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Emission Inventory of Greenhouse Gases in Yogyakarta for the Transportation Sector

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Abstract
D.I. Yogyakarta is one of the major provinces in Java, Indonesia, with a population of 3.8 million in 2020. The region is characterized as an education and tourism hub, which has driven continuous growth in transportation activities. The number of registered vehicles in Yogyakarta in 2020 reached approximately 3.5 million units, with motorcycles contributing more than 80% of the total. The increase in motor vehicle usage has raised concerns about the contribution of the transportation sector to greenhouse gas (GHG) emissions and air pollution. However, total emissions from this sector are not well documented. This study estimated GHG emissions from the transportation sector in Yogyakarta using a bottom-up emission inventory method based on vehicle activity data, fuel consumption, and emission factors. Policy interventions such as EURO IV implementation were evaluated using the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model to assess their effectiveness in reducing emissions. The results from 2015 data show that total emissions from the transportation sector reached approximately 2.05 Mt GHGs/year. The implementation of EURO IV alone shows a relatively limited reduction; therefore, it is expected that this scenario should be combined with other control measures such as the adoption of electric vehicles, CNG, electronic road pricing (ERP), and other complementary strategies.

Keywords: *Emission inventory, pollutants, transportation, Yogyakarta*

Introduction

Rapid urbanization in *D.I.* Yogyakarta has resulted in environmental challenges, particularly air pollution. The city of Yogyakarta and its surrounding regencies (*Sleman*, *Bantul*, *Kulon Progo*, *Gunungkidul*) are highly dependent on motorcycles and private vehicles as the main mode of transport, due to limited public transportation systems ((IEA), 2021; Indonesia, 2017; (IPCC), 2022). This has caused steady growth in fuel consumption and corresponding pollutant emissions ((MEMR), 2019; Sims et al., 2014).

The transportation sector has emerged as one of the major contributors to GHG emissions in Yogyakarta, with vehicle ownership reaching approximately 3.5 million units in 2020, with motorcycles constituting more than 80% of the total fleet (Creutzig et al., 2015). Despite this significant contribution, there is a lack of comprehensive and up-to-date emission inventories specifically for the transportation sector in Yogyakarta, making it difficult to formulate effective mitigation strategies and evaluate the impact of existing policies (Bertello Ardha M. & Cierra M., 2016; Bieker, 2023; Province, 2025).

The urgent need for this research stems from Yogyakarta's unique position as both an education and tourism hub, which continuously drives transportation activities (Murphy et al., 2025). Without proper intervention, emissions from this sector are projected to increase substantially, contributing to climate change and deteriorating air quality (Jaikumar et al., 2019). The implementation of evidence-based policies is crucial to mitigate these impacts and support sustainable urban development (Hidrue et al., 2017).

Previous studies on emission inventories in Indonesia have primarily focused on major metropolitan areas like Jakarta, with limited attention to secondary cities like Yogyakarta (Ratnawati et al., 2025; Shahbazi et al., 2022). While some research has addressed general air quality issues in the region, comprehensive studies specifically targeting GHG emissions from the transportation sector remain scarce (Nilrit et al., 2022). Existing literature also shows a gap in the evaluation of policy effectiveness, particularly regarding the implementation of EURO IV standards and other emission control measures in the context of Yogyakarta's unique vehicle composition and usage patterns (Fong et al., 2016).

This study introduces several novel aspects: (1) development of a comprehensive GHG emission inventory specifically for Yogyakarta's transportation sector, considering its unique vehicle fleet dominated by motorcycles; (2) evaluation of policy interventions, including EURO IV implementation, in the context of a motorcycle-dominated transportation system; (3) spatial distribution analysis of emissions to identify hotspots and support targeted policy interventions; and (4) projection of emission trends under various scenarios up to 2030.

The main objectives of this research are: (1) to develop a comprehensive GHG emission inventory for Yogyakarta's transportation sector; (2) to evaluate the effectiveness of various emission control scenarios, particularly EURO IV implementation; and (3) to provide policy recommendations for emission reduction strategies. The benefits of this research include providing policymakers with evidence-based data to support decision-making, contributing to the development of effective emission reduction strategies, and serving as a reference for similar studies in other Indonesian cities with comparable transportation characteristics. The findings are expected to support Yogyakarta's efforts in achieving sustainable urban transportation and contributing to national climate change mitigation goals (Lestari et al., 2022).

Similar to other urban regions in Indonesia, transportation is one of the main contributors to GHG emissions in Yogyakarta. Policy measures such as the planned implementation of EURO IV standards, promotion of compressed natural gas (CNG), and restrictions on vehicle operations are potential solutions to mitigate emissions. This research provides an emission inventory for Yogyakarta's transport sector and evaluates control scenarios to identify the most effective emission reduction strategies.

Methodology

This study consisted of several stages: literature study to determine the scope of the study, determination of objectives, data collection, data calculation, determination of control scenarios, construction of air pollution models using GAINS, scenario comparison and analysis, construction of spatial distribution models using GIS, conclusions, and determination of scenario recommendations. Before being able to build a model of air pollution using the GAINS model and GIS, some calculations are required in advance from the secondary data that has been obtained. These calculations include the projection of vehicle population numbers, the calculation of energy needs obtained from fuel requirements and VKT (Vehicle Kilometers Travel) values. Then, the results of the calculations are prepared in the GAINS model input format. The following section presents the formulas used and the principles of the formulas in the GAINS online model.

$$Emission = \sum_{abcd}\left(EF_{0bcd}\left(1-\eta_{0bcd}\right)X_{0bcd}\right) * Activities_{0bcd}) \quad (1)$$

Emission: total emission; EF: emission factor (mass per unit of activity; Activities: activity data (fuel/energy consumption); □: efficiency of control technology; and X: absorption of strategy control.

Control Scenarios

Before determining the control scenario, the first step is to calculate the emissions without any treatment or application of any scenario, namely the calculation of BAU (Business as Usual) emissions. Furthermore, the determination of control scenarios is carried out simultaneously with the calculation of secondary data. The purpose of developing control scenarios is to be able to compare the results of reducing or controlling air pollution between the initial air pollutant database (without control scenarios) and the air pollution data after certain controls are implemented. In this research, control scenarios are carried out as follows, along with their explanations: the application of EURO IV standards for passenger vehicles, buses, and trucks that takes effect from October 2018 (for gasoline-powered vehicles) and from April 2021 (for diesel-fueled vehicles).

Results and Discussion

Vehicle Population and Energy Needs

The rapid increase in vehicle ownership in Yogyakarta highlights a transportation system dominated by motorcycles. In 2020, motorcycles accounted for 83% of the 3.5 million registered vehicles, followed by gasoline passenger cars, diesel passenger cars, trucks, and buses. This trend is consistent with other Indonesian provinces where motorcycles serve as the most affordable and flexible mode of transport. Projections indicate that by 2030, the motorcycle fleet will surpass 3.6 million units, maintaining its dominance. Figure 1 shows the projection of vehicles population in Yogyakarta (Shrestha et al., 2020).

This growth translates into significant increases in energy demand. Fuel consumption is largely driven by motorcycles and passenger cars, which also makes them the largest contributors to carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions. Consequently, the transportation sector has emerged as one of the major sources of GHG emissions in Yogyakarta. Projections until 2030 indicate continuous growth, with motorcycles remaining dominant. Energy demand calculations show that motorcycles and passenger cars are the primary fuel consumers, significantly influencing CO_2 and other pollutant emissions.

The implications of this trend are twofold: (1) a steep rise in energy demand, particularly gasoline, and (2) a disproportionate contribution to GHG emissions from motorcycles relative to their fuel efficiency. Motorcycles, despite their smaller engines, contribute heavily to emissions due to their sheer numbers, relatively low fuel efficiency per passenger-kilometer, and limited adoption of advanced emission control technologies.

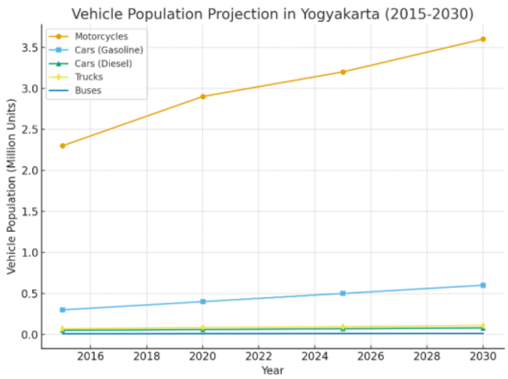

Figure 1. Vehicle Population Projection in Yogyakarta

Source: Processed from BPS data for DIY Province (2025) and the author's projections

Pollutant Emissions

The emission inventory shows that GHG emissions from the transportation sector in Yogyakarta were approximately 2.05 Mt CO_2-eq/year in 2015, projected to rise to 3.45 Mt CO_2-eq/year by 2030 under the Business as Usual (BAU) scenario. Motorcycles contribute around 65% of the total emissions. The evaluation of control scenarios demonstrates 6% reduction by 2030. However, even the most effective combination modeled in this study does not fully offset the projected emission increase. This suggests that without more ambitious interventions—such as large-scale electrification, modal shifts to public transport, and demand management—emissions from Yogyakarta's transport sector will continue to rise (Siregar et al., 2025).

Figure 2 shows the GHGs emission Projection in Yogyakarta. The spatial analysis highlights clear emission hotspots in Yogyakarta City, especially in areas with heavy traffic volumes such as Malioboro Street, the Northern Ring Road, and major corridors connecting Sleman and Bantul. In contrast, peripheral districts such as Kulon Progo and Gunungkidul exhibit significantly lower emissions due to reduced traffic intensity (Sheldon et al., 2025). This spatial pattern underlines the importance of targeted interventions. Policies such as traffic restrictions and public transport promotion are likely to be most effective in high-density urban centers.

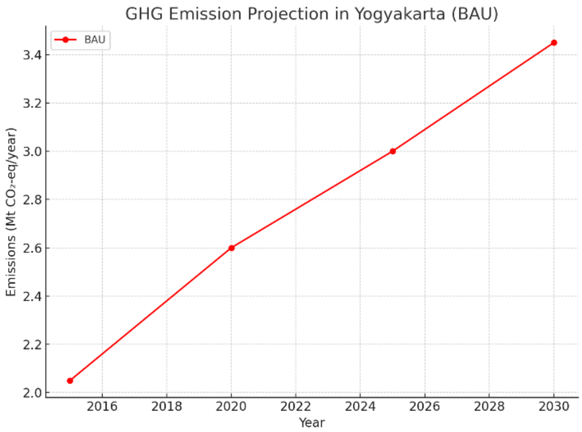

Figure 2. GHG Emission Projection in Yogyakarta

Source: Processed from BPS data for DIY Province (2025) and the author's projections

Conclusion

This study demonstrates that the transportation sector is a critical driver of GHG emissions in *D.I.* Yogyakarta, with motorcycles as the predominant contributor. The BAU scenario forecasts a steady rise in emissions through 2030, underscoring the urgent need for intervention. While EURO IV adoption marks an important milestone, its emission reduction potential is modest (6%). This indicates that while EURO IV provides a necessary regulatory baseline, it is not sufficient on its own to significantly curb future emission growth. Therefore, EURO IV should be considered a baseline policy, not a standalone solution. It must be complemented with transformative strategies, including electrification of transport fleets, particularly motorcycles and public buses; compressed natural gas (CNG) adoption to diversify cleaner fuel options; electronic road pricing (ERP) and other demand management tools to discourage excessive use of private vehicles; expansion of public transport networks and promotion of non-motorized modes to provide viable alternatives; and urban planning reforms aligned with transit-oriented development to reduce travel demand. These integrated measures are essential not only to achieve meaningful emission reductions but also to deliver co-benefits in terms of improved air quality, reduced congestion, and enhanced public health.

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