International Journal of Eco-Innovation in Science and Engineering (IJEISE) Vol.06 (1), 2025 (7-14)
https://ijeise.upnjatim.ac.id/ E-ISSN: 2721-8775

Article

Life Cycle Assessment (LCA) Analysis Operational Vehicles Telecommunication Industry at PT. X in East Java Using OpenLCA Software and the ReCipe Midpoint H Method

Agges Brian Darmawan[a], Muhammad Abdus Salam Jawwad[b]*

[a,b]Department of Environmental Engineering, Faculty of Engineering and Science, Universitas Pembangunan Nasional Veteran Jawa Timur, Surabaya, 60294, Indonesia

E-mail: [a]22034010057@student.upnjatim.ac.id, [b]muhammad.abdus.tl@upnjatim.ac.id
*Corresponding author: muhammad.abdus.tl@upnjatim.ac.id |Phone number: +6285132456434

Received: 06th May 2025; Revised: 19th May 2025; Accepted: 28th May 2025;
Available online: 30th May 2025; Published regularly: May and November

Abstract

The telecommunications industry heavily relies on operational vehicles to support network maintenance and customer service activities. This study aims to analyze the environmental impact resulting from the emissions of operational vehicles at PT. X, focusing on the East Java operational region. A Life Cycle Assessment (LCA) was conducted in accordance with ISO 14040, emphasizing the vehicle use phase. Primary data includes gasoline consumption and a total distance during the 2024 operational year. The analysis was performed using OpenLCA software with the Ecoinvent 3.3 database and the ReCipe Midpoint (H) method to quantify emissions and their associated environmental impacts. Results indicate that carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM_{10}) are the primary contributors to environmental impact categories such as climate change, marine eutrophication, particulate matter formation, photochemical oxidant formation, and terrestrial acidification. The findings provide a quantitative basis for evaluating the environmental burden of operational fleets and highlight the importance of implementing efficient fleet management, eco-driving practices, and integrated emission reduction policies as part of corporate sustainability strategies.

Keywords: analyze environmental impact, LCA, OpenLCA, ReCipe Midpoint (H), vehicle emissions.

1. Introduction

Transportation serves as a fundamental component in supporting various socio-economic activities, including those in the telecommunications industry. Operational vehicles, which are utilized for tasks such as network maintenance, equipment distribution, and on-site customer services, play a strategic role in ensuring service continuity and performance [1]. The reliability and availability of these vehicles significantly influence the operational efficiency and quality of services delivered by the company.

Despite their functional importance, the use of fossil fuel-powered vehicles contributes to various environmental issues. Combustion of gasoline emits pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM_{10}), all of which are recognized as contributors to environmental degradation [2]. These pollutants are associated with adverse effects including global warming, acid deposition, declining air quality, and increased human health risks. According to national emissions inventories, the transportation sector is

DOI:10.4186

among the largest sources of greenhouse gas (GHG) emissions in Indonesia, with a consistent upward trend.

In light of these concerns, a comprehensive scientific approach is required to quantify and evaluate the environmental impacts associated with the operation of company vehicles. One of the most widely adopted methodologies for such assessments is the Life Cycle Assessment (LCA), a standardized approach for quantifying environmental impacts throughout the life cycle of a product or activity, from raw material extraction and production to distribution, use, and final disposal [3]. LCA facilitates the identification of critical emission hotspots and supports the development of data-driven strategies for emission reduction [4].

The utilization of transportation systems to support the operational activities of the telecommunications industry, particularly in a geographically vast and heterogeneous region such as East Java, has the potential to significantly increase the ecological footprint of corporate operations. The high frequency of vehicle mobilization and the presence of suboptimal routing patterns contribute to excessive fuel consumption, which in turn leads to elevated emission levels [5]. Prior research has indicated that fleet activities in service-based sectors are among the primary contributors to emissions, making them a critical focus for sustainability efforts. In this context, telecommunications companies are increasingly expected to implement operational strategies that align with national climate commitments and corporate sustainability goals encompassing Environmental, Social, and Governance (ESG) [6].

Recent technological innovations and evolving policy frameworks offer promising avenues for emission reduction [7]. The adoption of low-emission vehicles, the utilization of digital systems for route optimization, and the implementation of behavioral efficiency programs such as eco-driving training have proven effective in lowering energy consumption and minimizing environmental impacts [8]. Furthermore, the incorporation of Life Cycle Thinking into strategic decision-making enables organizations to assess environmental impacts not only from direct operations but also from upstream and downstream logistics activities. This comprehensive approach supports the transition toward more sustainable fleet management while creating opportunities for economically feasible and environmentally beneficial decarbonization initiatives [9].

This study aims to analyze the environmental impacts resulting from the operation of gasoline-fueled vehicles used by a telecommunications company in East Java. The assessment is carried out using OpenLCA software with the Ecoinvent 3.3 database and the ReCiPe Midpoint (H) impact assessment method. The study emphasizes the use phase of the vehicle life cycle, identified as the most emission-intensive stage [10]. The results are expected to provide quantitative data on environmental burdens and support the development of sustainable fleet management policies, such as vehicle optimization, implementation of eco-driving practices, and integration into corporate sustainability strategies [11].

2. Material and Method

Goal and Scope Definition

This stage involves defining the functional unit and creating a conceptual map of the transportation process (operational vehicles), followed by the collection of data on fuel consumption, distance traveled, and emissions of carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides, hydrocarbons (HC), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM_{10}) in East Java for the year 2024.

Inventory Analysis

The collected data from both primary and secondary sources are then entered into Microsoft Excel to calculate the input and output data used in the transportation process (operational vehicles) at PT. X throughout the year 2024 in the East Java region.

Impact Assessment

Input data based on gasoline fuel consumption in the East Java region for 2024 is used to calculate the emissions generated using emission factors derived from [12] concerning Air Pollution Control in the Region. Emissions from the transportation process (operational vehicles) are then entered as outputs in the OpenLCA software, due to limitations in the database for including the inputs used. Subsequently, an automatic calculation of the environmental

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impacts is performed using the characterization factors from the ReCiPe Midpoint (H) method in OpenLCA software.

Table 1. Emissions Factor

Polluter	CO (g/km)	HC (g/km)	NOx (g/km)	PM_{10} (g/km)	CO_2 (g/kg BBM)	SO_2 (g/km)
Motorcycle	14	5.9	0.29	0.24	3180	0.008
Gasoline Car	40	4	2	0.01	3180	0.026
Diesel Car	2.8	0.2	3.5	0.53	3172	0.44

Source: Peraturan Menteri Lingkungan Hidup No. 12/2010

Table 2. Characterization Emissions Factor ReCipe Midpoint H

Dampak Lingkungan	Kontribusi Emisi	Faktor Karakterisasi
Climate Change	Karbon Dioksida (CO2)	1.000 kg CO2-Eq/kg
Marine Eutrophicatiom	Nitrogen Oksida (NOx)	0.389 kg N-Eq/kg
Particulate Matter Formation	Nitrogen Oksida (NOx)	0.220 kg PM10-Eq/kg
	Sulfur Dioksida (SO2)	0.200 kg PM10-Eq/kg
Photochemical Oxidant Formation	Nitrogen Oksida (NOx)	1.000 kg NMVOC/kg
Terrestrial Acidification	Nitrogen Oksida (NOx)	0.560 kg SO2-Eq/kg
	Sulfur Dioksida (SO2)	1.000 kg SO2-Eq/kg

Source: Characterization Factor Impact Analysis OpenLCA method ReCipe Midpoint H

Tier 2 Method

For accurate estimation of emissions in the transportation sector, methodologies must consider variations in vehicle characteristics and usage patterns. The Tier 2 method, as recommended in the Intergovernmental Panel on Climate Change *Guidelines for National Greenhouse Gas Inventories*, utilizes more specific input data than Tier 1, such as vehicle type, fuel type, and actual fuel consumption or travel distance [13]. This enables more accurate GHG emission estimates and aligns with the requirements of LCA studies focusing on operational transportation systems [14].

Tier 2 method relies on more specific data compared to Tier 1 by taking into account factors such as vehicle type, fuel type, and actual fuel consumption or distance traveled. This approach enables more accurate emission estimates, as it incorporates emission factors specific to each vehicle and fuel category [15].

This method employs national emission factors as stipulated in [12] concerning Regional Air Pollution Control. The emission load (E) is calculated using the following formula:

$$E = Number\ of\ Vehicles \times L \times FE \times 10^{-3}$$

E = Emission load (kilograms)
L = Total distance travelled (km)
FE = National Emission Factor (g/km/vehicle)
10^{-3} = Conversion factor from grams to kilograms

Table 3. Emissions Factor Petrol Car

Polluter	CO (g/km)	HC (g/km)	NOx (g/km)	PM_{10} (g/km)	CO_2 (g/kg BBM)	SO_2 (g/km)
Gasoline Car	40	4	2	0.01	3180	0.026

Source: Peraturan Menteri Lingkungan Hidup No. 12/2010

Interpretation

After obtaining the environmental impact values from the transportation process (operational vehicles) in East Java for the year 2024, further analysis was conducted to identify the emission types that contributed most significantly to environmental impacts. Additionally, the analysis determined which cities exhibited the highest environmental impacts for each impact indicator. Based on these findings, improvement recommendations were proposed to help minimize the environmental burden and reduce the contribution of major emission sources.

3. Results and Discussion

PT. X is a telecommunications company analyzed in this study to assess the environmental impacts arising from the operation of its fleet vehicles, with a case study focused on the East Java region. The analysis covers seven areas, including Area 3 (Head Office), Branch Surabaya, Branch Sidoarjo, Branch Malang, Branch Lamongan, Branch Madiun, and Branch Jember. Each of these locations provided application-based data for individual vehicles, presenting monthly records of travel distance and gasoline fuel consumption.

Table 4. Distance and Fuel Consumption Data by Region

		JAN	FEB	MAR	APR	MEI	JUN	JUL	AGU	SEP	OKT	NOV	TOTAL
AREA 3	Distance (km)	30299	28332	30174	21217	36361	29692	37223	36175	26912	35431	36016	347833
	Total fuel (lt)	3125	2825	3042	2218	3721	3179	3887	3820	2968	3997	4299	37081
BRANCH SURABAYA	Distance (km)	19925	15606	16422	14448	20219	16376	18992	18428	16912	20145	17414	194887
	Total fuel (lt)	2431	1926	1963	1921	2672	2197	2517	2404	2350	2954	2687	26022
BRANCH SIDOARJO	Distance (km)	22791	18917	21620	21616	26140	21126	28363	23934	19639	24373	20869	249388
	Total fuel (lt)	2330	1974	2286	2393	2807	2343	3050	2740	2309	2895	2423	27550
BRANCH LAMONGAN	Distance (km)	17314	15690	19357	18316	19520	22167	22319	23163	19961	23417	20382	221607
	Total fuel (lt)	2177	1988	2297	3064	3363	3847	4170	3987	3363	3895	3677	35830
BRANCH MADIUN	Distance (km)	28820	27294	25150	30776	29922	26823	29567	29534	23034	30654	30455	312028
	Total fuel (lt)	3285	2835	2737	3914	4183	4360	4184	4173	3355	4308	4256	41590
BRANCH JEMBER	Distance (km)	18342	18405	20039	21038	26839	19318	27089	23092	19101	23983	21516	238761
	Total fuel (lt)	1815	1802	1982	2057	2919	2153	2889	2455	2028	2644	2240	24983
BRANCH MALANG	Distance (km)	0	0	0	0	0	0	21924	17071	18566	20796	20280	98637
	Total fuel (lt)	0	0	0	0	0	0	3106	2437	2509	2839	2666	13557

Source: Operational Vehicle Data of the Telecommunications Industry at PT. X in 2024

The data above presents the monthly travel distance and fuel consumption for each region within the East Java area throughout 2024 (January–November). The data were aggregated monthly for each region, covering fuel consumption (with a gasoline density of 0.75) and travel distance, based on a total of 86 operational vehicles in the East Java area in 2024.

3.1. Tier 2 Method

Formula Emissions Load (kilograms)

$$E = Number\ of\ Vehicles \times L \times FE \times 10^{-3}$$

1. Area 3 (Head Office)

$$E = 14 \times 347{,}833 \times FE \times 10^{-3}$$

Table 5. Emission Load Calculation Tier-2 Method in Area 3 (Head Office)

Polluter	CO (kg/km)	HC (kg/km)	NOx (kg/km)	PM_{10} (kg/km)	CO_2 (kg/kg BBM)	SO_2 (kg/km)
Gasoline Car	19,478.648	1,947.864	973.932	4.869	123,813.459	12.661

2. Branch Surabaya

$$E = 11 \times 194{,}887 \times FE \times 10^{-3}$$

Table 6. Emission Load Calculation Tier-2 Method in Branch Surabaya

Polluter	CO (kg/km)	HC (kg/km)	NOx (kg/km)	PM_{10} (kg/km)	CO_2 (kg/kg BBM)	SO_2 (kg/km)
Gasoline Car	8,575.028	857.502	428.751	2.143	68,267.717	5.573

3. Branch Sidoarjo

$$E = 9 \times 249{,}388 \times FE \times 10^{-3}$$

Table 7. Emission Load Calculation Tier-2 Method in Branch Sidoarjo

Polluter	CO (kg/km)	HC (kg/km)	NOx (kg/km)	PM_{10} (kg/km)	CO_2 (kg/kg BBM)	SO_2 (kg/km)
Gasoline Car	8,977.968	897.796	448.898	2.244	59,136.075	5.835

4. Branch Lamongan

$$E = 11 \times 221{,}607 \times FE \times 10^{-3}$$

Table 8. Emission Load Calculation Tier-2 Method in Branch Lamongan

Polluter	CO (kg/km)	HC (kg/km)	NOx (kg/km)	PM_{10} (kg/km)	CO_2 (kg/kg BBM)	SO_2 (kg/km)
Gasoline Car	9,750.708	975.070	487.535	2.437	94,000.005	6.337

5. Branch Madiun

$$E = 15 \times 312{,}028 \times FE \times 10^{-3}$$

Table 9. Emission Load Calculation Tier-2 Method in Branch Madiun

Polluter	CO (kg/km)	HC (kg/km)	NOx (kg/km)	PM_{10} (kg/km)	CO_2 (kg/kg BBM)	SO_2 (kg/km)
Gasoline Car	18,721.680	1,872.168	936.084	4.680	148,788.225	12.169

6. Branch Jember

$$E = 14 \times 238{,}761 \times FE \times 10^{-3}$$

Table 10. Emission Load Calculation Tier-2 Method in Branch Jember

Polluter	CO (kg/km)	HC (kg/km)	NOx (kg/km)	PM_{10} (kg/km)	CO_2 (kg/kg BBM)	SO_2 (kg/km)
Gasoline Car	13,370.616	1,337.061	668.530	3.342	83,418.237	8.690

7. Branch Malang

$$E = 12 \times 98{,}637 \times FE \times 10^{-3}$$

Table 11. Emission Load Calculation Tier-2 Method in Branch Malang

Polluter	CO (kg/km)	HC (kg/km)	NOx (kg/km)	PM_{10} (kg/km)	CO_2 (kg/kg BBM)	SO_2 (kg/km)
Gasoline Car	4,734.576	473.457	236.728	1.183	38,800.134	3.077

3.2. Life Cycle Assessment Analysis

Life Cycle Assessment (LCA) is an environmental assessment tool that serves as a

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basis for informed decision-making regarding a production system. According to ISO 14040, the LCA consists of four key phases: goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation. The environmental impact assessment of the transportation process (operational vehicles) in the telecommunications industry at PT. X follows these stages:

Goal and Scope Definition

The goals of this study are:

1. To identify the environmental emission contributions from gasoline - fuelled operational vehicles over one year of operation.
2. To provide a foundation for decision-making related to carbon emission reduction and operational efficiency.

The scope of the study includes:

1. Product function: Operational transportation for PT. X in conducting technical and logistical activities.
2. System boundaries: Gate-to-Gate, including distribution (operational) processes and fuel consumption in vehicles.
3. Impact assessment method: ReCiPe Midpoint (H), using the Eco invent 3.3 database.

Life Cycle Inventory (LCI)

The inventory data input into OpenLCA for the East Java area includes:

1. Vehicle type: Gasoline-powered cars
2. Total fuel consumption: 206,613 litters
3. Total distance: 1,663,140 km
4. Emission data calculated using the Tier-2 method and aligned with the characterization factors for each impact category

Life Cycle Impact Assessment (LCIA)

The impact assessment was conducted using the ReCiPe Midpoint (H) method, which produces 18 impact categories. The five categories that were analyzed due to their significant impact are:

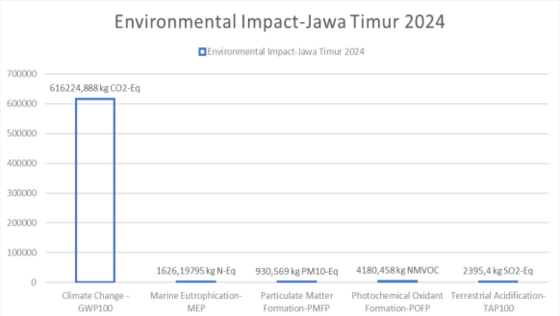

Fig 1: Result Environmental Impact Jawa Timur 2024

1. Climate Change:
   Impact value: 616,224.888 kg CO2-Eq
2. Marine Eutrophication:
   Impact value: 1,626.19795 kg N-Eq
3. Particulate Matter Formation:
   Impact value: 930.569 kg PM10-Eq
4. Photochemical Oxidant Formation:
   Impact value: 4,180.458 kg NMVOC
5. Terrestrial Acidification:
   Impact value: 2,395.4 kg SO2-Eq

1. Climate Change

Vehicle activities emit greenhouse gases such as carbon dioxide (CO_2). The accumulation of these gases in the atmosphere leads to global climate change, characterized by rising average global temperatures, sea level rise, and increased frequency of extreme weather events such as droughts and floods. These impacts pose serious risks to natural ecosystems, food security, and human livelihoods [16].

2. Marine Eutrophication

Nitrogen oxide (NO_x) emissions from vehicles can be deposited into water bodies via wet deposition. This leads to excessive nutrient enrichment in marine environments, triggering algal blooms. When the algae die and decompose, dissolved oxygen levels decline sharply, resulting in the formation of "dead zones" that threaten the survival of fish and other marine organisms. This phenomenon also disrupts marine food chains and degrades water quality for human use [17].

3. Particulate Matter Formation

Vehicles emit both primary particulates and precursor gases such as NO_x and SO_2, which contribute to the formation of secondary particulates ($PM_{2.5}$ and PM_{10}) in the atmosphere. These fine particles can be inhaled deep into the human respiratory system, leading to severe health issues including asthma, chronic bronchitis, cardiovascular diseases, and even lung cancer. Moreover, particulate matter reduces air quality and visibility, particularly in urban areas [18].

4. Photochemical Oxidant Formation

Emissions of volatile organic compounds (VOCs) and NO_x from motor vehicles can react under sunlight to produce tropospheric ozone (ground-level ozone). This process leads to the formation of photochemical smog, which poses respiratory health risks and damages agricultural crops. Elevated ozone concentrations in urban areas further degrade the quality of life [19].

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5. Terrestrial Acidification

Emissions of NO_x and SO_2 also contribute to soil acidification through the formation of acid rain. This lowers soil pH, damages soil structure, reduces agricultural productivity, and impairs forest growth. Moreover, acidified soils can release toxic heavy metals into groundwater, thereby threatening the quality of drinking water [20].

Interpretation

1. Climate Change

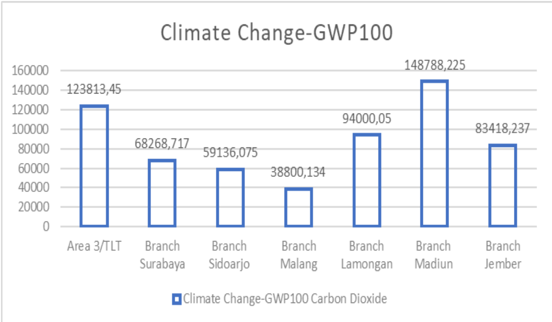

Fig 2: Result Chart Climate Change

In the Climate Change impact category, each region exhibits varying levels of contribution, which depend on the concentration of carbon dioxide (CO_2) emissions associated with fuel consumption and distance by operational vehicles. The emission values recorded are as follows: Area 3 with 123,813.45 kg CO_2-Eq, Branch Surabaya with 68,268.717 kg CO_2-Eq, Branch Sidoarjo with 59,136.075 kg CO_2-Eq, Branch Malang with 38,800.134 kg CO_2-Eq, Branch Lamongan with 94,000.05 kg CO_2-Eq, Branch Madiun with 148,788.225 kg CO_2-Eq, and Branch Jember with 83,418.237 kg CO_2-Eq.

2. Particulate Matter Formation

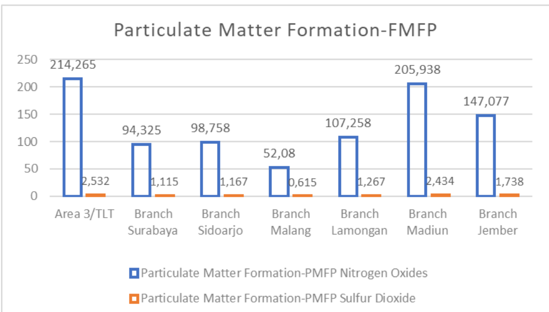

Fig 3: Result Chart Particulate Matter Formation

In the Particulate Matter Formation impact category, each region exhibits varying levels of contribution, which depend on the concentration of nitrogen oxides (NOx) and sulfur dioxide (SO_2) emissions associated with fuel consumption and distance by operational vehicles. The emission nitrogen oxides (NO_x) values recorded are as follows: Area 3 with 214.265 kg N-Eq, Branch Surabaya with 94.325 kg N-Eq, Branch Sidoarjo with 98.758 kg N-Eq, Branch Malang with 52.08 kg N-Eq, Branch Lamongan with 107.258 kg N-Eq, Branch Madiun with 205.938 kg N-Eq, and Branch Jember with 147.077 kg N-Eq. The emission sulfur dioxide (SO_2) values recorded are as follows: Area 3 with 2.532 kg SO_2-Eq, Branch Surabaya with 1.115 kg SO_2-Eq, Branch Sidoarjo with 1.167 kg SO_2-Eq, Branch Malang with 0.615 kg SO_2-Eq, Branch Lamongan with 1.267 kg SO_2-Eq, Branch Madiun with 2.434 kg SO_2-Eq, and Branch Jember with 1.738 kg SO_2-Eq.

3. Marine Eutrophication

In the Marine Eutrophication impact category, each region exhibits varying levels of contribution, which depend on the concentration of nitrogen oxides (NO_x) emissions associated with fuel consumption and distance by operational vehicles. The emission values recorded are as follows:

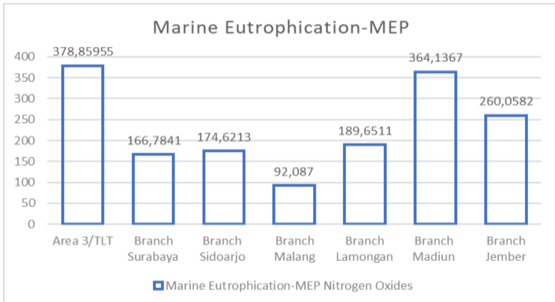

Fig 4: Result Chart Marine Eutrophication

Area 3 with 378.85955 kg N-Eq, Branch Surabaya with 166.7841 kg N-Eq, Branch Sidoarjo with 174.6213 kg N-Eq, Branch Malang with 92.087 kg N-Eq, Branch Lamongan with 189.6511 kg N-Eq, Branch Madiun with 364.1367 kg N-Eq, and Branch Jember with 260.0582 kg N-Eq

4. Photochemical Oxidant Formation

In the Photochemical Oxidant Formation impact category, each region exhibits varying levels of contribution, which depend on the concentration of nitrogen oxides (NO_x) emissions associated with fuel consumption and distance by

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operational vehicles. The emission values recorded are as follows:

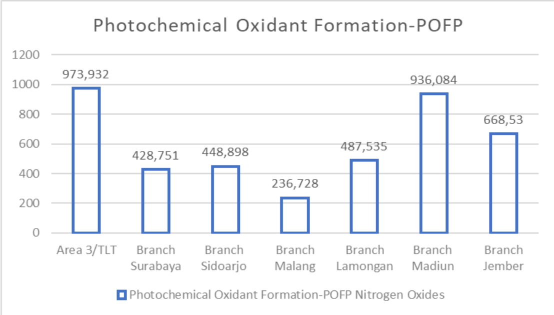

Fig 5: Result Chart Photochemical Oxidant

Area 3 with 973.932 kg N-Eq, Branch Surabaya with 428.751 kg N-Eq, Branch Sidoarjo with 448.898 kg N-Eq, Branch Malang with 236.728 kg N-Eq, Branch Lamongan with 487.535 kg N-Eq, Branch Madiun with 936.084 kg N-Eq, and Branch Jember with 668.530 kg N-Eq

5. Terrestrial Acidification

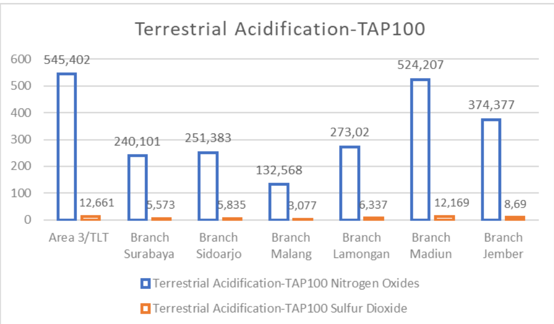

Fig 6: Result Chart Terrestrial Acidification

In the Terrestrial Acidification impact category, each region exhibits varying levels of contribution, which depend on the concentration of nitrogen oxides (NOx) and sulfur dioxide (SO_2) emissions associated with fuel consumption and distance by operational vehicles. The emission nitrogen oxides (NO_x) values recorded are as follows: Area 3 with 545.402 kg N-Eq, Branch Surabaya with 240.101 kg N-Eq, Branch Sidoarjo with 251.383 kg N-Eq, Branch Malang with 132.568 kg N-Eq, Branch Lamongan with 273.02 kg N-Eq, Branch Madiun with 524.207 kg N-Eq, and Branch Jember with 374.377 kg N-Eq. The emission sulfur dioxide (SO_2) values recorded are as follows: Area 3 with 12.661 kg SO_2-Eq, Branch Surabaya with 5.573 kg SO_2-Eq, Branch Sidoarjo with 5.835 kg SO_2-Eq, Branch Malang with 3.077 kg SO_2-Eq, Branch Lamongan with 5.337 kg SO_2-Eq, Branch Madiun with 12.169 kg SO_2-Eq, and Branch Jember with 8.69 kg SO_2-Eq.

4. Conclusions

Based on the results of the LCA study analyzing the transportation process (operational vehicles) of PT. X in 2024 in the East Java area. The total fuel (gasoline) consumption was 206,613 liters, with a travel distance of 1,663,140 km and a fleet of 86 vehicles. From this data, the environmental impact values obtained using OpenLCA with the ReCiPe Midpoint (H) method were: 616,224.888 kg CO_2-Eq Climate Change, 1,626.19795 kg N-Eq Marine Eutrophication, 930.569 kg PM_{10}-Eq Particulate Matter Formation, 4,180.458 kg NMVOC Photochemical Oxidant Formation, and 2,395.4 kg SO_2-Eq Terrestrial Acidification.

These findings emphasize the implementation of more sustainable transportation solutions, such as transitioning to low-emission or electric vehicles and optimizing travel routes. The adoption of environmental policies and effective fleet management practices can help reduce the environmental impacts associated with mobility in the telecommunications sector.

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DOI:10.4186