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ESTIMATION OF NITROGEN OXIDE (NO_X) EMISSIONS FROM MOTOR VEHICLES BASED ON FUEL CONSUMPTION IN KUALA LUMPUR METROPOLITAN CITY, MALAYSIA

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Abstract

One of the major sources of urban air pollution in Kuala Lumpur is attributed to more than 17 million units of motor vehicles that have an impact on human health. This study focused on nitrogen oxide (NOx) emissions from four classes of motor vehicles such as private cars, motorcycles, and goods vehicle from 2010 to 2014 using fuel consumption analysis. The study revealed that private cars were responsible for the majority of NOx emissions, with 3,854 kg in 2010 increasing to 5,726 kg in 2014. During the same period, motorcycles emitted 1,200 kg in 2010 and 1,750 kg in 2014, while goods vehicles emitted 199 kg in 2010 and 219 kg in 2014.The results of this study are important to policymakers and stakeholders. In particular, for the planning of various strategies to reduce and control the impact of air pollution from motor vehicles, especially on human health, in Kuala Lumpur.

Keywords: Urban Air Pollution, Motor Vehicles, NOx Emissions, Kuala Lumpur

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INTRODUCTION

The primary cause of urban air pollution in Malaysia is attributed to mobile sources, as stated by the Department of Environment (DOE, 2017). Motor vehicles emit harmful substances, including carbon monoxide (CO), hydrocarbons (HC), nitrogen dioxide (NO_2), nitrogen oxides (NOx), sulphur dioxide (SO_2), and suspended particulate matter which is less than 10 microns in diameter (PM_{10}). These substances are released during the combustion process in vehicle engines, which is necessary for movement (Ong et al., 2011; Mohd Shafie & Mahmud, 2015a; Mohd Shafie & Mahmud, 2015b; Abdullah et al., 2024).

The direct discharge of pollutants has a detrimental effect on several areas, including public health, specifically causing respiratory issues in Malaysia (Mabahwi et al., 2015; Ling et al., 2010; Ling et al., 2012; Hoon Leh et al., 2011). In 2016, air pollution was responsible for 7.6 per cent of global mortality, as reported by the World Health Organisation (WHO, 2016). This disease is affected by the individual's level of exposure to pollutants and the length of that exposure, which may occur over both short and extended periodsof time. NOx induces pulmonary inflammation and impairs pulmonary immunity, leading to various respiratory problems such as wheezing, coughing, colds, and bronchitis.

NOx is a component of air pollutants that are generated by cars and the combustion of fossil fuels. The presence of this substance in the air contributes to the creation and alteration of other kinds of air pollution, such as ozone and suspended particles. It also leads to the development of acid rain and smog when it reacts with sulphur oxide. Acid rain, airborne particulates, and even low-level ozone pose an urgent threat to human health. NOx is a greenhouse gas (GHG) that contributes to the production of ozone through photochemical reactions in the atmosphere. NOx also impacts the greenhouse gas budget by influencing hydroxyl radicals. Hence, the emission of NOx by motor vehicles directly influences the quantity of GHG that will eventually impact climate change. The function of GHG, which capture solar radiation, is to trap and retain heat in the atmosphere, leading to a substantial increase in the Earth's temperature.

LITERATURE REVIEW

Vehicle Pollutant Emissions in Malaysia

The high number of motor vehicles was identified as the main reason for the deterioration of air quality in the urban areas. The proliferation of motor vehicles was pinpointed as the primary cause for the degradation of air quality in metropolitan regions. DOE Malaysia has published statistics indicating a consistent upward trend in motor vehicle registrations. The total number of registered vehicles increased from 4,335,863 units in 2003 to 28,224,407 units in 2017, representing a growth rate of 8.16 per cent. The occurrence of this circumstance may be attributed to the quick economic forces in Malaysia, namely, the consistent expansion of the Gross Domestic Product (GDP) in conjunction with the increasing number of motor vehicles. The number of motor vehicles and GDP per capita had a simultaneous upward trend, with 11,302,545 units and RM 14,672 in 2001, rising to 25,044,872 units and RM 38,887 in 2015, respectively (WDI, 2017). This condition immediately enhances the buying power and spending capacity of people, enabling them to satisfy their demands more effectively and expediting the process of mobilising products and services. The road infrastructure bore the increased strain due to a lack of space, resulting in a significant traffic congestion issue in the city centre. This was caused by the maximum density of motor vehicles.

The rising number of motor vehicles has a direct impact on the quantity of gasoline that is used by an engine during the vehicle's propulsion. The Malaysia Energy Statistics Handbook study in 2017 documented a consistent rise in diesel consumption from 2,368 ktoe to 9,167 ktoe between 1980 and 2008. Similarly, petrol consumption in Malaysia grew from 10,843 ktoe to 12,804 ktoe between 2012 and 2015. In contrast, petrol had a significant increase in volume from 8,634 ktoe in 2009 to 12,804 ktoe in 2015, surpassing diesel. The fuel consumption in the transport sector witnessed a steady rise, growing from 16,395 ktoe in 2008 to 23,435 ktoe in 2015, as reported in the Energy Emission of Malaysia (2017) compared to the industrial sector. Consequently, the annual rise in motor vehicle numbers in Malaysia results in the direct emission of significant amounts of pollutants. Statistics released by the DOE prove that the production of pollutant emissions from motor vehicles is the highest and dominates compared to other sources, which are fixed sources represented by industry, power, and other sources from 1998 to 2014 (Table 1).

Table 1: Pollutant emissions ('000 metric tons) by type and source in Malaysia from 1998-2014

Year	Point Source		Motor Vehicles	Others[1]	Total
	Industry	Power Plant			
1998	706.5	-	2402.8	146.5	3255.8
1999	461.4	-	2563.1	114.2	3138.7
2000	566.7	-	2642.6	29.2	3238.5
2001	308.0	-	2561.7	8.6	2878.3
2002	702.1	-	2939.9	14.6	3656.6
2003	125.1	127.4	1649.1	163.2	2064.8
2004	372.4	359.0	1478.6	38.7	2248.7
2005	157.3	148.8	1538.0	23.1	1867.2
2006	158.7	150.7	1631.4	44.9	1985.7
2007	132.9	178.2	2172.8	49.4	2533.4
2008	148.7	221.4	1630.8	54.4	2055.3
2009	166.3	595.9	1762.8	60.3	2585.3
2010	113.9	619.2	1829.7	60.4	2623.2
2011	116.4	633.5	1905.6	90.6	2746.1

Year	Point Source		Motor Vehicles	Others[1]	Total
	Industry	Power Plant			
2012	86.4	693.2	2024.6	151.5	2955.8
2013	86.0	701.8	2025.6	142.4	2955.8
2014	101.9	742.9	2092.0	88.1	3024.9

Source: Department of Environment, Malaysia 2015

Note:
[1]Data 1998-2002 refers to industrial waste incineration from 2003, including hotels, commercial centres, institutions, and night markets.

The overall emissions of pollutants from motor vehicles in 2017 were CO (1,996,256 metric tonnes), HC (449,895 metric tonnes), NO_2 (224,096 metric tonnes), SO_2 (14,514 metric tonnes), and PM_{10} with 4,121 metric tonnes (DOE, 2015). Md. Zubir et al. (2017) conducted an estimation of NOx inventory emissions for passenger cars using petrol and diesel fuel in Peninsular Malaysia from 2008 to 2014. They also made comparisons across the states. The research revealed a consistent rise in yearly NOx emissions from gasoline-powered passenger cars, with an increase from 1,130 metric tonnes in 2008 to 1,670 metric tonnes in 2014. Nevertheless, there were several years that saw a decline in comparison to the preceding year. Specifically, in 2011, there was a reduction of 1,100 metric tonnes from the 1,320 metric tonnes recorded in 2010. Additionally, there was a dip from 1,700 metric tonnes in 2013 to 1,670 metric tonnes in 2014.

Private cars powered by diesel faced a similar trend, with the emission of NOx increasing from 827 metric tonnes in 2008 to 1,370 metric tonnes in 2014. However, in 2010, the NOx emissions from diesel passenger cars decreased compared to the previous year. Specifically, the emissions decreased from 858 metric tonnes in 2009 to 792 metric tonnes in 2010. In summary, the data demonstrates that petrol fuel is the primary source of NOx emissions from passenger cars in Peninsular Malaysia between 2008 and 2014, surpassing diesel fuel. Kuala Lumpur had the greatest levels of NOx emissions from passenger cars using petrol and diesel, with 7,320 metric tonnes and 11,400 metric tonnes respectively, between 2008 and 2014 (Md. Zubir et al., 2017).

Consequently, the air quality will worsen and pose a direct threat to human health. The air quality status is assessed using the Air Pollutant Index (API), which is calculated based on five criterion pollutants which is CO, NO_2, SO_2, PM_{10} and O_3. The pollutant index measurements indicate the air quality classification of a region, as shown in Table 2.

Table 2: Air Pollutant Index (API) of Malaysia

API Index	Status
0 - 50	Good
51 - 100	Moderate
101 - 200	Unhealthy
201 - 300	Very Unhealthy
Above 300	Hazardaous

Source: Environment of Department, Malaysia 2014

The API index in Kuala Lumpur, as detected at the Cheras station by the DOE, indicates that the air quality is now at an unhealthy status. This surpasses the index range of 100 to 200 that was recorded from 1998 to 2014. The API index, which measures the effect of transboundary haze caused by land and forest burning in Central Sumatra and West Kalimantan, Indonesia, reached a level of 390 in 2005, indicating the severity of the problem. The haze event on March 14, 2014, also registered an API of over 300 in two regions, including Port Klang and Banting, Selangor, indicating a hazardous level of air pollution. The identification of this scenario was attributed to the occurrence of arid and scorching seasons, as well as the burning of biomass (DOE, 2010-2014). From 1998 to 2014, the API index in Kuala Lumpur was consistently above the index of 100.

This research specifically examines the projected NOx emissions from three categories of officially registered motor vehicles in Kuala Lumpur between 2010 and 2014. These categories include petrol-powered automobiles and motorcycles, as well as diesel-powered cargo trucks. The estimation of emissions is based on fuel consumption data. The choice of the Kuala Lumpur research region was determined by the significant levels of fast urbanisation and building saturation, as well as the substantial number of motor vehicles that has been documented by the Road Transport Department, Malaysia (RTD) throughout the study period. Furthermore, the research only considers motor vehicles that are registered by the RTD Headquarters in Wangsa Maju district, Kuala Lumpur, as the major data source for determining the total number of private cars in the city.

MATERIALS AND METHODS

Study Area: Kuala Lumpur Metropolitan City

Kuala Lumpur (3.1080° N; 101.1440° E) is a sub-region within the Klang Valley. It is governed by Kuala Lumpur City Hall (KLCH) and includes the districts of Petaling, Gombak, Hulu Langat, the Federal Territory of Putrajaya, and Sepang. Kuala Lumpur covered an area of 243 square kilometres or 24,221 hectares and was divided into six key strategic zones based on urban land use planning: Sentul-Manjalara, Wangsa Maju-Maluri, Bandar Tun Razak-Sungai Besi, Damansara-

Penchala, and Kuala Lumpur City Centre (KLCH, 2004) (Figure 1). Notably, Kuala Lumpur's geography consists of a valley that extends from the eastern boundary of the Titiwangsa range to the western Malacca Strait, with other short mountains in the north and south.

The density and size of fully developed urban districts in Kuala Lumpur were concentrated in the city centre. The area increased significantly from 456.99 square km in 1989 to 1,663.23 square km in 2014, representing a rise of 46.67 per cent. The urbanisation and population density of Kuala Lumpur has seen a four-fold rise over a span of three decades, increasing from 51.81 per cent in 1989 to 60.22 per cent in 2001, and ultimately reaching 64.36 per cent in 2014. Regarding the proximity of urban density to the city centre, the data from 2014 indicates that the urban density in the city core exceeded 95 per cent. According to Boori et al. (2015), within a range of 1 to 3 km from the city centre, the city's area and population density have declined by up to 75 per cent. However, beyond a distance of 3 to 6 km, both the area and density have grown. Finally, at a distance of 50 km from the city centre, the area and density have fallen to 0 per cent.

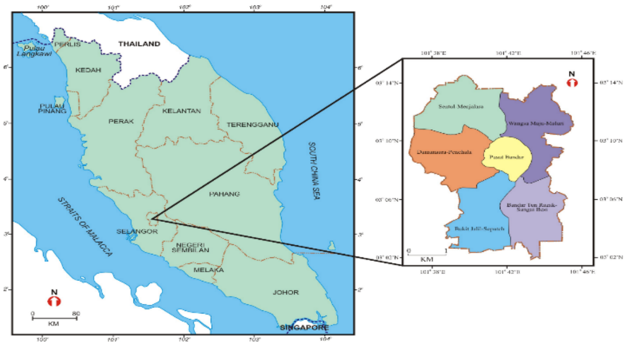

Figure 1: Map of Peninsular Malaysia and Kuala Lumpur
Source: Modified from RSGIS Laboratory, Faculty of Social Sciences and Humanities, UKM 2019

Data and Methods: Registered Motor Vehicle Data

The primary data utilised to estimate the emission of NOx pollutants in Kuala Lumpur comprises the total count of registered motor vehicles, including private cars, motorcycles, and goods vehicles. These statistics are obtained from the RTD Headquarters in Wangsa Maju district, Kuala Lumpur, covering the period from 2010 to 2014.

Calculation of NOx Emissions

The estimation of NOx petrol emission is conducted using a fuel-based analysis for each vehicle class, using equation 1 (Kakouei et al., 2012). The calculation of

NOx pollutant emission is then determined by utilising fuel, as described in equation 2 (Masjuki et al., 2004).

$$Fc = Ac \times V \times Rd \quad (1)$$

Where:
Fc = daily fuel consumption (diesel or petrol) (litres)
Ac = average fuel consumption for each class per kilometre (litres/ km).
V = number of vehicles by class
Rd = total vehicle travel per day (km).

The "Rd value" refers to the distance that is travelled by a vehicle, and is measured in kilometres. The data collected from a survey of 200 people in Kuala Lumpur indicates that the sample size is quite modest and has been calculated (Mohd Shafie, 2019). The acquired figure is diminutive because of its correlation with the mean distance covered by the inhabitants of Kuala Lumpur. The mean daily travel distance is 14 km.

$$TMi = CF \times (FE\ 1p + FE\ 2p + FE\ 3p + \ldots + FE\ np) \quad (2)$$

Where:
TMi = pollutant emissions (year i) (kg)
ES = energy consumption by fuel (year i)
CF = conversion factor (default)
FE n/p = emissions per energy unit year per fuel n (kg/GJ)
*The value of the conversion factor (CF) used in this study is 1 toe = 41.86 GJ (EIA, 2004; IEA, 2002; UN, 1991).

The ES value in ktoe is derived by combining the total number of motor vehicles that are registered annually with the energy consumption data available from the Malaysia Energy Statistics Handbook report from 2010 to 2014 (Energy Commission, Malaysia, 2014). The emission factor for petrol and diesel fuel is determined based on the contaminants listed in Table 3.

Table 3: Emissions per unit of petrol and diesel energy (FE) (kg/GJ)

Fossil Fuel	Emision	
	CO	NOx
Petrol	3.490	1.368
Diesel	0.102	0.284

Source: Masjuki et al., 2004

RESULTS AND DISCUSSION

Vehicle Statistics in Kuala Lumpur

According to RTD Headquarters in the Wangsa Maju area of Kuala Lumpur, the total number of registered motor vehicles between 2010 and 2014 was 1,748,367 units. These vehicles included private cars, motorcycles and goods vehicles. The upward trajectory continues annually with the number of private cars, which amounted to 3,161,406 units in 2010, showing consistent growth, reaching 3,812,124 units in 2014, reflecting a rise of 3.72 per cent.

Private vehicles, namely cars and motorcycles, accounted for the largest proportion of motor vehicle registrations from 2010 to 2014. There were 10,906,065 units of private cars, representing 62.37% of the total registrations, and 6,030,752 units of motorcycles, accounting for 34.49%. The heavy vehicle class, including goods vehicles, had a minimum registration of 498,837 units, accounting for 2.85 per cent of the overall registration of motor vehicles.

The registration data for motor vehicles, categorised by class and year, indicates a consistent upward trend from 2010 to 2014. Private cars dominated the vehicle category, with a total of 1,960,081 units in 2010, which rose to 2,382,526 units in 2014, reflecting a growth rate of 2.41%. Motorcycles saw a similar upward trajectory, with their numbers rising from 1,094,113 units to 1,317,578 units (1.27%) between 2010 and 2014. In 2010, the number of good vehicles was 97,611 units. By 2014, these numbers had increased to 102,364 units, with a percentage rise of 0.0003% and 0.02%, respectively. Hence, private vehicles, namely, cars and motorcycles, are the primary sources and factors responsible for urban air pollution in Kuala Lumpur (Figure 2).

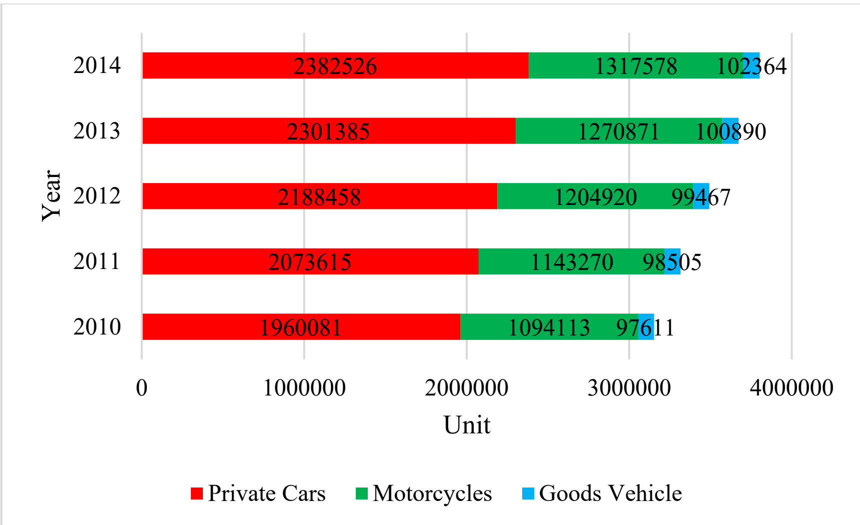

Figure 2: Motor vehicles by class in Kuala Lumpur (2010-2014)

NOx Emissions from Motor Vehicles

In 2010, private cars emitted 3,854 kg of NOx, which grew to 5,726 kg in 2014. This makes private cars the dominant vehicle type in Kuala Lumpur in terms of NOx emissions. Furthermore, motorcycles exhibited a rise in NOx emissions from 1,200 kg in 2010 to 1,750 kg in 2014. Heavy vehicles, such as good vehicles, had a distinct pattern. In 2010, they emitted the lowest levels of NOx at 199 kg and 193 kg, respectively. However, by 2014, these emissions had climbed to 219 kg and 195 kg, as seen in Figure 3.

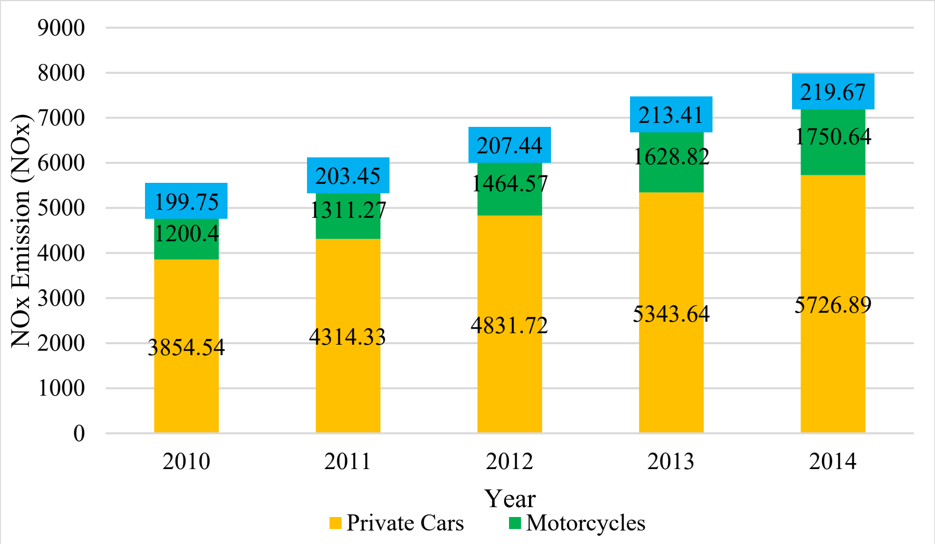

Figure 3: NOx emissions from motor vehicles in Kuala Lumpur (2010-2014)

The elevated levels of pollutants were identified due to the rise in the maximum vehicle count in Kuala Lumpur. The data from RTD regarding the number of motor vehicle registrations by vehicle class is a crucial factor contributing to the rise in emissions. This is evident in the land transport sector, which comprises three vehicle classes- private cars, motorcycles, and goods vehicles. Between 2010 and 2014, more than 17 million units were recorded (RTD, 2016). The primary driver behind the rise in motor vehicle numbers, particularly in urban areas, is the consistent expansion of household income, which directly impacts individuals' capacity to own a motor vehicle. Consequently, significant traffic congestion issues arise, particularly at road junctions and signalised crossings, as well as on roads that are flanked by high-rise structures. Thus, significant emission levels of pollution from motor vehicles and traffic were observed, particularly on weekdays in downtown Kuala Lumpur, in contrast to the weekends. Conspicuously, the position and topography of Kuala

Lumpur city centre, with its proximity to office spaces, industrial premises, residential areas, and major shopping centres in Malaysia, contribute to higher levels of pollutant emissions from traffic activities and motor vehicles. The morning NOx concentration consistently exhibits a higher daily average compared to the evening, with a minimum average of 0.04 ppm and a maximum of 0.18 ppm, as shown by Sulaiman et al. (2010). Traffic is the primary source of pollution that causes the urban air quality to decline due to elevated levels of pollutants, particularly in the city centre. This is primarily due to the congested and dense traffic network, as well as the high concentration of urban space with various service activities.

IMPACT OF URBAN AIR ON ENVIRONMENT AND CLIMATE CHANGE

Researchers are currently investigating the potential impact of severe climate change on public health. This includes studying the direct consequences of warmer weather events and intense heat waves, the potential decrease in food security, the indirect effects on the prevalence of infectious diseases, and the impact of air pollution. The World Health Organisation (WHO) has affirmed that robust scientific evidence indicates that global warming would significantly impact fundamental human necessities, including food insecurity, air pollution, and lack of access to clean water (Jacob & Winner, 2009). The presence of greenhouse gases, such as carbon dioxide (CO_2) and nitrogen oxides (NOx), in the air will have a direct or indirect impact on the weather patterns in the affected region due to climate change. Subsequently, urban regions are more likely to have a higher prevalence of health complaints, such as asthma (Zanolin et al., 2004). Each year in China, over 1 million individuals experience early deaths as a result of air pollution. This is compounded by the anticipated rise in severe events and unfavourable weather conditions due to climate change (Schellnhuber, 2019).

Hence, the issue of urban air pollution that is caused by motor vehicles necessitates the attention of stakeholders' and government agencies in order to regulate the emission of pollutants and greenhouse gases, thereby mitigating the consequences of climate change. The influence of greenhouse gas emissions on human health manifests through several means, such as elevated ozone levels, alterations in allergen distribution, and shifts in infectious disease vectors. Consequently, the emission of air pollutants in the city not only affects the air quality but also significantly impacts the health of individuals, especially those with respiratory and other ailments (D'Amato et al., 2010).

STRATEGIES TO TACKLE MOTOR VEHICLES EMISSIONS IN MALAYSIA

To tackle this significant environmental concern, the Malaysian government must enforce more stringent emission regulations for newly manufactured automobiles, to diminish the release of NOx. The standards should align with internationally recognised best practices and include the most recent technology breakthroughs in the automobile sector. The government needs to promote the use of low-emission vehicles, such as electric and hybrid automobiles, by offering tax incentives, subsidies, and other financial inducements. This will not only decrease NOx emissions but also encourage the use of cleaner and more sustainable methods of transportation. Correspondingly, the authorities have to enforce a vehicle inspection and maintenance initiative to guarantee that current automobiles are in optimal operational state and adhering to emission regulations. This will aid in mitigating the emission of excessive NOx into the environment. The government must provide funds towards the advancement of alternative fuels, such as compressed natural gas (CNG) and liquefied petroleum gas (LPG), since they generate lower levels of NOx emissions compared to conventional petrol and diesel fuels. This will provide customers with a wider range of options and promote the adoption of more environmentally friendly technology.

The government should actively and proactively promote the use of public transit, such as buses and trains, in order to reduce the quantity of private automobiles on the road. This would decrease NOx emissions and mitigate traffic congestion, which consequently enhance the air quality in metropolitan areas. Malaysia also needs to enforce a congestion fee or road pricing scheme in order to deter the use of private vehicles during periods of high traffic volume. By promoting the use of public transportation or carpooling, the outcome will be a reduction in NOx emissions. The government should also allocate resources towards the advancement of eco-friendly infrastructures, such as green roofs and walls, with the purpose of mitigating NOx emissions and enhancing the air quality in metropolitan regions. Implementing this measure would decrease the emission of NOx, and will also provide other ecological and societal advantages such as mitigating the urban heat island phenomenon and enhancing the overall well-being of urban residents.

Furthermore, Malaysia must actively engage in cooperation with adjacent nations to formulate a regional approach that is aimed at mitigating NOx emissions originating from motor vehicles. This measure will effectively tackle the problem of transboundary air pollution and enhance the overall air quality in the area. Regular air quality monitoring and evaluation should be conducted by the government to track NOx emissions and pinpoint locations for intervention. This would empower the authorities to implement precise and efficient strategies to mitigate NOx emissions and enhance air quality. The government need to engage many stakeholders, including the automobile sector, consumers, and environmental organisations, in the formulation and execution of programmes that are aimed at reducing NOx emissions. This will guarantee that the strategies are feasible, efficient, and agreeable to all parties concerned.

CONCLUSION

The cause of air pollution in Kuala Lumpur was attributed to a significant surge in the number of registered motor vehicles, reaching a total of 1,748,367 units including private cars, motorcycles and good vehicles between 2010 and 2014. The emission of NOx emissions from private cars was the primary contributor, reaching a peak of 3,854 kg in 2010 and rising to 5,726 kg in 2014. Therefore, it is imperative for the government, interest groups, and urban community to establish and implement a range of policies, measures, and control strategies to effectively address, manage, and mitigate the adverse effects of air pollution. This will help to ensure a more sustainable and safer environment for the local community. These are suggestions and enhancements for managing and mitigating air pollution in Kuala Lumpur. The focus is on fostering collaboration and synergy between the government, the economic sector, and the community to effectively regulate and minimise the impact of air pollution. Regulating the release of harmful gases from automobiles and greenhouse gases will have a positive influence on the well-being of the city's residents, and to a certain degree aid in mitigating environmental pollution and the global effects of climate change.

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CONFLICTS OF INTERESTS

The authors declared no conflict of interest.

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