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Assessment and Management of Air Pollutant Emissions from Vehicles in the Bangkok Metropolitan Region

Manwipa Kuson[1,*], Jukkrit Mahujchariyawong[1], Tunlawit Satapanajaru[1], Tassanee Prueksasit[2]

[1]Department of Environmental Technology and Management, Faculty of Environment, Kasetsart University, Bangkok 10900, Thailand
[2]Department of Environmental Science, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand

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ABSTRACT

Air pollution has emerged as a critical issue, especially in urban areas, with vehicle emissions being a major contributor to the problem. To effectively address this pressing concern, accurate estimation of current and future traffic emissions is of utmost importance. This study focuses on investigating the emission status and predicting future trends of various vehicles in the Bangkok Metropolitan Region (BMR). To conduct the study, comprehensive statistical analysis was performed to assess the technical characteristics, activity patterns, and operating conditions of different vehicle types, including passenger vehicles, light-duty trucks, heavy-duty buses, heavy-duty trucks, and motorcycles. The Computer Programme to Calculate Emissions from Road Transport (COPERT) model was utilized to calculate the emissions of CO, NOx, $PM_{2.5}$, VOCs, and CO_2 from these vehicle types in the BMR for the period spanning 2021 to 2050. The COPERT model employs emission factors and adjusts them based on actual operating conditions using correction coefficients. Three distinct scenarios were developed to gauge the potential outcomes. The first scenario, Business as Usual (BAU), represents the continuation of current practices. The second scenario, emission reduction standards (ERS), implements measures to reduce emissions. Finally, the third scenario combines emission reduction standards with the widespread adoption of electric vehicles (ERS and REV). The number of vehicles in each scenario was predicted using the gray model and combined with calibrated emission factors to forecast emissions under different scenarios. The results of the study demonstrate the significance of emission reduction strategies. By implementing ERS alone, the study indicates potential reductions of approximately 0.68% in CO emissions, 2.27% in NOx emissions, 6.71% in $PM_{2.5}$ emissions, 2.36% in VOCs, and 0.04% in

***Corresponding author:** manwi.k73@gmail.com
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CO_2 emissions by 2050, compared to the BAU scenario. Even more promising results were observed with the ERS and REV scenario. In this case, the study suggests substantial decreases, including approximately 91.05% in CO emissions, 72.81% in NOx emissions, 78.74% in $PM_{2.5}$ emissions, 88.25% in VOCs, and 79.38% in CO_2 emissions compared to the BAU scenario. These findings highlight the potential of emission reduction strategies and the adoption of electric vehicles in significantly improving air quality and reducing pollution levels in the BMR. As such, the study provides valuable insights for policymakers and stakeholders, offering guidance to develop effective measures for sustainable transportation and environmental protection in the region.

Keywords: Bangkok Metropolitan; Emission factor; Forecast emission; Region COPERT; Vehicle emission

1. Introduction

Air pollution is a significant global environmental challenge, especially in densely populated urban areas with high levels of vehicular traffic. In recent years, Thailand's rapid economic growth has led to a focus on improving public transportation, resulting in increased energy consumption and a surge in the number of vehicles on the roads. As of 2021, Thailand has a total registered vehicle count of 42.3 million, with passenger vehicles accounting for 27% (11.4 million), light-duty trucks 16% (7.0 million), motorcycles 52% (21.8 million), and heavy-duty trucks and buses 3% (1.3 million). These vehicles are considered aged and equipped with outdated engine technology and pollution control devices, contributing significantly to air pollution emissions that cannot be adequately addressed with current solutions [1].

Consequently, air pollution from vehicles, especially in urban areas like Bangkok and its surrounding metropolitan regions, has been rapidly increasing. The Bangkok Metropolitan Region faces notable air pollutant emission issues due to rapid urbanization and population growth. Extensive research has highlighted the adverse effects of air pollution on human health, ecosystems, and climate change. Vehicular emissions, including carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (HC), and particulate matter (PM), significantly contribute to urban air pollution [2, 3]. The main pollutants from gasoline engines are HC, CO and NOx. They are contained in exhaust emissions, but hydrocarbons are contributed both with the exhaust, and with the evaporative emissions. Particulate matter is usually negligible and is produced mainly from oil components brought into the combustion chamber by the piston. Diesel engine, both light- and heavy-duty diesel engines have considerably higher compression ratios and better fuel efficiency, which leads to lower CO and hydrocarbon emissions. Light duty vehicles also emit less nitrogen oxides than comparable gasoline engines, but nitrogen oxides from heavy-duty diesel engines are higher. Particulate matter and the polycyclic carcinogenic hydrocarbons adsorbed on it are eight to ten times as much as in gasoline counterparts and pose a serious problem for diesel engines [4].

The main question for improving air quality and reducing pollution from vehicles is how to control the release of pollutants effectively while considering real-world driving conditions. Creating a record of vehicle emissions can provide essential data to help control and reduce pollutants from vehicles in the medium and long term [5]. One of the key methods to obtain vehicle emission factors is by using a vehicle emission model. Popular models include MOVES, IVE, EMFAC, MOBILE, CMEM, and COPERT [6-14]. The COPERT model, developed by the European Environment Agency, is the most commonly utilized vehicle emission model in Europe [15]. The calculation principle of the

COPERT model is based on the basic emission factor, and the column correction coefficient is used to calculate the vehicle emission factor under actual conditions. The COPERT model can be adjusted to reflect emission levels specific to different countries and regions by incorporating user-inputted local information, resulting in a customized emission inventory. Feng et al. used COPERT to check how much pollution comes from big diesel buses in Hainan Province. They found that if we make buses cleaner or switch to electric ones, we can cut down on harmful emissions like CO, CO_2, NOx, and PM [16]. The COPERT model primarily relies on bench test data collected by EU countries. As Thailand follows similar classifications, emission standards, and test conditions for motor vehicles as the EU, the latest version of the COPERT model incorporates advanced technologies from vehicle emission testing. This update includes key parameters and actual road emission factors specific to Thai motor vehicles, resulting in calculation results that closely align with the actual emissions produced [17]. Therefore, the COPERT model is also applicable to the establishment of the emission inventory of vehicles in Bangkok and its surrounding metropolitan areas.

The gray model is a methodology that utilizes limited and incomplete information to create a gray differential prediction model, offering a fuzzy depiction of development patterns. It serves as a useful tool for predicting systems that involve uncertain factors. By analyzing a series of numerical values representing characteristics observed at specific time intervals, the gray model establishes a prediction model to estimate future feature quantities or the time needed to reach specific feature quantities. The gray model finds patterns in system changes by assessing the discrepancy among various developmental factors, generating a data sequence with strong regularity. It then establishes a corresponding differential equation model to forecast future trends [18, 19]. To achieve the prediction of emissions under future scenarios, this study uses gray prediction models to predict the number of vehicles in various scenarios. Combined with the adjusted emission factors, statistical mileage, and other parameters, the total amount of emissions in the future scenario can be predicted. Accurate data regarding the quantity of air pollutants generated by vehicles are crucial for government agencies and policymakers responsible for implementing control measures and addressing air pollution concerns. Such data can help identify vehicle types that exhibit high pollutant generation and emission rates, enabling the establishment of appropriate standards for these vehicles. Furthermore, pollutant quantity data obtained through forecasting can assess the effectiveness of policies. For instance, studies conducted in countries like China and Mexico have utilized mathematical models to compare pollutant quantities and evaluate the impact of implementing more stringent emission standards on air quality, influencing future emission control policies [20-22].

The primary objectives of this research endeavor are twofold. Firstly, it aims to conduct a comprehensive analysis of the present air pollutant emissions scenario in the Bangkok Metropolitan Region and its surrounding areas. Specifically, the study focuses on the quantification and characterization of fine particulate matter ($PM_{2.5}$), carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (VOCs), and carbon dioxide (CO_2) emissions originating from different categories of vehicles, namely passenger cars, light-duty trucks, heavy-duty trucks, heavy-duty buses, and motorcycles. The data collected and analyzed for this purpose will be based on the year 2021, serving as the baseline against which future comparisons will be made. Secondly, this study aims to explore the anticipated trajectory of pollutant emissions when novel air pollutant emission standards are implemented and enforced for the aforementioned vehicle types. By comparing various scenarios spanning the years 2021 to

2050, the objective is to discern and propose viable strategies that effectively address the management of vehicle-related air pollution [2, 3].

2. Materials and Methods

The scope of this study is centered solely on the Bangkok Metropolitan Region (BMR) and its surrounding areas, comprising five provinces: Pathumthani, Nonthaburi, Samut Prakan, Samut Sakhon, and Nakhon Prathom, as illustrated in Fig. 1. The BMR region is confronted with significant traffic challenges, ranking among the top 10 most congested cities in the world [23].

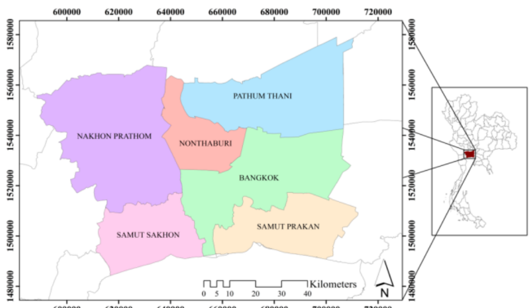


Fig. 1. Coverage area of the research study in the Bangkok Metropolitan Region (BMR).

2.1 Estimation of emissions from the on-road transport sector

Road transport plays a significant role as a source of air pollutants, including ozone precursors such as CO, NOx, and VOCs, as well as greenhouse gases like CO_2 and particulate matter. According to the European Monitoring and Evaluation Programme (EMEP)/European Environment Agency (EEA) air pollutant emission inventory guidebook [24], which provides a technical guide for emission inventory development, emissions from road transport originate from four primary sources. These sources encompass emissions from the combustion process of fuel within vehicle engines, evaporation emissions resulting from fuel evaporation in the fuel tank, emissions from tire and brake wear due to abrasion, and emissions from road surfaces resulting from the interaction between tires and road paving. Regarding exhaust emissions, they are classified into two sub-categories: hot emissions emitted by vehicles during the driving stage after the vehicle engine has warmed up, and cold emissions emitted by vehicles during the warming-up stage. However, for the purpose of this study, the focus lies specifically on estimating exhaust emissions under hot stage conditions.

2.2 Establishing vehicles inventory by using COPERT model

The COPERT model, funded by the European Environment Agency, was developed with the objective of calculating annual pollutant emissions per vehicle or fleet. The model's estimation procedure, illustrated in Fig. 2, outlines the steps involved. For this study, version V5.0.1145 of the COPERT model was utilized.

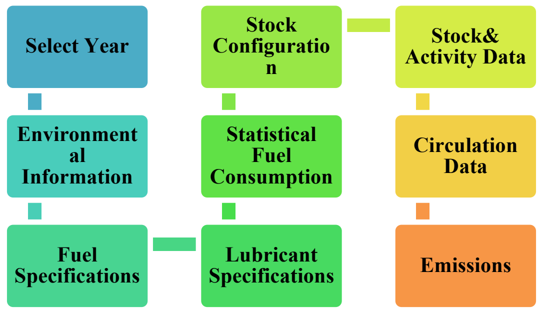


Fig. 2. COPERT model estimation procedure.

In analyzing emissions from various activities, the COPERT model specifically focuses on on-road transport activities, including exhaust emissions, fuel evaporation, tire and brake wear, and abrasion wear. Among these, exhaust gas emissions play a crucial role and serve as the primary contributor to emissions from on-road transport activities. The base year for calculation is 2021, and the environmental information data (temperature and humidity) were sourced from the Thai Meteorological Department. Default values for lubricant specifications were used in the model. Fuel specification and statistical fuel consumption data were obtained from the Department of Energy Business and the Department of Alternative Energy Development and Efficiency, Ministry of Energy. The model estimates the carbon, hydrogen, and other heavy metal atoms based on the type and amount of fuel used, as these values directly influence the calculation results of emissions.

Stock configuration data, as well as stock and activity data, were sourced from the Department of Land Transport and the Office of Transport and Traffic Policy and Planning, Ministry of Transport. The vehicles were categorized into five types: passenger car (LDC), light-duty truck (LDT), heavy-duty truck (HDT), heavy-duty bus (HDB), and motorcycle (MC). The fleet consisted of these five types of vehicles, as shown in Table 1. Mean activity and lifetime cumulative activity data were obtained from a study on the sources of fine particulate matter not exceeding 2.5 microns ($PM_{2.5}$) and the secondary pollutants related to $PM_{2.5}$ in the Bangkok Metropolitan Region and its vicinity conducted by the Asian Institute of Technology [25].

Table 1. Vehicles Inventory and Activity Data by Category in BMR, 2021.

Category	Stock (n)	Mean Activity (km/yr.)	Lifetime Cumulative Activity (km)
Passenger car	5,551,254	21,827	480,914
Light duty vehicle	1,687,871	36,792	735,840
Heavy duty truck	283,929	77,124	2,159,486
Heavy Duty bus	48,131	76,613	1,915,337
Motorcycle	4,760,483	29,346	352,152

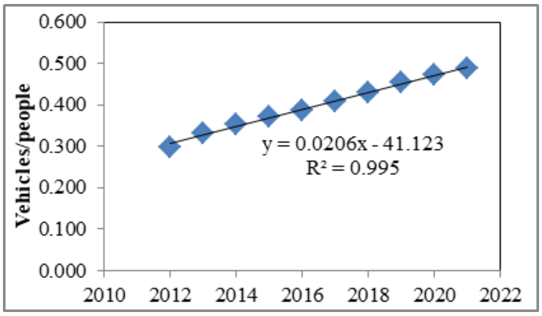
2.3 Prediction emission trends

In this study, the year 2050 is selected as the comparative research year, and three scenarios are established to assess the emission reduction potential of vehicles in the BMR.

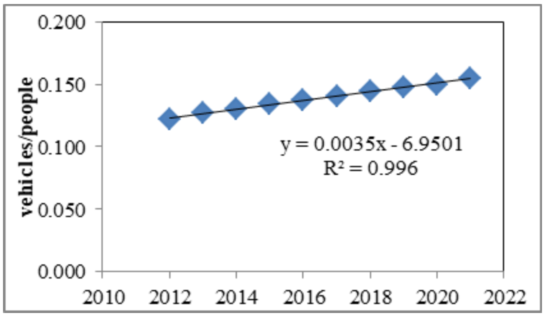
To predict the quantity of each vehicle type, a gray model is utilized. The raw data used for prediction comprise the number of vehicles registered from 2012 to 2021, and the predicted values represent the number of vehicles from 2012 to 2050. This forecasting approach takes into consideration the past ten years of vehicle registration data and the population in the region.

Furthermore, the quantity of new vehicles entering the BMR system from 2012 to 2050 is forecasted using vehicle registration data for new vehicles from previous years up to 2021. This estimation is crucial for projecting the future quantity of new vehicles until 2050.

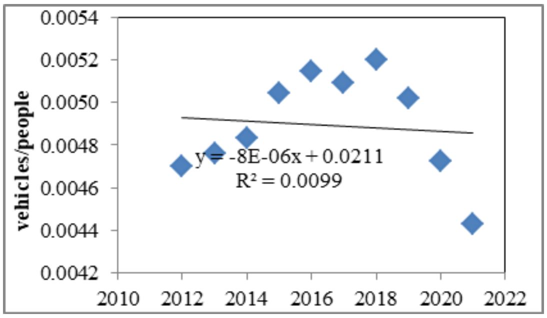
To estimate the quantity of vehicles being phased out of the system, a detailed analysis of the decreasing trend of cumulative registered vehicles is conducted. This analysis involves the utilization of the vehicle registration database from the Department of Land Transport for the BMR to establish a linear correlation between the number of registered vehicles and the population, with adjustments made for the number of vehicles deregistered each year. The examination of historical data concerning the correlation between the increasing number of vehicles and the population indicates the presence of a linear relationship; the forecast is depicted in Fig. 3.



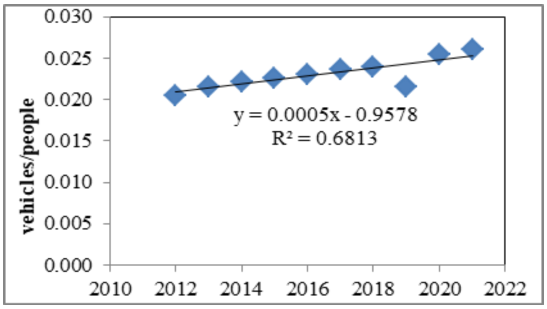
(a) Passenger car



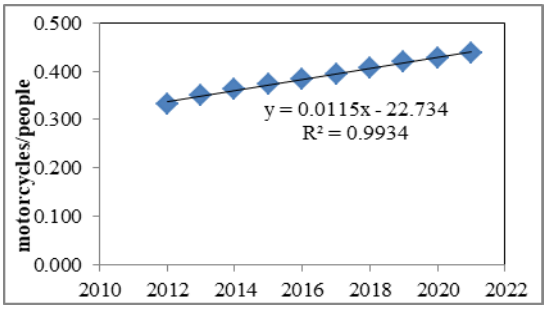
(b) Light-duty vehicle



(c) Heavy-duty bus



(d) Heavy-duty truck



(e) Motorcycle

Fig. 3. The relationship of the registered vehicles and the population in BMR.

The table presents the actual quantities of five types of vehicles registered in the BMR for the period 2012-2021 and the predicted quantities for the period 2022-2050. The BMR vehicle growth trends, projected using the gray prediction model, are illustrated in Fig. 4. Utilizing the time series equation, it becomes possible to forecast the cumulative number of registered vehicles per population from 2012 to 2050. The analysis reveals that by the year 2050, there will be approximately 27.6 million passenger cars, around 19 million motorcycles, about 6.3 million light-duty trucks, approximately 0.97 million heavy-duty trucks, and approximately 0.12 million heavy-duty buses in the BMR. These predictions are based on the application of the gray prediction model to assess the future trend of vehicle quantities in the region.

Three scenarios are compared as follows:
1) Business as Usual Scenario (BAU): In this scenario, the current situation is maintained, where regulations are in place to enforce standards for fuel quality and new vehicle standards. These regulations will be implemented from the year 2021 and continue until the year 2050.

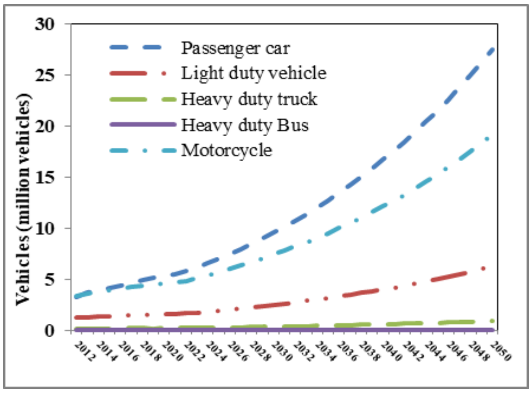


Fig. 4. Number of five types of vehicles growth trend prediction in BMR.

2) Emission Reduction Standard Scenario (ERS): This scenario involves the implementation of regulatory measures that impose stricter emission standards for new motorcycles, passenger cars, light-duty vehicles, buses, and trucks. These standards align with Euro 4 starting from 2021, Euro 5 starting from 2024, and Euro 6 starting from 2026. Additionally, fuel quality standards will be upgraded to match Euro 5 standards from.
3) Emission Reduction Standard and Replacement by Electric Vehicle Scenario (ERS and REV): Scenario 3 builds upon scenario 2, with additional promotion of electric vehicles. The aim is to produce electric vehicles that account for 30% of total vehicle production or around 1.4 million vehicles by 2030. Furthermore, this scenario encourages the use of electric vehicles and small trucks, which are expected to comprise 50% of total vehicle sales or 440,000 vehicles, electric

motorcycles that account for 30% of total motorcycle sales or 650,000 motorcycles, and electric buses or trucks that make up 35% of total bus or truck sales or 33,000 vehicles by 2030. It is anticipated that by the year 2050, electric vehicles will supplant all internal combustion engine cars as part of the effort to achieve carbon neutrality.

Each of these scenarios presents different approaches to address air pollution concerns and reduce emissions from the on-road transport sector in the Bangkok Metropolitan Region.

3. Results and Discussion

On the basis of the calculation results of the COPERT model, the emission factor of CO, NOx, VOCs, $PM_{2.5}$ and CO_2 emissions from each type of vehicles are shown in Table 2.

Table 2. Emission factors of each pollutant in each of type of vehicles.

category	Std.	Emission (g/km)				
		$PM_{2.5}$	CO	NOx	VOCs	CO_2
Passenger car	Pre ECE	0.018	126.6	9.2	11.1	270.148
	EURO1	0.018	9.0	1.4	0.9	190.991
	EURO2	0.018	3.5	0.7	0.4	191.35
	EURO3	0.016	2.6	0.3	0.1	195.675
	EURO4	0.016	1.0	0.2	0.1	199.903
	EURO5	0	1.1	0.1	0	0
	EURO6	0	1.0	0.1	0	0
Light duty car	Pre ECE	0.213	2.9	2.2	0.8	179.053
	EURO1	0.086	1.7	3.0	0.2	162.389
	EURO2	0.066	1.3	3.2	0.2	169.744
	EURO3	0.051	0.4	3.1	0.1	162.217
	EURO4	0.047	0.4	2.4	0.1	162.217
	EURO5	0	0.1	2.3	0	0
	EURO6	0	0.1	2.1	0	0
Heavy duty truck	Pre ECE	0.539	16.7	50.1	7.1	851.569
	EURO1	0.349	7.6	30.0	2.8	693.943
	EURO2	0.183	5.9	33.2	1.9	663.553
	EURO3	0.201	7.6	27.6	1.8	696.991
	EURO4	0	3.9	17.9	0.2	0
	EURO5	0	5.8	21.2	0.2	0
	EURO6	0	0.8	2.4	0.2	0
Bus	Pre ECE	0.633	12.6	51.3	4.2	976.019
	EURO1	0.368	10.2	40.4	3.8	834.324
	EURO2	0.22	8.6	46.1	2.7	814.688
	EURO3	0.206	10.5	42.6	2.6	853.422
	EURO4	0	6.1	26.4	0.3	0
	EURO5	0	10.3	32.4	0.3	0
	EURO6	0	1.4	3.1	0.2	0
Motorcycle	EURO3	0.011	4.5	0.3	0.3	58.065
	EURO4	0.007	4.1	0.1	0.4	55.071
	EURO5	0	3.6	0.1	0.2	0

3.1 CO emissions under different emission scenarios

Fig. 5 illustrates the CO emission trends of vehicles in the BMR under various scenarios. The results reveal a significant difference in the amount of CO emissions resulting from the implementation of different measures. When upgrading the emission standards for motorcycles from Euro 3 to Euro 4, and for passenger cars and light duty trucks from Euro 4 to Euro 5 and Euro 6, as well as for buses and large trucks from Euro 3 to Euro 5 and Euro 6 by the year 2026, the reduction in CO emissions is relatively small around 0.21% to 0.68%, almost negligible. This is attributed to the fact that the new vehicle standards for all vehicle types do not substantially differ in terms of CO emission criteria because CO emission value limits in EURO 5 and EURO 6 of all types of vehicles are not different from EURO 4. However, the adoption of electric vehicles shows great promise in substantially reducing CO emissions. By the year 2030, CO emissions can be reduced by up to 30.94%. The reduction becomes even more significant by the year 2050, reaching as high as 91.05%. These findings highlight the potential of electric vehicles in effectively addressing CO emissions and contributing to improved air quality in the BMR.

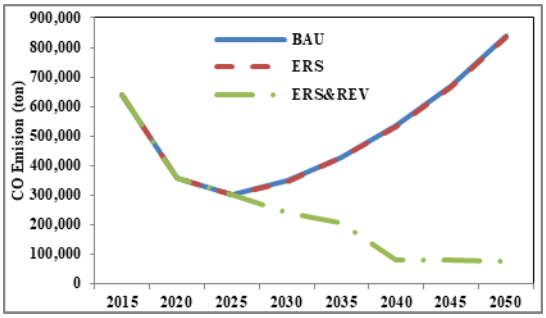


Fig. 5. Changes in CO emissions resulting from different measures implemented.

3.2 NOx emissions under different emission scenarios

In various scenarios, the NOx emission trends of vehicles in the BMR are depicted in Fig. 6. The results demonstrate that different measures lead to varying levels of NOx emissions. Upgrading the emission standards for motorcycles from Euro 3 to Euro 4, and for passenger cars and light duty trucks from Euro

4 to Euro 5 and Euro 6, as well as upgrading the emission standards for buses and large trucks from Euro 3 to Euro 5 and Euro 6 by the year 2026, can result in a slight reduction in NOx emissions. However, the substantial difference becomes more apparent in the later years of Euro 6 implementation, as the NOx emission limits are further reduced for light duty trucks, buses, and trucks. Furthermore, with the increased adoption of electric vehicles, significant reductions in NOx emissions are achievable. By the year 2030, NOx emissions can be reduced by up to 15.97%, and by the year 2050, this reduction can reach as high as 72.81%. These findings highlight the potential impact of electric vehicles in effectively mitigating NOx emissions and contributing to improved air quality in the BMR. After 2030, at least 30% of diesel vehicles will be changed to electric vehicles and the percentage will increase each year thereafter.

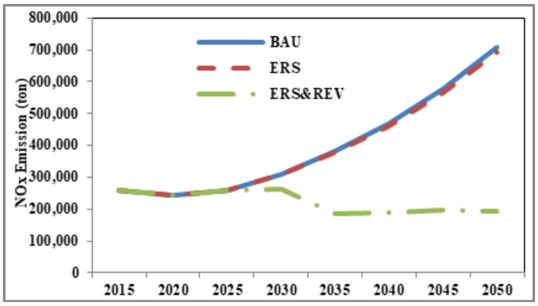


Fig. 6. Changes in NOx emissions resulting from different measures implemented.

3.3 VOCs emissions under different emission scenarios

In various scenarios, the VOCs (Volatile Organic Compounds) emission trends of vehicles in the Bangkok Metropolitan Region (BMR) are illustrated in Fig. 7. The results demonstrate that different measures lead to varying levels of VOCs emissions. Upgrading the emission standards for motorcycles from Euro 3 to Euro 4, and for passenger cars and light-duty trucks from Euro 4 to Euro 5 and Euro 6, as well as upgrading the emission standards for buses and large trucks from Euro 3 to Euro 5 and Euro 6 by the year 2026, would result in a relatively small reduction in VOCs emissions, almost negligible. This is attributed to the fact that the new vehicle standards for all vehicle types do not significantly differ in terms of the hydrocarbon emission criteria, which is a key component that contributes to VOCs formation. However, the adoption of electric vehicles shows significant potential in substantially reducing VOCs emissions. By the year 2030, VOCs emissions can be reduced by up to 23.83%, and by the year 2050, this reduction can reach as high as 88.25%. While applying EURO 5 standards to new motorcycles will decrease HC to the level of passenger cars, the reduction is not as significant as that achieved by electric motorcycles. Hence, it is evident that VOCs have not experienced a substantial decrease. These findings underscore the importance of electric vehicles in effectively mitigating VOCs emissions and contributing to improved air quality in the BMR.

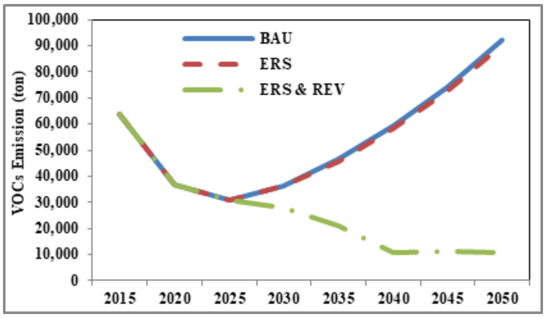


Fig. 7. Changes in VOCs emissions resulting from different measures implemented.

3.4 $PM_{2.5}$ emissions under different emission scenarios

In various scenarios, the $PM_{2.5}$ emission trends of vehicles in the BMR are depicted in Fig. 8. The results demonstrate that different measures lead to varying levels of $PM_{2.5}$ emissions. Upgrading the emission standards for motorcycles from Euro 3 to Euro 4, and for passenger cars and light duty trucks from Euro 4 to Euro 5 and Euro 6, as well as upgrading the emission standards for buses and trucks from Euro 3 to Euro 5 and Euro 6 by the year

2026, can lead to a significant reduction in $PM_{2.5}$ emissions. By the year 2030, $PM_{2.5}$ emissions can be reduced by approximately 6.87%, and the reduction continues progressively until the year 2050. This reduction is mainly due to the Euro 5 and Euro 6 standards for light duty trucks, buses, and trucks, which include stricter criteria for PM emissions. However, the adoption of electric vehicles shows substantial potential in significantly reducing $PM_{2.5}$ emissions. By the year 2030, $PM_{2.5}$ emissions can be reduced by up to 26.92%, and by the year 2050, this reduction can reach as high as 78.74%. These findings underscore the importance of electric vehicles in effectively mitigating $PM_{2.5}$ emissions and contributing to improved air quality in the BMR. The influence of electric vehicles on $PM_{2.5}$ is comparable to that on NOx due to the shift in the number of diesel vehicles, which are significant sources of both $PM_{2.5}$ and NOx.

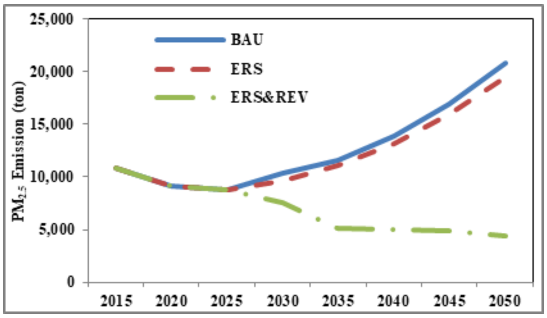


Fig. 8. Changes in $PM_{2.5}$ emissions resulting from different measures implemented.

3.5 CO_2 emissions under different emission scenarios

In different scenarios, the CO_2 emission trends of vehicles in the BMR are illustrated in Fig. 9. The results demonstrate that different measures lead to varying levels of CO_2 emissions. Upgrading the emission standards for motorcycles from Euro 3 to Euro 4, and for passenger cars and light duty trucks from Euro 4 to Euro 5 and Euro 6, as well as upgrading the emission standards for buses and trucks from Euro 3 to Euro 5 and Euro 6 by the year 2026, can lead to a relatively small reduction in CO_2 emissions. However, advancements in fuel efficiency technologies contribute to improved fuel consumption, resulting in a reduction in CO_2 emissions to some extent. Nevertheless, the adoption of electric vehicles shows significant potential in bringing CO_2 emissions down to zero. By the year 2030, CO_2 emissions can be reduced by up to 29.11%, and by the year 2050, this reduction can reach as high as 79.38%. These findings emphasize the importance of transitioning to electric vehicles to effectively mitigate CO_2 emissions and contribute to a sustainable and environmentally friendly transportation system in the BMR. Even though new vehicle emission standards aim for better fuel efficiency, the surge in the number of vehicles has led to an increase of CO_2 emission.

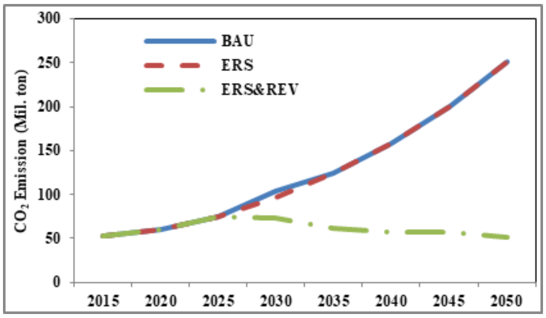


Fig. 9. Changes in CO_2 emissions resulting from different measures implemented.

4. Conclusion

The Computer Programme to Calculate Emissions from Road Transport (COPERT) is a valuable mathematical modeling tool used for predicting air pollutant emissions from the transportation sector. It plays a crucial role in decision-making processes by providing insights into reducing and controlling various types of air pollutants emitted by different vehicle types. The results obtained through this modeling exercise are vital for decision-makers to effectively address air pollution challenges and develop comprehensive solutions. Reducing emissions from road transport is of utmost importance, making the accelerated adoption of electric vehicles necessary, particularly as outlined by the resolution of the National Electric Vehicle Policy Committee, within the year 2030. Therefore, it is essential to consider the measures proposed in the three scenarios, which involve enforcing new vehicle emission standards as prescribed by government plans and expediting the execution of policies set by the National Electric Vehicle Policy Committee. However, leading up to the year 2030, it becomes crucial to enhance the stringency of emission standards as the current ones are insufficient to tackle the prevailing air pollution issues, especially the $PM_{2.5}$ crisis. Previous studies have revealed that the Euro 4 standard for passenger cars and light-duty trucks has limited benefits in reducing air pollution and has led to a continuous increase in ambient air pollution levels since 2014. Thus, it is imperative to implement stricter standards to effectively address air pollution, such as the Euro 5 standard for passenger cars, light-duty trucks, and buses, along with the Euro 6 standard that regulates particulate matter emissions. These standards are necessary to combat the majority of $PM_{2.5}$ emissions resulting from internal combustion engines. Additionally, the Euro 6 standard imposes stringent regulations on particulate matter and NOx emissions, both of which are primary contributors to the formation of $PM_{2.5}$ particles in the atmosphere.

Furthermore, there is a recommendation for the government to consider implementing measures to reduce the usage of outdated technology vehicles that have been continuously operating until the present day. This is particularly applicable to buses and trucks still adhering to the Euro 3 standard, which many countries worldwide phased out over 20 years ago. The pollution control technology in newer buses and trucks is more effective at addressing the current $PM_{2.5}$ crisis. Hence, it is necessary to enforce regulations on vehicles utilizing modern technology devices capable of addressing current air pollution issues. However, users often lack awareness, neglect maintenance, and sometimes even intentionally remove or disable modern technology devices, preventing them from functioning at their full efficiency. Raising awareness and ensuring proper maintenance and adherence to regulations are crucial in realizing the full potential of these emission reduction measures.

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