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Analysis of Carbon Footprint Emissions Generated From Operational Vehicle Activities at PT X

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ABSTRACT

Along with the increasing global awareness of environmental issues, companies are facing challenges in reducing carbon footprint emissions generated from their operational activities. The objectives of this study are to calculate the amount of carbon footprint emissions produced by operational vehicle activities; to analyze the existing carbon footprint emissions at PT X and to determine effective measures to minimize carbon footprint emissions resulting from PT X operational activities. The data collected consist of primary and secondary data, which are then processed and analyzed using quantitative descriptive analysis. The results show that the total annual greenhouse gas (GHG) emissions amount to 73,53 tons CO_2eq/year, representing the accumulation of three types of greenhouse gases, namely CO_2, CH_4, and N_2O. During 2023/2024, the highest GHG emissions were recorded in September & October, with a total of 6,63 tons CO_2eq/year. The high level of GHG emissions in 2023 was influenced by an increase in operational activity intensity, mainly due to most projects being in the completion phase toward the end of the year, which significantly increased mobility. The most effective measure to minimize carbon footprint emissions from PT X operational activities is the implementation of a gradual mitigation strategy through a combination of conventional vehicles and electric vehicles, accompanied by operational efficiency improvements. This approach is able to significantly reduce emissions while maintaining realistic costs and operational readiness for PT X.

Keywords: *Carbon emissions, Carbon footprint, Operational vehicles*

1. INTRODUCTION

Global warming is a phenomenon characterized by the continuous increase in the Earth's atmospheric temperature caused by the greenhouse effect [1]. Researchers estimate that the concentration levels of carbon monoxide and carbon dioxide in the atmosphere show the highest percentage compared to other emission variables. Human activities are one of the main sources of carbon emissions. The increase in carbon emissions is directly proportional to the intensity of human activities. The causes of global warming are closely related to the extensive combustion of fossil fuels, such as petroleum and coal, both of which produce large amounts of greenhouse gas emissions, particularly carbon dioxide (CO_2), which is estimated to reach approximately 18.35 billion tons annually [2].

Recent data indicate that the Earth's temperature has increased by 1.5°C, a condition that must be addressed seriously to prevent further escalation. Nationally Determined Contribution (NDC) represents commitments made by each country to reduce greenhouse gas emissions and adapt to climate change in accordance with the Paris Agreement 2015 [3]. Indonesia targets a 29% reduction in GHG emissions from the baseline by 2030. This commitment forms part of Indonesia's contribution to global efforts to limit global warming to no more than two degrees Celsius. Currently, the government's main efforts focus on the forestry and land-use sector, known as Forestry and Other Land Uses (FOLU), as well as the energy sector [4].

PT X is a company engaged in engineering consultancy and is a subsidiary of PT XYZ, which operates in the Engineering, Procurement, and Construction (EPC) sector. With increasing global awareness of environmental issues, companies face challenges in reducing carbon footprint emissions generated from their operational activities. This issue became more relevant during the 2023–2024 period, when post-COVID-19 conditions led to an increase in projects and workforce demand, resulting in higher employee mobility and fuel consumption. To address this challenge, PT X established Key Performance Indicators (KPI) in the environmental aspect, targeting carbon emission reduction through periodic monitoring every quarter as part of environmental performance evaluation.

The environmental performance overview in this study refers to the 2024 Sustainability Report of PT XYZ as the parent company. The report highlights the

obligation to disclose sustainability performance and shows significant environmental progress. In 2024, PT XYZ successfully reduced greenhouse gas emissions by 29,722.54 tons CO_2e, a substantial increase compared to 598.39 tons CO_2e in 2023. Additionally, the company recorded energy savings of 310,899.06 GJ in 2024. The GHG emission intensity for Scope 1 and 2 was recorded at 177.20 tons CO_2e per million USD revenue, while Scope 3 emissions reached 5,403.57 tons CO_2e per million USD revenue [5]. These achievements reflect continuous efforts to reduce environmental impact through energy efficiency and emission management.

As an entity involved in technical planning, project supervision, and field coordination, PT X operational activities are not limited to office work but also include employee mobility using operational vehicles to support project execution across various locations. In addition to vehicle activities, the physical workplace also plays a significant role in operational processes. Based on the office layout, PT X has two main buildings (front and rear) with four floors used for administration, technical planning, meeting rooms, and supporting facilities. Although not precisely measured, the building area is estimated to be between ±2,900–3,500 m², indicating a medium-scale office operation with high employee activity levels.

Based on the 2024 Sustainability Report of PT XYZ, the company regularly monitors greenhouse gas emissions, including emissions from operational vehicle fuel consumption. In 2024, a reduction of 29,722.54 tons CO_2e was achieved through various energy efficiency measures and operational adjustments, including optimized vehicle usage and reduced fossil fuel consumption [5]. Among various emission sources, operational vehicles were selected as the main focus because they are fully controlled by the company, allowing more accurate data collection on fuel consumption, travel distance, and maintenance. Based on this background, this study aims to calculate carbon footprint emissions from PT X operational vehicles, analyze existing emissions, and determine effective measures to minimize them.

2. LITERATURE REVIEW

Global warming results from solar radiation entering the Earth's atmosphere, where infrared radiation is converted into heat energy absorbed by air and the Earth's surface. Industrial activities, vehicle emissions, electricity generation, and forest fires are major contributors to greenhouse gas emissions that cause global warming [6]. One of the primary sources of greenhouse gas emissions is the transportation sector, which relies on fossil fuels to power engines and produces gases such as carbon dioxide (CO_2), methane (CH_4), and hydrocarbons [7].

A carbon footprint is the total measurement of carbon dioxide emissions, both direct and indirect, resulting from human activities or excessive product use in daily life [8]. It represents the impact of human activities on the environment and climate change, particularly through increased greenhouse gas emissions. Emissions are gases released into the atmosphere due to certain activities, typically from vehicles, factories, or power plants [9]. Emission factors are ratios that relate the amount of pollutant emissions to measurable activity levels, such as processed materials or fuel consumption [10]. Once emission factors and activity levels are known, their multiplication results in emission load values.

The growing demand for transportation increases energy consumption for mobility. Greater access to vehicle ownership leads to higher dependence on fossil fuels. The combustion of fossil fuels produces CO_2 and other greenhouse gases that contribute to global warming and climate change [11]. The first step in calculating emissions from transportation is determining energy consumption, followed by emission calculation. The formulas are [12]:

a. Energy Consumption = Fuel Volume (L) × Calorific Value
b. CO_2 Emissions = Energy Consumption × Emission Factor

The following are the emission factors for fuel combustion:

Table 1. Fuel Emission Factor Value

No	Fuel Type	Tier 1 (Kg CO_2/TJ)
1	RON 92	69300
2	RON 90	72600

The calculation of CO_2 emissions is carried out by multiplying the volume of fuel consumed by the emission factor corresponding to the type of fuel used. The emission factor represents the average value of air pollutant parameters released from a specific source. It is defined as the amount of greenhouse gas (GHG) emissions released into the atmosphere per unit of a particular activity [13].

The calculation method based on fuel consumption has a higher level of reliability compared to the method based on travel distance (Cunningham, 2008). Therefore, it is recommended to use the fuel-based method in calculating CO_2 emissions from fuel consumption. In general, the equation used to estimate GHG emissions can be expressed in a simple form, as shown in the following equation:

$$\text{Emisi GRK} = \text{DA} \times \text{FE}$$

Where:

- Activity Data (AD): level of human activity contributing to emissions.
- Emission Factor (EF): mission per unit activity

3. METHOD

This study was conducted using a quantitative descriptive method. This method involves data collection, data interpretation, as well as the presentation and analysis of results [14]. The research was carried out at PT X, located in West Jakarta, with an area of 2,997 m² and geographical coordinates of 6°09'50.6" S and

106°46'22.7" E. The study was conducted at the head office of PT X, and the objects of the research were limited to operational vehicles.

Data collection was carried out to obtain the necessary information to support the research. Primary data were obtained through observations and interviews, while secondary data were sourced from the IPCC 2006 guidelines and PT X. Data analysis was conducted based on the collected data, after both primary and secondary data had been obtained through direct observation and interviews with respondents.The carbon emission calculation method in this study refers to the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. 73 of 2017 concerning the National Greenhouse Gas Inventory, using the IPCC (Intergovernmental Panel on Climate Change) standard.

Carbon footprint calculations are performed by converting emission data into carbon dioxide equivalent (CO_2eq) [8]. The formula used to calculate the carbon footprint from vehicle activities applies the Tier 1 method [7] :

$$Emisi = KBB \times NCV \times FE \times GWP$$

Informations:
E : Total Emmision (kg CO_2eq)
KBB : Fuel Consumption (L)
NCV : Net Calorific Value (TJ/L)
FE : Faktor Emisi (kg CO_2/TJ)
GWP : *Global Warming Potential* (CO_2eq)

After obtaining the results of the CO_2 emission calculations, the next step is to determine appropriate emission reduction measures.

4. FINDINGS AND DISCUSSION

The total carbon footprint emissions are obtained from the accumulation of emissions generated by the use of operational vehicles. The details of total emissions and the percentage distribution of emissions from operational vehicle activities are visualized in the following diagram:
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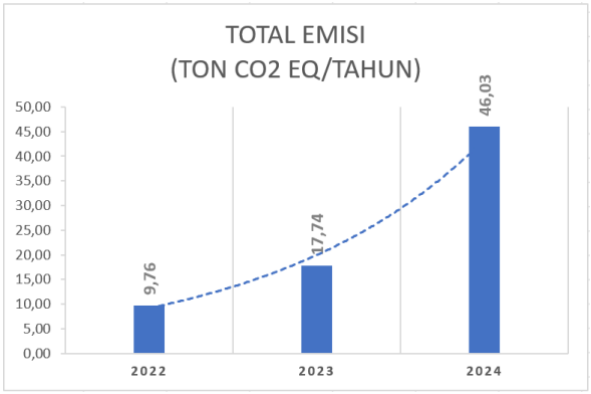


Figure 1. Total Carbon Emissions Diagram

Based on Figure 1, there is a significant increase in emissions from 2022 to 2024. In 2022, emissions were recorded at 9.76 tons CO_2eq, then increased to 17.74 tons CO_2eq in 2023. A sharper rise occurred in 2024, with total emissions reaching 46.03 tons CO_2eq.

This upward trend indicates an increase in operational activities alongside the growing number of projects, which contributed to the surge in annual emissions. The total carbon footprint emissions generated from 2022 to 2024 amounted to 73.53 tons CO_2eq/year.

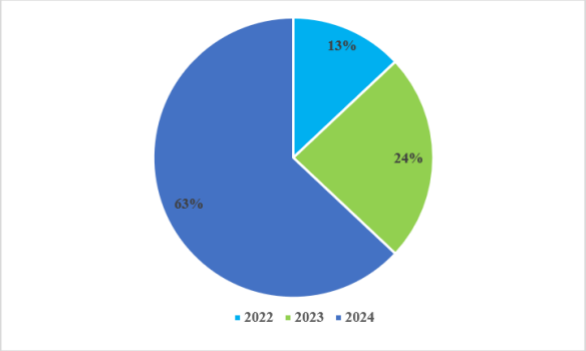


Figure 2. Total Carbon Emission Percentage Diagram

Based on Figure 4.6, the percentage of carbon footprint emissions shows a significant increase over the 2022–2024 period. In 2022, emissions were recorded at 13%, then increased to 24% in 2023, representing an 11% rise.

A much larger increase occurred in 2024, with the percentage reaching 63%, an increase of 39% compared to the previous year. Overall, emissions over the three-year period show a total increase of 50%, reflecting the growth in operational activities alongside the increasing number of projects undertaken.

The carbon footprint emission reduction program proposed in this study is implemented through two approaches, namely internal and external systems [15]. The internal system focuses on activities directly related to company operations, such as fuel switching from Pertalite to Pertamax and the replacement of production equipment with more efficient technologies to reduce emissions generated from operational processes. Meanwhile, the external system is directed at efforts outside the core production activities, one of which includes transitioning from conventional vehicles to electric vehicles (EV). This external strategy not only supports significant emission reductions in the transportation sector but is also aligned with national policies toward achieving the Net Zero Emission (NZE) target.The comparison of efficiency and operational costs across the scenarios is presented in Table 2

Table 2. Comparison of Efficiency and Operational Costs Between Scenarios

Scenario	Emmison (ton/tahun)	Emission Reduction (%)	Cost (Rp)	Cost Savings (%)
BBM	9,16 ton	–	Rp 51,8 jt	–
EV	4,90 ton	**46,5%**	Rp 10,2 jt	**80,4%**
combination	7,03 ton	**23,3%**	Rp 31,0 jt	**40,2%**

Based on various studies, operational efficiency in the context of sustainability is not only

measured by a company's ability to reduce carbon emissions, but also by aspects of operational cost savings and the ease of implementing strategies.

This is because there is a trade-off as well as co-benefits between cost and environmental impact, thus requiring an integrated approach in operational decision-making [16 [17].

a. Scenario 1: Fuel-Based Vehicles (Pertamax/RON 92)

This scenario produces emissions of 9.16 tons of CO_2eq per year. As it serves as a baseline condition based on fossil fuel use, this scenario does not demonstrate any emission reductions or operational cost savings. Its advantage lies in the ease of implementation, as it does not require changes to the fleet or infrastructure. However, operational costs remain high and are dependent on fossil fuel prices, making this scenario the least efficient from both environmental and long-term economic perspectives. A study by Hawkins et al. indicates that fossil fuel-powered vehicles (internal combustion engine/ICE) produce higher greenhouse gas (GHG) emissions compared to electric vehicles, particularly during the use phase (fuel combustion) [18].

b. Scenario 2: Electric Vehicles (EV)

The electric vehicle scenario produces emissions of 4.90 tons of CO_2eq per year, indicating an emission reduction of 46.5% compared to fossil fuel-powered vehicles. In terms of operational costs, this scenario also provides the greatest savings, at approximately 80.4%. This demonstrates that electric vehicles are highly efficient from both environmental and energy cost perspectives.

However, their implementation requires adequate infrastructure readiness and initial investment in electric vehicles, making full short-term adoption a potential challenge for companies. Recent studies show that electric vehicles can significantly reduce carbon emissions compared to conventional vehicles, especially when powered by low-carbon electricity [19].

c. Scenario 3: Combination of 50% Fuel-Based Vehicles and 50% EV

The combined scenario produces emissions of 7.03 tons of CO_2eq per year, with an emission reduction of 23.3% compared to full fossil fuel use. In terms of cost, this scenario is able to provide operational savings of approximately 40.2%. This indicates that a combined approach can significantly reduce both emissions and costs, while also minimizing the risk of large upfront investments.

Therefore, this scenario is more flexible and realistic as a transitional step toward a lower-emission operational transportation system. Review studies suggest that a transitional approach (a combination of conventional and electric/hybrid vehicles) is a practical strategy for gradually reducing emissions without requiring substantial immediate investment [20].

5. CONCLUSIONS

Based on the conducted study, the following conclusions can be drawn:

1. The total annual carbon footprint emissions from 2022 to 2024 amount to 73.53 tons CO_2eq/year, representing the accumulation of three types of greenhouse gases, namely CO_2, CH_4, and N_2O.
2. A significantly higher increase occurred in 2024, with the percentage reaching 63%, an increase of 39% compared to the previous year. This indicates a rise in operational activities alongside the increasing number of projects undertaken.
3. The most effective measure to minimize carbon footprint emissions from PT X's operational activities is the implementation of a gradual mitigation strategy through a combination of conventional vehicles and electric vehicles, supported by operational efficiency improvements. This approach is capable of significantly reducing emissions while maintaining reasonable costs and operational readiness for PT X.

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