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Emission inventory and climate benefits of alternative fuels for motorcycles in Ho Chi Minh City, Viet Nam

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Abstract. Transportation is a leading source of air pollution in Ho Chi Minh City (HCMC). Using the International Vehicle Emission (IVE) Model, an emissions inventory for motorcycles (MCs) was developed for 2024, with projections extended to 2030. The estimated CO_2 emissions were covered eight atmospheric pollutants, with climate forcers among them. To assess emissions from different vehicle types, data were collected through Global Positioning System (GPS) tracking and vehicle operational pattern surveys. Emission factors (EFs) for MCs were determined, and the potential reduction in pollutant emissions in terms of CO_2 equivalent (CO_2eq.) under fuel-switching scenarios was evaluated. The benefits resulting from enhanced air quality and efforts to reduce climate change impacts in CO_2eq., were quantified using the global warming potential (GWP) and EFs. Fuel switching is expected to yield substantial benefits. Specifically, under Scenario 1, in which 100 % of MCs transition to E5 fuel, total CO_2 emissions in 2030 would be reduced by 184 thousand tonnes (70.23 %). In Scenario 2, where 22 % of MCs are converted to electric power, emissions would decrease by 150 thousand tonnes (57.11 %).

Keywords: motorcycles, emission inventory, climate benefits, electricity, Ho Chi Minh.

Classification numbers: 3.4.5, 3.5.1, 3.3.1.

1. INTRODUCTION

Emission from vehicles is identified as one of main causing sources of air pollution in big cities in Viet Nam, including Ho Chi Minh City (HCMC), that leads to climate change [1]. According to data from the Viet Nam Register in 2024, Viet Nam had approximately more than 75 million MCs. The number of these vehicles is on the rise, contributing to increased emissions of air pollutants, which affect human health and exacerbate the impacts of climate change [2–4].

In major cities, particularly in special-class urban areas, traffic congestion frequently occurs, leading to severe air quality degradation [5, 6]. Vehicles emit harmful pollutants such as fine particulate matter, volatile organic compounds (VOCs), and carbon monoxide (CO) when using fuel for operation. These vehicles also emit greenhouse gases (GHGs) such as CO_2, CH_4, and N_2O, as well as substances that cause acid rain (SO_2 and NO_x) [7–9]. Additionally, black carbon and tropospheric ozone are recognized as potent climate change agents, with black

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carbon being emitted from diesel vehicles and tropospheric ozone formed through the photochemical reactions of NO_x, VOCs, and CO emissions [3, 10].

Due to the significant impacts of vehicle emissions on air quality, climate change, and human health, the Vietnamese government issued Decision No. 2157/QD-TTg on December 21, 2021, establishing a National Steering Committee to implement Viet Nam's commitments at COP26. The committee's mandate includes developing an action program for green energy transition, carbon and methane emission reduction in the transportation sector. Furthermore, the Prime Minister's Decision No. 876/QD-TTg on July 22, 2022, approved the action program for transition to green energy and mitigation of carbon dioxide and methane emissions from transportation, and Decision No. 1191/QD-BGTVT, promulgated a plan to reduce greenhouse gas emission in the transport sector by 2030.

Studying the shift toward more environmentally friendly fuels for vehicles in HCMC, a major urban center with a high volume of traffic, is crucial at this stage. There are multiple strategies to minimize vehicle emissions in large cities. This study aims to investigate the integration of alternative low-emission fuels, including compressed natural gas (CNG), liquefied petroleum gas (LPG), ethanol (E5), and electricity, in order to analyze their impact on vehicular emissions and to assess their potential contributions to enhancing air quality and mitigating climate change. The study will utilize the International Vehicle Emissions (IVE) model, developed by the University of California in collaboration with the College of Engineering-Center for Environmental Research and Technology (CE-CERT) and the Center for Sustainable Systems Research and Global Sustainable Systems Research [11]. The findings will help identify and recommend alternative fuels that effectively reduce emissions, ultimately enhancing air quality and contributing to climate change mitigation as well as ensuring the commitment of Viet Nam at COP26.

2. METHODOLOGY

2.1. Research design

The IVE model necessitates three categories of input data: location files, fleet files, and an optional base adjustment file [11]. While the location and fleet files are essential for model execution, the base adjustment file, requiring empirically measured local emission factors (EFs), was excluded due to the unavailability of such data for Ho Chi Minh City's vehicle fleets in 2024. Accordingly, this study employed only the location and fleet inputs for model simulation.

Upon integrating the location and fleet files, which were derived from local data surveys, into the IVE model, the model generated EFs for each identified vehicle technology category. Subsequently, total emissions, specifically the annual emissions for HCMC in 2024, were estimated by integrating the emission factors (EFs) with vehicle activity data, covering overall travel distance and how often the engine was started. This study quantified the emissions of a range of air pollutants, encompassing carbon monoxide (CO), volatile organic compounds (VOCs) originating from both exhaust and evaporative processes, nitrogen oxides (NO_x), nitrous oxide (N_2O), methane (CH_4), particulate matter (PM), sulfur dioxide (SO_2), and carbon dioxide (CO_2).

Data for the location and fleet input files were collected in accordance with the procedures specified in the IVE model's data collection guidelines. The analysis encompassed three road categories: highways, arterial roads, and residential streets, across three demographically and

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functionally distinct area within HCMC: a commercial district (Area A), a high-income residential area (Area B), and a low-income residential area (Area C), as depicted in Figure 1.

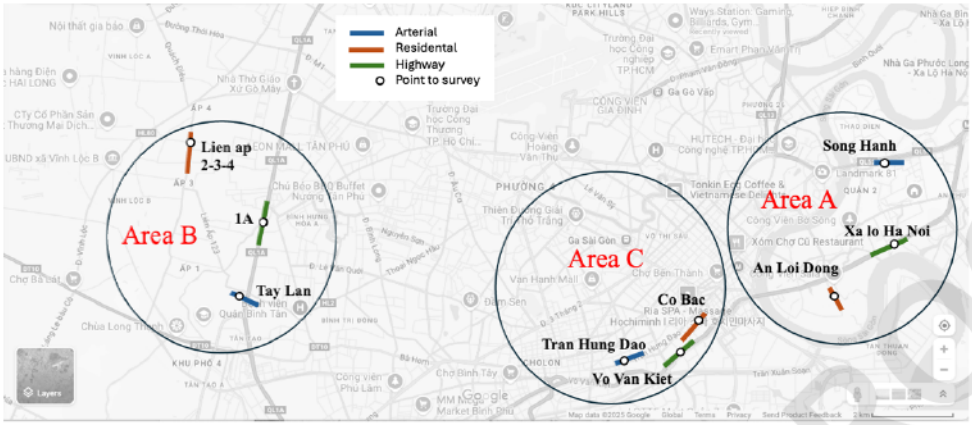

Figure 1. Map of the urban area of HCMC indicating the three designated study areas, the GPS-based route survey paths, and the locations of nine vehicle observation and counting points.

2.2. Methodology for data acquisition and preprocessing

Data were collected in HCMC over a six-month period, from October 2023 to March 2024. The dataset encompassed both primary and secondary sources. Primary data were obtained through field surveys of parking facilities and fuel stations, traffic volume counts, and observations of vehicle operational patterns. Secondary data consisted primarily of meteorological parameters. A summary of the methodology and the specific input variables utilized in the IVE model is provided in Table 1.

Table 1. Overview of the data acquisition process conducted in HCMC.

Type of data		Method	Input data in IVE model	Description
Primary	Parking lots and fuel stations survey	Questionnaire	Location file and Fleet input file	300 MCs
	Vehicle count	Manually	Fleet input file	Vehicle counts were conducted for 180 minutes at each of the nine selected road segments.
	Vehicle operational patterns (driving behaviours, engine start characteristic)	GPS logging device	Binning of vehicle activity and soak time intervals, as inputs for the fleet emission	Activity data were obtained by equipping 10 MCs with two GPS devices.
Secondary	Meteorological parameters and essential supplementary datasets	Publicly accessible datasets obtained from official governmental and institutional websites	Location file and fleet input file	Examples include vehicle registration statistics, ambient temperature and humidity records, and documentation from relevant research or infrastructure projects, etc.

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2.2.1. Survey of parking and refueling facilities

A stratified random sampling approach was employed to administer a questionnaire survey targeting MC fleets at multiple parking and refueling facilities across three distinct urban areas in HCMC. Employing the Taro Yamane sampling formula with a 10 % margin of error, a representative sample size of 300 vehicles was calculated to reflect the population of MCs in the city. This dataset facilitated a detailed characterization of vehicle technologies and usage patterns, encompassing vehicle classification, production year, age, engine configuration, average daily mileage, fuel type, and the presence of emission control technologies. The resulting information was subsequently used to derive key technological input parameters for the IVE model.

2.2.2. Monitoring of vehicle flow

Manual traffic counts were performed at a designated survey location along each of the nine selected roadways to quantify vehicular flow. Data collection occurred during three time periods per day: 07:00–09:00, 10:00–11:00, and 17:00–19:00. Consequently, a cumulative 180 minutes of data collection was conducted per selected road, a standardized protocol involving 15 minutes of uninterrupted vehicle counting with a 10-minute pause for rest thereafter was implemented.

2.2.3. Global position system survey

Driving and engine startup behaviors were characterized using data collected via a GPS survey. Each monitored vehicle was equipped with a Garmin GPSMAP 78S device throughout each observation day. The device recorded geospatial and temporal parameters, including longitude, latitude, altitude, velocity, and timestamp - at one-second intervals over continuous 24-hour periods on both weekdays and weekends. A total of 10 MCs were randomly selected for this monitoring campaign. The resulting GPS datasets facilitated the calculation of Vehicle Specific Power (VSP) (Equation (1)) and engine stress (ES) (Equation (2)) [10], which are critical metrics for profiling driving behavior. The classification framework included twenty VSP-defined operating modes and three levels of engine stress, yielding sixty distinct VSP bins per vehicle per monitored hour. Additionally, vehicle startup patterns were analyzed using GPS data, as these factors are integral to accurately quantifying vehicular exhaust emissions.

$$VSP = v\times[1.1\times a+9.81(\arctan(\sin(grade))) + 0.132] + 0.000302\times v^3, \text{ kW/ton} \quad (1)$$

Where: a – acceleration (m^2/s); v – speed (m/s); grade – road grade (radian)

$$ES \text{ (unitless)} = RPMIndex + (0.08 \text{ ton/kW})\times \text{Pre-averagePower} \quad (2)$$

Where: Pre-average Power = Average ($VSP_{t=-5 \text{ to } -25sec}$) (kW/ton); RPMIndex = $Speed_{t=0}$/ SpeedDivider (unitless), minimum RPMIndex = 0.9.

2.2.4. Secondary data acquisition

Hourly meteorological data, including temperature and humidity for Ho Chi Minh City, were obtained from the online weather data platform (www.climatereanalyzer.org). Key properties of conventional fuels, including diesel and gasoline were derived based on the specifications provided by Petrolimex standards, which specify a sulfur content limit of 0.05 mg/kg for diesel oil and 150 mg/kg for gasoline. The entire dataset served as input for the location-specific configuration file in the IVE modeling framework.

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2.2.5. Scenarios formulation of alternative fuels and quantification of climate – benefit

The emission inventory (EI) for MCs was established for the baseline year 2024. Based on data provided by the HCMC Department of Transport, which recorded an estimated 8.4 million registered MCs, and under the assumption of no significant changes in vehicle technologies or operational practices, a projection of the EI for the year 2030 was conducted. To assess the impact of cleaner fuel adoption, two alternative fuel-switching scenarios were developed, based on Decision No. 876/QD-TTg on July 22, 2022 approved the action program for transition to green energy and mitigation of carbon dioxide and methane emissions from transportation. Scenario 1 assumes that by 2030, 100 % of MCs will use E5 fuel and scenario 2 envisions a transition to 22 % of electric MCs. To evaluate the climate impact of these scenarios, the GWP in CO_2 equivalent was used. The CO_2 equivalent emissions for each pollutant were calculated based on Equation (3) [10].

$$CO_2 \text{ eq.} = \Sigma E_i \times GWP_i \quad (3)$$

Where: E_i: emission mass of species i (tonnes/year); GWP_i: global warming (+) or cooling (-) potential of species i.

In which, emission mass is calculated by multiplying the emission factor (EF) with the activity data (typically derived from vehicle kilometers traveled - VKT and number of starts). The VKT is estimated by the volume of MCs and average distance traveled and the number of start represents by the volume of MCs and average start number.

Table 2. The GWP metrics assigned to each studied pollutant species.

Pollutants	GWP (20 – year horizon)	Source
CO_2	1	
CH_4	27.2	[12]
N_2O	273	[12]
NO_x, per kg N	43	[13]
VOC	14	[14]
Sulphate	-140	[13]
CO	6	[15]
BC	3.200	[16]
OC	-240	[13]

As shown in Table 2, the majority of air pollutant emissions exert warming influences, while sulfate and organic carbon (OC) are associated with cooling effects. Because the IVE model does not directly output black carbon (BC) and OC emissions, their respective proportions were derived following the U.S. Environmental Protection Agency (EPA) guidelines, employing the conversion factors: OC = 0.48 PM and BC = 0.10 PM [17, 18].

3. RESULTS AND DISCUSSION

3.1. Vehicular mobility patterns in Ho Chi Minh City

3.1.1. Vehicular traffic flow

Table 3 presents the mean hourly traffic volume of MCs and electric motorcycles (EMs) across all surveyed roadway sections. Arterial roads and highways exhibited higher average

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hourly traffic volumes compared to residential roads, particularly during peak hours. Considerable variation in hourly traffic flow across variation of road types and areas was reflected by high standard deviations (SD). Empirical traffic data obtained from nine roadway segments during both weekdays and weekends were utilized to construct the location-specific input files for the IVE model location files, which served to estimate the EI of MCs in HCMC.

Table 3. Average hourly traffic volumes recorded across nine selected road segments in HCMC in 2024.

Road name	Road types	Hourly traffic flow (vehicle/ hour)			
		MCs		EMs	
		Weekday	Weekend	Weekday	Weekend
Tay Lan	Arterial	3938 ± 4686	3785 ± 5195	14 ± 15	10 ± 10
Lien ap 2-3-4	Residential	304 ± 175	947 ± 409	4 ± 2	5 ± 2
Quoc lo 1A	Highway	13694 ± 76940	11175 ± 45040	24 ± 14	20 ± 90
Song Hanh	Arterial	5334 ± 3216	4565 ± 2769	42 ± 23	33 ± 18
An Loi Dong	Residential	2851 ± 2983	1898 ± 1489	21 ± 15	19 ± 12
Ha Noi highway	Highway	13312 ± 75800	8694 ± 5774	38 ± 18	23 ± 90
Tran Hung Dao	Arterial	12944 ± 69870	12359 ± 59670	71 ± 42	62 ± 41
Co Bac	Residential	2130 ± 1311	1650 ± 9780	18 ± 12	13 ± 80
Vo Van Kiet	Highway	13889 ± 76460	12811 ± 61660	71 ± 45	58 ± 31
Average hourly flow (vehicle/hour)		7600 ± 2921	6432 ± 2302	34 ± 14	27 ± 12
Average hourly flow (vehicle/hour) (This study, 2024)		7266 ± 2744		32 ± 13	
Average hourly flow (vehicle/hour) (HCMC, 2021 [3])		4169 ± 2290		-	

Also, Table 3 reveals a significant increase in MC volume in HCMC over the last decade. In the study of Thu and Nguyet (2021), the average hourly flow of MCs was 4,169 ± 2,290 vehicles/hour in 2014. By 2024, this figure increased to 7,266 ± 2,744 vehicles/hour. This sharp increase is consistent across road types, particularly on highways (e.g., Quoc lo 1A and Ha Noi highway), where the flow exceeded 13,000 MCs/hour in 2024. In addition, the emergence of EMs in the 2024 dataset highlight shifts toward new mobility patterns and technologies that were absent or negligible in the earlier study.

3.1.2. Technological composition of vehicle fleet

Results obtained from the structured questionnaire, summarized in Table 4, indicate that the majority of MC engines complied with the Euro 3 emission standard in 2024, accounting for approximately 72 % of the fleet. This reflects national regulatory requirements mandating that all MCs manufactured after 2017 comply with Euro 3 standards. The surveyed MC fleet was relatively new, with an average age of around six years.

Regarding fuel usage, the majority of MCs were gasoline-powered (92 %), followed by a smaller proportion using E5 (3 %) and electricity (5 %). The survey revealed a complete lack of MCs utilizing environmentally friendlier fuels like compressed natural gas (CNG) or liquefied petroleum gas (LPG). These findings underscore the limited diversification of fuel types within the MC fleet and the early-stage adoption of electric EMs in HCMC.

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Table 4. Findings from MC fleet survey.

Parameters	MCs (This study, 2024)	MCs (HCMC, 2021) [3]
Number of the vehicle	8,431,000	6,352,926
Average age (years)	6	5.9
Engine capacity (%)	< 100 cc: 3.86 % 100 – 300 cc: 96.14 %	-
Fuel used (%)	Gasoline: 92 % E5: 3 % Electricity; 5 %	Gasoline: 100 %
Engine standard (%)	Euro 3: 72 % Euro 2: 20 % Pre – Euro: 3 %	Euro 2: 50 % Euro 3: 10 % Pre-Euro: 40 %
Number of startups per day (start/day)	15	9.4
Average number of km travelled (km/day)	14.5	14.9

A comparative analysis between the research in 2024 and 2021 datasets reveals several notable trends that underscore the evolving characteristics of the MC fleet in HCMC. The total number of MCs increased significantly from 6.35 million in 2021 to 8.43 million in 2024, indicating a growing demand for two-wheeled transport. Although the average vehicle age remained relatively stable (6 years in 2024 vs. 5.9 years in 2021), there has been a marked improvement in engine technology. The share of Euro 3-compliant MCs rose sharply from 10 % in 2021 to 72 % in 2024, while the proportion of older Pre-Euro models declined from 40 % to just 3 %. Additionally, fuel diversification was observed in the 2024 study, with 8 % of MCs using E5 biofuel or electricity, in contrast to the 100 % gasoline reliance in 2021. These changes reflect ongoing efforts toward cleaner and more sustainable mobility. The increase in the average number of startups per day (from 9.4 to 15) may also have implications for cold-start emissions. These differences highlight the importance of regularly updating emission inventories to reflect current fleet characteristics and ensure more accurate emission modeling under rapidly changing urban conditions.

Table 5. Distribution of MC technologies matched with IVE default in HCMC of 2024.

Index type	Description	Share (%)
1218	Petrol: Med: 4-Cycle Carb: Improved: None: < 25K km	4.91
1219	Petrol: Med: 4-Cycle, Carb: Improved: None: 26-50 K	4.56
1220	Petrol: Med: 4-Cycle Carb: Improved: None > 50 K	3.86
1242	Petrol: Lt: 4-Cycle FI: Catalyst: PCV: < 25 K	1.40
1243	Petrol: Lt: 4-Cycle FI: Catalyst: PCV: 26-50 K	1.75
1244	Petrol: Lt: 4-Cycle FI: Catalyst: PCV: > 50 K	0.70
1245	Petrol: Med: 4-Cycle FI: Catalyst: PCV: < 25 K	43.51
1246	Petrol: Med: 4-Cycle FI: Catalyst: PCV: 26-50 K	11.23
1247	Petrol: Med: 4-Cycle FI: Catalyst: PCV: > 50 K	24.93
1308	OEM Ethanol: Med: 4-Cycle FI: Catalyst: PCV: < 25 K	1.75
1309	OEM Ethanol: Med: 4-Cycle FI; Catalyst: PCV: 26-50 K	0.70
1310	OEM Ethanol: Med: 4-Cycle FI: Catalyst: PCV: > 50 K	0.70

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3.1.3. Vehicle speed

Using data from the GPS survey, the diurnal variation in MC speeds was estimated. As illustrated in Figure 2, MC speeds were generally lower on weekdays compared to the same time periods on weekends. The highest speeds were observed during late-night and early-morning hours, particularly between midnight and 6 AM. In contrast, the lowest speeds occurred during specific traffic periods, such as noon time that people finished their morning shift (11:00 – 12:00) and rush hours (7:00 – 8:00 and 17:00 – 18:00). However, due to the complexity of the traffic system in HCMC, variations in driving speed across different roads align with typical urban traffic patterns.

This study and the study in 2021 consistently show pronounced diurnal variations and weekday–weekend differences in MC speed dynamics, with lower average speeds observed on weekdays compared to weekends [17]. This reduction was particularly evident during peak hours, likely due to increased traffic congestion. The previous study reported average MC speeds of 17.5 ± 7.9 km/h on weekdays and 21.9 ± 8.9 km/h on weekends, with the highest speeds recorded in the morning and the lowest during rush hours. Similarly, the 2024 study, based on GPS data, confirmed that MC speeds peaked during late-night to early-morning hours (midnight to 6 AM) and decreased significantly during noon and rush hour periods. These findings indicate that despite the decade-long gap, traffic congestion during peak hours remains a persistent issue in HCMC, emphasizing the need for more effective traffic management strategies.

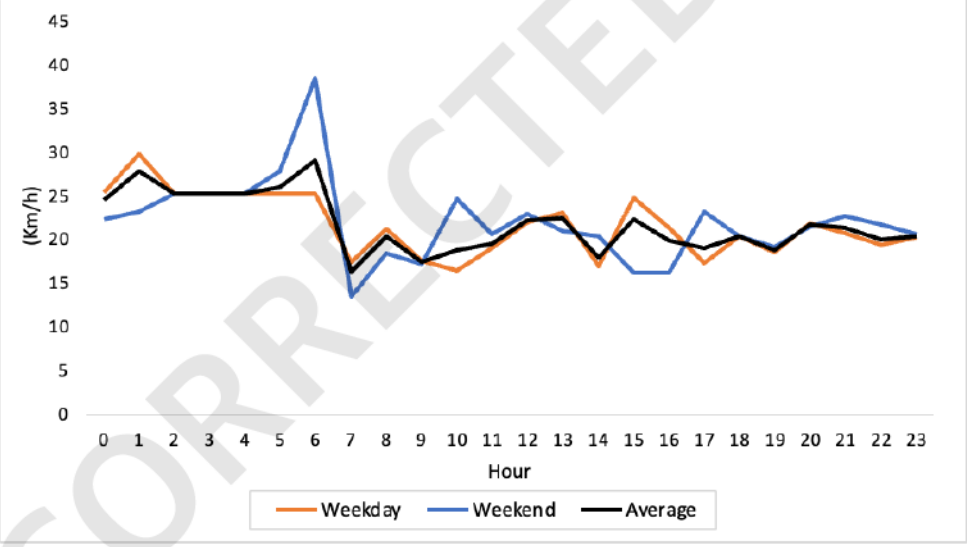

Figure 2. Daily fluctuations in MC velocity in HCMC, 2024.

3.1.4. Vehicle specific power

Driving behaviors were characterized using 60 bins, defined by the combination of 20 Vehicle Specific Power (VSP) categories and three levels of engine stress. As shown in Figure 3, the average hourly bin allocation during a-day periods exhibited minimal variation between weekdays and weekends. Bin 11 corresponds to a velocity of zero (VSP = 0), indicating MC stopping points. Bin 12 represents MCs operating at relatively low acceleration and speed, whereas Bin 13 indicates higher acceleration and speed. Additionally, the weekend bin composition suggests faster MC movement compared to weekdays, as evidenced by a

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greater number of bins corresponding to higher speed and acceleration (Bins 14–16). Furthermore, a small proportion (0.01–0.17 %) of higher bin numbers (21–40) was observed, which is associated with mid-level engine stress coupled with high vehicular speed.

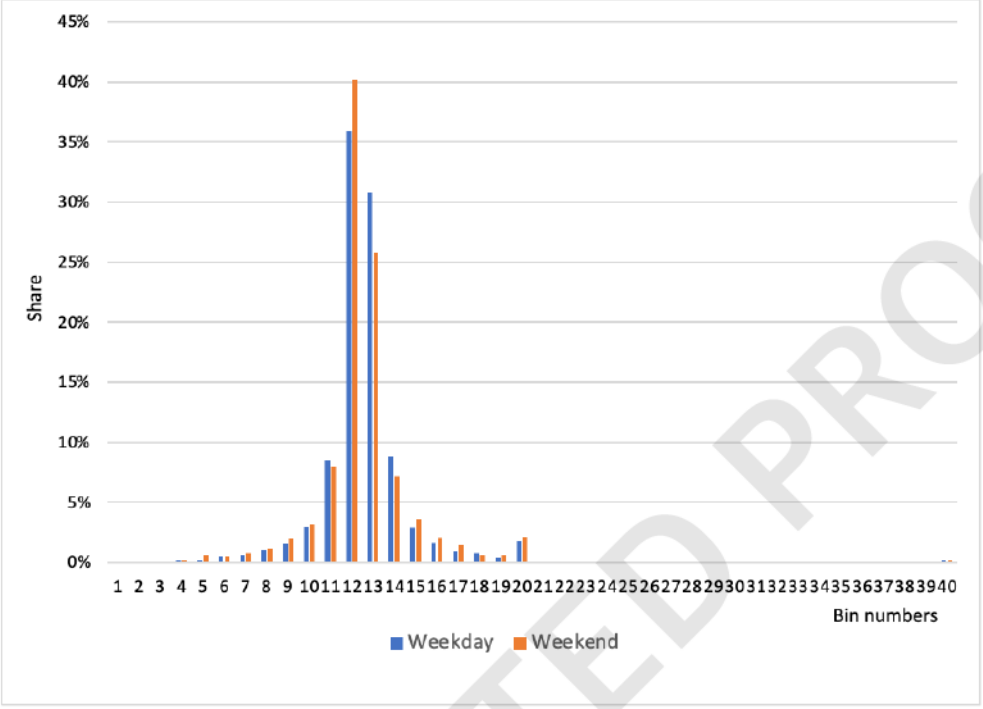

Figure 3. Diurnal average power bin distribution.

3.2. Emission factors

3.2.1. Vehicle specific emission factors

The IVE model was employed to estimate hourly emissions from MCs along a surveyed roadway, encompassing both weekdays and weekends. Emissions were computed for each vehicle type and corresponding technology index, and subsequently used to derive EFs for both the running and startup phases. Table 6 presents the average EFs for the pollutants under investigation. The results demonstrate that running-phase emissions (EFs Running) were substantially higher than those recorded during vehicle startup (EFs Startup).

Table 6. Emission factors for the analyzed pollutants from MCs in HCMC, 2024.

MC	CO	VOC	$VOC_{evap.}$	PM_{10}	NO_x	CO_2	SO_2	N_2O	CH_4
Startup (g/start)	8.033	1.901	0.308	0.072	0.668	5.834	0.001	0.001	0.416
Running (g/km)	15.253	1.933	0.305	0.066	0.381	112.486	0.020	0	0.374

Substantial discrepancies are evident when comparing the running-phase emission factors (EFs Running) with those reported in previous studies conducted in Viet Nam (Table 7). The current study (2024) reports an EF of CO is 15.25 g/km, which is slightly lower than the 2021 study (15.9 g/km) [3] but significantly higher than the 2012 study in Hanoi (5.49 g/km) [4]. This indicates persistently high CO emissions from MC in HCMC, likely due to high vehicle density and difference in adoption of cleaner technologies.

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Table 7. A comparative analysis of EFs (g/km) for MCs with findings from previous studies.

Motorcycle	CO	SO_2	NO_x	PM_{10}
HCMC (Current study, 2024)	15.25	0.02	0.38	0.07
HCMC (2021) [3]	15.9	0.02	0.70	0.20
Hanoi (2012) [4]	5.49	0.01	0.20	0.09

For NO_x, the EF in 2024 (0.38 g/km) is notably lower than that of 2021 (0.70 g/km), suggesting improvements possibly linked to better fuel quality, partial fleet renewal, or implementation of stricter emission regulations. Nevertheless, the NO_x level remains higher than that reported in Hanoi (0.20 g/km).

In terms of PM, the 2024 EF is lower (0.07 g/km) compared to both the 2021 value (0.20 g/km) and the Hanoi study (0.09 g/km). This positive trend may reflect increased awareness of particulate pollution and the early impacts of EM adoption. SO_2 levels remain low and constant at 0.02 g/km in both 2021 and 2024 studies in HCMC, but still higher than in Hanoi (0.01 g/km), potentially reflecting differences in fuel sulfur content or fuel standards. These discrepancies may also stem from variations in on-road transportation practices between HCMC and Hanoi, alongside heterogeneity in fleet configuration and vehicular characteristics.

3.2.2. Temporal distribution of EFs

As illustrated in Figure 4, the highest emission factors (EFs) occur during peak traffic hours, specifically between 8:00 AM – 10:00 AM and 4:00 PM – 7:00 PM, which aligns with periods of maximum traffic congestion. Additionally, a notable increase in emissions is observed around 11:00 AM – 12:00 PM, likely aligning with the termination of morning hours in offices and schools' schedules. With the varied distribution of EF during a day, the estimated emissions from MCs over a day (from 12:00 AM to 11:00 PM) range as follows: CO (33.44–2212.91 kg), VOC (12.19–217.76 kg), evaporative VOC (3.36–27.35 kg), NO_x (1.66–46.86 kg), SO_2 (0.16–1.99 kg), PM_{10} (0.40–7.71 kg), CO_2 (946.69–11381.44 kg), and CH_4 (2.31–42.38 kg).

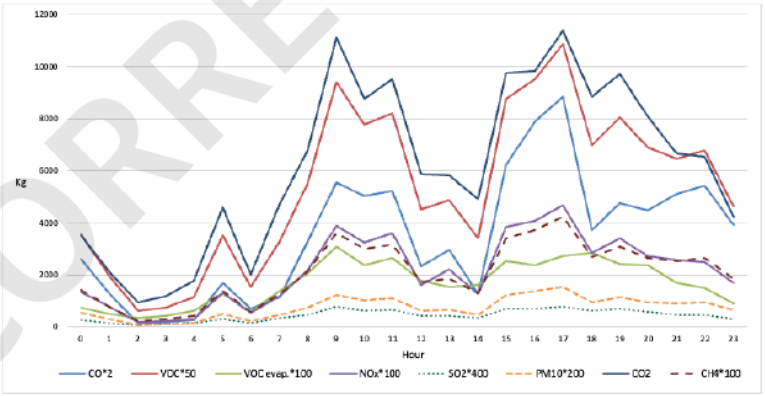

Figure 4. Variability in EFs among targeted pollutants.

3.3. Co-benefits of air quality and climate

3.3.1. Air quality improvement benefit

Scenario 1 demonstrates a substantial reduction in emissions for most pollutants relative to the base state scenario. Notably, NO_x emissions are highly eliminated, with a reduction rate of

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80.54 %. The lowest reduction is observed for CH_4, at 33.13 %. Other pollutants, including CO, VOC and PM_{10}, also exhibit significant decreases in emissions under Scenario 1 compared to the base state scenario, with more than 60 % of reduction.

The estimation of CO_2 emissions from electric vehicles is based on an emission factor of 4.7 g CO_2/km and the total vehicle kilometers traveled (VKT) by electric vehicles. In Scenario 2, which assumes a 22 % transition to EMs. The findings indicate that converting 22 % of MCs to electric vehicles could lead to a reduction of up to 57.11 % in CO_2 eq. emissions compared to the base state scenario.

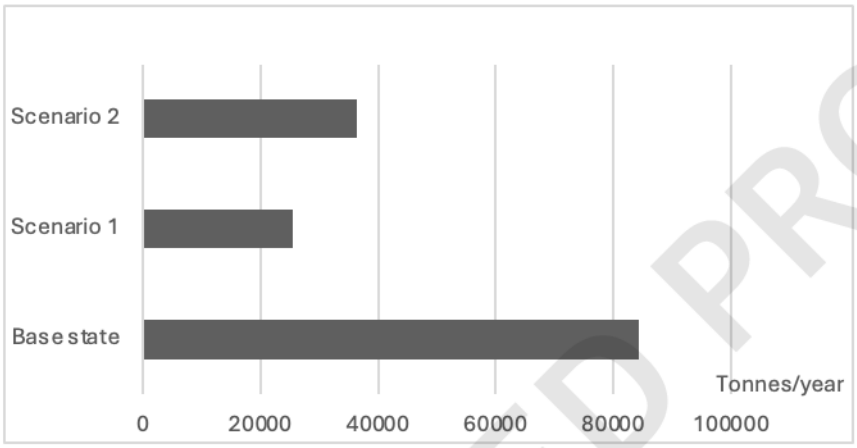

Figure 5. Emission reduction of different scenarios in 2030.

3.3.2. Climate change mitigation benefit

Mitigation of greenhouse gases (GHGs) emission and associated climate-relevant pollutants (in CO_2 eq.) is regarded as a critical determinant contributing to climate change, as illustrated in Table 8. Scenario 1 is anticipated to offer more substantial climate advantages for MC fleets compared to Scenario 2, achieving reductions of 70.23 % and 57.11 % in climate forcers, respectively, as measured in CO_2 eq.

Table 8. Projected reductions in climate forcers (tonnes of CO_2 eq.) across various scenarios in 2030.

Pollutants	Base state	Scenario 1		Scenario 2	
	CO_2 eq.	CO_2 eq.	% of reduction	CO_2 eq.	% of reduction
CO_2	65281	23731	63.65	30167	53.79
CH_4	5900	3945	33.13	3625	38.57
N_2O	0.08	0.04	48.53	0.04	46.26
NO_x	9505	1850	80.54	3586	62.27
VOC	15710	5074	67.70	6936	55.85
SO_2	-1592	-0.83	99.95	-446.06	71.97
CO	53128	14659	72.41	22205	58.20
BC	123448	31097	74.81	50114	59.40
OC	-9259	-2332	74.81	-3759	59.40

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4. CONCLUSIONS

This study provides a comprehensive emissions inventory for MCs in HCMC using the IVE Model, focusing on current (2024) and projected (2030) conditions. By integrating GPS tracking, activity surveys, and emission factor analysis, the research quantifies CO_2 and eight air pollutants, including climate forcers, from MC use. Under two hypothetical fuel-switching scenarios, the study tests the hypothesis that transitioning from conventional fuels to E5 and electricity will significantly reduce GHG emissions.

In 2024, the MC fleet in HCMC primarily consisted of older technologies, predominantly Euro 3 engines. Euro 3 was the highest engine emission standard currently implemented, accounting for 72 % of MCs. The primary fuel types were gasoline, E5 and electricity. While the overall vehicle flow remained relatively stable, differences were noted depending on the type of road and the specific urban area. MCs typically traveled 10 to 15 kilometers per day, with significantly reduced speeds observed during high-traffic time frames.

Assessing combined air quality and climate impacts under the baseline and two alternative fuel-switching strategies revealed that transitioning to cleaner fuels such as E5 and electricity could significantly reduce emissions. Among these options, switching from gasoline to electricity, starting at 22 %, yielded the most substantial benefits for both air quality improvement and climate change mitigation.

To effectively reduce traffic-related air pollution and contribute to comply with the commitment of Viet Nam at COP26, fuel-switching strategies should be complemented by the progressive implementation of cleaner vehicle technologies. Additionally, a comprehensive emissions inventory should be conducted to include vans, personal cars, and trucks, ensuring a more detailed and accurate assessment of the city's overall transportation emissions.

CRediT authorship contribution statement. Tran Thu Trang: Conceptualization, Methodology, Supervision, Review and Editing, Writing Manuscript. Tran Thi Nhu Hoa: Formal analysis, Investigation, Writing Manuscript. Nguyen Thanh Danh: Data collection, Investigation, Writing Manuscript.

Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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