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Assessment of Greenhouse Gas Emission Reduction Potential through Transition from Gasoline-Powered to Electric Motorcycles by using SUMO: Preliminary Case Study of Sathorn Area in Bangkok

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ABSTRACT

This research investigates the potential environmental impact of transitioning from gasoline-powered motorcycles to electric motorcycles in terms of greenhouse gas emissions in road transport. The handbook emission factors for road transport have been deployed in the simulation of urban mobility traffic simulator to perform a thorough analysis of the Sathorn road network area in Bangkok, Thailand, as a case study of a highly congested urban scenario. The objective of this research is to increase sustainability and provide clean energy solutions in the transport sector through the adoption of electric motorcycles. A mix of gasoline-powered motorcycles and cars has been set up in the simulation to emulate real-life traffic situations, serving as the baseline scenario. Afterwards, all gasoline-powered motorcycles have been replaced with electric motorcycles to serve as the post-transition scenario. We have analyzed the simulation results from both scenarios to quantify the impact of electric motorcycle usage on emissions and to understand how the adoption of electric motorcycles can significantly advance clean energy and foster a sustainable transport system. Emission outputs from the baseline Sathorn morning rush hour scenario have been measured and compared with the outputs from the post-transition scenario. The simulation result suggests that carbon monoxide, carbon dioxide, hydrocarbons, particulate matter, and nitrogen oxides can be reduced by 25.5%, 11.8%, 54%, 61.4%, and 40.3%, respectively. Hence, this preliminary finding shows that electric motorcycles play a significant role in reducing emissions and advancing clean energy to foster a sustainable transport system.

1. INTRODUCTION

The transportation industry is one of the major global contributors to greenhouse gas (GHG) emissions and over the years, the emissions from this industry have continued to increase with limited success in the efforts to reduce them [1]. As of February 2024, statistics from the department of land transport (DLT) show that Thailand is home to about 22.6 million motorcycles which constitute more than half of the entire vehicle fleet in the country [2] as seen in Figure 1. This can be attributed to the fact that in most developing countries, motorcycles are relatively more affordable than cars, have lower taxi fares and fuel costs per travelled distance, and greater flexibility during congestion periods, making them mostly used for personal and commercial purposes [3]. For these reasons, they should not be exempted from being a contributing factor to carbon footprints, but the past focus of literature mainly on cars and other larger vehicles, has often ignored motorcycles. As such, it becomes necessary to redirect attention toward motorcycles and analyze their environmental impacts.

As the urgency to address environmental concerns intensifies, the international energy agency (IEA) has set a formidable goal of achieving net zero emissions by 2050 [3]. This ambitious objective necessitates a thorough examination of all modes of transportation to accelerate progress toward a sustainable and environmentally friendly future. The main gases emitted by gasoline-powered vehicles are carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC), particulate matter (PM_x), and nitrogen oxides (NO_x) [5]. The negative effects these emissions have on human health and general well-being cannot be over-emphasized. For this reason, a comprehensive study is needed to evaluate the benefits of shifting from conventional gasoline-powered motorcycles to electric ones and offer more details into how the adoption of electric motorcycles can play an important role in advancing clean energy and fostering a more sustainable transport system.

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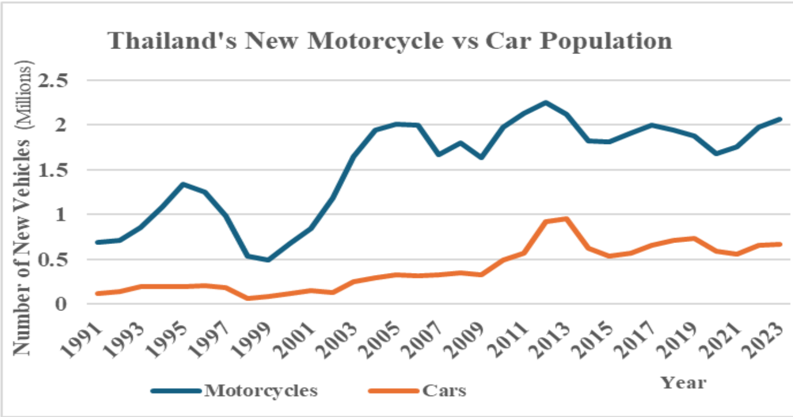


Fig. 1. Statistics of car vs motorcycle population in Thailand [2].

2. LITERATURE REVIEW

This section provides a brief overview of research articles that seek to expand on the potential environmental impacts of the transition, the willingness of consumers to adopt electric motorcycles, required technological advancements, and trade-offs of transition, providing a concise overview and analysis of the articles published in the past decade.

2.1 Potential Environmental Impacts of Transition

In-depth research on the energy utilization of gasoline-powered motorcycles and electric motorcycles in Thailand has been presented in [6]. Using the artificial neuro-fuzzy inference systems technique, the study focuses on identifying factors affecting energy usage, including engine size, motorbike age, distance traveled, and speed. The research demonstrates that electric motorcycles are substantially more energy-efficient compared to gasoline-powered motorcycles.

A detailed investigation into the emissions from electric motorcycles compared to internal combustion engine (ICE) has been presented in [7]. The study is distinctive for the use of computer vision for classifying and counting motorcycles in traffic videos, combined with ambient pollutant concentration monitoring. The findings reveal a complex emission profile that while replacing ICE with electric motorcycles can reduce emissions of fine particles, CO_2, and CO significantly, emissions of coarse particles and PM_{10} can be increased. This underscores the importance of considering a wide range of pollutants in assessing the environmental benefits of vehicle electrification, beyond the typically focused exhaust emissions.

In [8], electric vehicles (EVs) have been shown to drastically reduce CO_2 emissions, up to 26 times lower than their gasoline counterparts. This reduction is achievable despite high CO_2 emissions from electricity generation, underscoring significant potential annual emission savings with the progressive implementation of electric vehicles. This article emphasizes the critical role of the energy matrix in influencing the environmental impact of switching to electric vehicles, demonstrating significant benefits in countries with renewable-dominant energy sources.

2.2 Consumer Willingness to Adopt Electric Motorcycles

In [9], the transition from gasoline-powered motorcycles to electric motorcycles has been found to improve local air quality and reduce hazardous emissions which in turn reduces local pollution and worldwide fossil fuel consumption. Also, the willingness of consumers to pay for enhanced electric motorcycle characteristics has been analyzed to determine their perceived worth and market growth.

Motorcycles contribute more to hydrocarbon emissions, while light and heavy-duty vehicles are the main contributors to PM_x with CO_2 being the main source of GHG pollution [10]. The acceptance of consumers to adopt electric motorcycles is influenced by factors like price, range, speed, and charging infrastructure.

According to [11], a thorough review of the pros and cons of electric vehicles in developing nations with a focus on electric four-wheelers, hybrid electric cars, and electric two-wheelers demonstrates that electric two-wheelers are a viable alternative due to their price and investigates several aspects impacting electric vehicle adoption. The study also identifies significant obstacles to widespread adoption of electric vehicles, such as the high cost, the lack of charging infrastructure, and the limited range of electric vehicles. The authors emphasize the importance of effective government policies to support the widespread adoption of EVs.

2.3 Required Technological Advancements

Insights into the technological achievability and environmental effects of electric motorcycles have been given in [12]. The information provided in this research can be particularly helpful in understanding the wider implications of motorcycle fleet electrification in developing countries as well as the associated issues, such as restricted range, battery life, and the need for enhanced electric vehicle regulations and battery recycling legislation.

The power quality impact of electric motorcycle charging on the electrical systems of households in Thailand, and the cost-effectiveness of electric motorcycles compared to ICE is the focus of [13]. Making use of three electric motorcycle models with varying battery capacities, the study simulates home power usage patterns in a laboratory, assessing the effect of electric motorcycles charging on different circuits.

With techniques to quantify and predict the energy usage of electric vehicles utilizing an innovative data collection technology [14], the data reveals electric vehicles perform better on in-city routes thanks to regenerative braking technology. An analytical model for predicting electric vehicle power based on vehicle dynamics and resistance forces, evaluated against real-world data has been recommended. The findings are relevant for future electric vehicle technology and transportation system management, suggesting real-time energy consumption feedback can drive more energy-efficient driving behaviors.

2.4 Transition Trade-offs

In [5], a detailed analysis of the environmental impact of transitioning from gasoline-powered commercial motorcycles to electric ones has been given. This study is significant in addressing the emission contributions of commercial motorcycles, a common means of transportation in many low and middle-income/developing countries, and presents an in-depth view of the emissions landscape, identifying reductions in CO, CO_2, HC, and NO_x emissions, but with a corresponding increase in PM_x which contributes to the understanding of the local and global environmental impacts of transport electrification, highlighting the complexities and trade-offs involved.

This research aims to fill the gap by quantifying the potential decrement in GHG emissions that can be achieved by transitioning from gasoline-powered motorcycles to electric motorcycles with a practical case study emphasis on urban congested area in Thailand. The research has been carried out by using the simulation of urban mobility (SUMO) traffic simulator and the handbook emission factors for road transport (HBEFA) emission model [15]. The focus is on the Sathorn road network area, which is in the heart of Bangkok and is, therefore, a perfect case study because of its highly congested traffic during morning traffic rush hours (6–9 am) on weekdays [17].

3. FORMULATION OF CASE STUDY AREA WITH PRACTICAL TRAFFIC SIMULATION

SUMO is an open-source, portable, and a microscopic traffic simulator mainly used for handling mobilities in road network simulations, developed by the German Aerospace Centre (DLR) [15]. Real-world traffic in large areas can be simulated for different vehicle types including cars, buses, motorcycles, trains, pedestrians, and other light-duty and heavy-duty vehicles [16]. This simulator finds application in a wide range of areas and is continually being developed to have a realistic/up-to-date features. SUMO has a large international user community and can be seamlessly used to simulate electric vehicles. In addition, SUMO has been calibrated with actual traffic data measurements to emulate the real-life traffic situations of the Sathorn road network area [17], chosen conveniently as a case study here and hence, the simulation finding validity expectedly obtainable in this study. Figure 2 shows the experimental design of simulation in SUMO. Simulation outputs can be directly used to evaluate realistic GHG emission outputs.

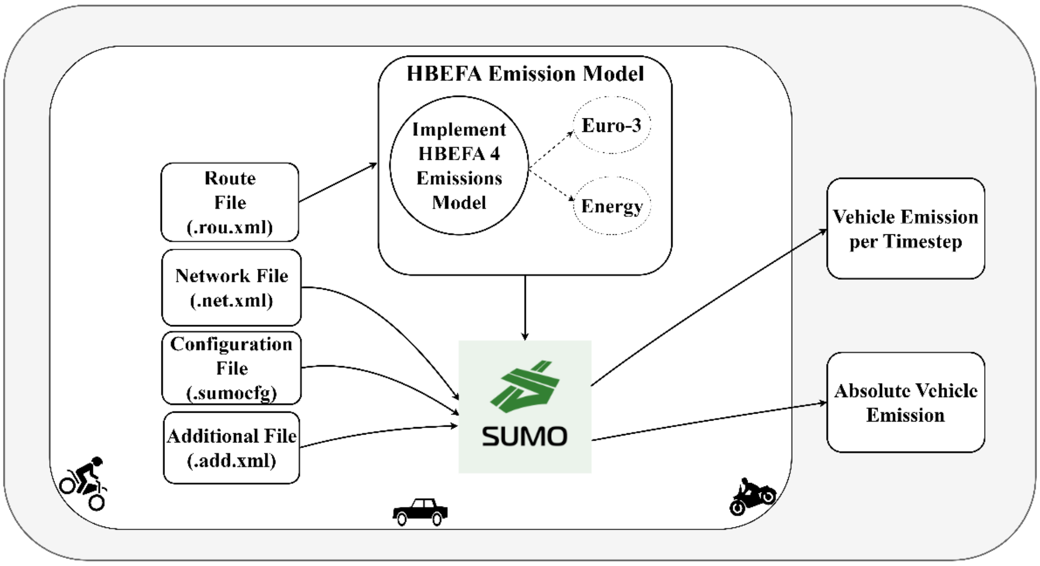


Fig. 2. Experimental design of simulation in SUMO.

4. HBEFA EMISSION MODEL AND EMISSION STANDARDS

HBEFA is a basis used for calculating road traffic emissions. The model has detailed emission factors for various pollutants emitted by different types of vehicles under different traffic scenarios. HBEFA defines emission factors for a wide range of vehicle classifications, fuel types, and technology standards, and is especially notable for having the capacity to compute emissions not just for individual vehicles but for complete vehicle fleets [15]. HBEFA is used by various interested parties including researchers, government agencies, policymakers, and transportation planners, to assess the environmental effects of road traffic, create and evaluate strategies for emission reduction, and comply with vehicle emissions standards. The occasional improvements in this emission model guarantee that the tool stays relevant and successful in the context of fast technological breakthroughs and shifting regulatory landscapes. This makes HBEFA a key resource for accurately projecting road transport emissions and driving toward sustainable transportation plans [17]. The HBEFA v4.2-based is used in this study because it is the latest version to record outputs for electricity consumption, and emissions specifically for motorcycles as well as other cars sharing the network.

The emission standards are a set of regulations that govern and limit the pollutant emissions from vehicles to improve air quality. The standards are categorized into Euro 1 up to Euro 5 for motorcycles and Euro 1 up to Euro 6 for cars as shown in Figure 3 and Figure 4, respectively. These standards are continually updated over time to be stricter and to allow for lower emissions of CO, HC, PM_x, and NO_x. Although the limit for PM_x has not been enforced until the advent of Euro 5, earlier motorcycles presumably emitted less than 0.0015 g/km of PM_x which is even less than the current 0.0045 g/km limit set for Euro 5 motorcycles [19].

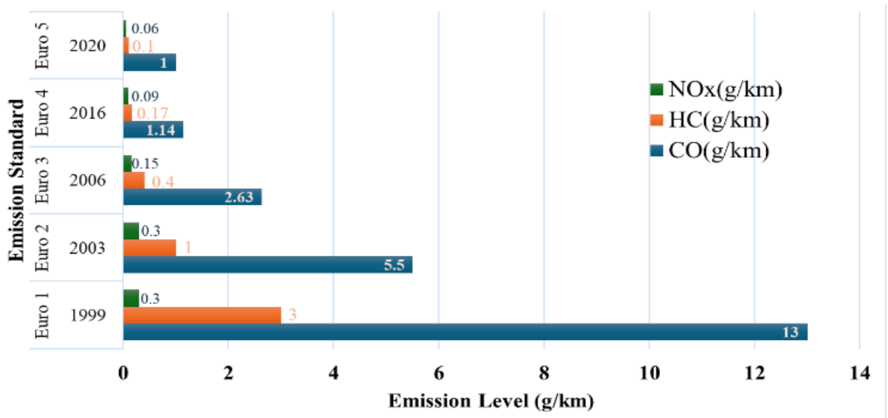


Fig. 3. Emission standards for motorcycles [19].

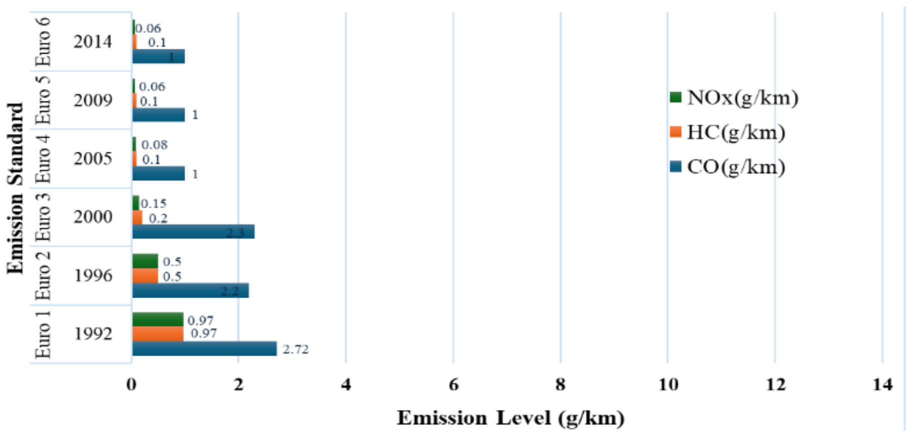


Fig. 4. Emission standards for cars [19].

4.1 Sathorn Road Network Area and Experimental Design

The Sathorn road network area is a study area for urban traffic management research in Bangkok Thailand. This area is known for heavy congestion during peak hours because the road network connects various residential and business districts across the province. For this reason, this area has been the focus of various traffic management research particularly the Chula-Sathorn SUMO simulator (Chula-SSS) [17] which has been designed to imitate and examine the movement of vehicles on roads by using real-time data for traffic signal control to reduce congestion with output evaluation by using the SUMO platform. The Chula-SSS contains information about vehicular flow, mainly cars, which must first be augmented in this paper with data on motorcycles to represent the vehicle distribution of cars and motorcycles. In this regard, the proportion of cars to motorcycles is 44:56 based on the statistics of the number of registered vehicles in Thailand from the Department of Land Transport averaged from 2018 to 2023 [2]. Figure 5 depicts the overall simulated area of Chula-SSS dataset [17]. So, the original traffic volume at each origin-destination route pair has been augmented by 56/44 times of the newly added motorcycle traffic volume at the same route pair. We have adopted the same settings as in [19] for other microscopic motorcycle mobility model parameters.

Fig. 5. Overall simulated area of Chula SSS dataset.

Table 1 shows the overall demand and network settings, while Table 2 shows the vehicle attribute settings, SUMO mobility model parameters for simulated cars and motorcycles [19] together with emission class settings.

Table 1. Overall demand and network settings.

Parameter	Settings
Simulation time	6-9 am weekdays
Number of edges	4,517
Number of routes	170
Number of intersection nodes	2,375
Number of vehicles	Over 55,000

Table 2. Vehicle attribute settings.

Parameter	Settings
Vehicle types	Cars, Motorcycles
Emission classes	HBEFA4/Euro-3, Electric
Acceleration	Motorcycles 4.0 m/s^2, Cars 2.0 m/s^2
Deceleration	Motorcycles 4.0 m/s^2, Cars 2.5 m/s^2
Free-flow speed	12.5 m/s
Length	Motorcycles 1.9m, Cars 4.62m
Width	Motorcycles 0.5m, Cars 1.7m

5. EXPERIMENTAL RESULTS

This section presents a comprehensive analysis of the simulated scenario results, discussing the observed trends and variations. The analysis provides insights into the effectiveness of transitioning from gasoline-powered to electric motorcycles for reducing emissions.

5.1 Simulation Result Analysis

Data visualization tools and statistical approaches have been used to reveal important insights from the emission outputs. This process improves the understanding of emission interdependence.

Figure 6 reveals several key relationships between the emission outputs of motorcycles. Results on emission of CO show a moderate negative correlation with HC and a strong negative correlation with CO_2, PMx, NOx, and fuel, suggesting an inverse relationship. Emission on CO_2 is strongly positively correlated with fuel consumption, PM_x, and NO_X indicating that as fuel consumption increases, CO_2, $PM_{x,}$ and NO_X emissions increase proportionally. HC emissions have a moderately positive correlation with CO_2, NOx, and PMx, implying that higher HC emissions are associated with higher CO_2, NOx, and PMx emissions. PM_x shows strong positive correlations with NO_x and fuel, suggesting interconnected emissions. NO_x emissions also have strong positive correlations with CO_2, $PM_{x,}$ and fuel consumption. Fuel consumption has a perfect positive correlation with CO_2 and PM_x, highlighting that fuel usage directly influences these emissions. This analysis underscores the interconnected nature of motorcycle emissions and fuel consumption.

Table 3 displays the statistics for gasoline-powered motorcycle emissions produced during the simulation.

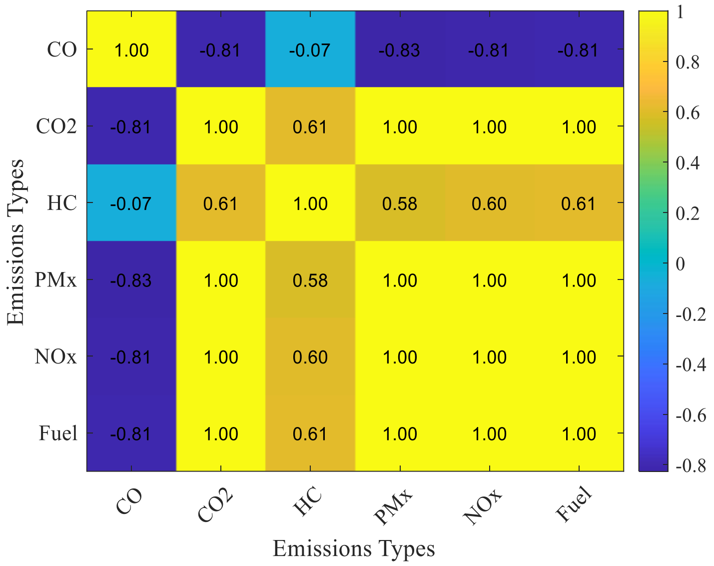
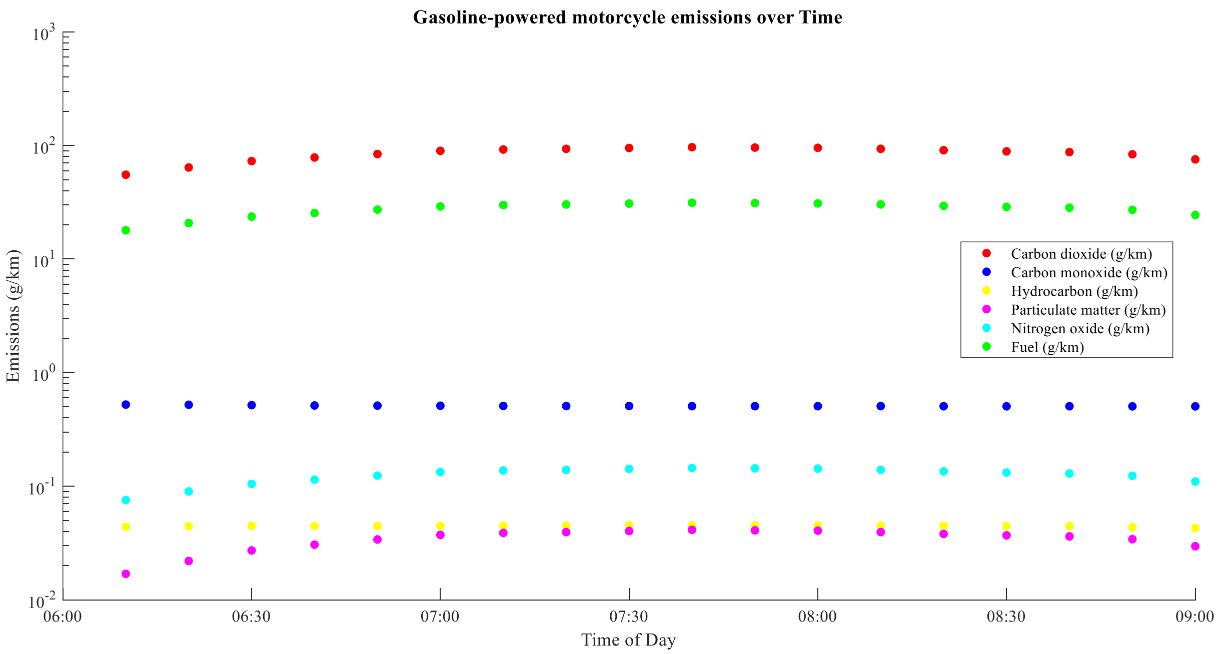


Fig. 6. Correlation of emissions from gasoline-powered motorcycles.

Table 3. Statistics of Euro-3 emission for gasoline-powered motorcycles.

Emission and fuel consumption output (g/km)	Mean value	Standard deviation (σ)	Min. value	Max. value	Emission standard limit	25^{th} percentile	75^{th} percentile
CO	0.5100	0.0054	0.5049	0.5231	2.6300	0.5063	0.5119
CO_2	85.0821	11.3813	55.2376	96.5433	-	79.6818	93.3439
HC	0.0446	0.0006	0.0429	0.0453	0.4000	0.0445	0.0450
PM_x	0.0346	0.0067	0.0169	0.0413	0.0015	0.0314	0.0395
NO_x	0.1257	0.0190	0.0755	0.1448	0.1500	0.1167	0.1395
Fuel	27.5827	3.6897	17.9074	31.2984	-	25.8319	30.2611



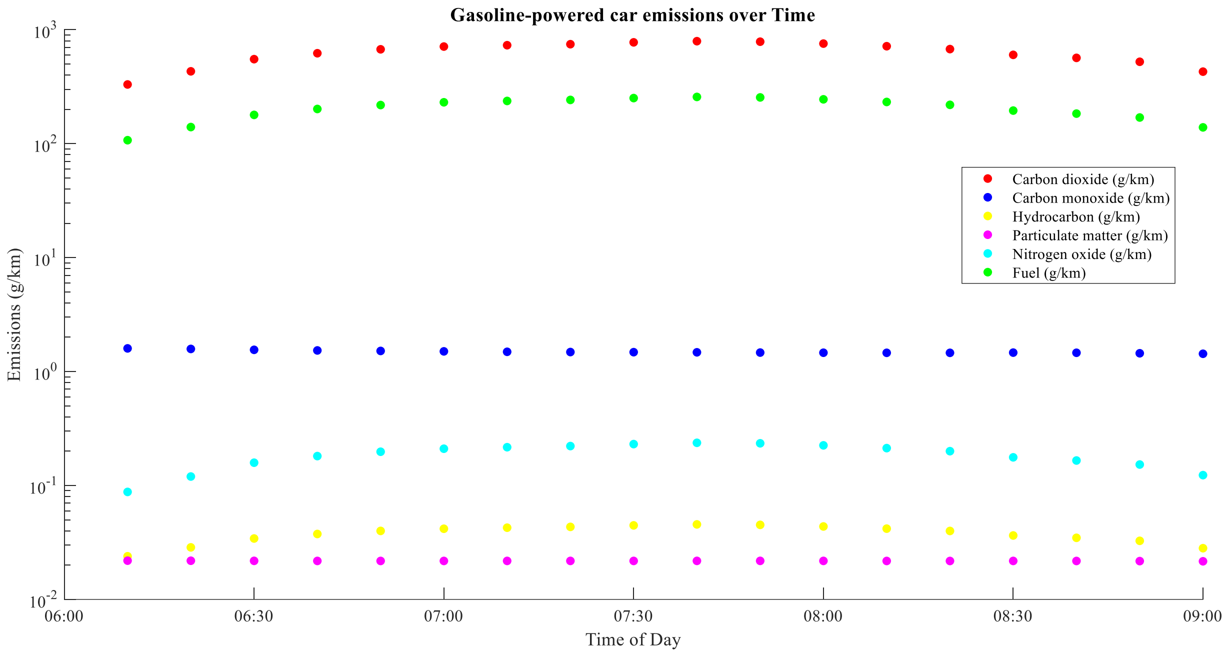
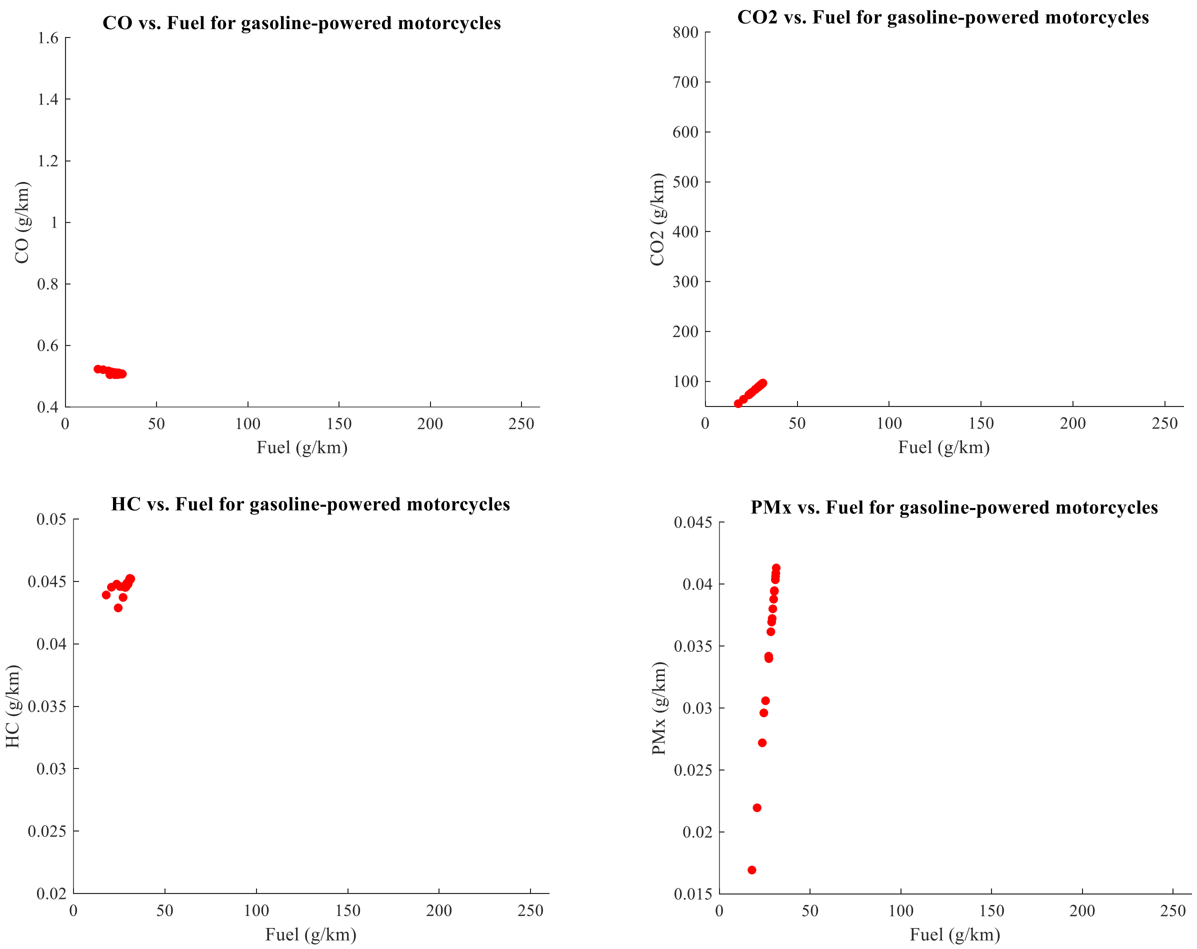


Fig. 7. Euro-3 emissions from gasoline-powered motorcycles and cars in baseline scenario during morning traffic rush hours.



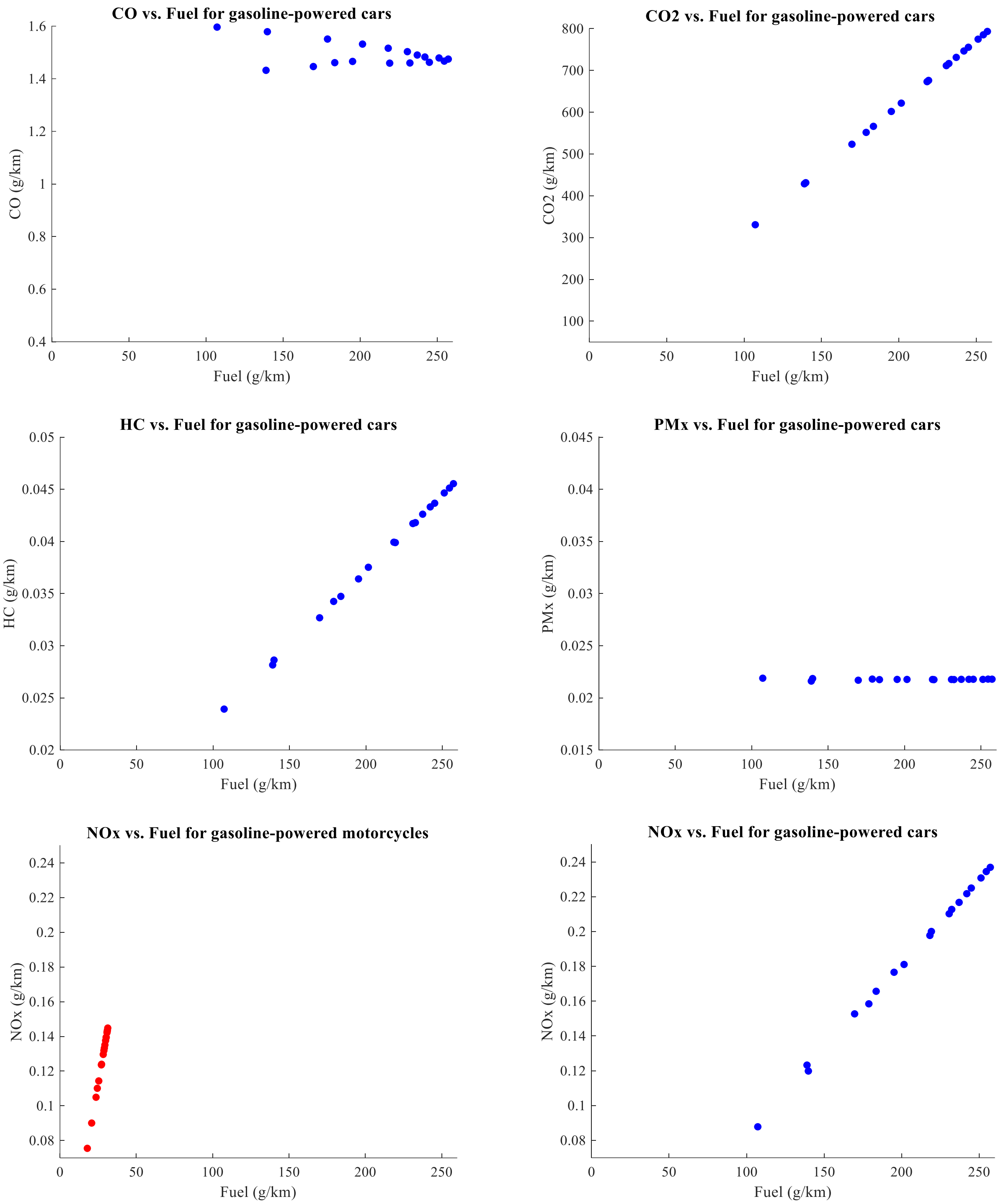


Fig. 8. Relationship between emissions and fuel consumption for Euro-3 gasoline-powered motorcycles and cars in baseline scenario during morning traffic rush hours.

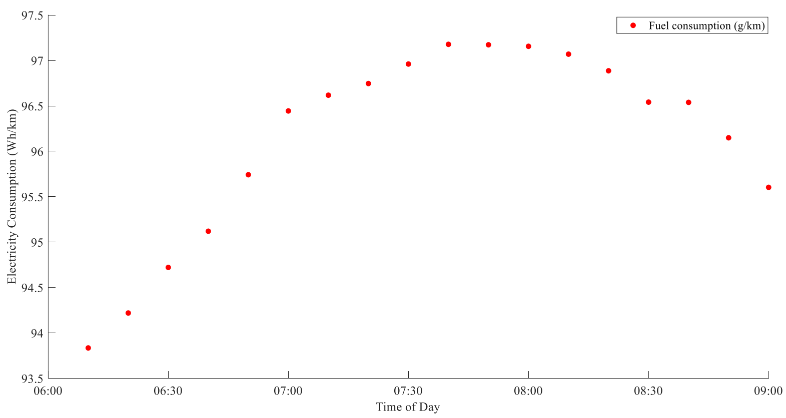


Fig. 9. Electricity consumption for electric motorcycles during morning traffic rush hours over time.

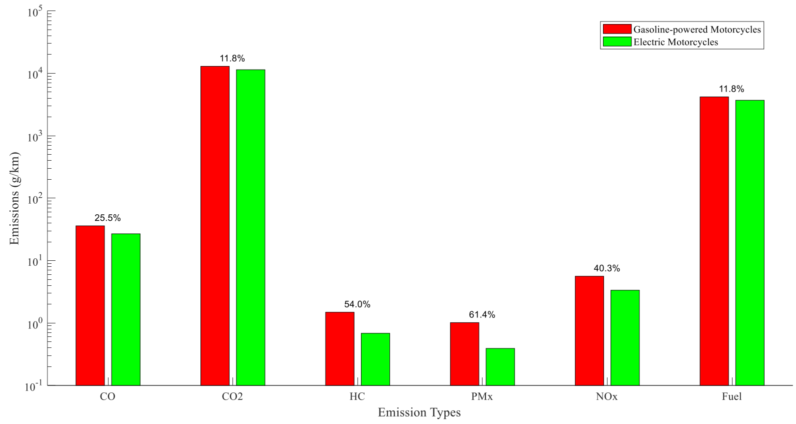


Fig. 10. Comparison of emissions between baseline scenario and post-transition scenario with numbers showing percentages of reduction.

5.2 Result Discussion

The transition from gasoline-powered to electric motorcycles presents a promising opportunity to reduce greenhouse gas emissions and improve urban air quality. Our study utilizes SUMO traffic simulator and HBEFA emission model to assess the emission outputs of both gasoline-powered and electric motorcycles under similar traffic conditions. The results indicate significant reductions in several key pollutants.

In Figure 7, we see the chart for Euro-3 emissions for morning configuration with 100% gasoline-powered motorcycles and cars during morning traffic rush hours. The charts in Figure 8 shows the relationships between each of the emissions and fuel consumption for both gasoline-powered motorcycles and cars from the baseline scenario. Although the average emissions per motorcycle appear to be lower than the average emissions per car for vehicles in the same emission class, the larger number of motorcycles in the area makes the total emissions from all gasoline-powered motorcycles higher than the total emissions from all gasoline-powered cars in the simulation. Figure 9 shows the average electricity consumed by each motorcycle during morning traffic rush hours in the post-transition scenario.

As a result of the total replacement of all gasoline-powered motorcycles with electric motorcycles, a reduction in emissions has been recorded, as seen in Figure 10. The study suggests that CO has been reduced by 25.5%, CO_2 by 11.8%, HC by 54%, PM_x by 61.4%, and NO_x by 40.3% by allowing all motorcycles to transition from gasoline-powered to electric motorcycles.

6. CONCLUSION

This study provides a comprehensive analysis of the potential for greenhouse gas emission reductions through the transition from gasoline-powered to electric motorcycles, using the SUMO traffic simulator and HBEFA emission model. The findings indicate significant reductions in emissions of CO, CO_2, HC, PM_x, NO_x, and fuel consumption when switching to electric motorcycles. The data suggests that the adoption of electric motorcycles can contribute substantially to reducing urban air pollution and mitigating climate change impacts. This transition not only supports environmental sustainability but also enhances urban air quality, thereby promoting public health.

7. STUDY IMPLICATION AND FUTURE RESEARCH

The results from this study illustrate the enormous environmental benefits of switching to electric motorcycles. Policymakers and urban planners should consider these findings when formulating solutions for sustainable urban transportation. A reduction in hazardous emissions can help cities reach their air quality and climate targets more successfully. Future research will focus on widening the study's scope to cover diversed traffic circumstances and geographical considerations. Future studies that follow the real-world data of emissions of electric motorcycles over extended periods would provide more comprehensive insights. Furthermore, future studies on the economic consequences of transitioning to electric motorcycles, including cost-benefit evaluations and the influence on energy infrastructure, would also be worth investigating.

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