystems produce impacts of 0,000031904 kg NO_{Xeq}. Impact categories Terrestrial Acidification produces an impact of 0,000007825 kg SO2eq. Impact categories Water Consumption results in an impact of 0.000657 m^3. Endpoint impacts produce impact categories in the form of Human Health 0,000000136 DAILY, and for the Ecosystems impact category of 0,000000000412

Species.yr. The results of the characterization based on the bar chart can be seen in Figure 3 to Figure 4.

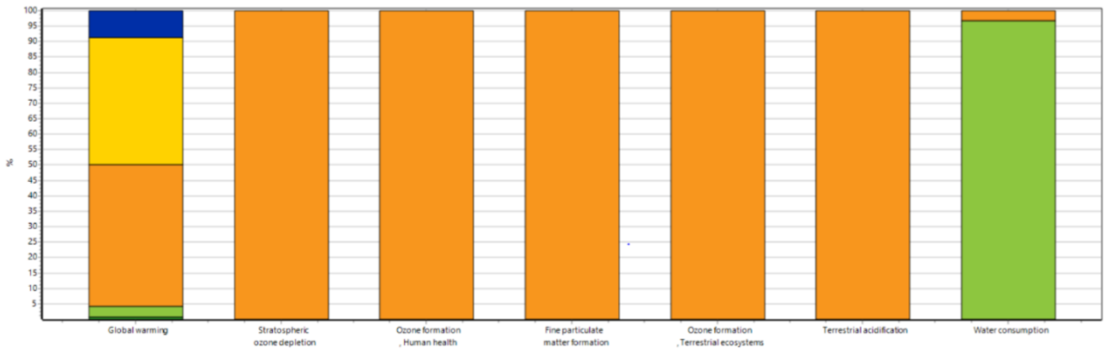


Figure 3. Midpoint Characterization Result Bar Diagram

Source: Observation Results, 2024

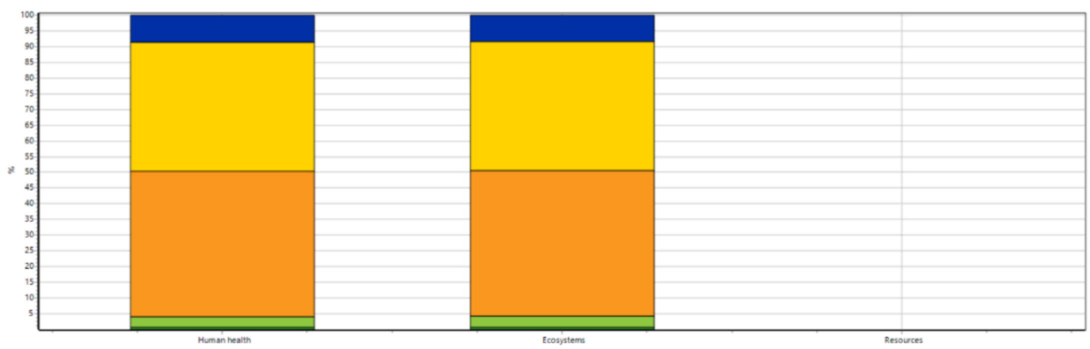


Figure 4. Endpoint Characterization Results Bar Chart

Source: Observation Results, 2024

Table 3. Results of Midpoint Impact Percentage Per Unit of Fuel Distribution Process

Impact Category	Total	Fuel Receipts	Fuel Storage Tank	Elmot Pump	Tank Car	Rail Tank Wagon
Global Warming	100 %	0,8%	3,4%	**45,9%**	41,3%	8,6%
Stratospheric Ozone Depletion	100 %	0%	0%	**100%**	0%	0%
Ozone Formation, Human Health	100 %	0%	0%	**100%**	0%	0%
Fine Particulate Matter Formation	100 %	0%	0%	**100%**	0%	0%

Impact Category	Total	Fuel Receipts	Fuel Storage Tank	Elmot Pump	Tank Car	Rail Tank Wagon
Ozone Formation, Terrestrial Ecosystems	100 %	0%	0%	**100%**	0%	0%
Terrestrial Acidification	100 %	0%	0%	**100%**	0%	0%
Water Consumption	100 %	0%	**96,8%**	3,2%	0%	0%

Source: Observation Results, 2024

The impact that has the highest value is the Global Warming impact category, based on a normalized value of 0.0000182. The unit that has the highest Global Warming impact value is the elmot pump unit 0.00000834 or 45.9%. This is due to the use of diesel in its operational activities. According to (Saklani & Khurana, 2019), the impact of Global Warming is most caused by CO emissions$_2$ on earth. In the distribution of CO emission fuel$_2$ produced from the process of burning diesel fuel to power the generator which is used as a backup energy source in fuel distribution operational activities.

For the Stratospheric Ozone Depletion impact category, the activities that produce this impact are activities at elmot pumps of 100%. This is because the impact of Stratospheric Ozone Depletion is caused by N_{2O} emissions. In fuel distribution activities, the unit that produces N_{2O} emissions is the elmot pump unit only, because in the elmot pump unit the use of diesel as generator fuel occurs. Solar combustion results in Global Warming Potential (GWP) emissions in the form of CO_2, CH4, and N2O emissions. Based on this, only the elmot pump produces the impact of Stratospheric Ozone Depletion because no other process unit has a diesel input and an N_2O emission output.

The impact categories of Ozone Formation, Human Health, Fine Particulate Matter Formation, Ozone Formation, Terrestrial Ecosystems, and Terrestrial Acidification are generated from 100% elmot pump activity process units. The normalized value of the impact of Ozone Formation, Human Health is 0.00000232. The Impact of Ozone Formation, Human Health is caused by NO emissions$_x$. In the activities of the elmot pump, NO emissions$_x$ produced from the diesel combustion process. According to (Atthoriqh & Sitogasa, 2023), NOx is a nitrogen oxide formed from 2 (two) gases, namely NO_2 and NO. Main sources of NO emissions$_x$ comes from combustion (combustion) from vehicles, energy production, and generator operation. According to (Huda & Kusnoputranto, 2020), emissions from the burning of gasoline, oil, diesel or wood produce the majority of PM pollution$_{2.5}$ found in the outdoor air. Impact categories Ozone Formation, Terrestrial Ecosystems has a value of 0.00000180. In fuel distribution activities, it is produced from the elmot pump unit. Contributors to this impact are NO emissions$_x$. Meanwhile, for the Terrestrial Acidification impact category, the result was 0.00000019. The impact comes from the onset of SO emissions$_x$ and NOx. Impact contributors Terrestrial Acidification The most important are anthropogenic activities, for example the burning of fossil fuels in industrial activities and vehicles. This activity releases sulfur dioxide and nitrous oxide into the atmosphere, which reacts with rainwater resulting in acid rain (Kholil et al., 2022). Impact Water Consumption caused by the use of water as an activity in fuel distribution. Results of normalization of impact categories Water Consumption has the highest value in the Fuel Storage Tank activity unit of 0.00000239 or 96.8%. In activities in the Fuel Storage Tank unit, water is needed to support activities in the form of cleaning up spills of fuel products and other supports. The second place is the impact producer Water Consumption is in the activity unit of the elmot pump. The use of water in the elmot pump activity unit as a coolant for generators and pumps that are in operation, as well as other supporting activities.

Environmental Impact Reduction Program Analysis

In the fuel distribution process, the hotspot of fuel distribution activities is the activity at the elmot pump unit. The elmot pump has the greatest impact among other units of activity. Therefore, in the activity of the elmot pump, it is necessary to make recommendations for improvement to minimize the impact produced. Program recommendations that can be carried out include the following.

Semi Auto Variable Speed Drive (VSD) Program

The Variable Speed Drive (VSD) feature functions as a speed controller for electric motors (which use AC current or alternating current), as well as a frequency controller for the supply of electrical power to the motor (Utomo et al., 2022). Based on Syamsuri et al. (2021), Variable Speed Drive (VSD) increases electrical energy efficiency by up to 30-60%, by being able to work at any load that causes the motor operation to remain at the ideal speed.

Solar Fuel Coupling Program with Biosolar (Solar Changer)

The Solar Changer program is a program to replace diesel fuel using biodiesel. This program is claimed to be able to reduce GHG emissions generated from the use of diesel. Biodiesel has the advantage of producing more efficient combustion due to its oxygen content, high setane number, and low sulfur content compared to diesel fuel (Wirawan et al., 2024).

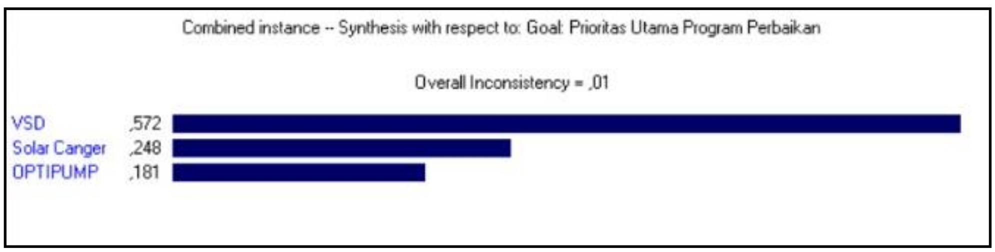
Optimization Program of Electric Motor Pump (OPTIPUMP)

The recommendation to optimize the elmot pump can potentially be an effort to reduce the environmental impact in fuel distribution activities, because it aims to improve pump operational efficiency by changing the medium-capacity pump system to a large capacity.

The determination of priority programs is carried out using the Analytical Hierarchy Process (AHP) approach. From the LCA, the environmental impact is known and alternatives that can be used have been analyzed. There are 3 (three) criteria used in this study, including the following:

1. Financial Aspect: Costs are based on the company's point of view interested in investing. Operational costs and savings that can be made in the running of the program.
2. Technical Aspects: Technical aspects are reviewed based on the operational technical ease of the program being carried out and the availability of resources in implementing the improvement program.
3. Environmental Aspects: The environmental aspect considers the potential environmental impacts that can be achieved with improvement programs, as well as the program's linkage with the SDGs.

A pair comparison was carried out based on the questionnaire data that had been obtained, then processed using Expert Choice software. If the inconsistency value is less than or equal to 0.1 or 10%, then the level of inconsistency is considered acceptable. However, if the inconsistency value is more than 0.1 or 10%, then there is a possibility that the comparison carried out is less consistent, and it is necessary to review the assessment carried out (Saputro, 2023). The results of the analysis of the priority of the improvement program based on all aspects can be seen in Figure 5.



Source: Observation Results, 2024

Figure 5. Analysis of Improvement Program Priorities Based on Overall Aspects

Priority programs based on all aspects obtained a weight value of 0.572 or 57.2% of the VSD program, 0.248 or 24.8% of the Solar Changer program, and a weight value of 0.181 or 18.1% of the OPTIPUMP program. Based on the 3 (three) recommended programs, the program that has the highest weight is the VSD program. The weight value of the VSD program is 0.572 or 57.2%. The VSD program based on all aspects is considered the most influential in the improvement program. The VSD program has a fairly high influence on the environmental aspect and on the financial aspect is also quite high. The inconsistency value obtained from the results of the analysis using Expert Choice was 0.02. This means that respondents tend to be consistent in choosing alternative improvement programs, so the level of inconsistency is considered acceptable because the inconsistency value < 0.1. It can be concluded that the VSD program is a top priority program that is set to reduce the environmental impact resulting from fuel distribution activities.

The Circular Economy Value of Selected Priority Programs

Based on the analysis carried out, the priority of the selected program is the semi-Auto Variable Speed Drive (VSD) program. In analyzing the potential of the circular economy, it can be assessed using the operational principles of the target (Suárez-Eiroa et al., 2019). The VSD program can be included in the principles of circular economy as follows.

Principle 1: Adapting Inputs to Systems with Regeneration Rates

To overcome the adjustment of inputs into the system to the level of regeneration, it is important to differentiate between renewable and non-renewable resources (Santo, Sormin and Hartini, 2023). Saves energy and materials (i.e. improving energy efficiency, resource productivity, product virtualization, etc.) (Kanchiralla et al., 2023). The VSD program can save energy in the form of the use of electrical energy, with the following calculations.

Absolute Value Before Program = [Power Usage Before Program x Daily Operating Duration x Number of Days of Use]

= [33 kWh x 9 Hours x 365 Days]

= 108,405 kWh/Year

= 108,405 kWh/Year / 1,000 kWh/MWh

= 108,405 MWh

= 108,405 MWh x 3,6 GJ/MWh

= 390,258 GJ/Year

Elmot Pump Inventory = 110,139.79 kWh/Year (PLN Electricity Input)

= 442,328 kWh/Year (Generator Power Input)

= 110,582,118 kWh/Year (Total Electricity Input in Elmot Pump Process Unit)

Allocation of Electricity Usage in Elmot Pumps = Total Electrical Inventory Input in Elmot Pump Process Unit – Elmot Pump Power Usage

= 110,582,118 kWh/Year - 108,405 kWh/Year

= 2,177,118 kWh/year (Supporting Operations)

= 108,405 kWh/year (Elmot Pump Operation)

Absolute Value After Program = [Power Usage After Program x Daily Operational Duration x Number of Days of Use]

= [23.1 kWh x 9 Hours x 365 Days]

= 75,883.5 kWh/Year

= 75,883.5 kWh/Year / 1,000 kWh/MWh

= 75,884 MWh

= 75,884 MWh x 3,6 GJ/MWh

= 273,182 GJ/Year

Absolute Value of the Program = [Absolute Value Before Program - Absolute Value After Program]

= [108,405 MWh - 75,884 MWh]

= 35,521 MWh/year

= 117,076 GJ/Year

Thus, an absolute value was obtained from the implementation of recommendations for efforts to reduce the environmental impact of the Semi Auto Variable Speed Drive (VSD) program of 117,076 GJ per year.

Calculations are made of savings obtained from the absolute value of the program. Based on data from PT. The State Electricity Company (Persero) (2024), the cost of electricity consumption for fuel distribution activities is included in group I-3/TM (above 200 KVa), which is Rp. 1,035.78 per kWh. Therefore, the calculation of savings from the environmental impact reduction program based on hotspots, namely Semi Auto Variable Speed Drive (VSD), is as follows:

Calculation of Savings of Recommended Programs= [Program Absolute Value x Electricity Consumption Cost]

= [35,521 MWh/Year x Rp. 1,035.78/kWh x 1,000 MWh/kWh]

= IDR 36,791,941.33/Year

The conclusion of the savings obtained from the implementation of recommendations for efforts to reduce the environmental impact of the Semi Auto Variable Speed Drive (VSD) program is Rp. 36,791,941.33 per year.

Principle 2: Adjusting the Output of the System with the Absorption Rate

In this principle, the waste output produced is minimized and replaced with technology that causes little emissions and biological waste produced (Peña et al., 2021). The VSD program can reduce GWP emissions of electricity use, with the following calculations.

- Absolute Value Before Program = [Power Usage Before Program x Daily Operational Duration x Number of Days of Use] x Jamali Plant Emission Conversion Factor

  = [33 kWh x 9 Hours x 365 Days] x 0.88 Tons CO2eq/MWh

  = 108,405 kWh/Year x 0.88 Tons CO2eq/MWh

  = 108,405 kWh/Year / 1,000 kWh/MWh x 0.88 Tons CO2eq/MWh

  = 108.405 MWh x 0.88 Tons CO2eq/MWh

  = 95.3964 Tons CO2eq/Year

- Absolute Value After the Program = [Power Usage After the Program x Daily Operational Duration x Number of Days of Use] x Jamali Plant Emission Conversion Factor

  = [23.1 kWh x 9 Hours x 365 Days] x 0.88 Tons CO2eq/MWh

  = 75,883.5 kWh/Year x 0.88 Tons CO2eq/MWh

  = 75,883.5 kWh/Year / 1,000 kWh/MWh x 0.88 Tons CO2eq/MWh

  = 75.884 MWh x 0.88 Tons CO2eq/MWh

  = 66.778 Tons of $CO_{2eq/}$Year

- Program Absolute Value= [Absolute Value Before Program – Absolute Value After Program]
  = 95.3964 Tons CO2eq/Year - 66.778 Tons$_{CO2eq/}$Year
  = 28.6185 Tons CO2eq/Year

The VSD program can reduce GWP emissions of electricity use by 28.6185 Tons of $CO_{2eq/}$year

CONCLUSION

Based on research on the circular economy potential of fuel oil (BBM) distribution activities, derived from the Life Cycle Assessment (LCA) study, it can be concluded that distributing 1 kL of fuel impacts the environment through several midpoints: Global Warming (0.1453 kg CO2eq), Stratospheric Ozone Depletion (0.0000000000724 kg CFC11eq), Ozone Formation impacting Human Health (0.00004768 kg NOxeq), Fine Particulate Matter Formation (0.0000010919 kg PM2.5eq), Ozone Formation affecting Terrestrial Ecosystems (0.000031904 kg NOxeq), Terrestrial Acidification (0.000007825 kg SO2eq), and Water Consumption (0.000657 m3). The endpoint impacts are in Human Health (0.000000136 Daily) and Ecosystems (0.000000000412 Species.yr). The elmot pump unit contributes the most significant environmental impact in fuel distribution, making it a hotspot. Recommended hotspot programs include the Variable Speed Drive (VSD), Solar Changer, and OPTIPUMP - Optimization of Electric Motor Pump. Using the Analytical Hierarchy Process (AHP) approach, the VSD program is prioritized with a weight value of 57.2% due to its significant influence on environmental, financial, and technical aspects. The circular economy value analysis shows that the VSD program can implement circular economy principles 1 and 2 by saving electrical energy and reducing GWP emissions from electricity use.

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