International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

Check for updates

SENSITIVITY OF VEHICLE EMISSIONS TO AVERAGE SPEED ASSUMPTIONS: EVIDENCE FROM MOTORCYCLES IN HANOI

Huy Dong Duc, Binh Pham Hoa, Anh Nguyen Ngoc, Vu Ngoc Quynh * and Vinh Nguyen Van

Faculty for Continuing Education, Hanoi University of Industry, 298 Cau Dien Street, Tay Tuu Ward, Hanoi, Vietnam.
* Corresponding Author

International Journal of Science and Research Archive, 2026, 21(02), 831–838

Publication history: Received on 12 October 2026; revised on 22 November 2026; accepted on 24 November 2026

Article DOI: https://doi.org/10.30574/ijsra.2026.21.2.2054

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

Average speed is widely used as a key input in macroscopic vehicle-emission models, yet its influence on motorcycle emission estimates remains insufficiently quantified under Vietnamese traffic conditions. This study evaluates the sensitivity of motorcycle emission factors to assumptions about average speed using real-world speed data collected in Hanoi. A total of 8,957 second-by-second speed observations were obtained from GPS measurements and used to derive representative speed scenarios ranging from 13 to 59 km/h. Emission factors for CO_2, CO, NOx, and VOC were estimated using the COPERT model, with all vehicle, fuel, and environmental parameters held constant. The results show that average speed substantially influences estimated emission factors. CO_2 emissions decreased from 146.8 g/km at 13 km/h to 76.5 g/km at 59 km/h, corresponding to a reduction of approximately 48%. VOC emissions were the most sensitive to speed assumptions, varying by approximately 157% across the investigated speed range, whereas CO and NOx exhibited lower sensitivities of approximately 30% and 31%, respectively. Comparison with experimental measurements reported for Hanoi motorcycles indicated that locally derived speed values produced more realistic emission estimates than generic assumptions. The findings demonstrate that average speed is a critical modeling parameter and may introduce considerable uncertainty into motorcycle-emission inventories. The use of locally representative speed data is therefore essential for improving the reliability of transport-emission assessment in motorcycle-dominated cities.

Keywords: Motorcycle Emissions; Average Speed; Emission Factors; Sensitivity Analysis; COPERT; Hanoi.

1 INTRODUCTION

Motorcycles are an important component of urban mobility in Vietnam. Their widespread use makes the characterization of motorcycle activity and exhaust emissions relevant to both local air-quality management and greenhouse-gas assessment (Huu & Ngoc, 2021; Nguyen & Than, 2023). Emission inventories commonly combine vehicle activity with emission factors, but the resulting estimates depend on how vehicle technology and operating conditions are represented. A factor derived for one fleet or driving pattern should therefore not be assumed to describe another without examining its underlying conditions.

Local evidence illustrates the importance of these conditions. Tong et al. (2011) measured emissions from eight motorcycles on a Hanoi-specific chassis-dynamometer cycle and reported vehicle-specific and composite emission factors. Nguyen et al. (2022) subsequently characterized on-road motorcycle driving in Hanoi and documented the

distribution of operating modes. These studies provide valuable local context, but differences in period, sample, and method prevent their direct substitution for new observations. More generally, comparisons between motorcycle driving cycles and measurement methods show that estimated emission factors can vary with the test protocol and engine characteristics (Kumar et al., 2011).

Motorcycle emissions are influenced by a combination of vehicle, operational, and environmental factors (see Fig. 1). Vehicle-related characteristics such as engine displacement, fuel-delivery system, emission-control technology, age, and maintenance condition affect the amount and composition of exhaust emissions. At the same time, operational variables including average speed, acceleration, deceleration, stop frequency, idling activity, and engine load play a critical role in determining real-world emission performance.

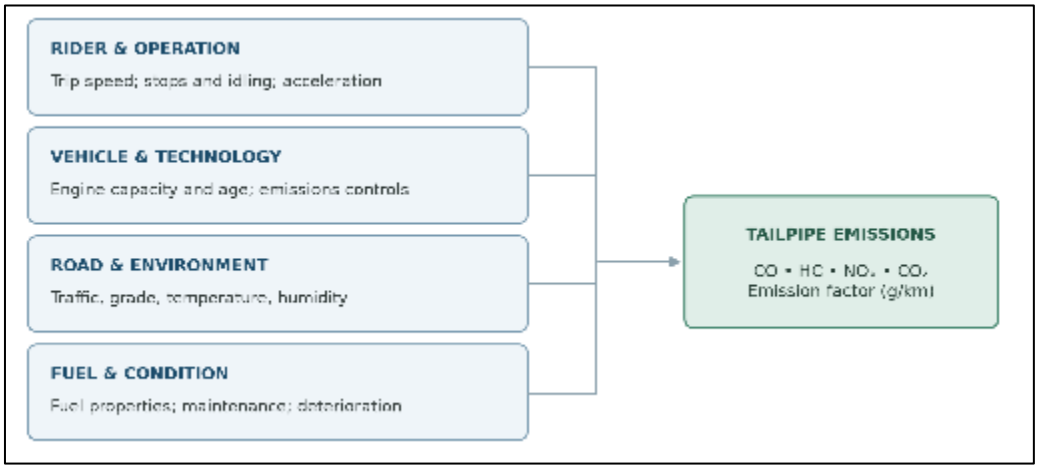

Figure 1: Factors influencing motorcycle tailpipe emissions.

Previous studies in Hanoi and other developing cities have shown that traffic conditions can substantially modify these operating characteristics and consequently alter vehicle emissions (Ghaffarpasand et al., 2021; Seedam et al., 2017; Tong et al., 2011). Understanding the sensitivity of modeled emissions to speed assumptions is therefore important for ensuring transparency and robustness in inventory development and emission assessments.

Average speed is a practical input for macroscopic emissions analysis. Nevertheless, it compresses a time-varying driving profile into a single quantity and does not uniquely describe acceleration, stops, or engine load. Motorcycle measurements in Hanoi relate operating conditions to fuel consumption (Nguyen et al., 2023), while on-road modeling in Thailand has used both speed and acceleration to represent motorcycle emissions (Satiennam et al., 2017). Thus, an average-speed model can provide an interpretable scenario comparison, but it cannot independently resolve all transient driving effects.

This study addresses a focused methodological question: how much do estimated motorcycle emission factors change when alternative average-speed assumptions are supplied to COPERT under otherwise fixed conditions? The objectives are to characterize available motorcycle activity in Hanoi; estimate running-exhaust factors across explicitly defined speed scenarios; quantify pollutant-specific sensitivity; and compare an appropriately matched model estimate with the historical measurements of Tung et al. (2011). The analysis is a model-based sensitivity study, not a measurement of the causal effect of congestion or an unconditional validation of COPERT for Hanoi.

2 MATERIALS AND METHODS

2.1 Selecting representative motorcycle sample

In Vietnam, Honda was the most frequently reported manufacturer in the Hanoi fleet survey by Tung et al. (2011), accounting for 72% of the motorcycles surveyed. At the national level, Honda held 71.8% of Vietnam's two-wheeler market in 2020 (Le et al., 2022). In the Hanoi survey, motorcycles with engine displacements between 70 cm^3 and 100 cm^3 formed the largest group (53%), followed by those with displacements between 100 cm^3 and 125 cm^3 (42%) (Tung et al., 2011).

On this basis, a Honda Wave RS with a 100 cm^3 four-stroke gasoline engine is selected as the target motorcycle for the case study. This choice combines a widely represented manufacturer with the most common displacement group in the historical Hanoi survey. Importantly, the Wave RS was also among the eight motorcycles tested by Tung et al. (2011),

providing vehicle-specific emission factors for comparison. Their tested Wave RS was in the 3–7-year age group. The selected characteristics and their sources are summarized in Table 1.

Table 1: Motorcycle sample and activity data

Information	Value	Description and source
Motorcycle model	Honda Wave RS	Individual test motorcycle selected as historical benchmark; Tung et al. (2011), Table 1. Honda was 72% of surveyed Hanoi motorcycles in 2008; nationally, Honda held 71.8% of the two-wheeler market in 2020 (Huong Le et al., 2022; Le & Posada, 2022).
Age	4 years	According to the study of Kim Oanh et al. (2012). The vehicle age considered in this study falls within the age category of the Honda Wave RS tested by Tung et al. (2011).
Vehicle kilometres travelled	7,641 km/vehicle/year	Historical average for surveyed motorcycle users, not a Wave RS-specific annual value (Tung et al., 2011). Use as an illustrative activity assumption only.
Engine displacement	100 cm^3	Wave RS test vehicle (Tung et al., 2011).

2.2 Determining average-speed scenarios

As discussed previously, vehicle emissions are influenced by multiple factors, including vehicle characteristics, traffic conditions, roadway characteristics, fuel properties, and driving behavior. Among these factors, the present study focuses specifically on the influence of average vehicle speed on estimated emission factors. Therefore, all other variables were assumed to remain unchanged, while only average speed was varied in the emission simulations.

To ensure that the measured speeds reflect actual operating conditions in Hanoi, real-world motorcycle driving data were collected using a portable Global Positioning System (GPS) device (Fig. 2). This approach allows direct measurement of vehicle operation without requiring a physical connection to the motorcycle under test, thereby avoiding interference with normal traffic behavior. The GPS receiver continuously recorded instantaneous vehicle speed at 1 Hz, providing sufficient temporal resolution to capture key driving characteristics, including speed, acceleration, deceleration, and stopping events. Data collection was conducted under representative urban traffic conditions, including both peak periods (06:30–08:30, 10:30–12:00, and 16:30–19:00) and normal traffic periods (06:00–06:30, 08:30–10:30, and 12:00–16:30). Figure 2 presents the GPS device used in this study.



Figure 2: GPS device

The collected speed database was subsequently subjected to descriptive statistical analysis to determine representative speed values, including the minimum, maximum, mean, first quartile (Q1), median (Q2), third quartile (Q3), and 95th percentile. These representative speeds were then used as inputs to the COPERT model to evaluate the sensitivity of estimated emission factors to changes in average vehicle operating speed.

2.3 Collecting vehicle emission simulation model

Emission factors of motorcycles were estimated using the COPERT model following the Tier 2 methodology recommended in the EMEP/EEA Air Pollutant Emission Inventory Guidebook (The European Environment Agency et

al., 2026). COPERT estimates vehicle emission factors as a function of vehicle category, engine characteristics, fuel type, emission standard, and average operating speed. Among these variables, average speed is one of the most influential factors governing motorcycle emissions and therefore represents the focus of this study.

Using these speed inputs, the COPERT model was applied to estimate emission factors of major pollutants, including CO_2, CO, NOx, VOC, $PM_{2.5}$, PM_{10}, and black carbon (BC). This approach enables a systematic assessment of the sensitivity of motorcycle emission estimates to average-speed assumptions and provides insights into the implications of speed selection in emission inventories and transport-related air-quality assessments.

2.4 Ambient conditions

In addition to speed, vehicle category and fuel, relevant model settings and, where required for the selected emissions process, ambient conditions must be specified. The proposed annual mean temperature and relative humidity for Hanoi are summarized in Table 2. The year, observation station, precise statistical source, and relevance of these values to the selected COPERT calculations must be verified before modeling; cold-start calculations can require more detailed temperature inputs.

Table 2: Ambient conditions for Hanoi.

No.	Parameter	Value (SI units)	Converted value to suitable COPERT's requirement
1	Annual mean temperature	25.88 °C	78.58 °F
2	Annual mean relative humidity	75.17%	75.17%

(Source: General Statistics Office of Vietnam, https://www.nso.gov.vn/)

2.5 Sensitivity metrics and uncertainty

To quantify the influence of average-speed assumptions on modeled emission factors, a sensitivity-analysis framework was implemented. The Honda Wave RS motorcycle described in Section 2.1 was used as a reference case, while all vehicle-specific and environmental parameters were held constant throughout the simulations. Only the average speed input was varied according to the representative values derived from the real-world driving-speed database described in Section 2.2.

For each speed scenario, COPERT was used to estimate emission factors of CO_2, CO, NOx, and VOC. The sensitivity of each pollutant to average-speed assumptions was assessed by comparing the resulting emission factors with those obtained using the reference average speed. The relative change in emission factor was calculated as:

$$SC_i = \frac{EF_i - EF_{ref}}{EF_{ref}} \times 100 \quad (1)$$

where SC_i is the relative change in the emission factor (%) for speed scenario i, EF_i is the corresponding emission factor (g/km), and EF_{ref} is the emission factor estimated using the reference average speed.

The objective of this analysis is not to validate COPERT for Hanoi motorcycles but rather to quantify how alternative average-speed assumptions influence estimated emission factors under otherwise identical modeling conditions. Any differences observed among scenarios, therefore, reflect the sensitivity of the modeling results to speed selection rather than to actual changes in vehicle technology or operating environment.

3 RESULTS AND DISCUSSION

3.1 Motorcycle speed distribution

After screening and preprocessing, the GPS dataset contained 8,957 unique instantaneous-speed observations collected under real-world traffic conditions in Hanoi. The resulting speed database was used to characterize motorcycle operating conditions and to derive representative speed scenarios for the subsequent sensitivity analysis of COPERT emission factors.

The mean speed is 23.23 km/h, and the median is 25.24 km/h (Table 3). Fig. 3 illustrates one source file rather than a continuous trajectory across all files.

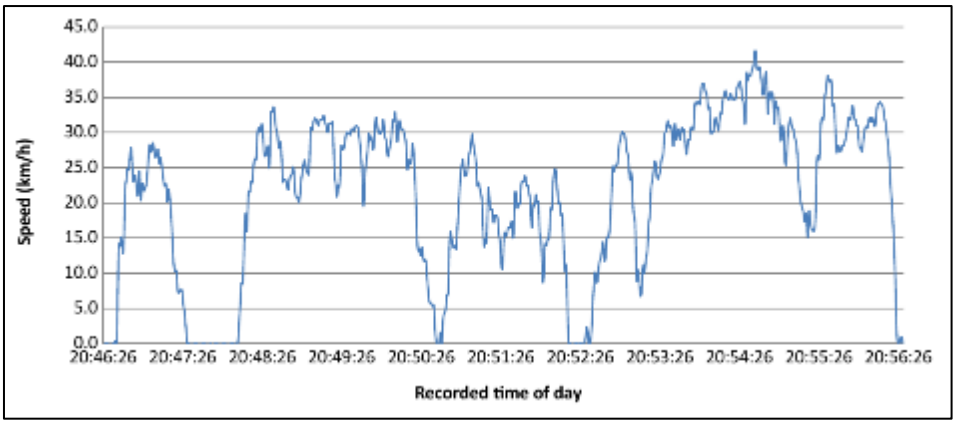

Figure 3: Example real-world motorcycle speed profile recorded in Hanoi. The plot is illustrative and does not depict the entire dataset.

The speed distribution exhibits substantial variability, ranging from complete stops (0 km/h) to a maximum observed speed of 59.08 km/h (Fig. 4). The largest proportion of observations falls within the 20–<30 km/h interval (27.36%), indicating that motorcycles in Hanoi most frequently operate within a relatively narrow urban speed range. This result is consistent with the mixed-traffic conditions and recurrent congestion typically observed on major urban roads in the city.

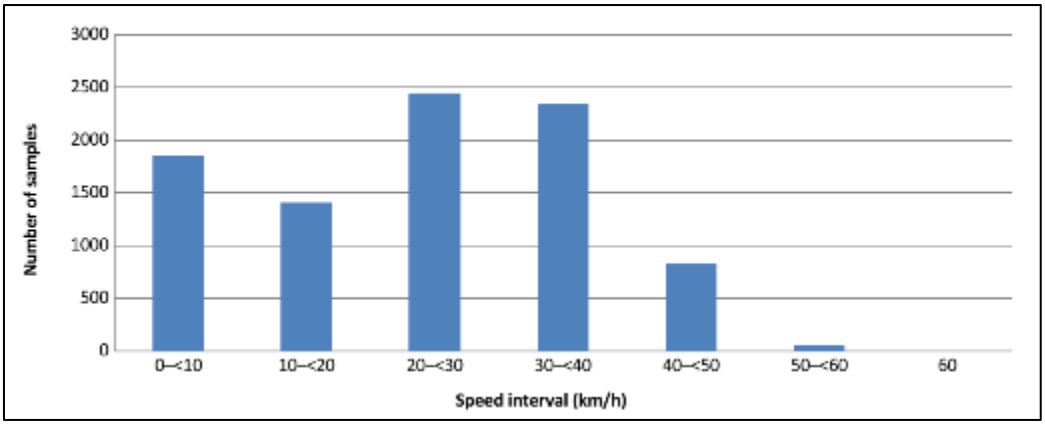

Figure 4: Distribution of instantaneous motorcycle speeds observed in Hanoi.

Table 3: Descriptive speed statistics and candidate COPERT sensitivity inputs.

Statistic	Speed (km/h)	Role or interpretation
Minimum	0.00	Observed endpoint; check model validity before use
First quartile (Q1)	13.79	Hypothetical sensitivity input
Median (Q2)	25.24	Hypothetical sensitivity input
Mean	23.23	Reference input; sample arithmetic mean
Third quartile (Q3)	33.73	Hypothetical sensitivity input
95th percentile (P95)	42.77	Hypothetical sensitivity input
Maximum	59.08	Hypothetical sensitivity input

Note. Values are calculated over screened, deduplicated instantaneous samples, including zeros; percentiles use inclusive linear interpolation.

Table 3 shows that the selected speed scenarios cover a wide range of traffic conditions observed in Hanoi, from complete standstill conditions to free-flow operation. The mean speed (23.23 km/h) was adopted as the reference scenario because it reflects the average operating condition of the entire dataset. The remaining speed values were used to assess the sensitivity of the estimated emission factors to plausible variations in average speed. Together, these scenarios provide a systematic basis for assessing the robustness of emission estimates under different assumptions

regarding motorcycle activity. The average speed reported by Tung et al. (2011) for the CEMDC driving cycle was 20.1 km/h, which lies between the first quartile and the sample mean of the present dataset. This similarity supports the use of the selected speed scenarios as realistic representations of motorcycle operation in Hanoi.

3.2 Emission factors across speed scenarios

The representative speed scenarios presented in Table 3 were subsequently used as inputs to the COPERT model to evaluate the sensitivity of motorcycle emission factors to changes in average operating speed. By keeping all vehicle, fuel, and environmental parameters constant while varying only average speed, the resulting differences can be attributed solely to speed-related effects within the emission model. The estimated emission factors for the investigated pollutants are summarized in Table 4.

Table 4: Emission factors across speed scenarios.

Pollutants	Emission factor speed across scenarios (g/km)					Comparison with the study of Tung et al. (2011)
	Q1-speed (13 km/h)	Q2-speed (25 km/h)	Mean (23 km/h)	Q3-speed (34 km/h)	Max speed (59 km/h)	
CO_2	146.7838	100.3312	105.596	84.3934	76.5029	29.24
CO	11.6407	8.9978	9.2759	8.2605	8.98	10.02
NOx	0.0496	0.0424	0.0422	0.0449	0.0545	0.06
VOC	3.3423	2.1024	2.2524	1.6235	1.3043	1.28

The results indicate that average speed has a substantial influence on estimated motorcycle emission factors. Among the pollutants investigated, CO_2 had the highest emission factor in the lowest-speed scenario (13 km/h), at 146.8 g/km. As speed increased, estimated CO_2 emissions decreased continuously, reaching 76.5 g/km at 59 km/h. Compared with the highest-speed scenario, the lowest-speed condition resulted in approximately 92% higher CO_2 emissions. This trend suggests that low-speed operation substantially increases fuel consumption per unit distance traveled, thereby amplifying greenhouse gas emissions.

A similar pattern was observed for CO and VOC emissions. CO emissions decreased from 11.64 g/km at 13 km/h to 8.98 g/km at 59 km/h, corresponding to a reduction of approximately 23%. VOC emissions were even more sensitive to speed assumptions, decreasing from 3.34 g/km to 1.30 g/km over the same speed range, equivalent to a reduction of approximately 61%. These findings indicate that low-speed urban traffic conditions may substantially increase emissions associated with incomplete combustion.

In contrast, NOx emissions exhibited a relatively weak sensitivity to average speed. The estimated NOx emission factor varied within a narrow range of 0.042–0.055 g/km across all speed scenarios. The minimum NOx value occurred near the mean operating speed, whereas slightly higher values were estimated at both very low and very high speeds. This behavior reflects the more complex relationship between engine load, combustion temperature, and NOx formation.

The comparison with the experimental measurements reported by Tung et al. (2011) further demonstrates the importance of speed selection in emission modeling. The average speed of the Hanoi motorcycle driving cycle developed by Tong et al. was 20.1 km/h, which lies between the first quartile (13.79 km/h) and the mean speed (23.23 km/h) of the present dataset. Under these speed conditions, the modeled CO emission factors (9.0–11.6 g/km) were close to the measured value reported for the Honda Wave RS (10.02 g/km). Similarly, the estimated NOx emission factors were broadly consistent with the experimental result (0.06 g/km). However, substantial discrepancies were observed for CO_2 and VOC emissions, highlighting the uncertainty associated with applying generic emission models under local operating conditions.

Overall, the results demonstrate that average speed represents a critical modeling assumption when estimating motorcycle emissions. The sensitivity is particularly pronounced for CO_2 and VOC emissions, whereas NOx emissions appear comparatively robust. These findings suggest that the use of non-representative average-speed values may introduce considerable uncertainty into urban emission inventories and transport-related air-quality assessments.

3.3 Sensitivity and inventory implications

The results presented in Table 4 indicate that the estimated motorcycle emission factors are highly sensitive to the average-speed assumptions supplied to the emission model. However, the magnitude of this sensitivity varies considerably among pollutants. Among all investigated pollutants, VOC exhibited the highest sensitivity to speed assumptions, with estimated emission factors varying by approximately 157% between the minimum- and maximum-speed scenarios. Similarly, CO_2 emissions showed substantial sensitivity, with a variation of approximately 92% across the investigated speed range. In contrast, CO and NOx emissions were comparatively less sensitive, exhibiting variations of approximately 30% and 31%, respectively.

These findings suggest that inaccuracies in average-speed assumptions can introduce significant uncertainty into motorcycle emission inventories, particularly for pollutants closely associated with fuel consumption and transient operating conditions. For example, selecting a low average speed representative of heavily congested conditions (13 km/h) instead of a high-speed condition (59 km/h) nearly doubled the estimated CO_2 emissions and increased the estimated VOC emissions by more than 150%. Such variations are sufficiently large to influence the outcome of emission-control assessments and transport-sector greenhouse-gas inventories.

The comparison with the experimental measurements reported by Tung et al. (2011) further highlights the importance of selecting a representative speed. The average speed of the CEMDC driving cycle developed for Hanoi (20.1 km/h) lies between the first quartile and the mean speed obtained in the present study. Under these operating conditions, the modeled CO emission factors were reasonably close to the measured values for the Honda Wave RS, suggesting that speed values derived from local driving data improve the realism of inventory estimates.

From an inventory-development perspective, the results demonstrate that using generic or non-representative average-speed assumptions may lead to substantial over- or underestimation of vehicle emissions. This issue is particularly relevant in developing cities such as Hanoi, where traffic conditions are highly heterogeneous and operating speeds vary considerably among routes and time periods. Therefore, the use of locally derived speed data should be prioritized whenever motorcycle emission inventories or emission-modeling studies are conducted.

4 CONCLUSIONS

This study evaluated the sensitivity of motorcycle emission factors to average-speed assumptions using real-world speed data collected in Hanoi and the COPERT emission model. The observed speed distribution ranged from complete stops to 59.1 km/h, with an average operating speed of 23.2 km/h.

The results showed that average speed has a substantial influence on estimated motorcycle emissions. Among the investigated pollutants, VOC and CO_2 were the most sensitive to speed assumptions, whereas NOx exhibited comparatively limited variability. The estimated CO_2 emission factor decreased from 146.8 g/km under heavily congested conditions (13 km/h) to 76.5 g/km under free-flow conditions (59 km/h). Similarly, VOC emissions varied by approximately 157% across the investigated speed range.

Comparison with the experimental measurements reported by Tong et al. demonstrated that locally derived speed values provide more realistic emission estimates than generic assumptions. These findings indicate that average speed should not be treated as a fixed or universal parameter in motorcycle-emission modeling.

Overall, the study demonstrates that the use of non-representative average-speed assumptions may result in substantial over- or under-estimation of motorcycle emissions. Therefore, locally derived speed data should be prioritized in transport-emission inventories and air-quality assessments for motorcycle-dominated cities such as Hanoi. Future studies should further evaluate the influence of second-by-second driving characteristics and compare the sensitivity of different emission models under Vietnamese operating conditions.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

The authors would like to express their sincere gratitude to the Faculty for Continuing Education, Hanoi University of Industry, for its valuable support throughout the research process.

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

REFERENCES

[1] Ghaffarpasand, O., Talaie, M. R., Ahmadikia, H., Khozani, A. T., Shalamzari, M. D., & Majidi, S. (2021). Real-world evaluation of driving behaviour and emission performance of motorcycle transportation in developing countries: A case study of Isfahan, Iran. *Urban Climate, 39*:100923. https://doi.org/10.1016/j.uclim.2021.100923.

[2] Huong Le, Posada, F., & Yang, Z. (2022). Electric two-wheeler market growth in Vietnam: An overview. *International Council on Clean Transportation*. https://theicct.org/wp-content/uploads/2022/10/asia-pacific-lvs-NDC-TIA-E2W-mkt-growth-Vietnam-nov22.pdf

[3] Huu, D., & Ngoc, V. (2021). Analysis Study of Current Transportation Status in Vietnam's Urban Traffic and the Transition to Electric Two-Wheelers Mobility. Sustainability 2021, 13, 5577. In: s Note: MDPI stays neutral with regard to jurisdictional claims in published ….

[4] Kim Oanh, N. T., Phuong, M. T. T., & Permadi, D. A. (2012). Analysis of motorcycle fleet in Hanoi for estimation of air pollution emission and climate mitigation co-benefit of technology implementation. *Atmospheric environment, 59*:438-448. http://doi.org/10.1016/j.atmosenv.2012.04.057

[5] Kumar, R., Durai, B., Saleh, W., & Boswell, C. (2011). Comparison and evaluation of emissions for different driving cycles of motorcycles: A note. *Transportation Research part D: Transport and Environment, 16*(1):61-64. doi:10.1016/j.trd.2010.08.006.

[6] Le, H., & Posada, F. (2022). Promoting the development of electric vehicles in Vietnam *International Council on Clean Transportation*.

[7] Nguyen, T. Y.-L., Duc, K. N., Minh, Q. C., Hai, Y. T. T., & Le Hong, M. B. (2022). A study on the determination of the real-world driving characteristics of motorcycles in Hanoi. *Transport and Communications Science Journal, 73*(4):412-426. https://doi.org/10.47869/tcsj.73.4.6.

[8] Nguyen, Y.-L. T., Duc, K. N., Le, A.-T., Nghiem, T.-D., & Than, H.-Y. T. (2023). Impact of real-world driving characteristics on the actual fuel consumption of motorcycles and implications for traffic-related air pollution control in Vietnam [SCIE, IF (2023) = 6.6, Q1, ELSEVIER]. *Fuel, 345*:1-12. https://doi.org/10.1016/j.fuel.2023.128256.

[9] Nguyen, Y. L. T., & Than, H. Y. T. (2023). Estimating the greenhouse gas emission factor of motorcycles under real-world driving conditions in Hanoi: a case study. *Transport and Communications Science Journal, 74*(7):764-774. https://doi.org/10.47869/tcsj.74.7.1.

[10] Satiennam, T., Seedam, A., Radpukdee, T., Satiennam, W., Pasangtiyo, W., & Hashino, Y. (2017). Development of on-road exhaust emission and fuel consumption models for motorcycles and application through traffic microsimulation. *Journal of Advanced Transportation, 2017*. https://doi.org/10.1155/2017/3958967.

[11] Seedam, A., Satiennam, T., Radpukdee, T., Satiennam, W., & Ratanavaraha, V. (2017). Motorcycle on-road driving parameters influencing fuel consumption and emissions on congested signalized urban corridor. *Journal of Advanced Transportation, 2017*:1-6. https://doi.org/10.1155/2017/5859789.

[12] The European Environment Agency, The Institute for Energy and Transport of the European Commission Joint Research Centre, & S.A., E. (2026). *COPERT 4: Estimating emissions from road transport* http://emisia.com/products/copert

[13] Tong, H. Y., Tung, H. D., Hung, W. T., & Nguyen, H. V. (2011). Development of driving cycles for motorcycles and light-duty vehicles in Vietnam. *Atmospheric Environment, 45*(29):5191-5199. https://doi.org/10.1016/j.atmosenv.2011.06.023.