APPLICATION OF COPERT 5.5 EMISSION SOFTWARE TO DEVELOP VEHICULAR EMISSION INVENTORIES, ESTIMATE LOCKDOWN IMPACT AND PREDICT FUTURE TREND OF EMISSIONS FOR BANGLADESH

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JUNE 2022

APPLICATION OF COPERT 5.5 EMISSION SOFTWARE TO DEVELOP VEHICULAR EMISSION INVENTORIES, ESTIMATE LOCKDOWN IMPACT AND PREDICT FUTURE TREND OF EMISSIONS FOR BANGLADESH

A Thesis

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Bachelor of Science in Civil Engineering

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DECLARATION

We hereby declare that the thesis work entitled **"Application of COPERT 5.5 Emission Software to Develop Vehicular Emission Inventory, Estimate Lockdown Impact and Predict Future Trend of Emission for Bangladesh"** submitted to the Ahsanullah University of Science and Technology done by the members of this group collectively. We also state that the materials embodied in this report have not been published or submitted anywhere before date for any other purpose to award of any degree.

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This thesis titled entitled **"Application of COPERT 5.5 Emission Software to Develop Vehicular Emission Inventory, Estimate Lockdown Impact and Predict Future Trend of Emission for Bangladesh"** has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Civil Engineering on June, 2022.

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DEDICATED TO

PARENTS, FAMILY & TEACHERS

ACKNOWLEDGEMENTS

First of all, we would like to begin by expressing our gratitude to the Almighty for providing us the strength, wisdom, skill and opportunity to carry out this thesis and complete it successfully.

Secondly, we are grateful and would like to express our deepest gratitude to our supervisor, Dr. Md. Shahid Mamun, Professor, Department of Civil Engineering, Ahsanullah University of Science and Technology, for his constant guidance and assistance during this thesis. He has always been a source of inspiration for us because of his constructive suggestions and supportive remarks. Completing this task without his instructions and advices would never have been possible.

We would like to pay our deepest homage to our parents and family members for their undying support and encouragement.

We are indebted to the Department of Civil Engineering, AUST for having provided us with all facilities, which enabled us to carry out our thesis work.

Finally, we would like to thank Ms. Shahanaj Rahman, Deputy Director, Department of Environment for providing necessary data which was vital for this work. We would also like to express sincere thanks to all who have helped them by providing valuable suggestions and information throughout this work.

ABSTRACT

With Bangladesh being ranked 1st as the country with the worst air quality in the world in 2021, air pollution has become one of the leading risk factors for mortality in our nation, its predominant sources being brick kilns, vehicle fumes and PM from construction sites. To combat air pollution, it is imperative to address the vehicular emission crisis by accurately quantifying the harmful pollutants and greenhouse gases released by motorized vehicles in Bangladesh and hence determine effective mitigation measures. The purpose of this research is to initiate the establishment of a suitable vehicular emission model for Bangladesh by checking the applicability of the European model for this country. This research aims to estimate the vehicular emission inventory for the last 6 years, compare the percent contribution of emission by each vehicle category, propose emission factors for each vehicle category running in Bangladesh and predict future emissions for the year 2025. Also, it goes without saying that the rapid increase in the number of vehicles that emit various types of harmful pollutants and GHG's in the form of exhaust fumes was causing a downward spiral for the air quality Bangladesh, until a seemingly deadlier problem struck the world and forced people to stay at home in fear. COVID-19 not only took thousands of lives but also the lockdown due to covid-19 adversely affected the economic, agricultural, industrial, educational and social sector immensely. However, every cloud has a silver lining. Due to the lockdown, there was a substantial decrease in vehicular emission. That being said, this research also aims to investigate the reduced quantity of vehicular emissions due to the covid-19 lockdown during 2020 and 2021. Using the European emission model COPERT 5.5, this study estimated and analyzed yearly emissions of 13 major pollutants by different vehicular classes in Bangladesh from 2016 to 2021 and compared the results of yearly total quantity of primary GHG i.e. CO_2 emission in the transport sector of Bangladesh against a similar study made by World Bank. Next, the study estimated the vehicular emissions of the years 2020 and 2021 two times; once by applying normal vehicular activity information before the lockdown and again by applying actual vehicular activity information that was found during the lockdown. Lastly, this study forecasted emissions for the year 2025 using expected vehicular stock and activity information.

Keywords: Air Pollution; Greenhouse Gases; Vehicular Emissions; Emission Model; COPERT 5.5;

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LIST OF ABBREVIATIONS

BRTA	Bangladesh Road Transport Authority
CH_4	Methane
CMEM	Comprehensive Modal Emissions Model
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COPERT	Computer Program to Estimate Emissions from Road Traffic
DOE	Department of Environment
DScE	Dhaka School of Economics
EC	Elemental Carbon
EEC	European Environment Agency
EF	Emission Factor
EPA	Environment Protection Agency
EU	European Union
GHG	Greenhouse Gas
HC	Hydro Carbon
HDV	Heavy Duty Vehicles
IPCC	Intergovernmental Panel on Climate Change
IVE	International Vehicle Emissions
km/hr	Kilometer Per Hour
LDT	Light Duty Trucks
LDV	Light Duty Vehicles
LGED	Local Government Engineering Department
LGV	Large Goods Vehicle
MOVES	Motor Vehicle Emission Simulator
N_2O	Nitrous Oxide
NH_3	Ammonia
NMVOC	Non-Methane Volatile Organic Compound
NO	Nitrogen Monoxide
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides

OC	Organic Carbon
PAH	Polycyclic Aromatic Hydrocarbons
PEM	Portable Emission Measurement system
PM 10	Particulate Matter with an aerodynamic diameter of 10 microns or less
PM 2.5	Particulate Matter with an aerodynamic diameter of 2.5 microns or less
RHD	Roads arid Highways Departments
RUC	Road User Cost
SO_2	Sulfur Dioxide
STP	Strategic Transport Planning
SUV	Sport Utility Vehicles
VOC	Volatile Organic Compound

CHAPTER 1
INTRODUCTION

1.1 General

The economic growth of all countries is greatly influenced by road transportation, making it one of the primary principles of a country's standard of living. Nonetheless, it indicates a slew of negative societal consequences: pollution, noise, accidents, and so on. The transportation sector is the leading cause of air pollution in urban areas. It is the root cause of many problems with the air quality in the area, including high levels of benzene and carbon monoxide in the atmosphere, as well as the generation of photochemical smog. The consistent adoption of innovative emission regulations, the majority of which have been geared at lowering the amount of pollutant emissions produced by automobiles, has had a discernible and significant bearing on the recent pollution growth. On the other hand, thanks to the collaboration of automobile manufacturers, energy companies and national administrative agencies, local emissions have been cut down by a substantial amount. CO_2 emissions are a global pollutant that is produced as a consequence of the use of fossil fuels. Contradictorily, the percentage of contemporary automobiles, which are more fuel-efficient, has been steadily increasing over the last several decades. This has not yet been sufficient to restrict the emission of CO_2 gas. This is connected to the vast and continuous increase in mobility that has been taking place.

Road transport also contributes significantly to global warming due to carbon dioxide and other greenhouse gas emissions. As the world's growing economies and developed countries, such as Asia and Europe, increasingly rely on motorized transportation, it's reasonable to expect that already-high levels of air pollution will only deteriorate in the future. All of the above facts demonstrate the need for reliable air pollution simulations in such scenarios as local impact on environmental assessments, urban and regional air quality studies, national emission estimates, and forecasts for the future. As a result, reliable motor vehicle emission models may become more important for the development and assessment of air pollution management plans. As a conclusion of this research, a suggested integrated system for air quality and traffic planning has been developed. This system is designed to meet the requirements of the majority of organizations and people that operate in both of these domains. The Computer Program to Estimate Emissions from Road Traffic (COPERT), which is used throughout Europe as well as 28 other countries, serves as the foundation for this approach.

The significant growth in the number of cars on Bangladesh's metropolitan highways, notably gasoline and diesel vehicles, has resulted in increased traffic congestion and air pollution concerns. With the growth of the urban economy in Bangladesh, carbon emissions from automobile emissions have risen to the point that it has become a severe environmental concern with several adverse effects on human health. The first step in attempting to halt this ongoing damage and detriment to our environment is to conduct quantitative and qualitative analyses of the emissions produced by various automobiles used by individuals in order to bring it to their attention and warn them about using a model of car or type of fuel that generates more emissions than others. As a result, individuals may convert to alternative energy sources or means of transportation to positively influence this problem on an individual scale. This thesis aims to build in Bangladesh an approach that is often utilized in European nations. A modified strategy for emission profiles with high geographical and temporal resolution based on the same methodology is also described along with specific case studies. This paper also discusses a strategy for producing trustworthy emission projections and shows a variety of findings from relevant applications. Separately, the remaining uncertainties in car emission models are described. The approaches that have been created have been outlined in previous articles and studies. The findings of the model's use for predicting emissions for Bangladesh are the major focus of this research.

1.2 Significance of the Study

For the last few years, the Global Livability Report has ranked Dhaka as one of the world's least livable cities, while Bangladesh was ranked 146th in the Human Development Index in 2011. These poor rankings may be attributed to a combination of factors, including traffic congestion and air pollution (Asian Development Bank, 2012). A wide range of issues, including excessive traffic congestion, insufficient public transit, a lack of pedestrian comforts and safety issues, and increasing levels of air pollution (World Bank, 2009), characterizes the transportation conditions in Dhaka. Estimated emissions are beneficial for improving emission control methods, determining the suitability of licensing and control programs, determining the impacts of sources and adequate ways to mitigate, and a variety of other application areas by a wide range of users, including national, state, and local departments, consultants, and industry. A statistical result from different source-specific emission trials or continuous emission monitoring is often chosen for estimating a source's emissions since they give the most accurate depiction of the emissions of the tested source. However, testing data from specific links are not always accessible, and even when they are, they may not accurately represent the variation of absolute emissions over time. Despite their limitations, emission factors are usually the best or only approach available for measuring emissions. Around 15% of total CO_2 emissions are generated from Bangladesh's transportation sector. Bangladesh contributes 0.21% share of global CO_2 emission (Worldometer, 2022). When we analyze the road public transport sector, which is a key source of greenhouse gas emissions. Emissions from gasoline and diesel fuel use may be divided into two categories. Emissions from motor vehicles are caused mainly by gasoline combustion, the primary fuel used in them. Volatile fuels and lubricants may also lead to evaporation and loss of moisture. The emphasis of this research is on emissions caused by combustion. However, driving a car has many negative consequences including fatalities, road damage, poor air quality, congestion, and dependence on fuel.

The transportation sector is critical in calculating a metropolitan area's footprint. Every day, a large number of automobiles drive through the city. They use a lot of fossil fuels. When these fuels are used in the chambers of these cars, they emit a large quantity of CO_2 into the atmosphere on a regular basis. So, in order to mitigate the effects of the increased CO_2 in the air, we must implement certain measures that could also extract this additional CO_2 from the atmosphere.

Several variables impact the emission inventory of gasoline cars, including environmental parameters, vehicle circumstances, fuel specifications, traffic conditions and so on. There are several emission models from all around the globe that were established based on a certain element or mix of these variables to quantify different kinds of emissions. Our goal is to utilize COPERT 5.5 to determine if it is a suitable emission model for Bangladesh.

1.3 Objective of the Study

This research aimed to estimate pollutant emissions produced by vehicles in Bangladesh between 2016 and 2021. The information gathered from the study will be used to accomplish five goals:

1. First of all, this study will provide a clear and thorough picture of the existing situation of vehicular emissions from 2016 up to now.
2. Secondly, the study's findings are designed to serve as a foundation for making policy decisions that ensure increased mobility while reducing greenhouse gas emissions.
3. Thirdly, this study aims to suggest current emission factors for different vehicle types in Bangladesh.
4. Then, this research's outcomes will help show the silver lining of COVID lockdown reduced vehicular emission.
5. Finally, a scenario will be developed based on the study's results to guide further research into Bangladesh's emissions.

1.4 Scope of the Study

The research will only analyze and estimate the rate of vehicular emission in Bangladesh during the past six years, as well as project a clear picture for future years. This comprehensive study contains registered vehicle numbers, speed and annual kilometer driven. The study's data is mostly based on information acquired from journal sources and various governmental or non-governmental departments such as LGED, BRTA, World Bank and so on. Newspapers do not just publish total GHG emissions and environmental effects from vehicular emissions in order to inform people about engineering analyses. Some information is not accessible because data collecting formats need high-quality equipment and an effective technical framework which are not yet fully established in Bangladesh. It seems that government agencies have a range of data that they would have anticipated or are still using the older data for future work. This research separates the deficiencies and attempts to address them in the best conceivable manner.

1.5 Organization of the Study

This research-based study includes an overview of the project, previous research projects, a comprehensive method and justification for the study project, data collection and data analysis, a description of the study findings and their significance, and finally, the study concludes with possible recommendations and future work based on the findings. Therefore the thesis is categorized into six different chapters.

Chapter 1: The first chapter represents the overview of the full thesis and provides the basic foundation of the study. It also presents the background, significance, scope, and objective of this study.

Chapter 2: In this chapter, previous literature on this subject has been reviewed. This review summarizes the previous research, overview of emissions from the vehicle, and causes of vehicular emission.

Chapter 3: This chapter discusses the system's theoretical and analytical components, as well as research design and methodology in Bangladesh. The inventory of emission models and their components is described in this chapter.

Chapter 4: The fourth chapter provides an overview of the data collection method in the studied area and processes those data according to the methodology that has been followed throughout the research work.

Chapter 5: The total vehicle emission is shown in Chapter 5. The proportion of total emissions is investigated by vehicle type, year, pollutants, and other factors. Different cross-classifications of emissions were explored in an attempt to uncover variables.

Chapter 6: This chapter presents the study's key findings, conclusions, and discussion of the findings. This chapter also discusses limitations and recommendations for future research.

1.6 Overview

A general statement of the research effort has been presented in this chapter. The current state of the transportation system of Bangladesh as well as the scope of the issue has been addressed. The goal of the study and the purpose of this research project have also been identified. Finally, the structure of the thesis documentation work has been presented.

CHAPTER 2
LITERATURE REVIEW

2.1 General

Detailed literature research is conducted in order to get a fundamental understanding and knowledge of emissions from the transport sector and transportation systems of a modernized, efficient, and sustainable country as a whole, as well as the general description of emissions from the transportation sector. This chapter contains a quick description of that evaluation. Finally, a summary of previous research works on combustion procedure, stock configuration, vehicle activity parameter, vehicular fleet management and distribution in Bangladesh conducted by different governmental departments, weather properties, and emission estimation methodology using software named COPERT is discussed in this chapter, along with relevant research approaches, findings, and discussion on those works.

Estimation of emissions from vehicles requires so much information for a better outcome. This research review aims to help people comprehend the connection between transportation, personal travel habits, and climate change. It draws on data from a variety of sources, not all of which are directly related to climate change or transportation.

2.2 Distribution of Vehicle Fleet

Bangladesh Road Transport Authority (BRTA) collects registration data for the country's motorized vehicle fleet. According to BRTA, about 2984200 vehicles were registered in 2016-2017 (RHD, 2017). The utilization tables also showed that, with the exception of Utility and Motorcycles, each vehicle mileage traveled (kilometers) has decreased significantly over the previous 12 years, but the average number of hours traveled per vehicle has grown. As a result, compared to the RUC research conducted in 2004-05, the speed limit of various vehicle types decreased in 2016-17. In 2017, the average speed range for buses traveling on RHD national roads was 36 to 37 kilometers per hour, while in 2004-2005, the average speed range for these vehicles was 42 to 45 kilometers per hour. A commercial freight vehicle's speed restriction of 30 km/hr on the RHD network in 2017 compared to 41 km/hr in 2004-

05 was a significant decrease. When comparing the number of registered vehicles between 2004-05 and 2016-17, it is obvious that the majority of vehicle categories have seen significant growth. Although individual vehicle distances are reduced, the overall vehicle-km traveled by all vehicles on the roads and highways network is increased (RHD, 2017). According to the Roads and Highways Department (RHD) of Bangladesh, there is a wide range of vehicle fleets in Bangladesh. As a result, the RHD has created a categorizing system of motorized and non-motorized vehicles, which was primarily designed for traffic considerations as shown in Table 2.1.

Table 2.1: Types of RHD vehicle fleet in Bangladesh (Source: RHD, 2001)

	RHD Vehicle Category	Description
Motorized Vehicle	1. Heavy Truck	There are 3 or more axles. Tandem trucks with many axles, container carriers, and other articulated trucks are examples.
	2. Medium Truck	2 axle rigid trucks with a payload of 3 tonnes including tractors and trailers for agriculture
	3. Small Truck	2 axles are rigid with a payload range of 3 tonnes
	4. Large Bus	Greater than 40 seats and 36 chassis
	5. Small Bus	Less than 40 seats and 36 chassis.
	6. Mini Bus	16 to 39 seats and less than 36 chassis.
	7. Micro Bus	Up to 16 seats
	8. Utility	Jeeps, pick-ups, and four-wheel-drive vehicles
	9. Car	Cars and taxis of all sorts
	10. Motor Cycle	All motorized 2-wheeled vehicles
	11. Auto Rickshaw	Vehicles with three wheels including Baby taxis
	12. Tempo	Auto Tempo/Van with a large passenger and load capacity
Non-motorized Vehicle	13.Cycle Rickshaw	Non-motorized 3-wheel passenger vehicle
	14. Rickshaw Van	Non-motorized 3-wheel cargo vehicle
	15. Cart	Different types of carts
	16. Bicycle	All 2-wheel pedal cycles

2.3 About COPERT

COPERT is the European Union's (EU) standardized vehicle emissions calculator. It evaluates emissions and fuel consumption for a certain nation or area based on vehicle number, traveling distance, speed limit and other parameters like ambient temperature and humidity. COPERT is a Microsoft Windows application that calculates air pollution emissions from vehicle traffic. The European Environment Agency (EEA) funds COPERT's technical development as part of the operations of the European Topic Centre on Air and Climate Change. Since 2007, the European Commission's Joint Research Center supervised the model's scientific development. COPERT was designed in concept for National Experts to use in estimating greenhouse gases from road transport for inclusion in official yearly national inventories. Road transportation emissions may be computed using a software program, which provides a more open method of determining the emissions and a uniform data collection and reporting approach, resulting in consistent and comparable results in conformity with international agreements and protocols as well as EU regulations

Also, COPERT is:

- Globally accepted – several European nations use it to publish official emissions statistics.
- A research tool for calculating emissions on a national, regional, or local scale, with estimates ranging from annually to daily.
- COPERT's methodology is documented and peer-reviewed by UNECE LRTAP Convention specialists, making it technologically sophisticated and transparent.
- All major pollutants are included, including greenhouse gases, air pollutants, and hazardous species. (Source: EMISIA)

2.4 Effect of Different Factors on Developing Emission Inventory

2.4.1 Climate Change

Vehicular emission greatly depends on the weather condition surrounding the vehicle. That is why country-specific data like monthly average temperature and relative humidity are very important for estimating emissions from the vehicle as emission is directly affected by temperature and relative humidity. Global warming is no longer a future phenomenon but rather an existing one. Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as an adjustment in the mean and variability of the climate's features that can be characterized statistically. As a result of climate change, Bangladesh is among the most vulnerable nations (Harmeling, 2008).

Temperature

The emission factor is directly affected by ambient temperature. Because the temperature fluctuates during the day, fuel losses may occur. According to COPERT, HOT emissions from vehicles increase with the increase in ambient temperature. Emissions are greater in this phase and are highly dependent on environmental circumstances. Cold-start pushes emission zeroes as the vehicle warms up, leaving only hot emissions. On the other hand, COLD emissions from vehicles increase with decreasing temperature.

Previously Basak et al. (2013) conducted research on temperature change. The article assesses climate change and variability based on a study of historical temperature and rainfall data gathered at 34 meteorological stations throughout seven Bangladeshi areas from 1976 to 2008. A 0.0186ºC annual rise in the average maximum temperature, whereas a yearly 0.0152ºc rise, has been noted for the average minimum temperature. All months except January and April exhibited a rising monthly average maximum temperature trend. The upward tendency was especially noticeable from May through September and February. Except for January and November, every average monthly minimum temperature record indicated rising tendencies.

These findings are significant for estimating the emissions of Bangladesh because the annual emission rate is significantly influenced by temperature. Although this study was done in 2013 for the years 1976 to 2008, this temperature increase may not be fully justified in recent years because changing temperature depends on many factors whose are change year by year. It is also a fact that this type of research is not done frequently in Bangladesh. And since the changing temperature rate is not that large, this observation may be used to predict the temperature in the future.

Humidity

Choi et al. (2010) conducted research on the impact of temperature and humidity on emissions. The study showed that in terms of humidity sensitivity, HC and CO was affected at temperatures over 75 degrees Fahrenheit. In contrast, NOx was affected at temperatures exceeding 25 degrees Fahrenheit, with increased sensitivity as relative humidity rises. The humidity sensitivity of gasoline automobiles was higher than that of diesel vehicles. The findings also showed that overall PM2.5 was unaffected by humidity variations in both petrol and diesel cars.

Because of the large number of input parameters and their interdependences, this paper focuses mainly on temperature and humidity, analyzing changes in emissions from changes in these parameters separately and comparing the consequence of each individual parameter on emission findings by measuring percent change in emissions.

Mortuza et al. (2014) conducted a study on humidity and dew point temperature. Using data from 1961 to 2010, this study looked at seasonal and yearly trends in humidity and dew points in 15 vital locations in Bangladeshi. The slopes of Sen's estimator were used to calculate the magnitude of the climate trends. The Mann–Kendall test was used to examine the statistical significance of the patterns.

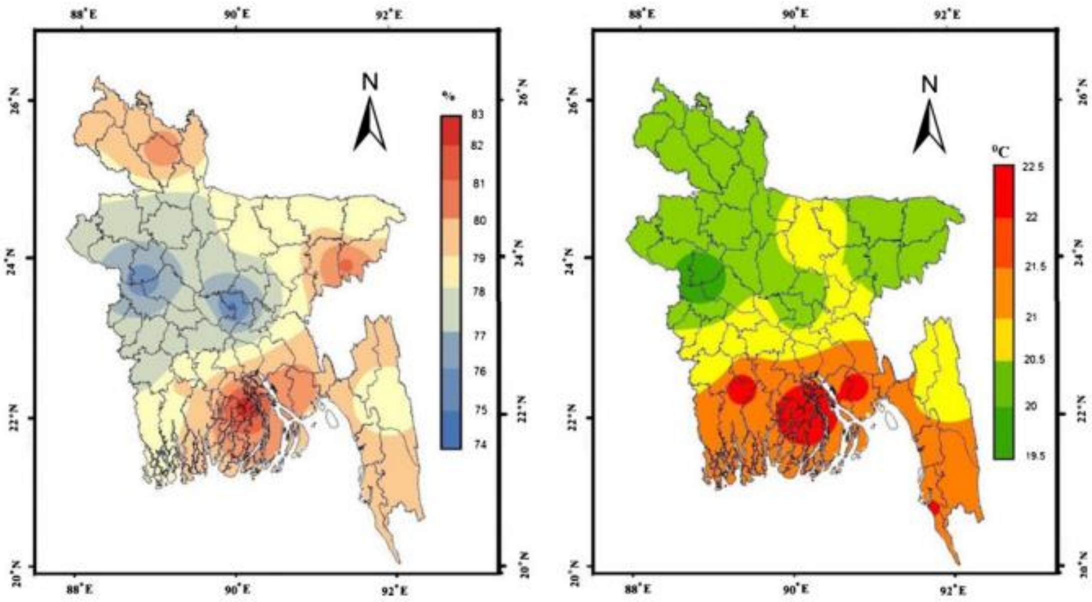

Figure 2.1: Spatial distribution of the mean annual relative humidity and dew point temperature over the period 1961–2010 (Source: Mortuza et al., 2014)

Allowing for a 95% confidence level, the study findings showed that the proportion of stations indicating a meaningful trend in relative humidity is mild but much greater in the dew point temperature series. On an annual, winter, and pre-monsoon scale, relative humidity in the western portion of the nation was growing at 0.53, 0.86, and 1.18 percent each decade, respectively. Significant negative patterns in relative humidity series could be seen during the monsoon season. On the other hand, neither the seasonal nor the annual dew point temperature time-series data at any site demonstrate any significant deterioration in their values. Again, the magnitude of the relevant trends was greater in the country's west. The major portions of the slopes are well above zero, showing that dew point temperatures in Bangladesh were rising on an annual and seasonal basis.

2.4.2 Emission Degradation Correction Factors

Only petrol cars and LGVs are subject to emission degradation. It is also used exclusively to change emission factors for Euro 1-4 cars, with no degradation factors for Euro 5 and 6 vehicles. Degradation corrections are also not required for diesel vehicles or LGVs. As per COPERT methodology, the emission factor obtained from the speed-emission coefficients is multiplied by the degradation correction factor. The degradation factors grow with increasing mileage, but vehicles of Euro 1 and 2 have a certain limit, which is only up to a maximum of 120,000km. The same goes for Euro 3 and 4, which have a limit of 160,000km. The value of the adjustment factor supplied for these mileages remains constant at mileages above this. Using COPERT 5 coefficients, a linear equation is used to calculate a degradation adjustment factor for a given cumulative mileage. There is only one series of coefficients to utilize for all engine sizes in Euro 1 and 2 petrol automobiles. There is a range of coefficients for vehicles 1.4l and cars >1.4l in Euro 3 and 4 automobiles. For each of these vehicle classes, a set of coefficients is used to calculate a degradation factor for speeds less than 19 km/hr as well as another set for speeds more than 63 kph. A degradation factor is calculated using an interpolation approach for intermediate speeds. (Murrells, 2017)

2.4.3 Vehicle Age

Previously Zachariadis et al. (2001) conducted a study on the influence of age on vehicular emission where relations among vehicle's age, mileage, and speed were shown. The study discussed the impact of motor vehicle aging and technology replacement on air emissions. To help with the inquiry, an existing model was used to look at the fleet dynamics and determine the emissions. The system's sensitivity to various ages and technical characteristics was investigated. The effects of deteriorating emissions, monitoring and control programs execution, and implementing alternative fuels were examined.

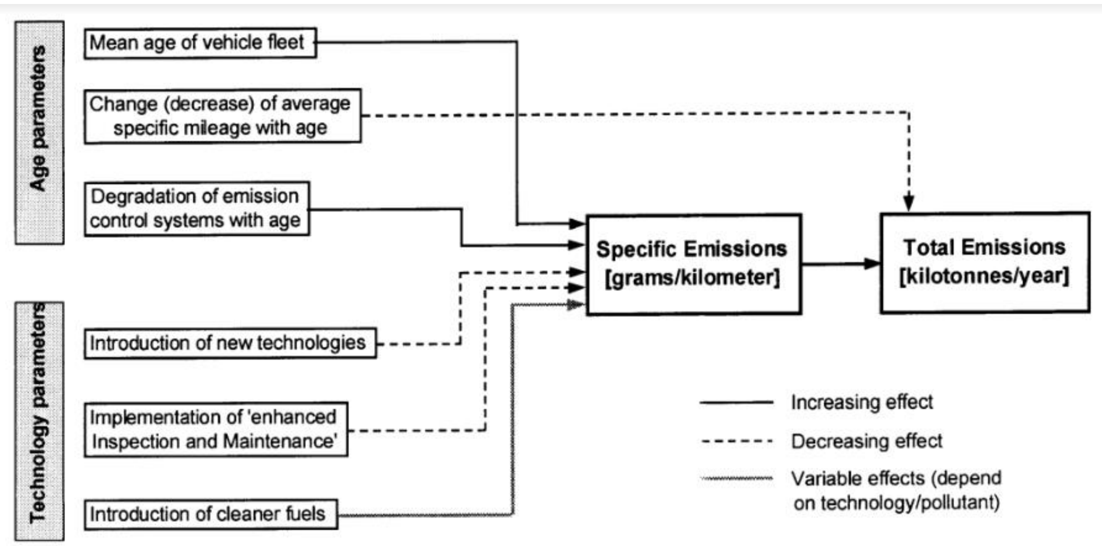

Figure 2.2: Overview of the parameter related to vehicle age and technology level that affect emissions (Source: Zachariadis et al., 2001)

Figure 2.2 shows age, technology, and vehicle emissions interdependencies. There are several pollution reduction alternatives that may be estimated by this model, which takes into consideration all characteristics of the vehicle stock's age and technology structure. The approach given here is advantageous due to its use in several countries and situations, the clarity of its built-in mathematical correlations, and its phenomenological approach. In this research, a graphical presentation was conducted between the mileage and age of vehicles.

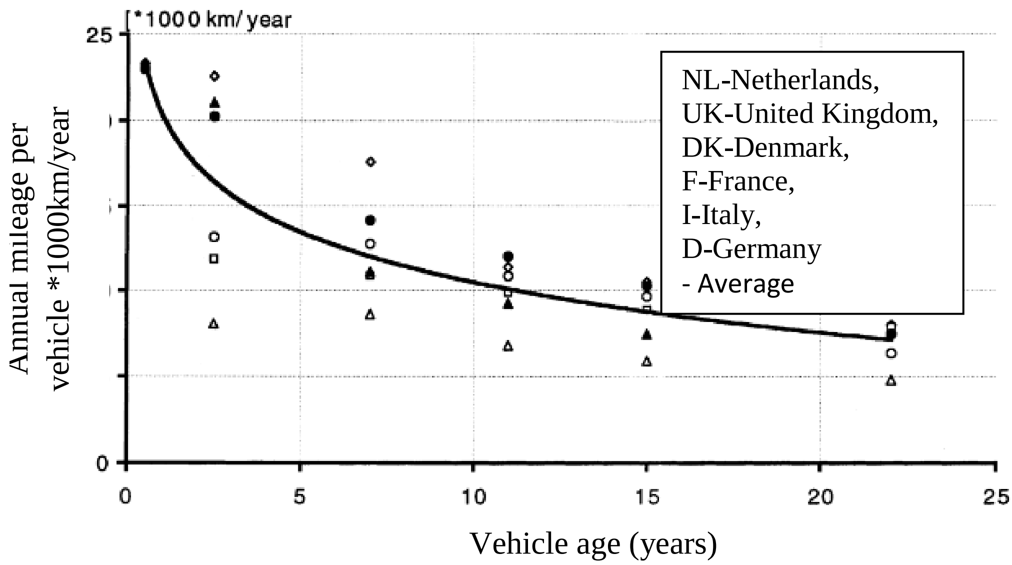

Figure 2.3: Six European nations' estimated mileage by vehicle age. (Source: Zachariadis et al., 2001)

Road traffic data in several nations demonstrate that when cars expand in size, they are driven less. Furthermore, the degradation of emissions control systems and the aging of the catalytic converters of older vehicles are the primary causes of an apparent worsening in emissions behavior as vehicles age. These factors must also be taken into consideration in order to get accurate emission estimations.

2.4.4 Specific Emission Factor

An emission factor may be used to calculate the quantity of a pollutant that is emitted into the atmosphere as a function of a particular activity. It has long been the principal component for compiling local and national level emission inventories for air quality control and management decisions. The emission factor is also used for formulating emission control strategies. The emission factor relates to the vehicle activity and the amount of pollutants from the vehicle. Dividing the weight of a pollutant by the unit weight/volume/net duration of activity that is responsible for generating the pollutant is the general way to measure the emission factor for that particular pollutant. (Eastern Research Group, 2013)

Emission = Activity × Emission Factor × % Reduction

Generally, developed countries have their own emission factor for specific emission inventory. To establish a set of country-specific emission factors, there needs to be massive number of emission data sets and corresponding information. Maximum states in the European region have their country-specific emission factors. In Asian territory, it is very rare to find; especially in Asian subcontinent countries such as India, Bangladesh, and Pakistan have lack of necessary information to form a set of emission factors. A bottom-up inventory was developed for exhausted transportation emissions, keeping 5-10% uncertainty of vehicle age composition (Baidya and Borken-Kleefeld, 2009). This set of emission factors was generalized to South-East Asian countries. A project was undertaken in Pune, India to develop emission factors for the transportation sector and air quality monitoring facilities. They performed a constant mass emission test on different vehicle fleet for different speed ranges, formed a set of emission factors on fuel exhaustion and used it as a part of emission inventory development and emission source appointment studies (ICAP, 2007). In Bangladesh, a project was undertaken by DoE to develop an emission inventory where the study area was divided into two sections (Dhaka and Chittagong) and the Indian emission factor was used for estimating total emissions from the transportation sector (Randall et al., 2015) that Bangladesh does not have its own specific set of emission factor which is becoming an obstacle to establishing obstacle to establish a perfect and accurate emission inventory.

2.5 Review of Vehicular Exhaust Emissions Related Studies

Vehicle emissions are a major source of fine particles, according to various studies on pollution emissions (e.g., PM 2.5). 15 to 50 percent of the finer particulate mass is found in the developed region. Toxic compounds and inorganic ions make up the bulk of secondary particles in automotive exhaust emissions, followed by organic carbon (OC) and elemental carbon (EC).

Previously Haddad et al. (2009) conducted research on vehicular exhaust emissions in France, where a primary particulate organic characterization (PM 2.5 and PM 10) was discussed. The research highlighted that 70% of the aerosol mass was carbonaceous, and 60% of it was elemental carbon (EC). OC's water-soluble percentage and functionalization were characterized. It was necessary to collect data on a wide range of organic pollutants, and alkanes to construct a perfect emission profile for use in mass balance modeling. Low PAH concentrations and a high EC/OC ratio make the chemical profile similar to that of diesel emissions ($\frac{EC}{OC}$ = 1.8). These figures are in line with France's high percentage of diesel-powered vehicles (about 49 %). These findings imply that organic component profiles from the emission of vehicle’s exhaustion are not impacted by geography and may be used in aerosol source apportionment models over large areas. This research doesn’t provide a clear view of greenhouse gas emissions from vehicles and does not explain the effect of climate change on the national scale.

A similar kind of research was also done on vehicular exhaust emissions in Bangladesh. Iqbal, et al. (2013) conducted research in Dhaka city on the different types of vehicle using a Gas Analyzer. In This research, different types of vehicles were analyzed by the Flue Gas Analyzer and computed several types of toxic pollutants which are very harmful to both public health and the environment. The primary focus of this study is to discuss vehicle emission reduction technologies and methods. The deployment of CNG automobiles in Dhaka has reduced traffic congestion pollution. Dhaka's vehicle emissions exhibit significant levels of C, NOx, and SOx.

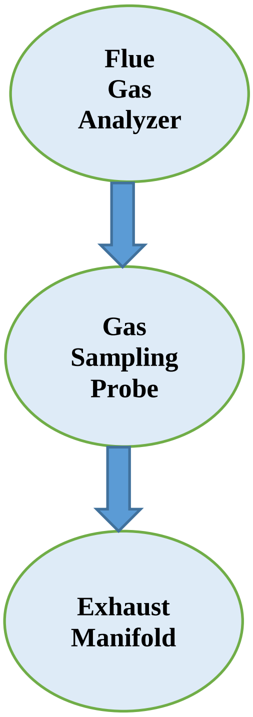

Figure 2.4: Experimental setup of the Flue Gas Analyzer (Source: Iqbal et al., 2013)

The internal combustion engines combust fuel in the presence of air and exhaust CO_2, H_2O, and N_2 as by-products. CO_2 is released because of full combustion, which is a primary greenhouse gas that contributes to global warming. Pollutants such as CO_2, NOx, SO_2, PM, and HC are also created as by-products of combustion processes.

The fundamental equation for the combustion of fuel is:

$$C_a H_b + (a + \frac{b}{4})(O_2 + 3.772N_2) = aCO_2 + \frac{b}{2} H_2O + 3.773\,(a + \frac{b}{4})\,N_2$$

The findings of the research showed that diesel engine CO averages 50.66 ppm, which was close to normal air quality if measured for 20-25 minutes. Thus, petrol engines produced an average of 72.33 ppm and CNG 46 ppm. Production of NO_2 averages 14.66 ppm in diesel engines. NO_2 was minimal for gasoline and CNG. The diesel engine had 1 ppm SO_2; others were insignificant. 1 ppm is insignificant for a gasoline engine. It was 75 ppm for CNG. The experiment revealed that Dhaka's car emissions are within Bangladesh's updated ambient air quality guidelines.

This research was only city-based and analyzed a limited number of cars. This research didn't show any emission standard which can be applicable throughout the country. There is another limitation in this research, and that is the duration of the analysis. The combustion analysis is done only for 20 to 25 minutes, and that is not sufficient for estimating or creating an emission inventory. However, this research provides a clear knowledge about vehicular combustion and the exhaustion of pollutants.

2.6 Review on COPERT Emission Inventory-Based Studies

Data from the country's vehicle fleet is provided into the COPERT model as inputs, which then calculates various metrics linked to the fleet, such as average speed and distance traveled by each vehicle, fuel consumption, emissions, and more. A study was conducted in Italy where the top-down methodology for estimating local emissions from vehicle transportation was the primary focus of this research (Saija et al., 2002). A bottom-up approach was beneficial when the data and information necessary for estimating approaches were accessible at the regional territorial level. Applying alternative variables, emissions were reduced to regional levels where there was no data available for the area. In order to effectively characterize local road transport emissions, this study stressed the need of strengthening the top-down strategy. A set of factors associated with transportation activities was used to define similar locations in the Italian region. It was decided to utilize the COPERT (Computer Program to Estimate Emissions from Road Traffic) technique to calculate the air emission levels for a variety of pollutants at each site, and the same approach was used to compute national road transport emissions.. The results are compared to those produced from a geographical decentralization of national surveys using simple surrogate variables defined by vehicle type and driving mode. This study was done by means of comparing between COPERT methodology and a new methodology for the betterment of urban emission inventory.

There was research before based on different emission inventories where COPERT methodology and MOVES methodology were discussed. Zachariadis et al. (1999) conducted research on motor vehicle emission estimation. This report detailed the history and current state of vehicular emission simulation in Europe. These studies led to the establishment of a set of computer-based models and methodologies that handle all motor vehicle emission concerns of relevance to policymakers, organizations, and the locomotive and oil sectors. COPERT approach for estimating road vehicle emissions was described and compared to other models. A COPERT-based technique for microscopic traffic emission estimation was defined and briefly reviewed in case examples. This research aimed to share a clear strategy for building up an emission inventory.

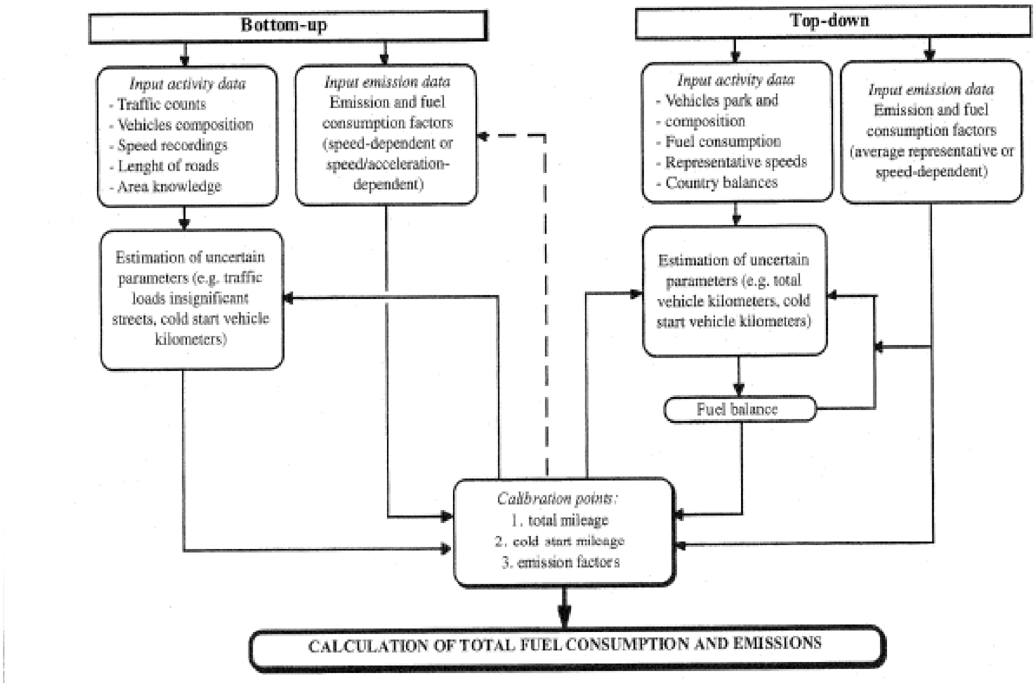

Figure 2.5: Different strategies to estimate traffic emission with a high spatial and temporal resolution. (Source: Zachariadis et al., 1999)

Figure 2.5 describe the process. In the bottom-up method, each street or road is considered a separate line source, and hourly vehicle emissions are estimated. Top-down simulations replicate the whole region yearly. The top-down strategy in this paradigm is COPERT. Top-down and bottom-up emissions estimations are independent. In each scenario, "hard facts" (such as traffic counts, car registration figures, and measured emission factors) are the starting point. Undefined parameters are then evaluated based on information and assumptions. The FOREMOVE model and the results gained from applying it in the European Auto/Oil project were presented to the audience. Finally, the crucial fields of automobile emissions research in Europe are listed.

Previously Burón et al. (2004) conducted a study on the estimation of road transportation emission in Spain where COPERT III was being used. This research presented the findings that looked at the emissions of pollutants caused by vehicle traffic in Spain during the years 1988 to 1999. The investigation had focused on two primary stages: the compilation of input data and the running of programs (COPERT III). The necessary models and algorithms have been built, and several assumptions have been established based on statistical criteria and the most recent research in the field. They presented the COPERT III program with data, and that data became a result in and of itself, delivering solid assessments on many vehicles and other situation elements. The COPERT software version was too old, and so many functions were not introduced then. So it is possible not to show accurate results from the older version.

Then Guo et al. (2018) conducted a study of gasoline vehicle inventory based on the COPERT emission model. By using regional differences in gasoline vehicle emission inventories, this study aided in the compilation of a list of gasoline vehicles with a variety of regional differences. The related adjustment factors were established after thoroughly examining and assessing numerous aspects affecting vehicle emissions. The gasoline emission inventory of vehicles was created using the Zibo city's complete emission factor method. Using this approach, it is possible to generate a more accurate inventory of the emissions from gasoline-powered cars in different cities and provide theoretical background for gasoline vehicle emission control schemes. In this research, different inventory was analyzed and compared with each other to find the error percentage among those.

O'Driscoll et al. (2016) performed a research on a portable emissions measurement system (PEMS) utilizing the COPERT emission factor, where emissions of NOx and NO_2 from Euro 6 diesel passenger cars were measured. This research reported specific NOx and NO_2 emissions from a wide sample of Euro 6 diesel passenger vehicles. According to the results, the approval limit of NOx emissions was exceeded in this study by 1 to 22 times. The urban route section had more acceleration occurrences, which resulted in higher emissions. PEMS test results were found to be 1.6 times greater for NOx and 2.5 times greater for NO2 when compared to the speed-dependent emissions factors of COPERT. This was discovered when the data from PEMS were compared to COPERT.

Another study was conducted by Condurat et al. (2017) on the environmental impact of road transport traffic. This article highlighted the ecological effect of road transportation traffic, as indicated in air pollutant emissions, for particular road networks in Romania's North-East Region. In connection to traffic pollution, the present study emphasized the exponential development of the greenhouse gas impact and fuel consumption, recommending particular measures for improving road network sustainability based on the study's findings. Environmental impact analysis necessitates a quantitative evaluation of power usage and CO_2 emissions caused by vehicle traffic. In this regard, air pollution-induced by traffic flow was evaluated in 2010 using the average daily traffic for the year in concern. The pollution status for 2015, 2020, and 2030 has been projected using traffic evolution factors. The assessment for this case study revealed that the environmental effect, as measured by pollutant emissions, is lowest considering the existing vehicle type and average speed. The environmental impact of road traffic is examined in the second case study using the current state of the road network pavement. This is due to the fact that road distress is increasing traffic congestion and pollution. According to this research, distressed road surfaces hamper cars speed and increase pollution. Passenger automobiles contribute the largest CO (72.18%) and CO2 (vehicle engines) pollution (47.43%).

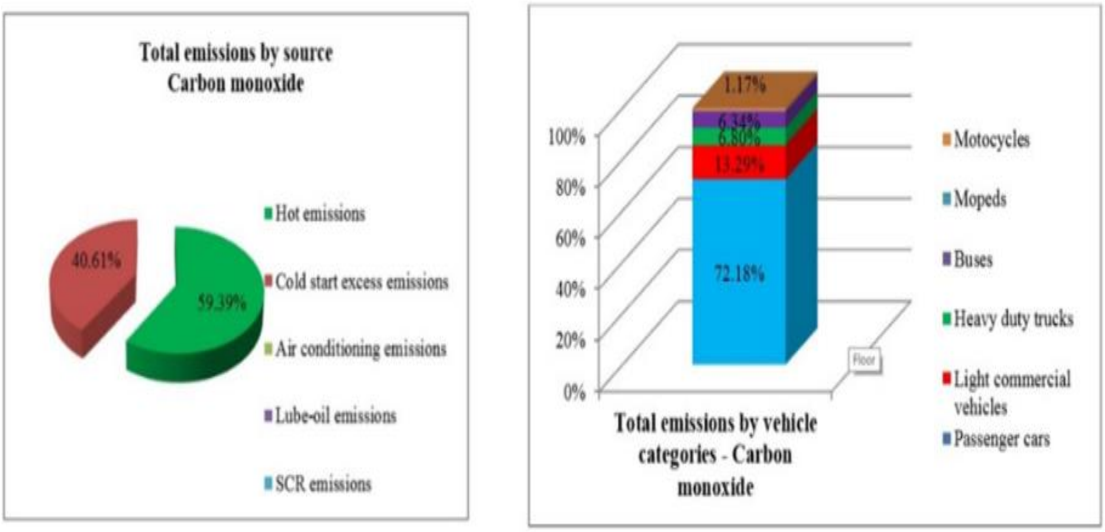

Figure 2.6: Distribution of total CO quantity due to traffic by emission source and vehicle category. (Source: Condurat et al., 2017)

On the other hand, 93.58% of all pollutant emissions were generated while a vehicle's engine was hot, regardless of driving style or fuel type. Alternative fuels and avoiding outdated vehicles were suggested to minimize CO_2 emissions; overheated engines emitted the most nitrogen oxides (98.09%), with heavy vehicles producing 41.7% compared to passenger cars' 18.9%.

Here in Bangladesh, Kamruzzaman and Mizunoya (2019) conducted research to determine the best possible corrective fuel tax for automobiles based on COPERT IV data. Using climate change policies as a benchmark, this study determines the most cost-effective ways to reduce gasoline prices in Bangladesh. The authors calculated the externalities starting with COPERT IV (European Road Transport Emission Model). On the other hand, they used the same approach to estimate the reduction in greenhouse gases that the fuel tax will bring about. A relationship between the gas tax and emissions reduction was finally established. This study attempted to combine the current fuel tax with a US$1.20 per gallon diesel tax in order to meet the country's de-carbonization goal. Fuel taxes may be used to promote climate change legislation. In this research, the vehicle fleet of Bangladesh was compared with the COPERT vehicle category and merged with each other as shown in Figure 2.7.

COPERT Class	Passenger car								Bus			LCV			HDV			Motorcycle
COPERT Sub class	PC medium (1.4–2 l)		PC large-SUV-executive (>2 l)			PC mini (1.4–2 l)			Coaches standard ≤ 18 t	Urban buses standard 15–18 t	Urban buses midi < = 15 t	N1-II, < 3.5 t			Rigid ≤ 7.5t	Rigid 14-20t	Rigid 20-26t	2-stroke < 50 cm^3
RHD class	Car/taxi		Utility			Auto rickshaw	Auto tempo		Bus	Mini bus	Microbus	Small truck			Truck			Motorcycle
BRTA class	Car	Taxi	Jeep	Ambulance	Pickup	Auto rickshaw	Auto tempo	Human hauler	Bus	Mini bus	Microbus	Cargo van	Covered van	Delivery van	Small truck	Medium truck	Heavy truck	Motorcycle

Figure 2.7: Rearrangement of vehicle class according to COPERT class
(Source: Kamruzzaman and Mizunoya, 2019)

Figure 2.7 shows that vehicles were categorized by their size and weight. Less than 7.5 tonnes of trucks were considered as small trucks, and greater than 14 tonnes of trucks were considered as heavy trucks. On the other hand, more than 18 tonnes of buses were considered as large buses, and less than 15 tonnes were considered as micro-buses. According to their COPERT IV model calculations, the study results claimed that total PM2.5 emissions from the road transport sector were 13,527.09 tons, with urban roads accounting for 39.75% of the pollution, rural roads accounting for 36.18%, and highways accounting for 24.07%.

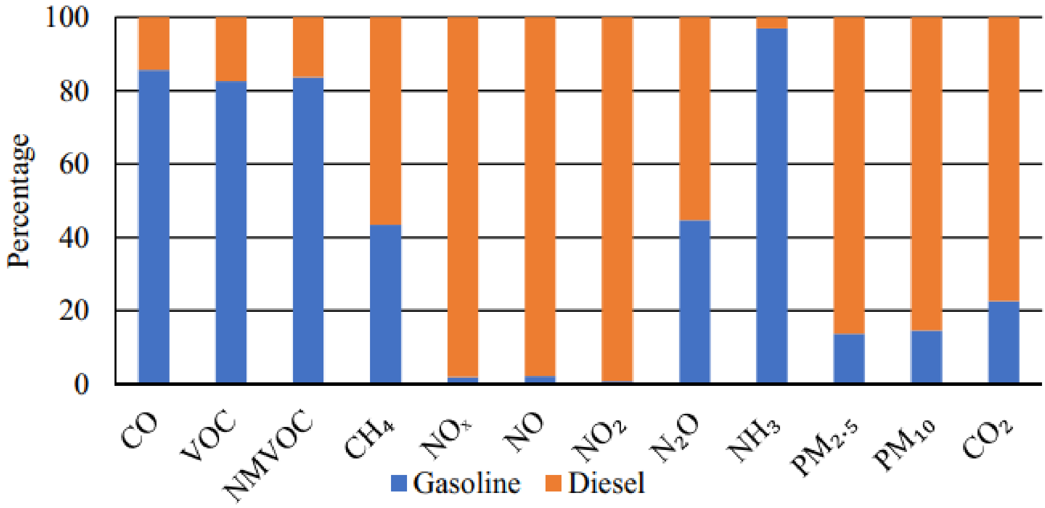

Figure 2.8: Share of fuel in total emission in BAU (calculation from COPERT IV). (Source: Kamruzzaman and Mizunoya, 2019)

Diesel cars were found to be primarily responsible for PM2.5 (Fig. 2.8), accounting for 86% of overall pollution, whereas gasoline vehicles account for just 14%. More than one-fifth of all emissions come from minibuses, heavy vehicles, and large buses, respectively. Jeeps contributed to 11% of total emissions, compared to less than 10% for all other vehicles. A whopping 93% of all gasoline vehicle emissions came from motorcycles. More than half of all emissions were emitted by buses, followed by heavy-duty trucks (26.96%), motorcycles (12.61%), passenger cars (7.586%), and light commercial vehicles (2.42%).

2.7 Some Other Emission Inventory Used for Vehicular Emission Estimation

Apart from COPERT, there are more emission inventory models that are very popular widely to estimate vehicle traffic emissions. Maximum inventory models follow European or American standards, but they can be useful for Asian countries. Many of the Asian countries use these models for regional emission estimation. International Vehicle Emissions (IVE) Model, EMIT model, The Comprehensive Modal Emissions Model (CMEM), MOtor Vehicle Emission Simulator (MOVES), and MOBILE are the popular emission inventory model. (Rakha et al., 2004)

2.7.1 The Comprehensive Modal Emissions Model (CMEM)

The Comprehensive Modal Emissions Model (CMEM) was created by UCR researchers. CMEM calculates LDV and LDT emissions by mode. "Comprehensive" refers to the model's capacity to anticipate emissions for several LDVs and LDTs in different operational conditions. In addition to the Federal Test Procedure (FTP), US06, and the Modal Emission Cycle (MEC), more than 300 automobiles, including 30 high-9 polluters, were tested in three driving cycles. Emissions from tailpipe and fuel consumption are estimated for a variety of vehicle and technology classes using CMEM's second-by-second calculations. Decomposition of the emission process into its constituent parts is the basis of the model. Temperature, speed, acceleration, and road grade are some of the vehicle and operating characteristics that are used as model inputs. (Rakha et al., 2004)

2.7.2 MOBILE6 Model

The Environment Protection Agency (EPA)'s Transportation and Air Quality Department was involved in the development of the MOBILE5a and MOBILE6 models (OTAQ). The MOBILE6 is the most up-to-date model of the MOBILE family, and as such, it will be discussed in more depth. The MOBILE6 deviates greatly from the MOBLE5a in its design. In particular, MOBILE6 was built with the assistance of data obtained from recent vehicle-emission tests carried out by the EPA, CARB, and automotive manufacturers, in addition to inspection and maintenance tests carried out in a number of different states. MOBILE6 makes estimations of emission variables by taking into account a variety of route types, including highways, airways, and others. Based on the results of vehicle testing carried out throughout a number of facility cycles, emission factors may be modified to account for various facility types as well as various average speeds. In addition, MOBILE6 is very useful to calculate emission factors. It counts the starting point of the journey and the trip length in a manner that is distinct from one another. (Rakha et al., 2004)

2.7.3 International Vehicle Emissions (IVE) Model

The International Vehicle Emissions Model (IVE) is a software program developed specifically to estimate the emissions produced by motor vehicles. In most countries, especially developing ones, there is a lack of understanding about emissions from automobiles, and the capacity to establish correct estimates of emissions is essential for planning air quality management. Specifically, a few nations, such as the United States and Europe, have created relatively accurate methods for projecting emissions, and these models are only built for those countries' specific areas. The models used in the United States and Europe are unable to take into account the unique technology and circumstances that prevail in the majority of emerging nations. Most of these current models do not take into account the complete spectrum of global warming and local hazardous emissions, which are essential to conduct an accurate assessment of the effect that motor vehicles have. IVE Model was developed with the express intention of providing developing countries with the necessary degree of freedom in order for them to combat mobile source air emissions successfully. (Rakha et al., 2004)

2.7.4 MOtor Vehicle Emission Simulator (MOVES)

As the name suggests, the MOtor Vehicle Emissions Simulator (MOVES) developed by the Environmental Protection Agency (EPA) is a cutting-edge emissions modeling system that predicts the emissions of pollutants into air from motor vehicles. The MOVES program includes both on-road and off-road vehicles and equipment, such as bulldozers and lawnmowers. Examples of on-road vehicles include buses, trucks, passenger cars, etc. MOVES software does not apply to airplanes, trains, or ships that are used for commercial purposes. MOVES takes into consideration the phasing in of federal emissions requirements, the activity of vehicles and equipment, fuels, temperatures, and humidity, as well as measures to manage emissions such as inspection and maintenance (I/M) programs. A bottom-up emission model (MOVES) was created to estimate emissions from various physical emission processes based on the source of the emissions data. Instead of modeling the emissions produced by individual cars or pieces of equipment, MOVES calculates the "fleet average" emissions. In addition, MOVES modifies emission rates so that they accurately reflect the circumstances of the actual world.

2.8 Overview

In this chapter, past research on automobile emissions is reviewed. Various factors that determine emission levels are briefly explored. This chapter discusses the several kinds of emission models used across the world. The entire purpose of this review chapter is to provide a comprehensive analysis of COPERT software and its use in the diverse literature produced by various authors.

CHAPTER 3
METHODOLOGY OF THE STUDY

3.1 General

COPERT is a software which is used in 28 countries around Europe to calculate vehicular emission. It is a software that calculates Nitrous oxide (N_2O), Carbon monoxide (CO), Methane (CH_4), Sulfur dioxide (SO_2), NOx, Volatile organic compound (VOC), and particulate matter (PM) emissions from various vehicle types, as well as CO_2 emissions depending on fuel use. Moreover, the emission data is reported officially to UNFCCC, the UNECE LRTAP convention and to the European Union (emisia.com). Vehicle emission depends on several factors such as sizes of vehicles and its types; technology used to control emission; age of vehicle or engine; vehicle maintained by user or owner; usage of fuels depending on types of engines; vehicular usage or activity annually; vehicle operating speed; driving conditions; vehicle operating environment. For European cars, a distinct road transport emission calculating software (COPERT-based) was created. To calculate pollutant emissions and energy consumption, the model needs input of data such as the yearly active number of vehicles, year of introduction of regulations, fuel intake and characteristics on its basis, average temperatures of a country, route distribution/ driving condition (urban, highway, rural), and mean speeds within a region or country

There are primarily three main sets of emission standards: United States, Japanese and European. Kholod et al. (2006) recommended utilizing the COPERT software to compute vehicular emissions, particularly in countries that have accepted to follow European emission rules. Cai and Xie (2007) have used to estimate vehicular emissions at national and local levels for non-European nations as well as Lang et al. (2007), and Diab (2011), and many other researchers. Bangladesh has been following the European emission regulations since 2005, with Euro I for diesel cars and Euro II for gasoline vehicles (Pundir, 2012). This paper aims to determine vehicular emissions by using COPERT 5.5 thus comparing it with standard data so that the results found are justified.

3.2 Calculation Method

3.2.1 Choice of Method

CO_2, $NH_{3,}$ SO_x ,CO, NOx , NMVOC, CH_4, exhaust PM, PAHs and POPs, PCBs, HCB, and heavy metals found in the fuel and lubricant are all included in the emission estimating approach (lead, arsenic, cadmium, copper, chromium, mercury, nickel, selenium and zinc). NOx emissions are further divided into two categories: NO and NO_2. As a result of vehicle technology, PM is also separated into two categories: elemental carbon and organic carbon. There is also a thorough speciation of NMVOCs, which includes homologous series such as alkanes, alkenes, alkynes, aldehydes, ketones, and aromatic compounds. The majority of PM mass emissions in vehicle exhaust are in the PM 2.5 size range. As a result, all mass emission factors for PM are considered to be equivalent to PM 2.5. For various particle size ranges, emission factors for particle number and surface are also presented.

In reality, road transport is most likely a major mode of transportation in all countries. As a result, if any more specific information rather than fuel data is not available, then Tier 1 technique should only be employed. If data on vehicle km for different vehicle technology is available, then tier 2 method is suitable. If data on vehicle km and mean travelling speed available per mode and vehicle technology is available, then tier 3 method is applied which is more accurate regarding determination of vehicular emission throughout the country. In this paper, tier 3 method was used as it is the most precise and detailed approach.

3.2.2 Tier 3 Method

Exhaust emissions are computed using a mix of firm technical data (Ex: emission factors) and activity data in the Tier 3 technique outlined here (Ex: total vehicle km). Alternative Tier 3 approaches may be found in tools like Artemis, the DACH-NL Handbook of Emission Factors, and various national models (such as EMV in Sweden, Liipasto in Finland, and Versit+ in the Netherlands), among others.

3.2.3 Algorithm

Total exhaust emissions from road transport are estimated using the Tier 3 technique as the sum of hot emissions (when the engine is running at its usual operating temperature) and emissions during transient thermal engine operation (also known as "cold-start" emissions). Here the term "engine" is used as a shorthand for "engine and any exhaust after treatment systems" in this context. Because of the significant difference in vehicle emission performance during these two states, a differentiation between emissions during the 'hot' stable phase and the transient 'warming-up' phase is required. Because the concentrations of some pollutants are several times greater during the warming-up period than during hot operation, estimating the extra emissions during this time requires a distinct scientific approach. To summarize, the following equation may be used to compute total emissions:

$E_{TOTAL}=E_{HOT}+E_{COLD}$ .... (1)

Where,

E_{TOTAL} = total emissions (g) of any pollutant for the spatial and temporal resolution of the application,

E_{HOT} = emissions (g) during stabilized (hot) engine operation,

E_{COLD} = emissions (g) during transient thermal engine operation (cold start).

The engine operation conditions have a big impact on vehicle emissions. Different driving situations necessitate different engine operation conditions and, as a result, different emission results. A contrast is drawn between urban, rural, and highway driving in this regard.

$E_{TOTAL} = E_{URBAN} + E_{RURAL} + E_{HIGHWAY}$ ....(2)

where:

E_{URBAN}, E_{RURAL} and $E_{HIGHWAY}$ are the total emissions (g) of any pollutant for the respective driving situations.

Activity data for each vehicle and appropriate emission factors are multiplied in order to calculate total emission. The emission factors vary depending on several factors (state of driving, situation of climate). A flow chart of the application of the baseline methodology is shown in Figure 3.1.

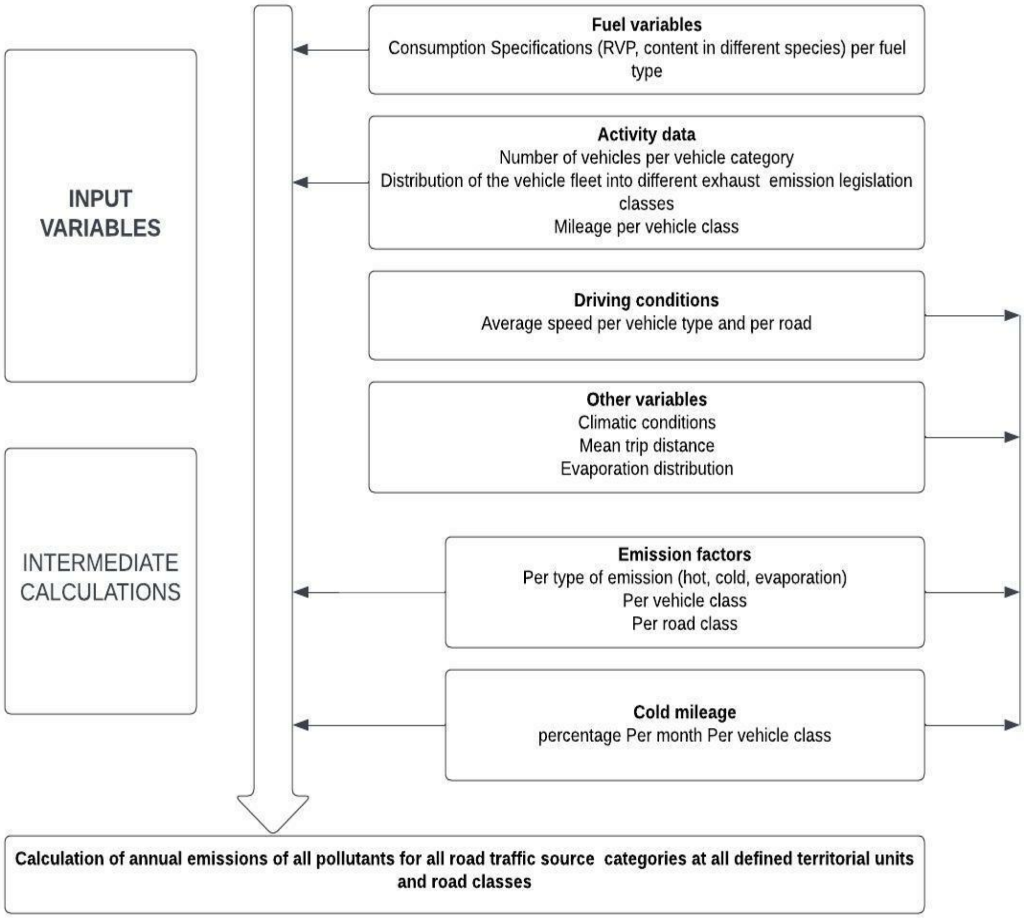

Figure 3.1: Flow chart of the application of the baseline methodology (Source: www.emisia.com)

3.3 Hot Emissions

The distance traveled by each vehicle, speed it travelled with (or road type), age of engine, sizes of engine, and weight are all factors that influence hot exhaust emissions. The basic formula for estimating hot emissions for a given time period, and using experimentally obtained emission factors is:

emission [g] = emission factor [g/km] × number of vehicles [veh] × mileage per vehicle [km/veh]

For each vehicle category and class, different emission factors, vehicle numbers, and vehicle mileages must be employed. The length of time (month, year, etc.) is determined by the applicant. Therefore, the formula to be applied for the calculation of hot emissions of pollutants in the case of annual emission estimation, yields:

$E_{HOT;\, i,\, k,\, r} = N_k \times M_{k,r} \times e_{HOT;\, i,\, k,\, r}$ .... (3)

where,

$E_{HOT;\ i,\ k,\ r}$ = hot exhaust emissions of the pollutant i [g], produced in the period concerned by vehicles of technology k driven on roads of type r,

N_k = number of vehicles [veh] of technology k in operation in the period concerned,

$M_{k,r}$ = mileage per vehicle [km/veh] driven on roads of type r by vehicles of technology k,

$e_{HOT;\ i,\ k,\ r}$ = emission factor in [g/km] for pollutant i, relevant for the vehicle technology k, operated on roads of type r.

3.4 Cold-Start Emissions

Exhaust emissions increase when a vehicle cold starts. It happens in all kinds of driving circumstances. They appear to be most probable for city and rural driving, given the number of starts on highways is quite low (as vehicles usually start from parking lots near highways). They occur in all vehicle types, but emission factors are only known, or can be reliably predicted, for petrol, diesel, and LPG automobiles, as well as light commercial vehicles that behave like passenger cars, therefore the technique only applies to these categories. Furthermore, they are not thought to be related to the age of the vehicle.

Cold-start emissions are computed as an additional to the emissions that would be expected if all cars were driven solely with hot engines and warmed-up catalysts. The proportion of kilometers driven with a cold engine is multiplied by a suitable factor, which corresponds to the ratio of cold to hot emissions. This is a variable that differs by nation. The time required to warm up the engine and/or the catalyst, and therefore the proportion of a trip driven with a cold engine, is affected by driving behavior (changing trip durations) and climatic circumstances. Cold-start emissions are introduced into the calculation as additional emissions per km using the following formula:

$E_{COLD;\ i,\ j} = \beta_{i,\ k} \times N_k \times M_k \times e_{HOT;\ i,\ k} \times (e^{COLD} / e^{HOT}|_{i,k} - 1)$ .... (4)

where,

$E_{COLD;\ i,\ k}$ = cold-start emissions of pollutant i (for the reference year), produced by vehicle technology k,

$\beta_{i,\ k}$ = fraction of mileage driven with a cold engine or the catalyst operated below the light-off temperature for pollutant i and vehicle technology k,

N_k = number of vehicles [veh] of technology k in circulation,

M_k = total mileage per vehicle [km/veh] in vehicle technology k,

$e_{HOT;\, i,\, k}$ = hot emission factor for pollutant i and vehicles of k technology,

$e^{COLD} / e^{HOT}|_{i,k}$ = cold/hot emission quotient for pollutant i and vehicles of k technology.

The β- parameter depends upon ambient temperature, here average monthly temperature is used, and the pattern of vehicle use - in particular the average trip length $l_{trip.}$ However, because l_{trip} information for all vehicle classes is not accessible in many countries such as Bangladesh, certain vehicle classifications have been simplified. In this paper BRTA data was used for average trip length in Bangladesh (The Daily Star, 2010) which is equal to 5.37 km.

Shorter times for the catalyst to achieve the light-off temperature have been enforced by the adoption of more rigorous pollution rules for catalytic petrol cars. The lesser mileage driven under cold-start circumstances reflects this. As a result, for petrol catalytic automobiles, the -parameter is also a function of the amount of emission control laws. Table 3.1 shows the elements to consider when estimating the parameter reduction for existing and future catalytic vehicles per pollutant.

Table 3.1: Reduction factors ($bc_{i,k}$) for post-Euro 1 petrol vehicles (relative to Euro 1) (Source: www.emisia.com)

Emission legislation	CO	NOx	VOC
Euro 2 — 94/12/EC	0.72	0.72	0.56
Euro 3 — 98/69/EC Stage 2000	0.62	0.32	0.32
Euro 4 and later	0.18	0.18	0.18

On the other hand, there is no evidence to back up the usage of various e^{COLD}/ e^{HOT} values for different vehicle classes. This means that the e^{COLD}/ e^{HOT} values derived for Euro 1 cars may be used without additional reductions to subsequent vehicle classes. Similarly, the Euro 1 value should be used as the hot emission factor in the assessment of cold-start emissions.

Therefore, in the case of post-Euro 1 vehicles, equation (4) becomes:

$$E_{COLD;i,k} = bc_{i,k} \times \beta_{i,Euro\ 1} \times N_k \times M_k \times e_{hot,\ i,\ Euro\ 1} \times (e^{COLD} / e^{HOT} - 1)|_{i,\ Euro\ 1} \quad ....(5).$$

The e^{COLD}/e^{HOT} cold/hot emission quotient is also affected by the ambient temperature and the pollutant in question. Although the model published in the first edition of this approach is still used to calculate emissions during the cold-start period, in earlier updates of this chapter, revised quotients for catalyst-equipped petrol cars were introduced. The suggested technique, however, is still unable to adequately characterize the cold-start emission behavior of modern car technology, and a modification is planned for the future version of this chapter.

As previously stated, cold start emissions are often only associated with urban driving. However, if the mileage fraction traveled in non-thermally stabilized engine circumstances (β-parameter) exceeds the mileage share attributable to urban conditions, a portion of cold start emissions may be attributed to country driving (S_{URBAN}). This necessitates a modification of equation (4), which yields:

If $\beta_{i,k} > S_{URBAN}$

$E_{COLD\ URBAN;\ i,k} = S_{URBAN;\ k} \times N_k \times M_k \times e_{HOT\ URBAN;\ i,k} \times (e^{COLD} / e^{HOT}|_{i,k} - 1)$

$E_{COLD\ RURAL;\ i,k} = (\beta_{i,k} - S_{URBAN;\ k}) \times N_k \times M_k \times e_{HOT\ URBAN;\ i,\ k} \times (e^{COLD} / e^{HOT}|_{i,k} - 1)$ ....(6)

Similar modifications should also be brought into equation (6) as done in equation (5) in cases where $bc_{i,k} \times \beta_{i,EURO\ 1} > S_U$. The corrected value should be applied to the

mileage fraction during the warm-up phase.

The complete distance travelled in urban conditions is allocated to warmup conditions in this scenario, while the remaining excess emissions are allocated to rural driving. Equation (6) illustrates an extreme example for a national inventory, and it can only occur when a very tiny number for l_{trip} has been specified. It is also worth noting that the urban hot emission factor is applied in both equations (6) because total cold-start emissions should not be separated by emission location.

N_2O, NH_3, and CH_4 emissions are calculated using 'cold urban,' 'hot urban,' 'rural,' and 'highway' driving conditions. The computation algorithm used to determine the emissions of various pollutants is described in the following paragraphs. The estimate is especially important for methane (CH_4) since NMVOC emissions are computed as the difference between VOCs and CH_4.

To begin, the percentage of miles traveled under thermally non-stabilized engine circumstances (β - parameter) surpasses the percentage of miles driven in urban conditions (S_{URBAN}) should be determined. The computation is as follows for each vehicle type j and pollutant (ι = CH_4, N_2O, NH_3):

if

$\beta_{i, k} > S_{URBAN; k}$ ....(7)

$E_{COLD\ URBAN; i, k} = \beta_{i,k} \times N_k \times M_k \times e_{COLD\ URBAN; i, k}$

$E_{COLD\ RURAL; i, k} = 0$

$E_{HOT\ URBAN; i, k} = 0$

$E_{HOT\ RURAL; i, k} = [S_{RURAL; k} - (\beta_{i,k} - S_{URBAN; k})] \times N_k \times M_k \times e_{HOT\ RURAL; i, k}$

$E_{HOT\ HIGHWAY; i, k} = S_{HIGHWAY; k} \times N_k \times M_k \times e_{HOT\ HIGHWAY; i, k}$

else if $\beta_{i, k} <= S_{URBAN; k}$ .... (8)

$E_{COLD\ URBAN; i, k} = \beta_{i,k} \times N_k \times M_k \times e_{COLD\ URBAN; i, k}$

$E_{COLD\ RURAL; i, k} = 0$

$E_{HOT\ URBAN; i, k} = (S_{URBAN; k} - \beta_{i,k}) \times N_k \times M_k \times e_{HOT\ URBAN; i, k}$

$E_{HOT\ RURAL; i, k} = S_{RURAL; k} \times N_k \times M_k \times e_{HOT\ RURAL; i,k}$

$E_{HOT\ HIGHWAY; i, k} = S_{HIGHWAY; k} \times N_k \times M_k \times e_{HOT\ HIGHWAY; i, k}$

where,

$S_{URBAN; k}$ = mileage share attributed to urban conditions for vehicle technology k,.

$S_{RURAL; k}$ = mileage share attributed to rural conditions for vehicle technology k,

$S_{HIGHWAY; k}$ = mileage share attributed to highway conditions for vehicle technology k,

$e_{COLD\ URBAN; i,k}$ = urban cold-start emission factor for pollutant i, by vehicle technology k,

$e_{HOT\ URBAN; i, k}$ = urban hot emission factor for pollutant i, by vehicle technology k,

$e_{HOT\ RURAL; i, k}$ = rural hot emission factor for pollutant i, by vehicle technology k,

$e_{HOT\ HIGHWAY; i,k}$ = highway hot emission factor for pollutant i, by vehicle technology k

It should be noted that, the urban share (S_{URBAN}) should be set to 100 percent when creating an urban inventory, whereas the rural (S_{RURAL}) and highway ($S_{HIGHWAY}$) shares should be set to zero. In any instance, the aggregate of the three shares must always equal to 100 percent, otherwise the computations will be incorrect.

CHAPTER 4
DATA COLLECTION

4.1 Introduction

This chapter includes necessary information regarding the collection of all the data required for COPERT 5.5 to calculate the yearly vehicular emission in Bangladesh such as total stock information which includes the types of vehicles running in Bangladesh, number of vehicles registered for each vehicular type, information regarding division of stock according to fuel and technology type, mileage and activity information which includes the annual average km travelled and average speed of each vehicle type, fuel specifications such as the density of different grades of fuels used in Bangladesh, monthly Reid vapor pressure and the constituents of these fuels and environmental information which includes monthly maximum and minimum temperature and monthly average humidity in Bangladesh throughout the particular year. This chapter also includes the information regarding collection of yearly CO_2 emission data by the transport sector in Bangladesh obtained from a study made by World Bank, and collection of emission factors from a study made by NILU. All the data used in this study are from secondary data sources.

4.2 Vehicle Classification and Stock Number

4.2.1 Number of Motorized Vehicles Registered in Bangladesh throughout the Years

The first major data required to create an emission inventory for Bangladesh is the number of each type of vehicle running in Bangladesh. The number of vehicles registered up to 2010 to 2021 was obtained from BRTA as shown in Table 4.1.

For the data before 2010, number of vehicles registered from 1988 to 2009 was obtained from Dhaka School of Economics (Obida, 2021) as shown in Table 4.2.

Table 4.1: Number of motor vehicles registered in Bangladesh from up to 2010 to 2021 (Source: BRTA, 2021)

Vehicle category	Up to 2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Grand Total
Ambulance	2486	218	181	240	337	472	374	493	563	665	788	755	7572
Auto Rickshaw	110623	20406	23528	15633	19828	18700	10656	8852	21593	29807	16724	9158	305508
Auto Tempo	9446	175	626	393	472	1081	1313	1592	609	224	77	25	16033
Bus	23385	1753	1438	1104	1486	2378	3832	3757	2755	3558	2395	1517	49358
Cargo Van	3363	489	282	686	605	398	1015	1413	1280	4	2	3	9540
Covered Van	6022	2480	1511	2347	2950	2442	3399	5201	5728	3070	2023	3800	40973
Delivery Van	15391	1037	802	941	1235	1779	2220	2420	2105	1523	1170	1436	32059
Human Hauler	4827	1151	714	385	225	1129	3443	3393	1418	509	122	52	17368
Jeep	28131	2141	1575	1303	1849	3564	4869	5419	5547	5627	4911	7602	72538
Microbus	62399	4037	3031	2530	4302	5177	5789	5571	4131	3682	2779	4941	108369
Minibus	23070	271	246	148	257	320	459	491	436	835	620	392	27545
Motor Cycle	755514	116534	101895	85321	90401	229010	315089	325876	393545	401452	311016	375252	3500905
Pick Up	29103	10314	7530	6443	9424	9992	11220	13454	13060	11918	10498	10897	143853
Private Passenger Car	207989	12942	9220	10456	14681	21029	20268	21952	18222	16779	12403	16049	381990
Special Purpose Vehicle	5022	391	225	228	174	298	613	994	1334	1179	703	518	11679
Tanker	2606	309	188	218	350	319	380	317	527	417	304	248	6183
Taxicab	35122	75	170	50	372	83	43	14	159	11	8	0	36107
Tractor	14648	5195	3494	1885	1521	1689	2535	2777	3553	2561	2498	2567	44923
Truck	65889	6853	4043	4838	7939	6022	6605	10329	12644	8318	4719	5789	143988
Others	22332	1265	1062	1064	1580	2059	3842	5018	5973	5293	3900	4029	57417
Total	1427368	188036	161761	136213	159988	307941	397964	419333	495182	497432	377660	445030	5013908

Table 4.2: Number of motor vehicles registered in Bangladesh from up to 1988 to 2009 (Source: Obida, 2021)

Year	Car	Jeep & Micro	Taxi	Bus	Truck	Auto	Bike	Others	Grand Total
Cumulative up to 1988	35,443	23,049	1,622	16,876	21,341	17,429	97,639	-	213,399
1989	2,835	1,844	97	1,155	1,280	1,133	10,740	-	19,084
1990	3,062	1,991	103	1,245	1,357	1,207	11,922	-	20,887
1991	2,620	1,789	92	599	926	3,661	9,991	-	19,678
1992	1,346	1,467	19	533	930	3,218	8,417	-	15,930
1993	29,937	3,337	847	7,061	14,539	17,215	26,651	-	99,587
1994	4,168	2,855	7	994	1,964	9,988	7,807	-	27,783
1995	6,964	2,181	17	1,021	3,468	14,188	8,868	-	36,707
1996	12,479	2,808	59	944	2,929	11,254	13,977	-	44,450
1997	8,354	1,759	14	970	1,282	6,546	12,080	-	31,005
1998	5,876	2,173	103	883	2,733	4,403	14,525	-	30,696
1999	4,986	1,223	216	746	2,018	2,140	16,511	-	27,840
2000	4,087	1,819	580	741	2,725	4,135	14,614	-	28,701
2001	6,587	2,465	771	1,812	2,575	-603	24,409	-	38,016
2002	6,757	3,038	2,233	3,054	2,377	5,469	29,047	-	51,975
2003	7,045	1,804	5,020	2,015	2,795	13,866	21,096	-	53,641
2004	5,410	2,514	540	1,479	2,583	8,974	24,941	2,761	49,202
2005	6,431	3,963	515	1,144	2,791	4,877	43,226	2,931	65,878
2006	8,447	5,540	275	1,261	3,065	6,898	51,106	3,713	80,305
2007	11,941	5,650	15	1,750	2,521	10,530	85,131	3,734	121,272
2008	16,927	6,537	9	1,649	2,609	19,071	93,541	4,076	144,419
2009	21,461	9,027	12	1,504	6,561	14,902	45,142	6,634	105,243

However the data for the year 2010 was not found from either of these sources and there is a difference of opinion about the number of vehicles registered up to 2010 between RHD and BRTA, which gives a negative value for the year 2010 by back calculation. To fix this problem, the number of vehicles registered up to 2010 value by BRTA was omitted in the analysis and data for the year 2010 was obtained from the Revisions of Vehicular Emission Standards for Bangladesh report (Pundir, 2012) as shown in Table 4.3.

Table 4.3: Number of motor vehicles registered in the year 2010 (Source: Pundir, 2012)

Vehicle Category	Number of vehicles registered in the year 2010
Car	20690
Jeep/ Station Wagon/ Microbus	8040
Taxi	0
Bus	1233
Minibus	311
Truck	10056
Auto Rickshaw/ Auto Tempo	19018
Motorcycle	88499
Others	13331
Total	161178

BRTA classified the vehicles into 20 different categories as shown in Table 4.1. On the other hand, DScE classified the vehicles into the following 8 categories: Car (private Car), Jeep and Micro (combination of Jeep, Microbus and Station Wagons), Taxi (Taxicabs), Bus (combination of Bus, Minibus and Human Hauler), Truck (combination of Truck, Tanker, Covered Van, Cargo Van), Auto (combination of Auto Rickshaw and Auto Tempo), Bike and Others (combination of Special Vehicle, Delivery Van, Ambulance, Tractor and Pick Up) as shown in Table 4.2 (Obida, 2021). In contrast, the vehicles were classified into 9 categories in the Revisions of Vehicular Emission Standards for Bangladesh report (RHD, 2012) as shown in Table 4.3. In order to obtain the motor vehicles registered from the last 34 years, it was necessary to combine the above mentioned three sets of data from three different sources, each with different vehicle classifications.

For greater accuracy, the 20 BRTA classifications as shown in Table 4.1 were preferred for this study. The combined data from 1989 to 2010 were broken down into its subcategories by the average ratio of the subcategories observed in the years 2011 to 2021 from the BRTA data. For example, Jeep and Micro (Total) was broken down into corresponding Jeep and Microbus by calculating the average ratio of Jeeps and Microbuses observed in the years 2011 to 2021 and then breaking down the given number of Jeep and Micro (Total) into the 2 subcategories using the respective ratios. The breakdown of Jeep and Micro (Total) into corresponding Jeep and Microbus is shown in Table 4.4.

Table 4.4: Calculation of average ratio of Jeep and Microbus observed during 2011-2021

Year	Jeep	Microbus	Ratio of Jeep with respect to Microbus	Ratio of Microbus with respect to Jeep
2011	2141	4037	0.346552	0.653448
2012	1575	3031	0.341945	0.658055
2013	1303	2530	0.339943	0.660057
2014	1849	4302	0.300602	0.699398
2015	3564	5177	0.407734	0.592266
2016	4869	5789	0.45684	0.54316
2017	5419	5571	0.493085	0.506915
2018	5547	4131	0.573156	0.426844
2019	5627	3682	0.604469	0.395531
2020	4911	2779	0.638622	0.361378
2021	7602	4941	0.606075	0.393925
Average ratio			0.464456	0.535544

The number of Jeep and Micro (total) was multiplied by the average ratio of Jeep with respect to Microbus to find the number of Jeeps and similarly, it was multiplied by the average ratio of Microbus to find the number of Microbuses for the previous years as shown in Table 4.5.

Table 4.5: Breakdown of Jeep and Micro (Total) into corresponding Jeep and Microbus

Year	Jeep & Micro (total)	Average Ratio of Jeep with respect to Microbus	Jeep = Total* Average ratio	Average Ratio of Microbus with respect to Jeep	Microbus = Total* Average ratio
1989	1,844		856		988
1990	1,991		925		1066
1991	1,789		831		958
1992	1,467		681		786
1993	3,337		1550		1787
1994	2,855		1326		1529
1995	2,181		1013		1168
1996	2,808		1304		1504
1997	1,759		817		942
1998	2,173		1009		1164
1999	1,223		568		655
2000	1,819		845		974
2001	2,465		1145		1320
2002	3,038		1411		1627
2003	1,804	0.464456	838	0.535544	966
2004	2,514		1168		1346
2005	3,963		1841		2122
2006	5,540		2573		2967
2007	5,650		2624		3026
2008	6,537		3036		3501
2009	9,027		4193		4834
2010	8040		3734		4306

Similar calculation was done for the remaining combined categories to break them down into 20 categories. The resultant stock from 1989 to 2009 is shown in Table 4.6.

Table 4.6: Number of registered vehicles from 1989 to 2010

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Ambulance	-	-	-	-	-	-	-	-	-	-	-
Auto Rickshaw	1088	1159	3514	3089	16525	9587	13619	10803	6283	4226	2054
Auto Tempo	45	48	147	129	690	401	569	451	263	177	86
Bus	740	798	384	342	4526	637	654	605	622	566	478
Cargo Van	59	63	43	43	674	91	161	136	59	127	93
Covered Van	363	385	262	264	4120	557	983	830	363	775	572
Delivery Van	-	-	-	-	-	-	-	-	-	-	-
Human Hauler	280	302	145	129	1714	241	248	229	236	214	181
Jeep	856	925	831	681	1550	1326	1013	1304	817	1009	568
Microbus	988	1066	958	786	1787	1529	1168	1504	942	1164	655
Minibus	134	145	70	62	821	116	119	110	113	103	87
Motor Cycle	10740	11922	9991	8417	26651	7807	8868	13977	12080	14525	16511
Pick Up	0	0	0	0	0	0	0	0	0	0	0
Private Passenger Car	2835	3062	2620	1346	29937	4168	6964	12479	8354	5876	4986
Special Purpose Vehicle	-	-	-	-	-	-	-	-	-	-	-
Tanker	39	41	28	28	442	60	105	89	39	83	61
Taxicab	97	103	92	19	847	7	17	59	14	103	216
Tractor	0	0	0	0	0	0	0	0	0	0	0
Truck	819	868	593	595	9303	1257	2219	1874	820	1749	1291
Others	-	-	-	-	-	-	-	-	-	-	-

Table 4.6: Number of registered vehicles from 1989 to 2010 (continued)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Ambulance	-	-	-	-	67	71	90	90	98	9	322
Auto Rickshaw	3969	4191	5250	13310	8614	4681	6621	10108	18306	14304	18255
Auto Tempo	166	175	219	556	360	196	277	422	765	598	763
Bus	475	1161	1957	1292	948	733	808	1122	1057	964	904
Cargo Van	126	119	110	129	120	129	142	117	121	304	466
Covered Van	772	730	674	792	732	791	869	714	739	1859	2850
Delivery Van	-	-	-	-	220	234	296	298	325	530	1064
Human Hauler	180	440	742	489	359	278	306	425	400	365	329
Jeep	845	1145	1411	838	1168	1841	2573	2624	3036	4193	3734
Microbus	974	1320	1627	966	1346	2122	2967	3026	3501	4834	4306
Minibus	86	211	355	234	172	133	147	203	192	175	311
Motor Cycle	14614	24409	29047	21096	24941	43226	51106	85131	93541	45142	88499
Pick Up	0	0	0	0	1544	1640	2077	2089	2280	3711	7457
Private Passenger Car	4087	6587	6757	7045	5410	6431	8447	11941	16927	21461	20690
Special Purpose Vehicle	-	-	-	-	81	86	109	109	119	194	390
Tanker	83	78	72	85	79	85	93	77	79	199	306
Taxicab	580	771	2233	5020	540	515	275	15	9	12	0
Tractor	0	0	0	0	417	443	561	564	615	1002	2013
Truck	1744	1648	1521	1788	1653	1786	1961	1613	1669	4198	6435
Others	-	-	-	-	432	458	581	584	638	1038	2085

However, the total number of registered vehicles from 1989 to 2021 is of course, not equal to the number of vehicles currently running in Bangladesh. Obida (2021) stated that Human hauler, Minibus, Auto Rickshaw and Auto Tempo registered before 2020 are scarcely running on the road. It is hard to find a vehicle on the road which was registered 30 years ago and on the odd occasion that a 30+ aged vehicle is still running, it is owed to very good maintenance of the vehicle by its owner, but that is not common for a country like Bangladesh. Aisudin (2014) stated that Toyota regards cars as unusable after 25 years and the average lifespan of a car is 20 years. In this research, it was assumed that vehicles running in the particular year of analysis were no more than 20 years of age. Therefore 20 years' stock data was taken into account for each year of analysis.

4.2.2 Prediction of Number of Motorized Vehicles Registered in Bangladesh for the Year 2025

The stock number for the year 2025 was predicted by using the rate of growth of different vehicle types observed in previous years. The stock number from the year 2021 was used to calculate that of the year 2022, which was used to calculate the stock number of 2023 and so on up to the year 2025 assuming a uniform rate of growth throughout all these years. The yearly rate of increase in the registration of each type of vehicle was collected from the Road User Cost (RUC) report (RHD, 2017) as shown Table 4.7.

Table 4.7: Yearly rate of increase in number of vehicles registered in Bangladesh (Source: RHD, 2017)

Vehicle Category	Yearly rate of increase
Car	5%
Utility (Jeep/Pickup)	12%
Auto Rickshaw	9%
Tempo	8%
Large Bus	6%
Micro Bus	6%
Mini Bus	1%
Small Truck	8%
Medium Truck	8%
Heavy Truck	8%
Motorcycle	16%

4.3 Breakdown of Stock into Fuel Type

Currently there is no data available on the exact percentage of fuel type used by different registered vehicle classes, but BRTA plans to maintain this type of record in the future. For this paper, data collected from the Revisions of Vehicular Emission Standards for Bangladesh report (Pundir, 2012) on the types of fuels of the vehicles running in Dhaka was taken into consideration as shown in the Table 4.8.

Table 4.8: Fuel split in Dhaka found from a previous study (Source: Pundir, 2012)

Vehicle Category	Vehicles running on CNG (%)	Vehicles running on Petrol (%)	Vehicles running on Diesel (%)
Cars and Taxis	96	4	0
Auto Rickshaws	97	3	0
Jeeps, Microbuses and Station Wagons	81	3	16
Delivery vans and Mini trucks	44	1	55
Buses and Minibuses	61	0	39
Motorcycles	0	100	0

To divide the stock into different fuel types using this data, sensible alterations were made where necessary considering the entire country not just Dhaka and the also considering the improvement in the automobile and fuel industry in Bangladesh during the interval between 2012 and the year of analysis.

4.4 Breakdown of Stock into Technology Type

To divide the stock into corresponding technology types that are available in COPERT 5.5, the launching year and ending year of production of different euro standard engines in Europe were considered which are as shown in Table 4.9.

Table 4.9: Timeline of implementation of different Euro standards in Europe (Source: Ntziachristos and Samaras, 2021)

Vehicle category	Type of fuel	Euro Standard	Launching year	Ending year of production
Passenger cars	Petrol	1	1992	1996
		2	1996	1999
		3	2000	2004
		4	2005	2009
		5	2011	2014
		6 a/b/c	2014	2016
		6 d-temp	2019	2020
		6 d	2021 and beyond	-
	Diesel	1	1992	1996
		2	1996	2000
		3	2000	2005
		4	2005	2010
		5	2010	2014
		6 a/b/c	2014	2019
		6 d-temp	2019	2020
		6 d	2021 and beyond	-
	CNG	4	2005	2009
		5	2010	2014
		6 a/b/c	2015	2016
		6 d-temp	2017	2019
		6 d	2020 and beyond	-
Light Commercial Vehicles	Petrol	1	1993	1997
		2	1997	2001
		3	2001	2006
		4	2006	2010
Light Commercial Vehicles	Petrol	5	2011	2015
		6 a/b/c	2016	2017
		6 d-temp	2018	2020
		6 d	2021 and beyond	-
	Diesel	1	1993	1997
		2	1997	2001
		3	2001	2006
		4	2006	2011
		5	2011	2015

Table 4.9 (continued)

Vehicle category	Type of fuel	Euro Standard	Launching year	Ending year of production
Light Commercial Vehicles	Diesel	6 a/b/c	2015	2017
		6 d-temp	2018	2020
		6 d	2021 and beyond	-
Heavy Duty Trucks	Diesel	1	1992	1995
		2	1996	2000
		3	2000	2005
		4	2005	2008
		5	2008	2013
		6 a/b/c	2013	2019
		D/E	2021 and beyond	-
Motorcycles	Petrol	Conventional		up to 1999
		1	1999	2003
		2	2003	2006
		3	2006	2013
		4	2016	2020
		5	2021 and beyond	-

Pundir (2012) stated that there would be a time lag of five to fifteen years for Asian countries like Bangladesh with respect to Europe for the implementation of Euro standards due to unavailability of required quality of fuel, lack of necessary infrastructure, slow technological growth and poor economic conditions. For imported vehicles in Bangladesh, Euro 3 standard was implemented for Dhaka city and Chittagong city and Euro 2 standard was implemented for the rest of the nation, effective since July 2014. The government also planned to implement the emission standard of imported vehicles to be Euro 4 standard for Dhaka city and Chittagong city and Euro 3 standard for the rest of the nation, from July 2019, This resulted in the import of new cars from India, Thailand, and Indonesia with emission standard of Euro 4 and the import of reconditioned cars from Japan and European countries with emission standard of Euro 5 or higher.

Furthermore, an age limit of for imported cars and second hand motorcycles, LCV's and HDV's was also implemented since July 2014 (Mansur, 2021). Considering local conditions and timeline of emission standards in Bangladesh, a minimum time lag of 5 years was considered with respect to Europe for this analysis.

4.5 Matching Vehicle Classifications from BRTA and RHD with Equivalent COPERT 5.5 Classification

Stock data has been collected and classified according to 20 BRTA classifications but mileage and activity data were found for 11 RHD classifications, so it was necessary to find COPERT 5.5 classifications equivalent to both BRTA and RHD classifications. This was done by studying the characteristics of representative models of the vehicles (most commonly purchased model in Bangladesh) like axle number, weight and dimensions collected from the RUC report (RHD, 2017) and with the help of a similar study (Kamruzzaman and Mizunoya, 2019), as shown in Table 4.10.

Table 4.10: COPERT 5.5 classifications equivalent to BRTA and RHD classifications

BRTA Classification(s)	RHD Classification	Equivalent COPERT 5.5 Classification
Cars and Taxicabs	Car	Passenger Car (Medium)
Ambulance, Jeep and Pickup	Utility (Jeep/Pickup)	Passenger Car (Large-SUV-Executive)
Auto Rickshaw	Auto Rickshaw	Passenger Car (Mini)
Tempo and Human Hauler	Tempo	Passenger Car (Small)
Large Bus	Large Bus	Buses (Coaches Standard <=18 t)
Minibus (Diesel fueled)	Mini Bus	Buses (Urban Buses Standard 15 - 18t)
Microbus (Diesel fueled)	Micro Bus	Buses (Urban Buses Midi <=15 t)
Minibus and Microbus (CNG fueled)	Mini Bus	Buses (Urban CNG Buses)
Cargo Van, Delivery Van and Covered Van	Small Truck	Light Commercial Vehicles (N1-II, <3.5t)
Tractors and Trucks	Small Truck	Heavy duty trucks (Rigid<=7.5t)
Trucks	Medium Truck	Heavy duty trucks (Rigid 14-20t)
Tankers and Trucks	Heavy Truck	Heavy duty trucks (Rigid 20-26t)
Motor Cycle	Motorcycle	4 stroke < 250 cm^3 Motorcycle

Because BRTA has one classification called "Trucks" and RHD classifies trucks as "Heavy", "Medium" and "Small" therefore the stock was equally divided into three. The BRTA Classes "Others" and "Special Purpose Vehicles" were also equally distributed into all the COPERT 5.5 classes. Since there is only one CNG fueled bus class available in COPERT called "Urban CNG Buses", the percentage of CNG fueled Minibuses and Microbuses were combined and used in the calculation.

4.6 Mileage and Activity Information

The annual km travelled and average speeds of vehicles were collected from RUC report (RHD, 2017). The data was collected by RHD by conducting field surveys in the National/Regional Highways and Zilla roads in seven divisions: Dhaka, Chittagong, Rajshahi, Rangpur, Sylhet, Khulna and Barisal as shown in Table 4.11.

Table 4.11: Annual mileage and average speed of different vehicles (Source: RHD, 2017)

Vehicle Category	2004-2005		2016-2017	
	Annual Km Driven (km) in 2004-2005	Average speed (km/hr) in 2004-2005	Annual Km Driven (km) in 2016-2017	Average speed (km/hr) in 2016-2017
Heavy Truck	-	-	72,200	31
Medium Truck	80,700	40	67,200	31
Small Truck	74,000	42	59,000	29
Large Bus	129,800	45	102,700	37
Mini Bus	66,700	31	56,300	26
Micro Bus	56,800	49	50,600	36
Utility (Jeep/Pickup)	22,000	25	31,800	26
Car	50,000	39	36,094	33
Tempo	44,000	21	40,900	21
Auto Rickshaw	46,000	27	28,700	17
Motor Cycle	13,000	22	24,000	27

Since data for heavy trucks were not collected in 2004-2005, the annual km travelled and average speed for heavy trucks were assumed to be the same as that of medium trucks. Average annual km travelled and average speed was found to decrease from 2004-2005 to 2016-2017 for all vehicle categories except for Utility (Jeep/Pickup) and Motor cycles, and speed for Tempo seemed to have stayed the same. However due to the rampant increase in vehicle population and congestion it is more appropriate for the analysis to consider that the average vehicle speed should decrease by a small amount or none at all, rather than increase. Therefore practical assumptions were made for Utility and motorcycle speeds during 2016-2017 for analysis. Since the annual km travelled for remaining eight vehicle categories were found to decrease, the annual km travelled by Utility and Motor cycle was also assumed to decrease at the average rate at which most vehicles' mileage decreased. Since exact information regarding trend of mileage and average speed of vehicles throughout the years in Bangladesh does not exist, it was required to assume a uniform yearly decrease of mileage per year in order to find the data for particular year of analysis as shown in Table 4.12.

Table 4.12: Decrease in mileage per year for different RHD vehicle categories

Vehicle Category	Annual Km Driven (km) in 2004-2005	Annual Km Driven (km) in 2016-2017	Change in 11 years (km)	Uniform change per year (km)
Heavy Truck	80,700	72,200	8,500	772.7273
Medium Truck	80,700	67,200	13,500	1227.2727
Small Truck	74,000	59,000	15,000	1363.6364
Large Bus	129,800	102,700	27,100	2463.6364
Mini Bus	66,700	56,300	10,400	945.4545
Micro Bus	56,800	50,600	6,200	563.6364
Utility (Jeep/Pickup)	22,000	19,800	2,200	200.0000
Car	50,000	36,094	13,906	1264.1818
Tempo	44,000	40,900	3,100	281.8182
Auto Rickshaw	46,000	28,700	17,300	1572.7273
Motor Cycle	13,000	11,700	1,300	118.1818

Similarly, a uniform yearly decrease in average speed was required to assume in order to find the data for particular year of analysis as shown in Table 4.13.

Table 4.13: Decrease in average speed per year for different RHD vehicle categories

Vehicle Category	Average speed (km/hr) in 2004-2005	Average speed (km/hr) in 2016-2017	Change in 11 years (km/hr)	Uniform change per year (km/hr)
Heavy Truck	40	31	9	0.818182
Medium Truck	40	31	9	0.818182
Small Truck	42	29	13	1.181818
Large Bus	45	37	8	0.727273
Mini Bus	31	26	5	0.454545
Micro Bus	49	36	13	1.181818
Utility (Jeep/Pickup)	25	24	1	0.090909
Car	39	33	6	0.545455
Tempo	21	21	0	0
Auto Rickshaw	27	17	10	0.909091
Motor Cycle	22	22	0	0

The lifetime mileage of vehicles for each year of analysis was found by calculating the weighted average age of vehicles in the 20 years stock and multiplying them with the annual km travelled by each vehicle as shown:

Lifetime mileage (km) = Σ (Age of vehicle* Stock number)/ 20 years stock * Annual km travelled

4.7 Change in Mileage and Activity Information Due to Lockdown

During the lockdown in 2020 and 2021 due to the corona virus outbreak, there was a significant decrease in annual km travelled by public transport and private passenger vehicles due to online classes and work from home and consequently due to reduction in the amount of vehicles running on the roads, there was a substantial decrease in congestion which caused the speed travelled by the vehicles to increase. In this paper, emission for the year 2020 and 2021 was once calculated using decreased annual km travelled and increased average speed to show the real scenario. Then the emission for the year 2020 and 2021 was again calculated using the average yearly uniform decrease of annual km travelled and average speed as shown above in order to determine the situation if lockdown had not occurred to ultimately compare the two scenarios. The on-road transport activity during the year 2020 was reportedly almost half of the average activity during the year 2019 (Sung and Monschauer, 2020). A study by EMISIA, the founder company of COPERT in March 2021 stated that mileage dropped by 25% for passenger cars with respect to 2019 and there was no change in mileage or activity for LCV's and HDT's (Papadimitriou, 2021). Significant information about changes in transport activity during lockdown in Bangladesh was found from a research paper (Anwari et al., 2021). Considering all practical circumstances in Bangladesh, mileage for public transport vehicles were reduced by 50%, mileage for passenger cars reduced by 25% for 2020 and 2021 with respect to 2019. An average increase of speed during lockdown for all types of vehicles for the year 2020 and 2021 was assumed considering general holidays, online classes conducted by educational institutions, deployment of forces, limitations on religious gathering and temporary shutting down of garments factories (Zafri et al., 2021)

4.8 Fuel Characteristics

The fuel characteristics were taken from the Revisions of Vehicular Emission Standards for Bangladesh report (RHD, 2012). Density and Sulfur content of Diesel fuel in Dhaka city, Chittagong city and for the rest of the country were given; density, Lead content and Sulfur content for regular and premium grade Petrol were also given for the years 2012, 2014 and 2019. 2012 was the year of the study, and the values for 2014 and 2019 were proposed standards for the future. Minimum value of fuel density and maximum values of Lead and Sulfur was considered for worst case scenario, and since the proposed standards of Sulfur and Lead content were found to decrease in the future, it was assumed that Sulfur and Lead content decreased at a uniform rate throughout the years. Maximum allowable Reid vapor pressure at 38°C was found to be 10 psi from this report. For the prediction of emissions in 2025, the same fuel specifications were used as that of 2021 assuming that there was no improvement in the fuel quality in order to determine the worst case scenario.

4.9 Environmental Information

4.9.1 Environmental Information from the Year 2016 to 2021

The data for 2021 was collected from Bangladesh Meteorological Department as shown in Table 4.14.

Table 4.14: Monthly maximum and minimum temperature and humidity for Bangladesh for the year 2021 (Source: Bangladesh Meteorological Department, 2021)

Month	Min Temperature (°C)	Max Temperature (°C)	Humidity (%)
January	12.5	25.2	76%
February	15.1	27.8	72%
March	19.6	31.6	71%
April	23.1	33.2	75%
May	24.5	32.9	79%
June	25.6	31.9	85%
July	25.6	31.1	86%
August	25.7	31.4	86%
September	25.4	31.5	85%
October	23.6	31.5	83%
November	19.2	29.5	79%
December	14.2	26.4	77%

The monthly maximum and minimum temperature and monthly average humidity from the year 2016 to 2020 was collected for the divisions Dhaka, Chittagong, Rajshahi, Khulna, Sylhet and Barisal and the average was calculated for the whole country as shown in Table 4.15.

Table 4.15: Monthly maximum and minimum temperature and humidity for Bangladesh from 2016 to 2020 (Source: Time and date Official Website, 2022)

Monthly Maximum Temperature in 2016 (°C)							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	27	29	30	29	29	29	28.8
February	35	34	36	35	34	34	34.8
March	35	35	37	37	35	35	35.8
April	36	36	43	41	36	36	38.0
May	37	37	41	40	37	37	38.4
June	36	40	40	40	36	36	38.4
July	35	36	34	35	35	35	35.0
August	36	37	35	36	36	36	36.0
September	35	34	35	35	38	38	35.8
October	35	36	35	35	35	35	35.2
November	34	37	33	32	34	34	34.0
December	30	33	30	29	30	30	30.4
Monthly Minimum Temperature in 2016 (°C)							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	8	8	11	11	8	8	9.2
February	10	10	16	15	10	10	12.8
March	16	16	21	22	16	16	17.8
April	19	20	21	26	20	20	21.0
May	20	21	21	22	21	21	21.0
June	23	25	22	21	24	24	23.2
July	24	27	25	26	24	24	25.0
August	25	24	24	25	24	24	24.3
September	25	26	26	25	25	25	25.4
October	20	18	24	23	20	20	20.8
November	15	14	16	16	15	15	15.2
December	12	12	11	10	12	12	11.4

Table 4.15 (continued)

Monthly Average Humidity in 2016							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	19%	77%	73%	72%	77%	77%	66%
February	67%	73%	71%	69%	73%	73%	71%
March	64%	71%	64%	65%	71%	71%	68%
April	74%	78%	65%	66%	78%	78%	73%
May	77%	81%	71%	72%	81%	81%	77%
June	76%	64%	78%	79%	80%	80%	76%
July	83%	30%	87%	87%	86%	86%	77%
August	77%	71%	85%	85%	81%	81%	80%
September	81%	67%	84%	83%	85%	85%	81%
October	77%	65%	76%	75%	83%	83%	77%
November	77%	48%	70%	70%	82%	82%	72%
December	79%	53%	74%	73%	83%	83%	74%
Monthly Maximum Temperature in 2017 (°C)							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	32	32	30	29	32	32	31.2
February	33	33	33	33	33	33	33.0
March	34	34	35	35	34	34	34.3
April	36	36	38	38	36	36	36.7
May	37	37	39	38	37	37	37.5
June	36	36	39	38	36	36	36.8
July	36	36	36	35	36	36	35.8
August	35	35	39	36	35	35	35.8
September	36	36	36	36	36	36	36.0
October	35	35	35	35	35	35	35.0
November	34	33	32	32	33	33	32.8
December	29	29	29	30	29	29	29.2

Table 4.15 (continued)

Monthly Minimum Temperature in 2017 (°C)							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	7	7	10	10	7	7	8.0
February	10	10	15	15	10	10	11.7
March	14	14	17	18	14	14	15.2
April	19	19	23	23	19	19	20.3
May	21	21	23	23	21	21	21.7
June	22	23	24	25	23	23	23.3
July	25	25	25	25	25	25	25.0
August	23	24	25	26	24	24	24.3
September	24	24	24	25	24	24	24.2
October	19	19	19	21	19	19	19.3
November	15	15	14	14	15	15	14.7
December	13	11	11	14	11	11	11.8
Monthly Average Humidity in 2017							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	71%	78%	68%	66%	78%	78%	73%
February	62%	72%	63%	63%	72%	72%	67%
March	68%	75%	68%	68%	75%	75%	72%
April	75%	80%	71%	71%	80%	80%	76%
May	74%	78%	70%	70%	78%	78%	75%
June	81%	84%	79%	79%	84%	84%	82%
July	84%	87%	86%	87%	87%	87%	86%
August	82%	86%	85%	85%	86%	86%	85%
September	83%	87%	81%	81%	87%	87%	84%
October	80%	85%	83%	82%	85%	85%	83%
November	74%	80%	71%	70%	80%	80%	76%
December	79%	84%	75%	74%	84%	84%	80%

Table 4.15 (continued)

Monthly Maximum Temperature in 2018 (°C)							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	27	27	29	28	27	27	27.5
February	34	34	36	34	34	34	34.3
March	35	34	37	36	34	34	35.0
April	36	36	40	39	36	36	37.2
May	36	36	38	38	36	36	36.7
June	35	34	41	40	34	34	36.3
July	36	36	36	36	36	36	36.0
August	36	36	35	36	36	36	35.8
September	36	36	36	36	36	36	36.0
October	36	35	38	36	35	35	35.8
November	32	32	34	33	32	32	32.5
December	29	29	28	34	29	29	29.7
Monthly Minimum Temperature in 2018 (°C)							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	7	7	9	10	7	7	7.8
February	13	13	14	15	13	13	13.5
March	15	15	17	20	15	15	16.2
April	19	19	20	21	19	19	19.5
May	21	20	20	22	20	20	20.5
June	23	24	23	25	24	24	23.8
July	25	25	25	26	25	25	25.2
August	25	25	24	25	25	25	24.8
September	25	25	25	25	25	25	25.0
October	20	20	19	20	20	20	19.8
November	13	13	16	18	13	13	14.3
December	7	8	10	9	8	8	8.3

Table 4.15 (continued)

Monthly Average Humidity in 2018							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	75%	81%	70%	68%	81%	81%	76%
February	66%	75%	61%	61%	75%	75%	69%
March	63%	70%	61%	61%	70%	70%	66%
April	68%	75%	69%	69%	75%	75%	72%
May	80%	84%	77%	75%	84%	84%	81%
June	81%	85%	80%	78%	85%	85%	82%
July	80%	84%	88%	86%	84%	84%	84%
August	78%	83%	87%	84%	83%	83%	83%
September	76%	81%	84%	81%	81%	81%	81%
October	74%	81%	76%	73%	81%	81%	78%
November	69%	77%	71%	69%	77%	77%	73%
December	71%	79%	69%	68%	79%	79%	74%
Monthly Maximum Temperature in 2019 (°C)							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	30	30	30	29	30	30	29.8
February	32	32	35	33	32	32	32.7
March	35	35	36	36	35	35	35.3
April	37	37	38	38	37	37	37.3
May	37	37	40	40	37	37	38.0
June	37	37	39	38	37	37	37.5
July	36	36	38	37	36	36	36.5
August	37	37	36	35	37	37	36.5
September	36	35	35	35	35	35	35.2
October	35	34	34	34	34	34	34.2
November	33	32	32	31	32	32	32.0
December	31	30	29	29	30	30	29.8

Table 4.15 (continued)

Monthly Minimum Temperature in 2019 (°C)							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	9	9	10	12	9	9	9.7
February	10	10	12	14	10	10	11.0
March	12	11	14	16	11	11	12.5
April	17	18	19	20	18	18	18.3
May	22	21	21	24	21	21	21.7
June	22	23	23	23	23	23	22.8
July	23	18	26	26	18	18	21.5
August	26	26	24	25	26	26	25.5
September	23	23	23	24	23	23	23.2
October	22	22	20	21	22	22	21.5
November	16	16	16	18	16	16	16.3
December	10	10	9	12	10	10	10.2
Monthly Average Humidity in 2019							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	65%	75%	66%	65%	75%	75%	70%
February	65%	74%	65%	64%	74%	74%	69%
March	64%	73%	69%	67%	73%	73%	70%
April	67%	75%	74%	71%	75%	75%	73%
May	74%	80%	79%	75%	80%	80%	78%
June	79%	83%	81%	78%	83%	83%	81%
July	82%	85%	83%	79%	85%	85%	83%
August	78%	83%	88%	86%	83%	83%	84%
September	79%	84%	89%	86%	84%	84%	84%
October	81%	86%	86%	81%	86%	86%	84%
November	77%	83%	80%	75%	83%	83%	80%
December	77%	84%	79%	74%	84%	84%	80%

Table 4.15 (continued)

Monthly Maximum Temperature in 2020 (°C)							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	29	30	29	29	30	30	29.5
February	32	32	30	30	32	32	31.3
March	37	37	36	36	37	37	36.7
April	37	37	39	38	37	37	37.5
May	37	37	39	38	37	37	37.5
June	36	36	37	36	36	36	36.2
July	36	36	37	36	36	36	36.2
August	36	36	37	36	36	36	36.2
September	37	36	36	36	36	36	36.2
October	35	35	40	35	35	35	35.8
November	33	33	33	33	33	33	33.0
December	30	30	30	30	30	30	30.0
Monthly Minimum Temperature in 2020 (°C)							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	9	9	10	12	9	9	9.7
February	8	8	11	12	8	8	9.2
March	15	15	16	17	15	15	15.5
April	21	17	20	22	17	17	19.0
May	21	21	20	21	21	21	20.8
June	24	24	23	24	24	24	23.8
July	24	25	24	24	25	25	24.5
August	24	25	25	26	25	25	25.0
September	25	25	25	25	25	25	25.0
October	23	23	22	23	23	23	22.8
November	2	14	14	17	14	14	12.5
December	9	9	10	12	9	9	9.7

Table 4.15 (continued)

Monthly Average Humidity in 2020							
Month	Dhaka	Chittagong	Rajshahi	Khulna	Sylhet	Barisal	Country
January	79%	86%	79%	76%	86%	86%	82%
February	66%	76%	69%	65%	76%	76%	71%
March	56%	65%	69%	64%	65%	65%	64%
April	56%	71%	75%	69%	71%	71%	69%
May	72%	79%	83%	76%	79%	79%	78%
June	81%	85%	87%	84%	85%	85%	85%
July	81%	86%	88%	84%	86%	86%	85%
August	77%	83%	90%	87%	83%	83%	84%
September	80%	86%	89%	84%	86%	86%	85%
October	79%	85%	85%	79%	85%	85%	83%
November	70%	79%	68%	66%	79%	79%	74%
December	74%	83%	73%	72%	83%	83%	78%

4.9.2 Expected Environmental Information for the Year 2025

The yearly average maximum temperature in Bangladesh is expected to increase by 0.018°C per year and yearly average minimum temperature is expected to increase by 0.015°C per year (Basak et al., 2013). Therefore the monthly normal maximum temperature in 2025 is expected to be 0.072°C greater than that of the year 2021, and the monthly minimum temperature for the year 2025 is expected to be 0.060°C greater than that of the year 2021.

The monthly dew point temperature from the year 2016 to 2021 was calculated using the given formula: (August-Roche-Magnus approximation)

$$\mathbf{T_d = 243.04 \times (\ln (Rh / 100) + ((17.625 \times T) / (243.04 + T))) / (17.625 - \ln (Rh/100)-((17.625 \times T) / (243.04 + T)))}$$

where, T_d is the dew point temperature, R_h is the average humidity of particular month and T is the average of maximum and minimum temperature observed in particular month. Using the average monthly dew point temperature for 6 years, approximate monthly humidity for 2025 was calculated with the given formula:

$$\mathbf{R_h =100 \times (EXP((17.625 \times T_d)/(243.04+T_d))/EXP((17.625 \times T)/ (243.04+T)))}$$

The calculation of average yearly dew point T_d and approximate monthly relative humidity R_h in 2025 is shown in Table 4.16.

Table 4.16: Calculation of average yearly dew point and approximate R_h for 2025

Month	Dew Point T_d (°C)						Yearly Average T_d (°C)	R_h for 2025 using average T_d (%)
	2016	2017	2018	2019	2020	2021		
January	12.48	14.65	13.38	14.16	16.43	14.53	14.27	71%
February	18.20	15.99	17.84	15.97	14.89	16.19	16.51	59%
March	20.34	19.25	18.72	18.07	18.74	19.95	19.18	68%
April	24.19	23.89	22.76	22.51	21.98	23.30	23.11	66%
May	25.27	24.61	24.93	25.58	24.94	24.70	25.00	77%
June	26.10	26.64	26.74	26.58	27.10	25.98	26.52	84%
July	25.42	27.88	27.64	25.85	27.56	25.78	26.69	82%
August	26.33	27.28	27.12	27.87	27.54	25.98	27.02	77%
September	26.95	27.15	26.80	26.25	27.81	25.68	26.77	95%
October	23.48	24.09	23.57	24.95	26.14	24.40	24.44	81%
November	19.09	19.23	18.37	20.53	17.77	20.47	19.24	76%
December	16.13	16.93	14.30	16.51	15.89	16.14	15.98	90%

The expected environmental information for the year 2025 is summarized in the Table 4.16.

Table 4.17: Expected environmental information in Bangladesh for the year 2025

Month	Minimum Temperature (°C)	Maximum Temperature (°C)	Humidity (%)
January	12.6	25.3	71%
February	15.2	27.9	59%
March	19.7	31.7	68%
April	23.2	33.3	66%
May	24.6	33.0	77%
June	25.7	32.0	84%
July	25.7	31.2	82%
August	25.8	31.5	77%
September	25.5	31.6	95%
October	23.7	31.6	81%
November	19.3	29.6	76%
December	14.3	26.5	90%

4.10 Collection of CO_2 Emission Data from Other Studies

CO_2 emission from the year 1990 to 2018 in Bangladesh was found from a study made by the World Bank (World Bank, 2018) and the percentage of CO_2 emissions by the transport sector with respect to total fuel combustion from 1971 to 2014 in Bangladesh was found from another study made by the World Bank (World Bank, 2014).

By analysis it was found that emissions calculated in COPERT 5.5 are most highly impacted by the annual mileage and average speed data. Since the vehicle activity and mileage data is the most accurate for the years 2016 and 2017 as it was directly collected from the RUC report 2016-2017 (RHD 2017), it was most compulsory to run analysis for the year 2016 and 2017 to check against the given World Bank data for examining the applicability of this software for Bangladesh. Since the total CO_2 emission data in Bangladesh collected by World Bank is available up to the year 2018, assuming little change in the mileage and activity data in one year, this study checked the vehicular emissions for the three years 2016, 2017 and 2018 against the World Bank data. The recent most data of percentage of CO_2 emissions by the transport sector in Bangladesh collected by World Bank was in 2014, which is equal to 14.2%. Climate Transparency (2020) stated that 15% of the total CO_2 emissions in 2020 Bangladesh was owed to the transport sector. Therefore it was assumed that the percentage of CO_2 emissions by the transport sector in Bangladesh was within the range 14.2%~15% of the total for the years 2016, 2017 and 2018. However, the value of CO_2 emissions from the transport sector includes emissions not only from on-road vehicles but also from the domestic aviation sector, domestic navigation sector, railway sector and pipeline transport sector. The average percent contribution of different sectors of transport in the emission of CO_2 in Bangladesh is shown in Figure 4.1.

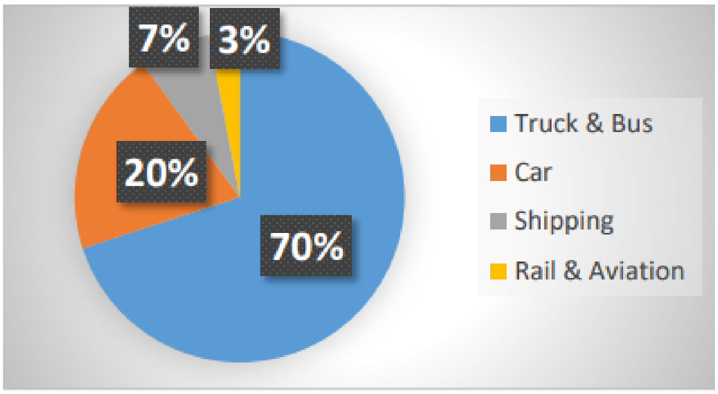

Figure 4.1: Percent contribution of CO_2 emission by different transport sectors (Source: Alam, 2019)

So in order to determine the amount of CO_2 emitted by on road vehicles only, it is necessary to deduct 10% (7% from shipping and 3% from rail and aviation).Therefore approximately 90% of the CO_2 emission from the transport sector is owed to on-road vehicles. So the total CO_2 emission of a particular year calculated by COPERT 5.5 was checked against 13.05% (90% of 14.5%) of the total CO_2 emission data from World Bank for that particular year.

4.11 Collection of Emission Factors for Bangladesh from Other Sources to Compare with the Emission Factors Generated by COPERT 5.5

Emission factors for CO_2 were found from the Bangladesh Air Pollution Studies report (Randall et al., 2015) as shown in Table 4.18.

Table 4.18: Emission factor for CO_2 from the BAPS report (Source: Randall et al., 2015)

Vehicle Type	Emission factor for CO_2 (g/km)
CNG bus 01-05	557
CNG bus 96-2000	557
Pass Car CNG	143.54
CNG taxi	196
Diesel bus 01-05	757
Diesel truck	706
Car EURO 3 D	237
Car EURO 3 G	242
Car EURO 4 D	148.76
Car EURO 4 G	172.95
MC-4 strokes	33
Minibus	306

CHAPTER 5
RESULTS AND ANALYSIS

5.1 Introduction

This chapter comprises of the current emission factors for different pollutants and different vehicles in Bangladesh generated by COPERT 5.5 which was checked against a similar study made by the DOE, the vehicular emission inventory of major pollutants in Bangladesh for the year 2016 to 2021, a likely scenario of the emissions in the years 2020 and 2021 if lockdown had not occurred and the percentage reduction in emission owed to the covid-19 lockdown. Furthermore, this chapter comprises of a comparative analysis of the emission characteristics of different types of vehicles and finally a prediction of emissions made for the year 2025.

5.2 Emission Factors Generated by COPERT 5.5

At first, COPERT 5.5 generated emission factors of each vehicle type using their average speeds, average trip length, temperature, humidity, etc. These coefficients are then used by the software to calculate emissions. Emission factors for 13 major pollutants and greenhouse gases are shown in Table 5.1.

Table 5.1: Emission factors generated by COPERT 5.5 (Unit: gm/km)

RHD Class	Fuel	Euro Standard	CH_4	CO	CO_2	N_2O	NH_3	NM-VOC	NO	NO_2	NOx	PM 10	PM 2.5	SO_2	VOC
Auto Rickshaw	Petrol	Euro 4	0.020	0.207	238.56	0.005	0.027	0.094	0.097	0.003	0.100	0.030	0.016	0.022	0.112
		Euro 5	0.020	0.315	238.56	0.002	0.015	0.092	0.056	0.002	0.058	0.031	0.018	0.022	0.109
		Euro 6 a/b/c	0.020	0.306	238.54	0.002	0.015	0.092	0.057	0.001	0.058	0.030	0.016	0.022	0.109
	CNG Bifuel	Euro 4	0.041	0.209	267.11	0.002	0.026	0.026	0.097	0.003	0.100	0.029	0.016	0.000	0.067
		Euro 5	0.041	0.209	267.11	0.002	0.015	0.026	0.076	0.002	0.078	0.029	0.016	0.000	0.067
		Euro 6 a/b/c	0.041	0.209	267.09	0.002	0.015	0.026	0.077	0.002	0.078	0.029	0.016	0.000	0.067
		Euro 6 d-temp	0.041	0.209	267.08	0.002	0.015	0.026	0.077	0.002	0.078	0.029	0.016	0.000	0.067
Tempo	Petrol	Euro 3	0.028	0.734	223.08	0.006	0.030	0.083	0.114	0.004	0.117	0.029	0.016	0.020	0.111
		Euro 4	0.020	0.233	237.08	0.005	0.030	0.066	0.092	0.003	0.095	0.029	0.016	0.022	0.085
		Euro 5	0.020	0.319	237.08	0.002	0.016	0.062	0.055	0.002	0.057	0.031	0.018	0.022	0.082
		Euro 6 a/b/c	0.020	0.307	237.06	0.002	0.016	0.062	0.056	0.001	0.057	0.030	0.016	0.022	0.082
	Diesel	Euro 3	0.002	0.172	206.96	0.008	0.001	0.029	0.665	0.222	0.887	0.065	0.052	0.061	0.029
		Euro 4	0.001	0.183	206.96	0.008	0.001	0.023	0.338	0.413	0.750	0.064	0.050	0.061	0.023
		Euro 5	0.000	0.058	206.96	0.008	0.002	0.002	0.424	0.282	0.706	0.029	0.016	0.061	0.002
		Euro 6 a/b/c	0.000	0.058	206.93	0.007	0.007	0.001	0.447	0.192	0.639	0.029	0.016	0.061	0.001
	CNG Bifuel	Euro 4	0.039	0.223	214.24	0.002	0.026	0.024	0.092	0.003	0.095	0.029	0.016	0.000	0.063
		Euro 5	0.039	0.223	214.24	0.002	0.016	0.024	0.073	0.002	0.076	0.029	0.016	0.000	0.063
		Euro 6 a/b/c	0.039	0.223	214.22	0.002	0.016	0.024	0.074	0.002	0.076	0.029	0.016	0.000	0.063
		Euro 6 d-temp	0.039	0.223	214.21	0.002	0.016	0.024	0.074	0.002	0.076	0.029	0.016	0.000	0.063

Table 5.1: Emission factors generated by COPERT 5.5 (Unit: gm/km) (continued)

RHD Class	**Fuel**	**Euro Standard**	**CH_4**	**CO**	**CO_2**	**N_2O**	**NH_3**	**NM-VOC**	**NO**	**NO_2**	**NOx**	**PM 10**	**PM 2.5**	**SO_2**	**VOC**
Car	Petrol	Euro 3	0.028	0.720	225.72	0.005	0.029	0.068	0.130	0.004	0.134	0.029	0.016	0.021	0.096
		Euro 4	0.020	0.242	230.05	0.005	0.029	0.051	0.092	0.003	0.095	0.029	0.016	0.021	0.072
		Euro 5	0.020	0.310	230.05	0.002	0.016	0.047	0.061	0.002	0.063	0.031	0.018	0.021	0.067
		Euro 6 a/b/c	0.020	0.294	230.03	0.002	0.016	0.047	0.062	0.001	0.063	0.030	0.016	0.021	0.067
	CNG Bifuel	Euro 4	0.039	0.242	182.23	0.002	0.026	0.025	0.092	0.003	0.095	0.029	0.016	0.000	0.063
		Euro 5	0.039	0.242	182.23	0.002	0.016	0.025	0.076	0.002	0.079	0.029	0.016	0.000	0.063
		Euro 6 a/b/c	0.039	0.242	182.20	0.002	0.016	0.025	0.077	0.002	0.079	0.029	0.016	0.000	0.063
		Euro 6 d-temp	0.039	0.242	182.19	0.002	0.016	0.025	0.077	0.002	0.079	0.029	0.016	0.000	0.063
Utility (Jeep/ Pickup)	Petrol	Euro 3	0.028	0.634	315.79	0.005	0.027	0.070	0.107	0.003	0.110	0.029	0.016	0.029	0.098
		Euro 4	0.020	0.208	381.90	0.005	0.027	0.056	0.085	0.003	0.088	0.029	0.016	0.035	0.074
		Euro 5	0.020	0.288	381.90	0.002	0.014	0.051	0.050	0.002	0.052	0.031	0.018	0.035	0.070
		Euro 6 a/b/c	0.020	0.275	381.88	0.002	0.014	0.051	0.051	0.001	0.052	0.030	0.016	0.035	0.070
	Diesel	Euro 3	0.002	0.160	270.71	0.008	0.001	0.056	0.636	0.212	0.848	0.064	0.050	0.080	0.057
		Euro 4	0.001	0.165	270.71	0.008	0.001	0.020	0.322	0.394	0.716	0.063	0.049	0.080	0.021
		Euro 5	0.000	0.056	270.71	0.008	0.002	0.001	0.406	0.271	0.676	0.029	0.016	0.080	0.001
		Euro 6 a/b/c	0.000	0.056	270.68	0.007	0.007	0.001	0.429	0.184	0.612	0.029	0.016	0.080	0.001
	CNG Bifuel	Euro 4	0.039	0.227	203.60	0.002	0.026	0.024	0.090	0.003	0.093	0.029	0.016	0.000	0.063
		Euro 5	0.039	0.227	203.60	0.002	0.014	0.024	0.072	0.002	0.075	0.029	0.016	0.000	0.063
		Euro 6 a/b/c	0.039	0.227	203.58	0.002	0.014	0.024	0.073	0.001	0.075	0.029	0.016	0.000	0.063
		Euro 6 d-temp	0.039	0.227	203.57	0.002	0.014	0.024	0.073	0.001	0.075	0.030	0.016	0.000	0.063

Table 5.1: Emission factors generated by COPERT 5.5 (Unit: gm/km) (continued)

RHD Class	Fuel	Euro Standard	CH_4	CO	CO_2	N_2O	NH_3	NMVOC	NO	NO_2	NOx	PM 10	PM 2.5	SO_2	VOC
Small Truck	Diesel	Euro 3	0.018	0.719	346.92	0.006	0.002	0.142	1.765	0.364	2.129	0.154	0.116	0.102	0.159
		Euro 4	0.001	0.427	332.17	0.007	0.002	0.031	1.071	0.404	1.475	0.103	0.065	0.098	0.033
		Euro 5	0.001	0.331	311.62	0.013	0.006	0.011	1.613	0.390	2.002	0.076	0.039	0.092	0.012
		Euro 6 a/b/c	0.001	0.050	315.08	0.012	0.008	0.008	0.512	0.170	0.683	0.076	0.038	0.093	0.009
Medium Truck	Diesel	Euro III	0.084	2.046	788.97	0.005	0.003	0.392	6.093	0.992	7.085	0.298	0.243	0.232	0.476
		Euro IV	0.005	0.997	722.91	0.012	0.003	0.051	3.940	0.641	4.582	0.147	0.092	0.213	0.056
		Euro V	0.005	1.500	719.76	0.033	0.011	0.050	5.759	0.640	6.399	0.110	0.055	0.212	0.055
		Euro VI A/B/C	0.005	0.192	718.70	0.036	0.009	0.036	0.556	0.062	0.618	0.110	0.055	0.212	0.041
Heavy Truck	Diesel	Euro II	0.090	1.997	954.60	0.009	0.003	0.518	9.627	1.190	10.817	0.329	0.271	0.281	0.607
		Euro III	0.084	2.525	1001.59	0.005	0.003	0.484	7.611	1.239	8.850	0.353	0.295	0.295	0.567
		Euro IV	0.005	1.201	932.47	0.012	0.003	0.067	5.015	0.816	5.832	0.167	0.109	0.274	0.072
		Euro V	0.005	1.827	927.31	0.033	0.011	0.062	6.539	0.727	7.265	0.120	0.062	0.273	0.067
Micro Bus	Diesel	Euro III	0.074	1.504	699.30	0.003	0.003	0.244	5.513	0.897	6.411	0.240	0.185	0.205	0.317
		Euro IV	0.004	0.799	646.56	0.006	0.003	0.039	3.499	0.570	4.069	0.142	0.087	0.190	0.043
		Euro V	0.004	1.346	630.77	0.017	0.011	0.034	3.904	0.434	4.338	0.110	0.055	0.185	0.038
		Euro VI A/B/C	0.004	0.159	643.01	0.021	0.009	0.024	0.287	0.032	0.319	0.110	0.055	0.189	0.028

Table 5.1: Emission factors generated by COPERT 5.5 (Unit: gm/km) (continued)

RHD Class	Fuel	Euro Standard	CH_4	CO	CO_2	N_2O	NH_3	NM-VOC	NO	NO_2	NOx	PM 10	PM 2.5	SO_2	VOC
Mini Bus	Diesel	Euro II	0.081	2.323	999.51	0.006	0.003	0.477	10.073	1.245	11.318	0.314	0.258	0.294	0.558
		Euro III	0.074	2.599	1048.70	0.003	0.003	0.446	8.547	1.391	9.938	0.312	0.256	0.308	0.520
		Euro IV	0.004	1.254	974.02	0.006	0.003	0.067	5.311	0.865	6.176	0.160	0.105	0.286	0.070
		Euro V	0.004	2.161	945.05	0.017	0.011	0.055	6.133	0.681	6.814	0.110	0.055	0.278	0.059
	CNG	Euro I	6.800	8.400	1525.19	0.000	0.000	0.200	15.840	0.660	16.500	0.115	0.060	0.000	7.000
		Euro II	4.500	2.700	1415.46	0.000	0.000	0.200	14.400	0.600	15.000	0.113	0.057	0.000	4.700
		Euro III	1.280	1.000	1250.86	0.000	0.000	0.020	9.600	0.400	10.000	0.113	0.057	0.000	1.300
		EEV	0.980	0.870	1041.50	0.000	0.000	0.000	3.565	0.149	3.713	0.121	0.065	0.000	0.893
Large Bus	Diesel	Euro III	0.074	2.415	994.32	0.005	0.003	0.528	7.667	1.248	8.915	0.342	0.286	0.293	0.602
		Euro IV	0.004	1.295	948.47	0.012	0.003	0.071	5.031	0.819	5.850	0.160	0.104	0.279	0.075
		Euro V	0.004	2.035	933.11	0.033	0.011	0.065	6.618	0.735	7.353	0.110	0.055	0.275	0.069
		Euro VI A/B/C	0.004	0.315	950.80	0.036	0.009	0.048	0.602	0.067	0.669	0.110	0.055	0.280	0.051
Motorcycle	Petrol	Euro 1	0.140	12.223	84.12	0.002	0.002	1.487	0.243	0.010	0.253	0.033	0.027	0.008	1.627
		Euro 2	0.114	4.592	76.83	0.002	0.002	0.544	0.219	0.009	0.228	0.018	0.012	0.007	0.658
		Euro 3	0.056	0.689	63.21	0.002	0.002	0.084	0.079	0.003	0.082	0.018	0.012	0.006	0.130
		Euro 4	0.056	0.519	60.37	0.002	0.002	0.090	0.027	0.001	0.028	0.014	0.008	0.006	0.143

The emission factors generated by COPERT 5.5 were checked against that from the recent most study done in Bangladesh (Randall et al., 2015) which is shown in Table 5.2.

Table 5.2: Comparison between emission factors generated by COPERT 5.5 and emission factors from the recent most study done in Bangladesh (Source: Randall et al., 2015).

Vehicle Type from the major study	Corresponding Vehicle type in COPERT 5.5	Emission factor for CO_2 (g/km) from the major study	COPERT 5.5 emission factor for CO_2 (g/km)
CNG bus 01-05	Buses- CNG-Urban CNG buses-Euro 2	557	1415.4588
CNG bus 96-2000	Buses- CNG-Urban CNG buses-Euro 1	557	1525.1914
Pass Car CNG	Passenger Cars CNG Bifuel total	143.54	215.1227
CNG taxi	Passenger Cars CNG Bifuel-Mini-total	196	267.0967
Diesel bus 01-05	Buses- Diesel- Urban buses standard 15-18tonne Euro 2	757	999.5083
Diesel truck	Heavy duty trucks- Diesel -Rigid 20-26tonne total	706	946.1169
Car EURO 3 D	Passenger car- Diesel- Large SUV Executive- Euro 3	237	270.7102
Car EURO 3 G	Passenger car- Petrol- Large SUV Executive-Euro 3	242	315.7910
Car EURO 4 D	Passenger car- Diesel- Small-Euro 4	148.76	206.9593
Car EURO 4 G	Passenger car- Petrol- Small-Euro 4	172.95	237.0829
MC-4 strokes	Motorcycle 4 stroke <250cm^3 total : Petrol	33	64.5253
Minibus	Urban buses midi <15tonne total	306	646.7990

The emission factors generated by COPERT 5.5 were found to be much greater than the emission factors found by the report. This could be due to the effect of age and lifetime mileage of the vehicles. The emission factors from the report were found during the year 2009 and the same vehicle technologies are not being produced anymore hence a certain lifetime mileage was given as an input in the analysis of current times by COPERT 5.5 thus resulting in greater emission factors. Another possible reason for this discrepancy could be the consideration of effect of temperature and humidity in the analysis of COPERT 5.5 which was not considered in the report (Baidya, 2009). However, it was not possible to compare the emission factors for vehicles from the year 1991 to 1995 because the emission factors generated by COPERT 5.5 are for the present times, and the analysis was carried out assuming that vehicles running in Bangladesh currently are no more than 20 years old. Also, the vehicle classifications found in the report are different from that of the RUC report, BRTA classifications and also from the COPERT 5.5 classifications so the synchronization of vehicle types between the report and COPERT 5.5 was carried out by using best judgment.

5.3 Emission Inventories

The quantity of 13 major pollutants, namely CO_2, CO, CH_4, NOx, SO_2, PM 10, PM 2.5, NO_2, N_2O, NH_3, NO, VOC and NVOC emitted throughout the years by Auto Rickshaw, Tempo, Car, Utility (Jeep/Pickup), Small Truck, Medium Truck, Heavy truck, Micro bus, Minibus, Large bus and Motorcycles were found for the years 2016, 2017, 2018, 2019, 2020 and 2021 which are represented in tabular format and bar diagrams.

5.3.1 Emission Inventory for the Year 2016

The emission inventory for the year 2016 calculated by COPERT is shown in Table 5.3.

Table 5.3: Emission inventory for the year 2016

Vehicle Category	**CO_2 (t)**	**CO (t)**	**CH_4 (t)**	**NO_X (t)**	**SO_2 (t)**
Auto Rickshaw	44202.900	66.525	4.715	14.952	9.692
Tempo	51025.735	35.078	1.385	130.006	32.877
Car	79451.320	127.457	8.039	29.472	17.424
Jeep/Pickup	203591.694	79.082	2.896	401.604	138.287
Small Truck	1540979.430	1071.717	10.183	6185.452	1268.617
Medium Truck	1053531.937	1258.953	20.947	5051.098	868.103
Heavy Truck	1649299.762	2965.437	46.217	12574.341	1359.234
Micro Bus	342945.132	393.977	5.614	1398.627	282.092
Mini Bus	141820.108	275.413	3.568	1067.798	116.662
Large Bus	2433854.169	2961.381	34.511	10940.813	2005.664
Motorcycle	2037383.385	51490.713	2329.245	2682.426	446.714
Total (t)	9578085.572	60725.733	2467.320	40476.589	6545.365
Vehicle Category	**PM 10 (t)**	**PM 2.5 (t)**	**NO_2 (t)**	**N_2O (t)**	**NH_3 (t)**
Auto Rickshaw	7.204	3.987	0.381	0.566	4.188
Tempo	8.829	5.461	46.111	0.890	1.785
Car	11.690	6.447	0.800	1.165	7.886
Jeep/Pickup	25.495	15.135	143.332	2.808	4.380
Small Truck	450.908	247.511	1382.874	52.886	32.196
Medium Truck	207.994	120.685	582.471	45.015	12.933
Heavy Truck	342.902	231.497	1486.865	39.015	12.553
Micro Bus	72.568	40.295	164.109	9.033	4.804
Mini Bus	26.828	18.380	129.317	1.540	0.971
Large Bus	402.779	251.097	1338.786	70.786	20.105
Motorcycle	570.939	356.630	107.297	69.394	69.394
Total (t)	2128.136	1297.125	5382.343	293.098	171.197

Table 5.3: Emission inventory for the year 2016 (continued)

Vehicle Category	NO (t)	VOC (t)	NMVOC (t)
Auto Rickshaw	14.571	24.212	20.453
Tempo	83.895	7.607	6.426
Car	28.672	27.192	19.408
Jeep/Pickup	258.272	12.831	10.587
Small Truck	4802.578	105.200	95.016
Medium Truck	4468.626	127.906	106.959
Heavy Truck	11087.476	317.539	271.322
Micro Bus	1234.518	28.946	23.332
Mini Bus	938.481	26.505	22.938
Large Bus	9602.027	321.528	287.017
Motorcycle	2575.129	9148.731	7051.821
Total (t)	35094.246	10148.197	7915.279

The quantity of emission of pollutants by different types of vehicles in the year 2016 is represented via bar diagrams in Figure 5.1.

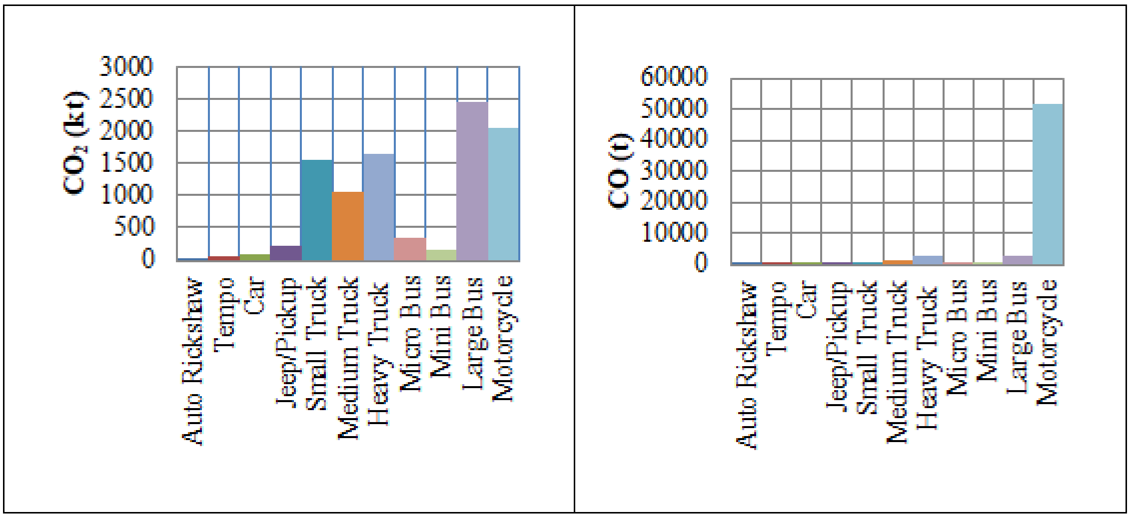

Figure 5.1: Emission of pollutants by different types of vehicles in the year 2016

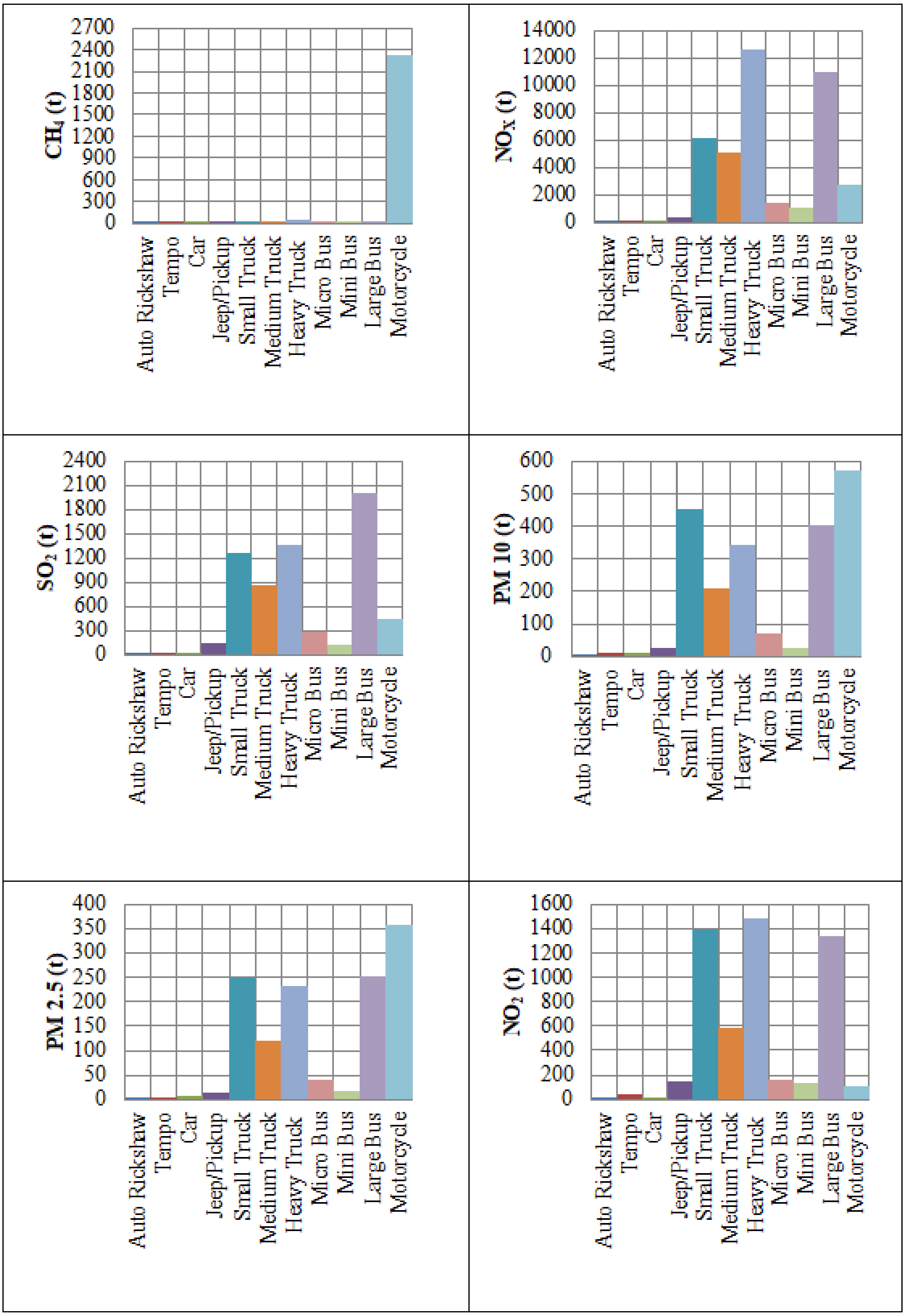

Figure 5.1: Emission of pollutants by different types of vehicles in the year 2016 (continued)

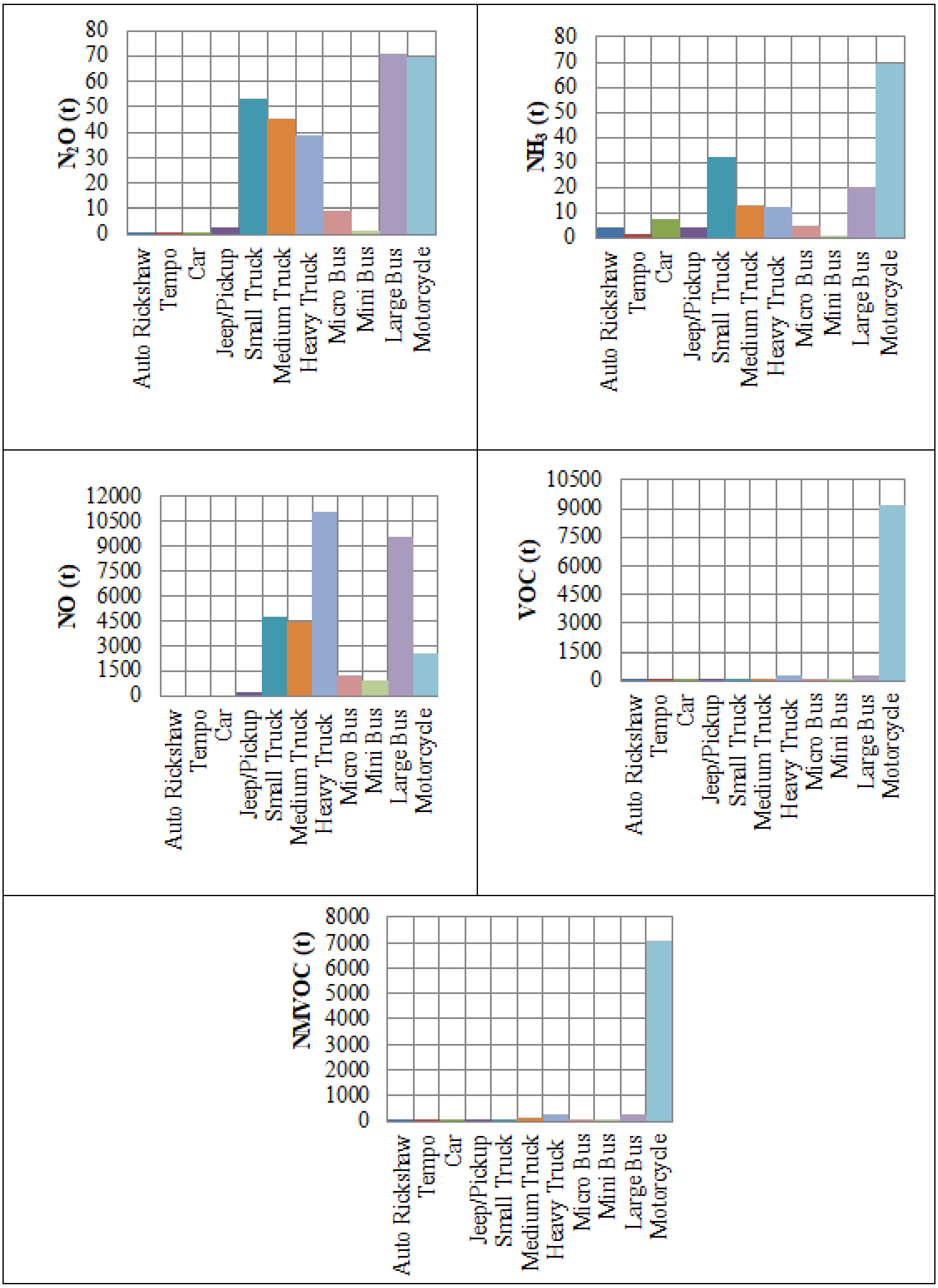

Figure 5.1: Emission of pollutants by different types of vehicles in the year 2016 (continued)

5.3.2 Emission Inventory for the Year 2017

The emission inventory for the year 2017 calculated by COPERT is shown in Table 5.4.

Table 5.4: Emission inventory for the year 2017

Vehicle Category	**CO_2 (t)**	**CO (t)**	**CH_4 (t)**	**NOx (t)**	**SO_2 (t)**
Auto Rickshaw	43932.379	63.275	4.510	14.291	7.760
Tempo	62758.114	43.427	1.758	157.438	31.669
Car	81528.486	132.296	8.217	29.811	14.403
Jeep/Pickup	156394.911	61.155	2.204	304.515	83.254
Small Truck	1763346.563	1255.159	10.894	7352.295	1140.648
Medium Truck	1199699.377	1397.716	22.599	5594.539	776.727
Heavy Truck	1894644.282	3430.786	48.654	14534.948	1226.855
Micro Bus	381002.697	431.695	6.178	1556.179	246.189
Mini Bus	163166.630	324.706	3.869	1242.038	105.455
Large Bus	2692372.455	3267.118	43.630	11867.328	1743.285
Motorcycle	1355522.603	35875.887	1426.621	1650.348	239.467
Total (t)	9794368.498	46283.221	1579.135	44303.729	5615.712
Vehicle Category	**PM 10 (t)**	**PM 2.5 (t)**	**NO_2 (t)**	**N_2O (t)**	**NH_3 (t)**
Auto Rickshaw	6.815	3.776	0.369	0.524	3.897
Tempo	10.623	6.483	54.259	1.084	2.261
Car	11.819	6.511	0.799	1.168	7.924
Jeep/Pickup	19.009	11.354	109.130	2.027	3.125
Small Truck	497.928	273.484	1604.204	58.109	36.138
Medium Truck	230.248	133.211	640.907	50.933	14.548
Heavy Truck	380.249	255.465	1702.719	45.126	14.509
Micro Bus	79.144	44.239	184.068	9.744	5.112
Mini Bus	29.915	20.313	147.203	1.852	1.169
Large Bus	450.911	286.895	1453.634	77.584	22.057
Motorcycle	343.791	213.793	66.014	42.094	42.094
Total (t)	2060.452	1255.524	5963.306	290.245	152.833

Table 5.4: Emission inventory for the year 2017 (continued)

Vehicle Category	NO (t)	VOC (t)	NMVOC (t)
Auto Rickshaw	13.921	24.257	20.234
Tempo	103.179	9.447	7.752
Car	29.012	28.914	20.697
Jeep/Pickup	195.385	11.240	9.245
Small Truck	5748.091	117.815	106.921
Medium Truck	4953.632	144.165	121.566
Heavy Truck	12832.229	352.889	304.235
Micro Bus	1372.110	33.072	26.894
Mini Bus	1094.834	29.799	25.930
Large Bus	10413.694	400.977	357.347
Motorcycle	1584.334	6613.629	5276.896
Total (t)	38340.423	7766.205	6277.716

The quantity of emissions in the year 2017 is represented via bar diagrams in Figure 5.2.

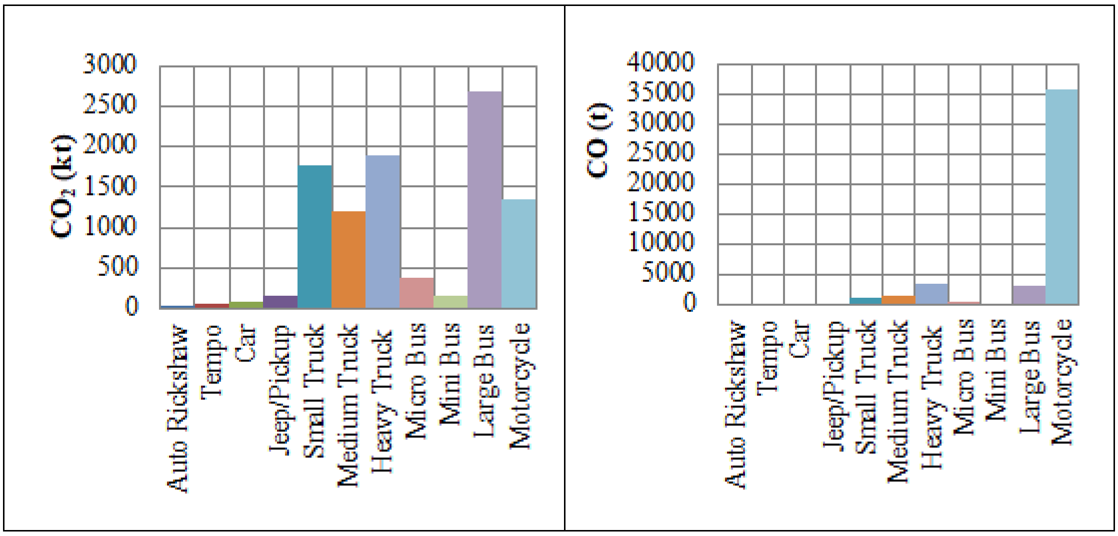

Figure 5.2: Emission of pollutants by different types of vehicles in the year 2017

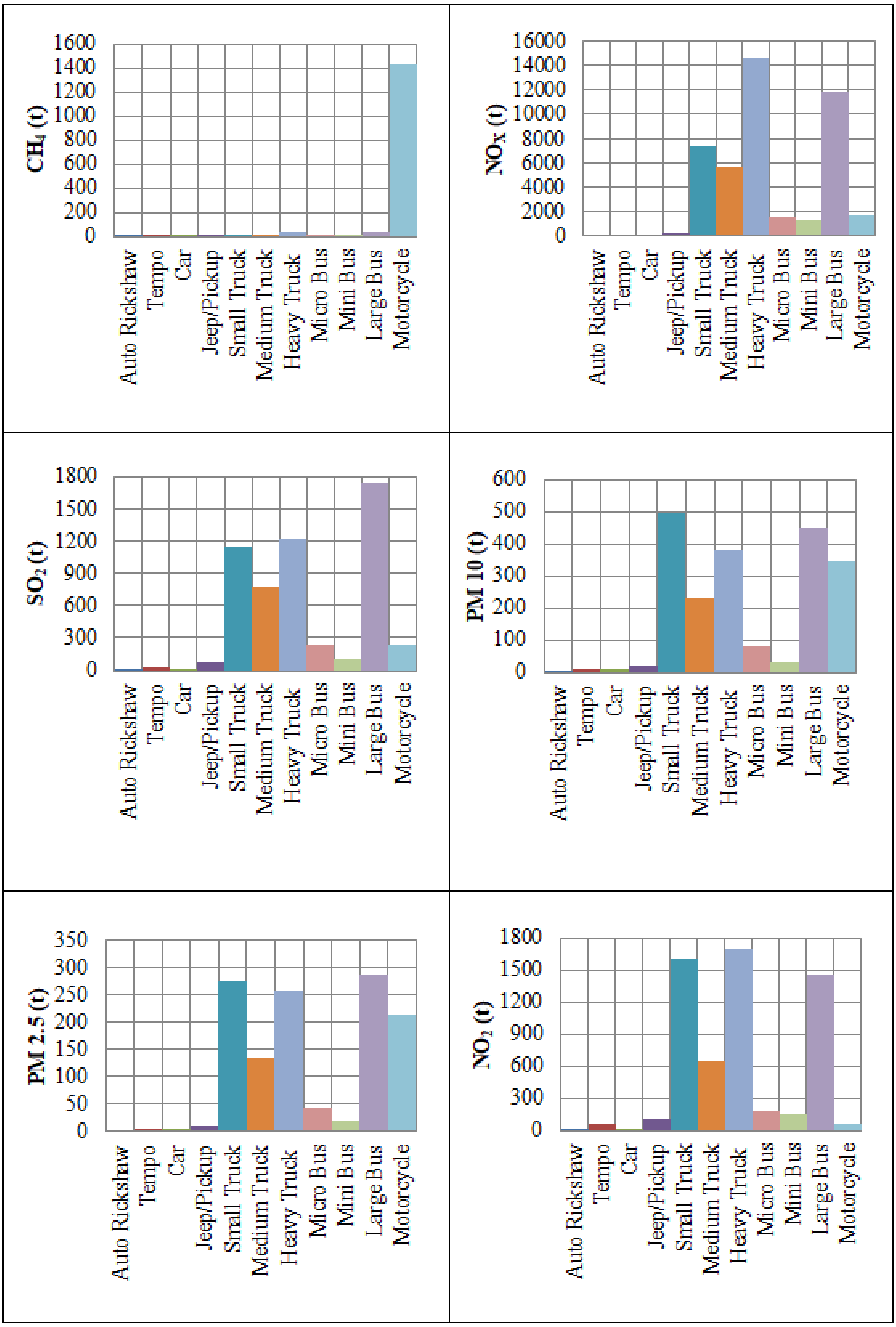

Figure 5.2 Emission of pollutants by different types of vehicles in the year 2017 (continued)

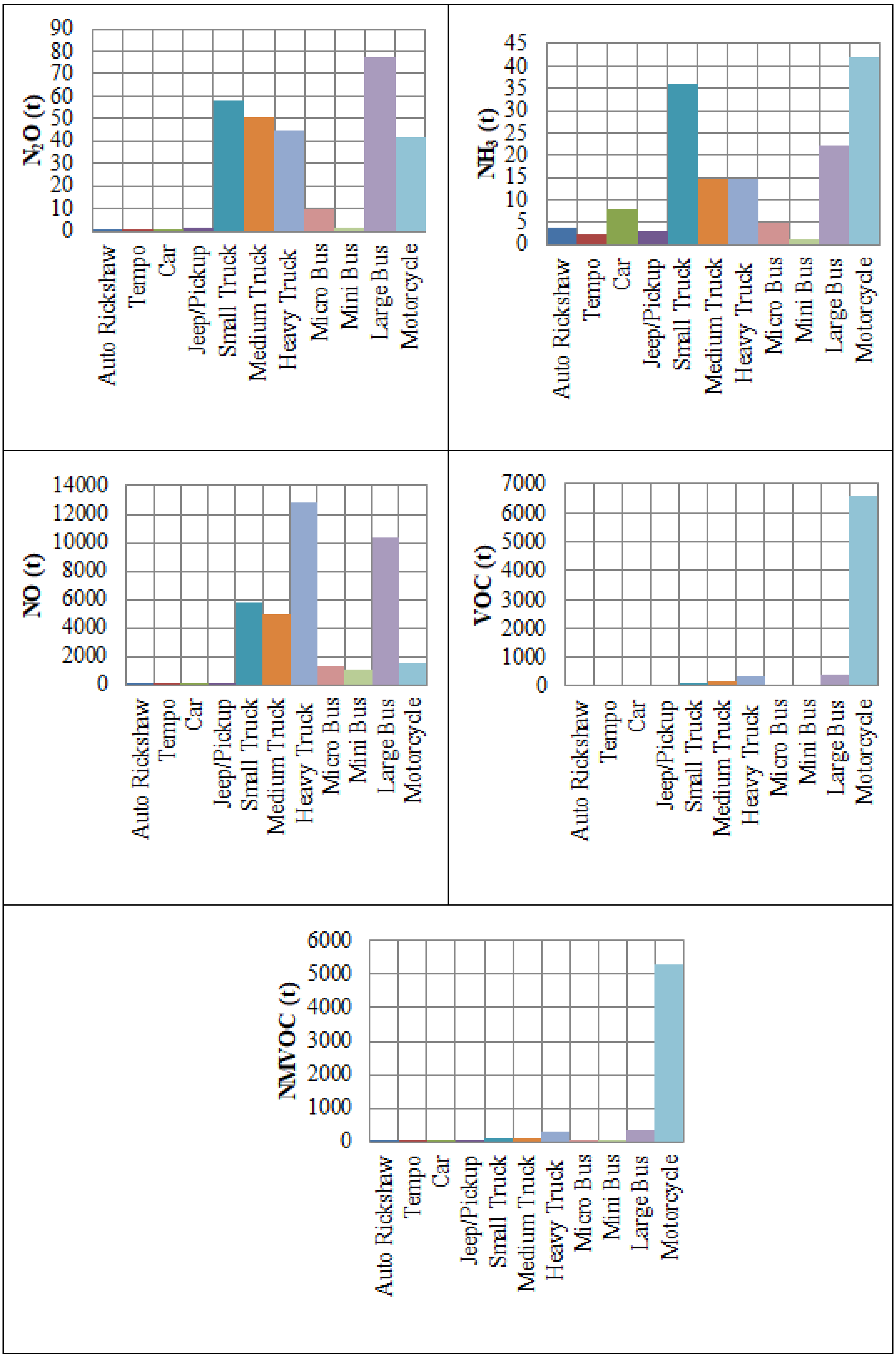

Figure 5.2 Emission of pollutants by different types of vehicles in the year 2017 (continued)

5.3.3 Emission Inventory for the Year 2018

The emission inventory for the year 2018 calculated by COPERT is shown in Table 5.5.

Table 5.5: Emission inventory for the year 2018

Vehicle Category	**CO_2 (t)**	**CO (t)**	**CH_4 (t)**	**NO_X (t)**	**SO_2 (t)**
Auto Rickshaw	47187.874	73.052	4.721	14.887	6.324
Tempo	71368.993	52.758	2.109	175.328	25.927
Car	85295.974	143.292	8.588	31.439	11.431
Jeep/Pickup	178000.616	71.321	2.550	343.760	68.863
Small Truck	2014120.041	1385.422	11.508	8338.419	947.553
Medium Truck	1372493.361	1534.660	23.569	6135.377	646.260
Heavy Truck	2180773.061	3951.787	49.778	16681.723	1027.014
Micro Bus	411150.466	450.075	6.153	1650.651	193.169
Mini Bus	187834.871	382.292	4.215	1434.853	88.283
Large Bus	2889704.119	3453.912	48.471	12448.979	1360.773
Motorcycle	1619495.875	42017.573	1710.205	1933.778	217.042
Total (t)	11057425.252	53516.145	1871.868	49189.194	4592.637
Vehicle Category	**PM 10 (t)**	**PM 2.5 (t)**	**NO_2 (t)**	**N_2O (t)**	**NH_3 (t)**
Auto Rickshaw	7.130	3.955	0.387	0.530	3.993
Tempo	12.066	7.366	59.432	1.224	2.671
Car	12.254	6.739	0.838	1.229	8.265
Jeep/Pickup	21.703	13.019	123.727	2.297	3.610
Small Truck	555.514	303.506	1820.340	65.650	40.863
Medium Truck	255.560	145.932	694.835	59.039	16.753
Heavy Truck	420.436	278.672	1937.463	53.278	17.113
Micro Bus	84.156	47.048	197.302	10.303	5.315
Mini Bus	33.439	22.449	167.273	2.233	1.419
Large Bus	484.201	310.281	1528.791	82.865	23.479
Motorcycle	404.654	249.113	77.351	50.365	50.365
Total (t)	2291.114	1388.081	6607.738	329.013	173.846

Table 5.5: Emission inventory for the year 2018 (continued)

Vehicle Category	NO (t)	VOC (t)	NMVOC (t)
Auto Rickshaw	14.500	26.558	22.073
Tempo	115.896	11.369	9.259
Car	30.601	31.072	22.484
Jeep/Pickup	220.033	13.063	10.662
Small Truck	6518.079	126.969	115.461
Medium Truck	5440.542	155.967	132.398
Heavy Truck	14744.260	377.577	327.800
Micro Bus	1453.350	34.577	28.424
Mini Bus	1267.580	33.230	29.015
Large Bus	10920.188	446.867	398.396
Motorcycle	1856.427	7844.530	6233.820
Total (t)	42581.456	9101.781	7329.793

The quantity of emissions in the year 2018 is represented via bar diagrams in Figure 5.3.

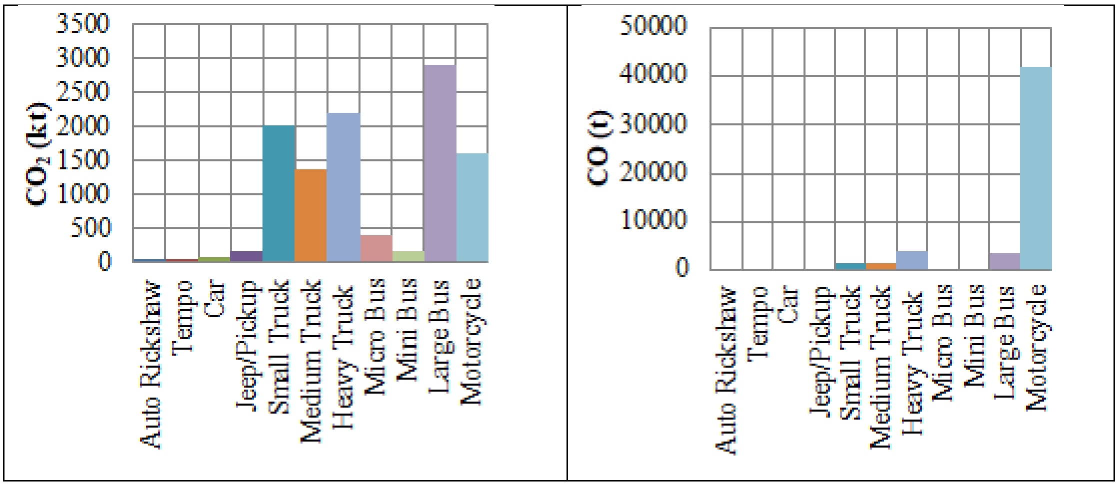

Figure 5.3: Emission of pollutants by different types of vehicles in the year 2018

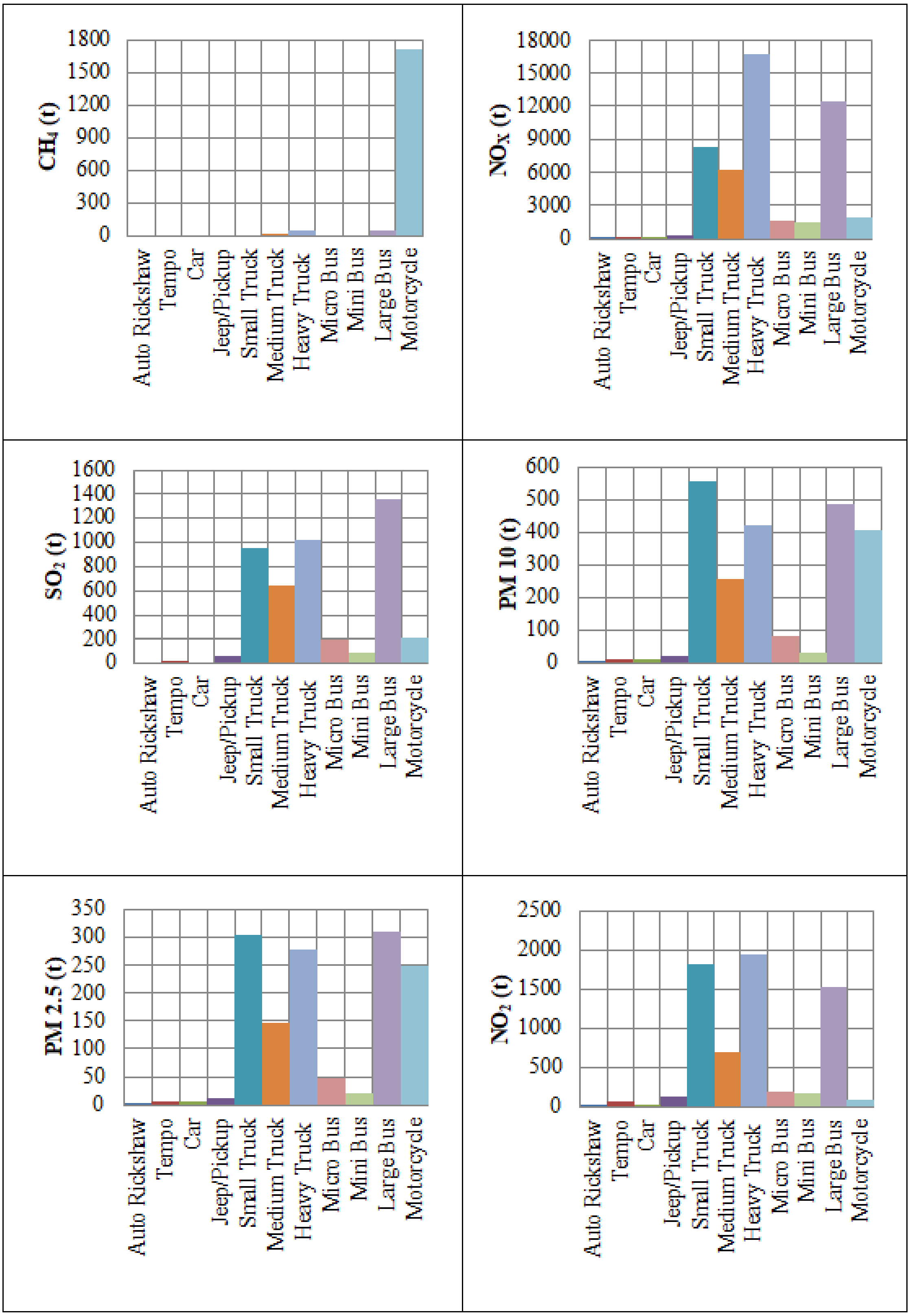

Figure 5.3: Emission of pollutants by different types of vehicles in the year 2018 (continued)

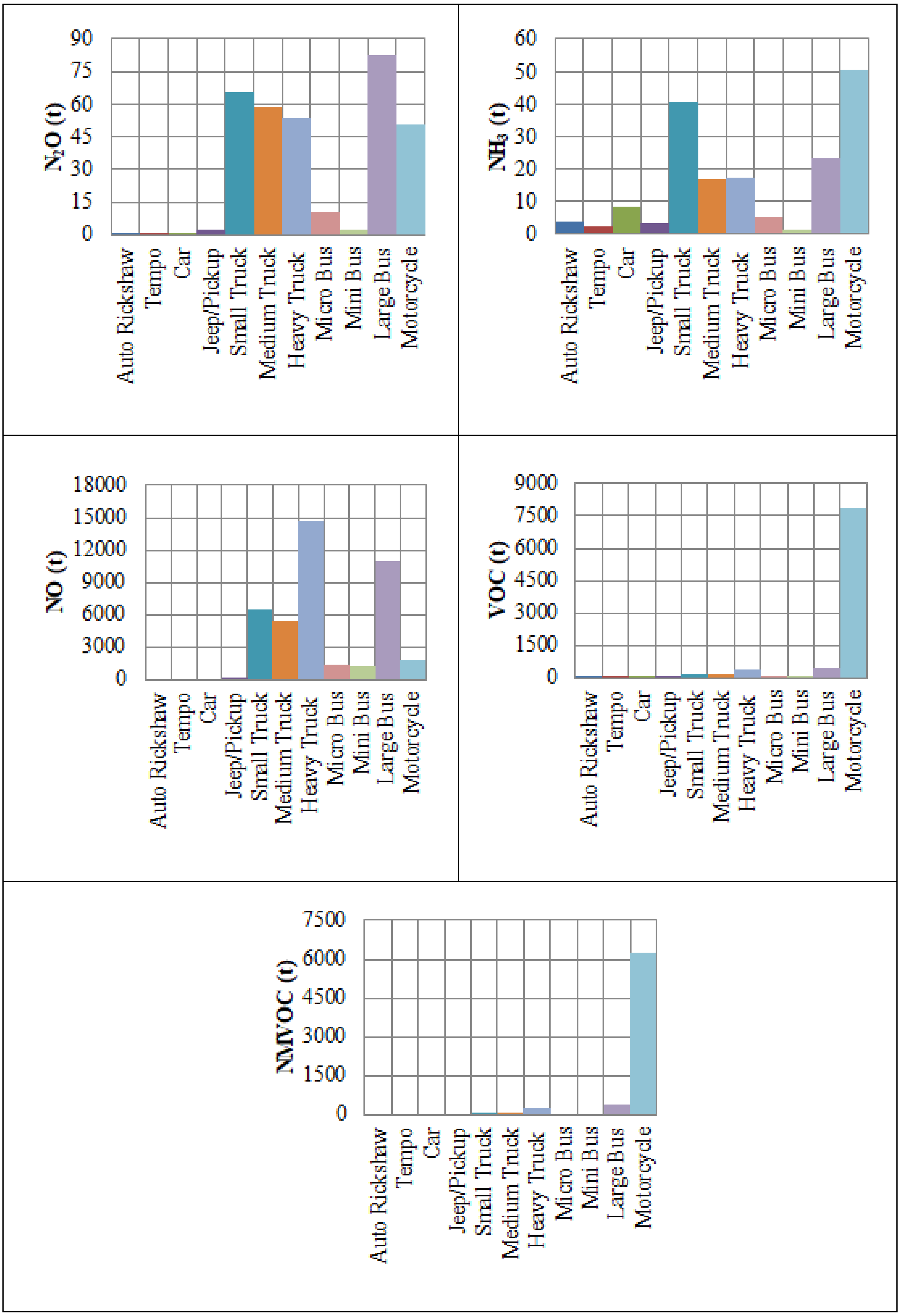

Figure 5.3: Emission of pollutants by different types of vehicles in the year 2018 (continued)

5.3.4 Comparison between COPERT Results and World Bank Data

The total amount of CO_2 emission in Bangladesh in the year 2016 was found to be 73740 kilo tonnes (World Bank, 2018). 13.05% of this was due to on-road vehicles which is equal to 9623.07 kt. The total amount of CO_2 emission in 2016 calculated by COPERT 5.5 was 9578085.572 tonnes or 9578.086 kt. Thus the percentage deviation between the COPERT 5.5 result and World Bank data was found to be 0.467% for the year 2016.

The total amount of CO_2 emission in Bangladesh in the year 2017 was found to be 78710 kilo tonnes (World Bank, 2018). 13.05% of this was due to on-road vehicles which is equal to 10271.655 kt. The total amount of CO_2 emission in 2017 calculated by COPERT 5.5 was 9794368.498 tonnes or 9794.368kt. Thus the percentage deviation between the COPERT 5.5 result and World Bank data was found to be 4.647% for the year 2017.

The total amount of CO_2 emission in Bangladesh in the year 2018 was found to be 82760 kilo tonnes (World Bank, 2018). 13.05% of this was due to on-road vehicles which is equal to 10800.180 kt. The total amount of CO_2 emission in 2018 calculated by COPERT 5.5 was 11057425.252 tonnes or 11057.425 kt. Thus the percentage deviation between the COPERT 5.5 result and World Bank data was found to be 2.382% for the year 2018.

The comparison between COPERT 5.5 results and World Bank data throughout the years is represented in Figure 5.4.

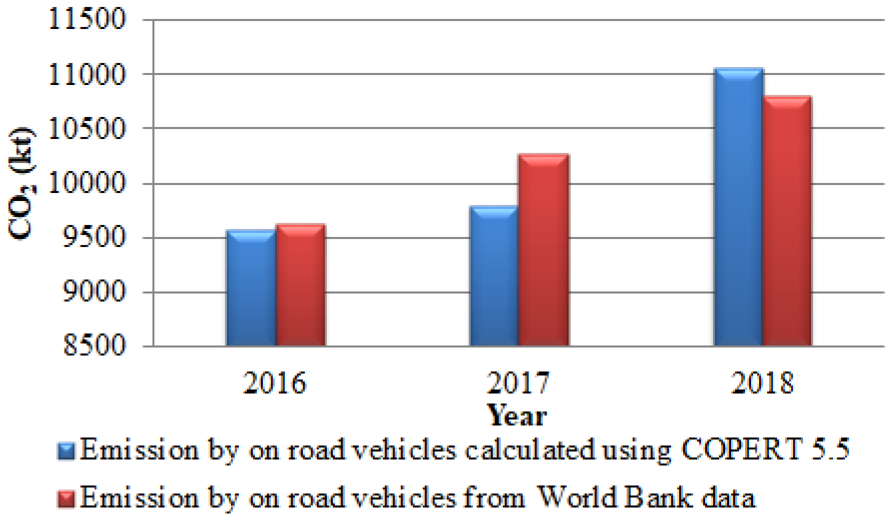

Figure 5.4: Comparison between COPERT 5.5 results and World Bank data

5.3.5 Emission Inventory for the Year 2019

The emission inventory for the year 2019 calculated by COPERT is shown in Table 5.6.

Table 5.6: Emission inventory for the year 2019

Vehicle Category	**CO_2 (t)**	**CO (t)**	**CH_4 (t)**	**NO_X (t)**	**SO_2 (t)**
Auto Rickshaw	51358.059	71.463	5.007	15.822	4.693
Tempo	77304.196	57.473	2.401	186.996	17.518
Car	88173.889	142.952	8.821	32.747	8.057
Jeep/Pickup	198050.150	80.412	2.887	383.087	48.160
Small Truck	2162282.952	1566.583	12.811	9128.517	635.798
Medium Truck	1485811.610	1730.378	24.715	6974.492	437.265
Heavy Truck	2386596.792	4345.133	56.801	18348.240	702.472
Micro Bus	441316.422	491.044	6.792	1848.820	129.552
Mini Bus	218075.160	451.026	4.663	1671.814	64.053
Large Bus	3153859.539	3716.111	51.774	13305.527	928.231
Motorcycle	1874200.650	45997.512	1958.746	2131.742	171.255
Total (t)	12137029.420	58650.085	2135.419	54027.801	3147.054
Vehicle Category	**PM 10 (t)**	**PM 2.5 (t)**	**NO_2 (t)**	**N_2O (t)**	**NH_3 (t)**
Auto Rickshaw	7.540	4.179	0.409	0.553	4.179
Tempo	13.141	8.057	62.966	1.319	2.986
Car	12.549	6.891	0.874	1.302	8.613
Jeep/Pickup	24.561	14.921	138.478	2.550	4.030
Small Truck	593.227	326.881	1982.307	68.520	42.213
Medium Truck	273.957	156.976	790.963	62.178	17.730
Heavy Truck	466.540	313.975	2152.931	55.350	17.791
Micro Bus	90.351	51.185	224.681	10.501	5.394
Mini Bus	37.922	25.249	192.758	2.661	1.698
Large Bus	520.939	333.354	1628.929	90.664	25.606
Motorcycle	465.564	284.626	85.270	58.589	58.589
Total (t)	2506.291	1526.293	7260.564	354.185	188.829

Table 5.6: Emission inventory for the year 2019 (continued)

Vehicle Category	**NO (t)**	**VOC (t)**	**NMVOC (t)**
Auto Rickshaw	15.413	29.412	24.832
Tempo	124.030	12.941	10.561
Car	31.872	32.392	23.571
Jeep/Pickup	244.609	15.216	12.516
Small Truck	7146.210	144.765	131.954
Medium Truck	6183.529	168.987	144.272
Heavy Truck	16195.309	435.753	378.952
Micro Bus	1624.139	38.863	32.071
Mini Bus	1479.056	37.622	32.958
Large Bus	11676.598	485.704	433.930
Motorcycle	2046.472	8832.516	6988.706
Total (t)	46767.237	10234.170	8214.324

The quantity of emissions in the year 2019 is represented via bar diagrams is shown in Figure 5.5.

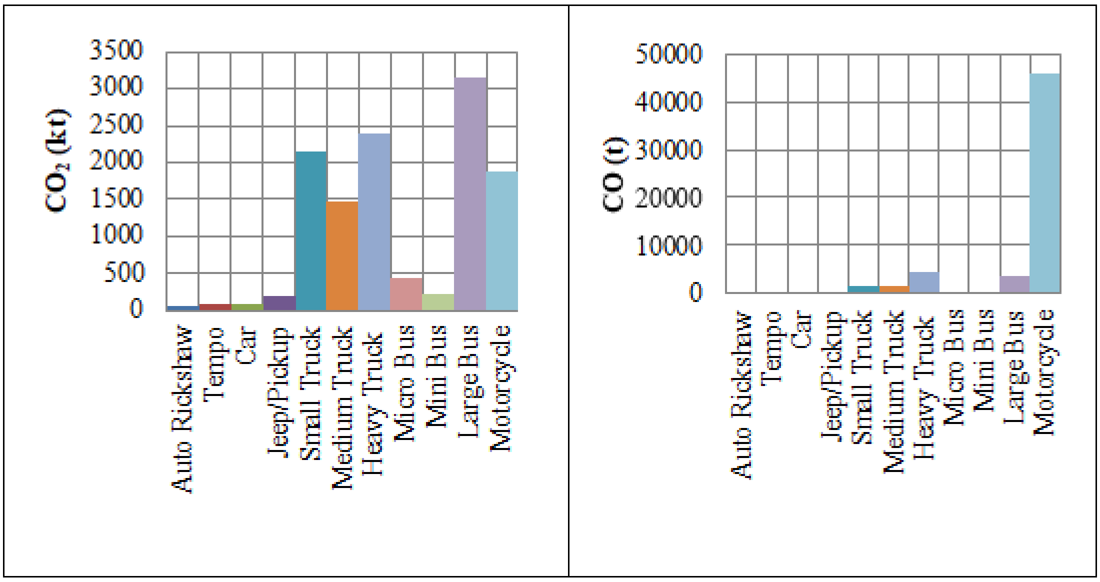

Figure 5.5: Emission of pollutants by different types of vehicles in the year 2019

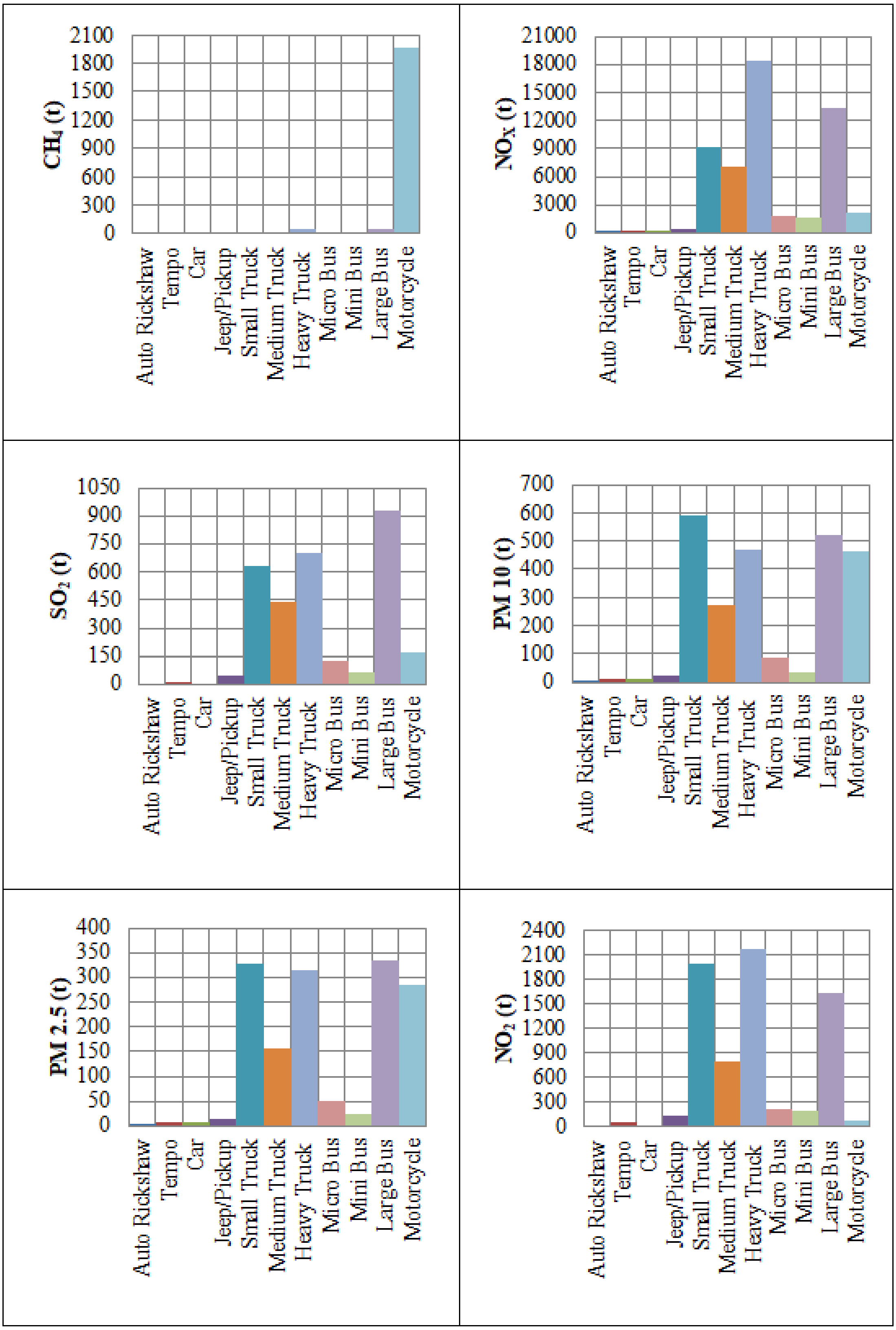

Figure 5.5: Emission of pollutants by different types of vehicles in the year 2019 (continued)

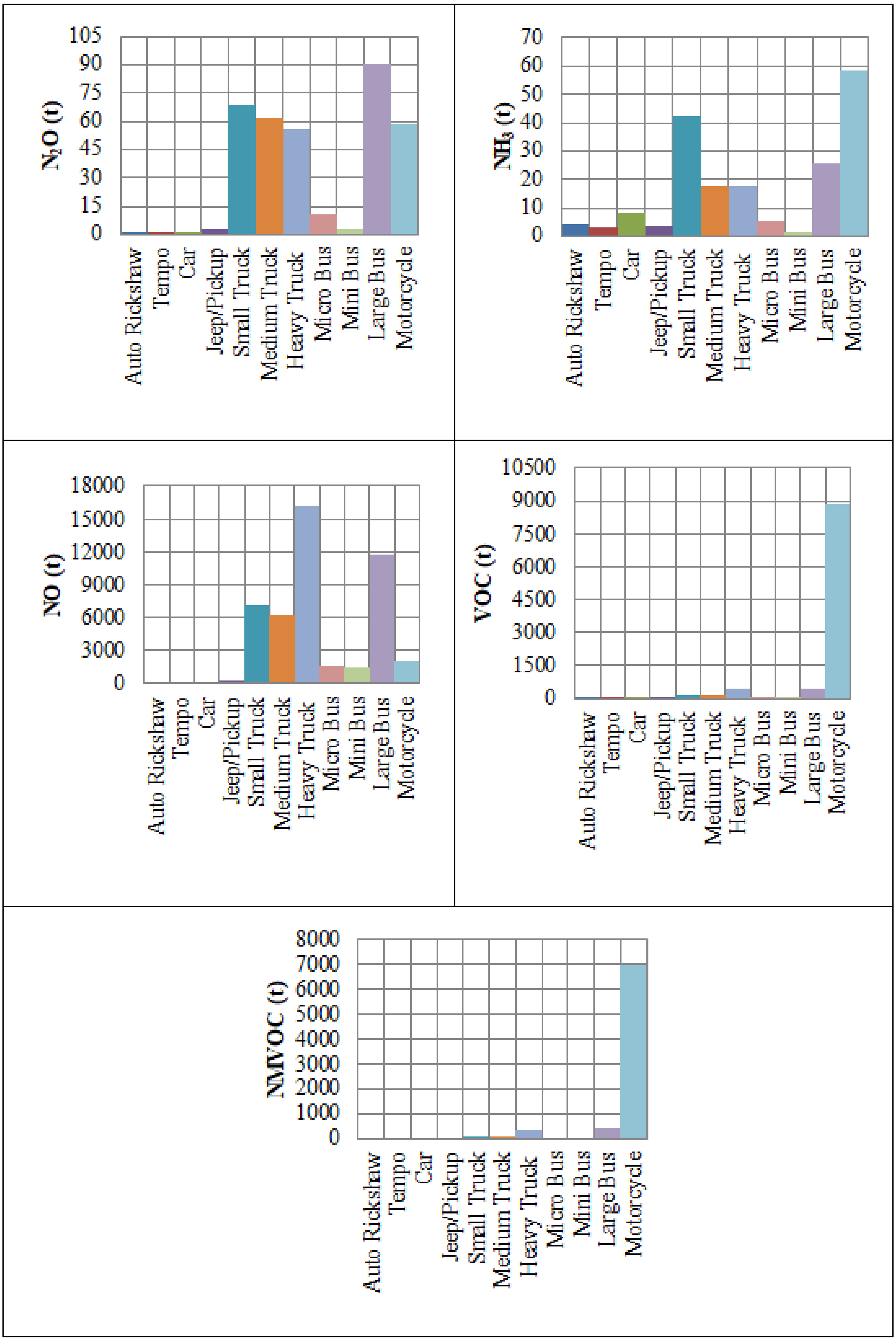

Figure 5.5: Emission of pollutants by different types of vehicles in the year 2019 (continued)

5.3.6 Emission Inventory for the Year 2020

The emission inventory for the year 2020 calculated by COPERT is shown in Table 5.7.

Table 5.7: Emission inventory for the year 2020

Vehicle Category	CO_2 (t)	CO (t)	CH_4 (t)	NO_X (t)	SO_2 (t)
Auto Rickshaw	26397.002	40.065	2.644	8.411	2.412
Tempo	39735.991	32.267	1.298	95.971	8.931
Car	68018.397	115.791	6.880	25.990	6.215
Jeep/Pickup	159008.930	68.535	2.381	310.685	38.659
Small Truck	2240623.707	1679.259	14.108	9408.980	658.814
Medium Truck	1514309.351	1773.481	25.322	7204.700	445.647
Heavy Truck	2441279.775	4502.683	67.839	18816.421	718.561
Micro Bus	340511.679	391.044	5.806	1499.163	99.922
Mini Bus	118554.941	244.229	2.794	905.847	34.815
Large Bus	1645303.727	1994.050	27.231	7157.235	484.231
Motorcycle	2051971.067	52331.648	2204.317	2480.879	187.491
Total (t)	10645714.566	63173.052	2360.620	47914.282	2685.699
Vehicle Category	**PM 10 (t)**	**PM 2.5 (t)**	**NO_2 (t)**	**N_2O (t)**	**NH_3 (t)**
Auto Rickshaw	3.998	2.217	0.219	0.261	2.024
Tempo	6.999	4.333	32.975	0.674	1.467
Car	9.803	5.379	0.702	1.008	6.523
Jeep/Pickup	20.709	12.817	113.901	2.092	3.233
Small Truck	632.361	351.992	2084.954	70.295	42.594
Medium Truck	285.687	164.365	831.472	62.424	17.762
Heavy Truck	503.243	344.763	2236.332	55.120	17.898
Micro Bus	71.643	41.080	184.288	7.864	4.080
Mini Bus	21.260	14.256	104.902	1.456	0.935
Large Bus	273.853	174.354	869.418	48.113	13.708
Motorcycle	526.797	325.078	99.235	65.318	65.318
Total (t)	2356.354	1440.633	6558.400	314.625	175.543

Table 5.7: Emission inventory for the year 2020 (continued)

Vehicle Category	**NO (t)**	**VOC (t)**	**NMVOC (t)**
Auto Rickshaw	8.192	17.266	14.674
Tempo	62.996	8.906	7.607
Car	25.288	26.480	19.600
Jeep/Pickup	196.784	13.116	10.885
Small Truck	7324.026	159.352	145.244
Medium Truck	6373.228	169.711	144.389
Heavy Truck	16580.089	491.532	423.693
Micro Bus	1314.875	31.748	25.942
Mini Bus	800.945	21.390	18.596
Large Bus	6287.817	250.463	223.232
Motorcycle	2381.644	9608.516	7556.044
Total (t)	41355.882	10798.480	8589.907

The quantity of emissions in the year 2020 is represented via bar diagrams as shown in Figure 5.6.

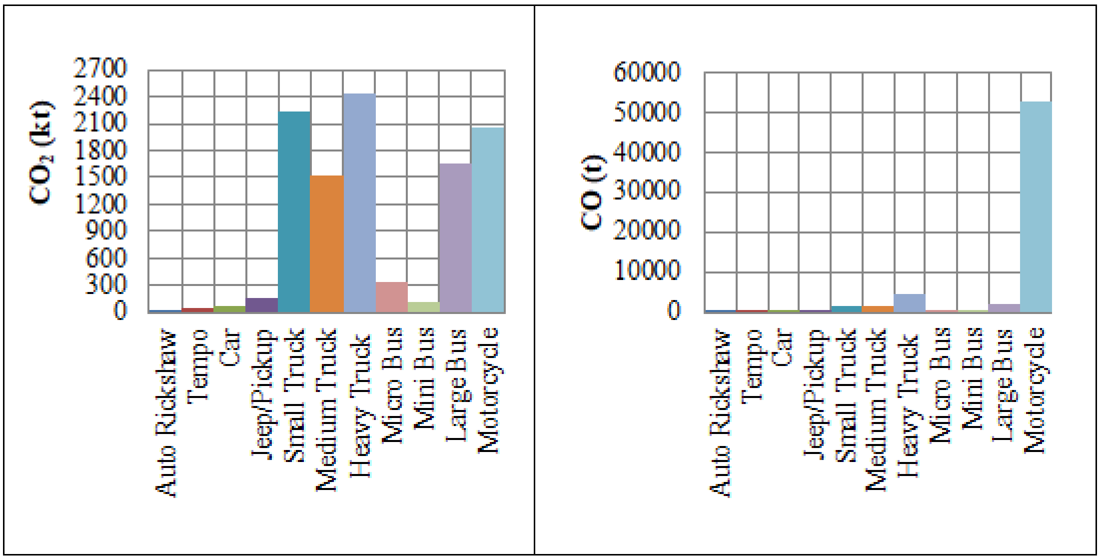

Figure 5.6: Emission of pollutants by different types of vehicles in the year 2020

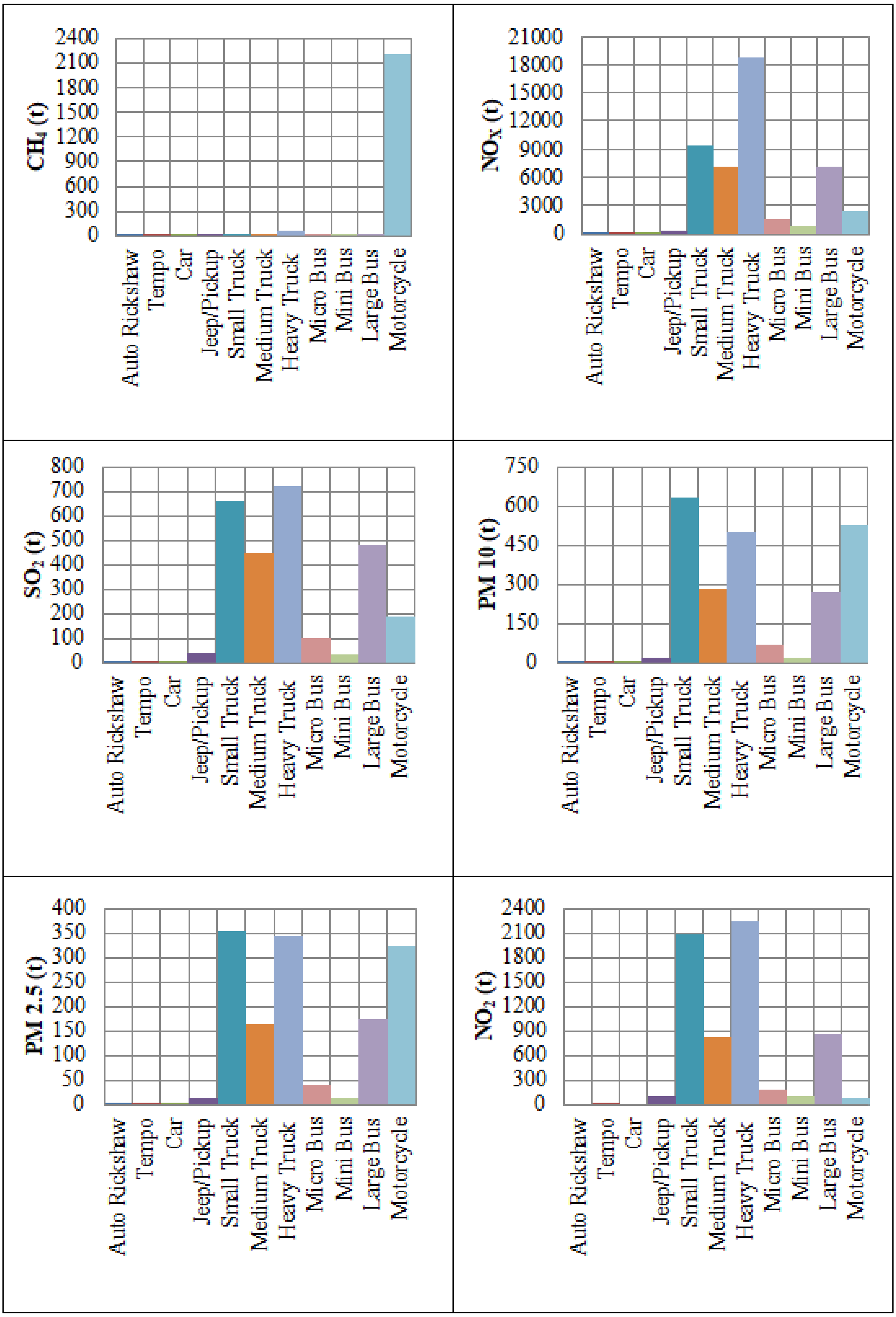

Figure 5.6: Emission of pollutants by different types of vehicles in the year 2020 (continued)

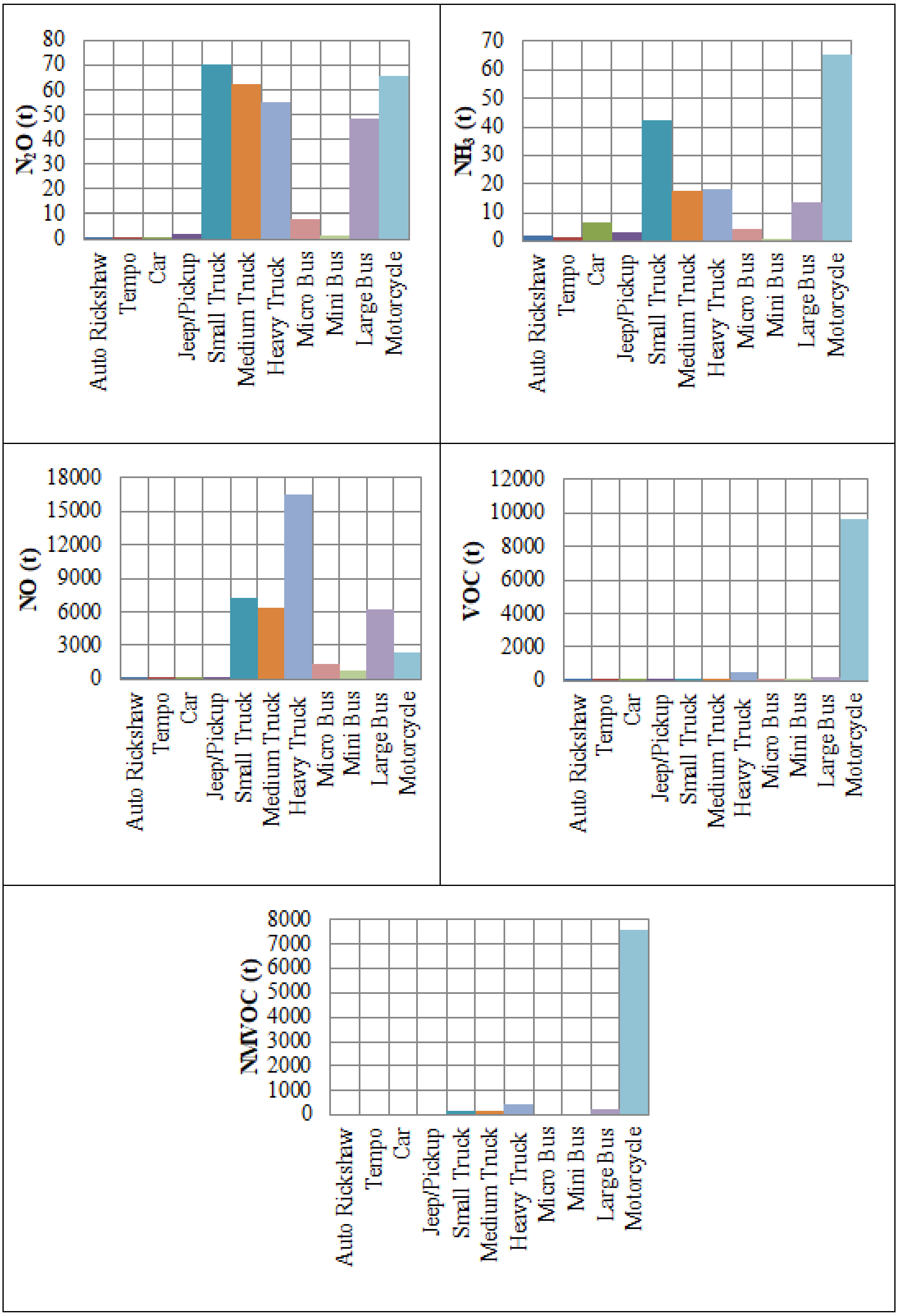

Figure 5.6: Emission of pollutants by different types of vehicles in the year 2020 (continued)

5.3.7 Emission Inventory for the Year 2021

The emission inventory for the year 2021 calculated by COPERT is shown in Table 5.8.

Table 5.8: Emission inventory for the year 2021

Vehicle Category	**CO_2 (t)**	**CO (t)**	**CH_4 (t)**	**NO_X (t)**	**SO_2 (t)**
Auto Rickshaw	29750.016	39.983	2.774	8.926	2.719
Tempo	43425.925	34.124	1.436	99.698	9.621
Car	76134.111	116.546	7.279	27.316	6.957
Jeep/Pickup	182672.545	77.971	2.739	343.304	44.275
Small Truck	2435500.714	1849.087	16.365	10099.755	716.133
Medium Truck	1585892.680	1892.399	26.541	7747.836	466.713
Heavy Truck	2560905.705	4794.268	79.796	19908.155	753.773
Micro Bus	361982.163	436.339	6.830	1678.215	106.202
Mini Bus	126576.018	257.154	3.035	965.670	37.171
Large Bus	1668639.105	2188.408	26.280	7948.944	491.096
Motorcycle	2311599.424	61135.548	2495.941	2926.584	211.216
Total (t)	11383078.408	72821.827	2669.015	51754.401	2845.877
Vehicle Category	**PM 10 (t)**	**PM 2.5 (t)**	**NO_2 (t)**	**N_2O (t)**	**NH_3 (t)**
Auto Rickshaw	4.139	2.294	0.236	0.288	2.160
Tempo	7.367	4.599	35.563	1.229	1.670
Car	10.237	5.620	0.744	1.064	6.852
Jeep/Pickup	23.297	14.642	127.132	4.253	4.167
Small Truck	683.670	385.693	2292.406	86.632	46.924
Medium Truck	302.302	175.286	906.923	63.271	17.989
Heavy Truck	549.424	383.671	2393.232	55.032	18.035
Micro Bus	77.240	44.793	206.674	8.136	4.286
Mini Bus	23.030	15.566	113.314	1.494	0.955
Large Bus	275.909	174.839	954.083	48.236	13.978
Motorcycle	599.798	373.476	117.063	73.284	73.284
Total (t)	2556.413	1580.480	7147.371	342.919	190.301

Table 5.8: Emission inventory for the year 2021 (continued)

Vehicle Category	NO (t)	VOC (t)	NMVOC (t)
Auto Rickshaw	8.690	17.378	14.900
Tempo	64.134	9.103	7.704
Car	26.572	26.883	19.605
Jeep/Pickup	216.172	14.318	11.901
Small Truck	7807.349	180.583	164.760
Medium Truck	6840.912	178.737	152.196
Heavy Truck	17514.923	565.929	486.134
Micro Bus	1471.541	36.299	29.469
Mini Bus	852.356	23.200	20.165
Large Bus	6994.861	246.832	220.553
Motorcycle	2809.520	10504.684	8186.663
Total (t)	44607.030	11803.947	9314.048

The quantity of emissions in the year 2021 is represented via bar diagrams as shown in Figure 5.7.

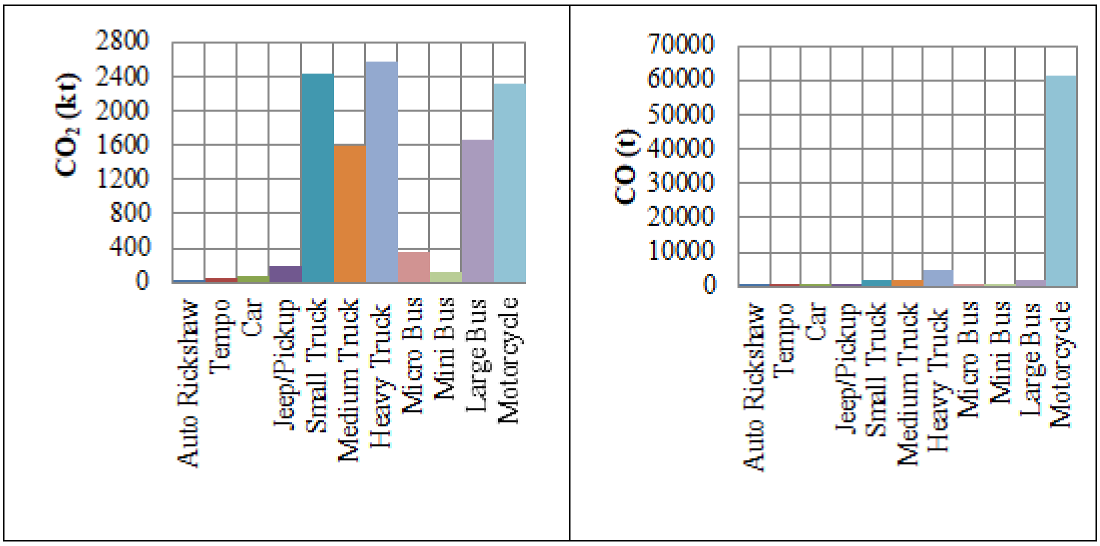

Figure 5.7: Emission of pollutants by different types of vehicles in the year 2021

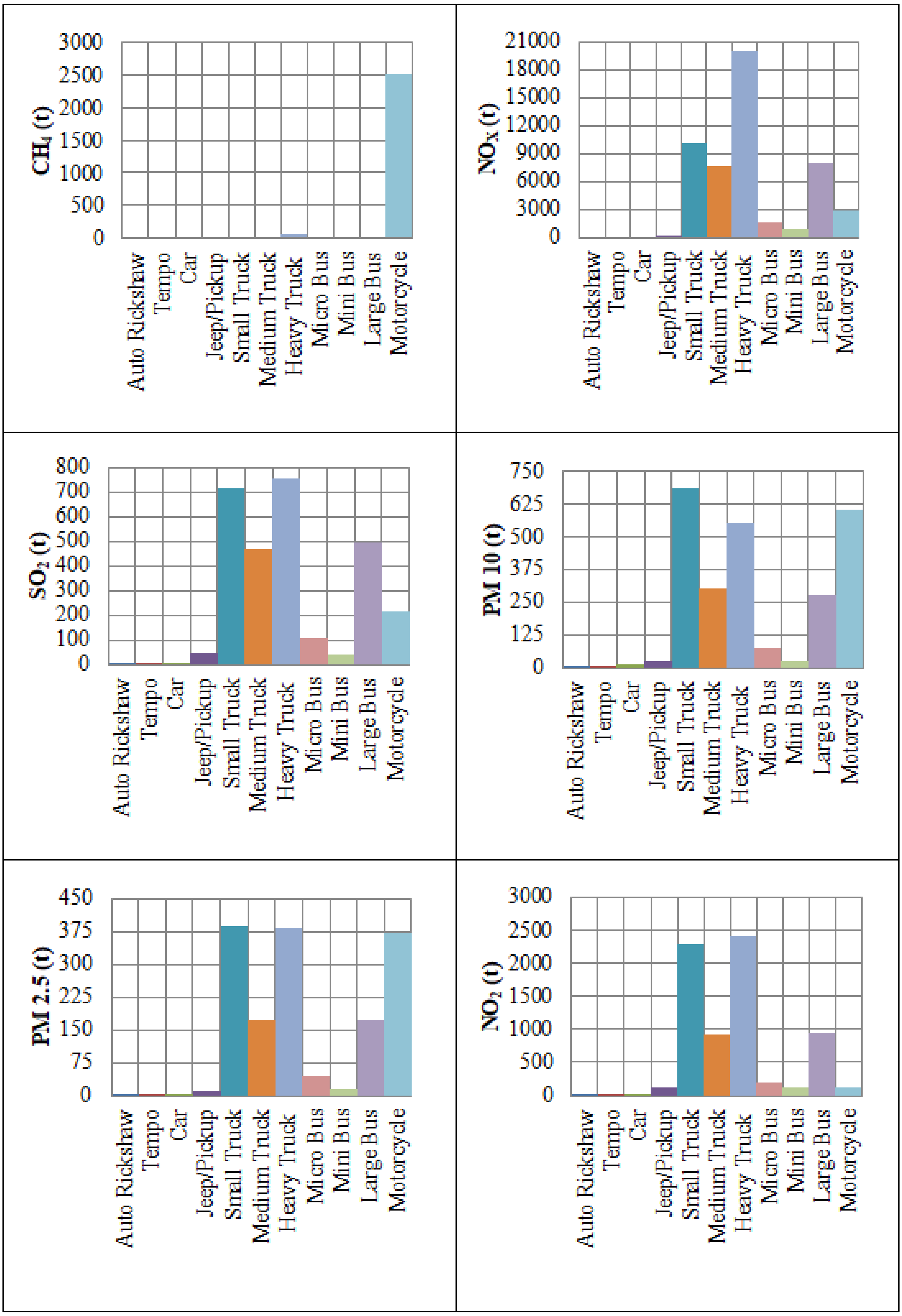

Figure 5.7: Emission of pollutants by different types of vehicles in the year 2021 (continued)

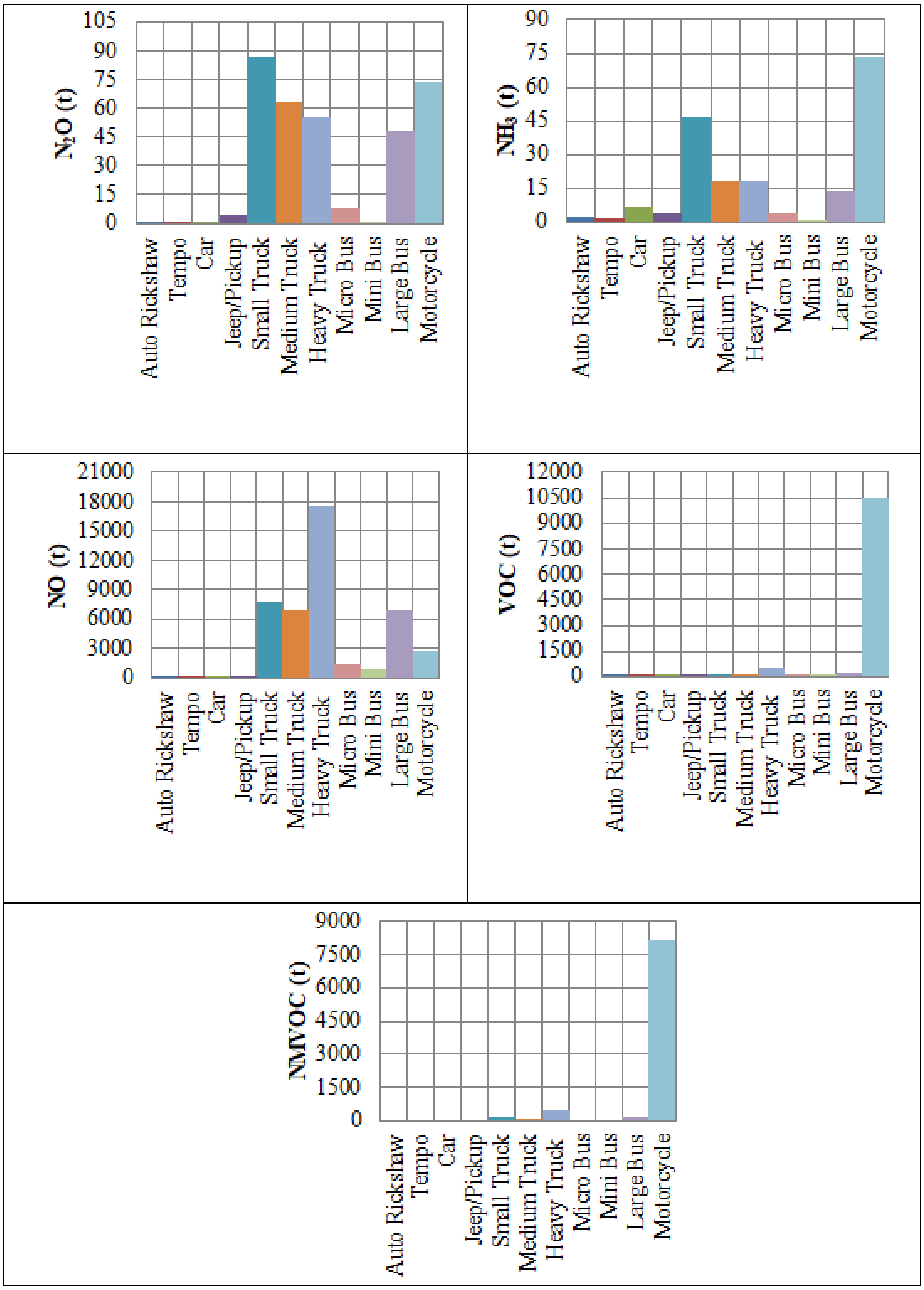

Figure 5.7: Emission of pollutants by different types of vehicles in the year 2021 (continued)

5.4 Analysis of the Reduction in Emission Due to Covid-19 Lockdown

The possible emission inventory in 2020 if lockdown had not occurred is shown in Table 5.9.

Table: 5.9: Emission inventory for 2020 if lockdown due to covid-19 had not occurred

Vehicle Category	CO_2 (t)	CO (t)	CH_4 (t)	NO_X (t)	SO_2 (t)
Auto Rickshaw	52365.311	74.745	4.941	15.842	4.785
Tempo	80574.602	64.466	2.578	193.857	18.094
Car	88999.870	147.694	8.815	33.444	8.132
Jeep/Pickup	214277.352	91.775	3.141	417.279	52.073
Small Truck	2261063.664	1737.373	13.758	9638.487	664.860
Medium Truck	1534424.885	1822.660	24.832	7410.333	451.577
Heavy Truck	2499132.691	4658.195	67.090	19479.716	735.603
Micro Bus	461983.700	544.478	7.652	2083.163	135.582
Mini Bus	239344.582	505.030	5.490	1864.276	70.292
Large Bus	3297116.965	4061.538	53.054	14574.857	970.395
Motorcycle	2076252.108	53353.574	2181.417	2462.375	189.719
Total (t)	12805535.731	67061.527	2372.768	58173.629	3301.112
Vehicle Category	**PM 10 (t)**	**PM 2.5 (t)**	**NO_2 (t)**	**N_2O (t)**	**NH_3 (t)**
Auto Rickshaw	7.472	4.143	0.413	0.548	4.121
Tempo	13.930	8.636	66.654	1.382	3.179
Car	12.559	6.891	0.904	1.353	8.785
Jeep/Pickup	27.385	16.972	153.055	2.777	4.361
Small Truck	620.038	346.630	2105.379	68.549	41.537
Medium Truck	282.230	163.253	853.447	61.217	17.418
Heavy Truck	506.477	349.748	2310.641	54.510	17.700
Micro Bus	94.979	54.698	255.495	10.365	5.377
Mini Bus	42.280	28.520	215.601	2.860	1.837
Large Bus	539.301	345.445	1767.892	93.739	26.707
Motorcycle	521.325	321.701	98.495	64.640	64.640
Total (t)	2667.975	1646.636	7827.976	361.940	195.663

Table: 5.9 (continued)

Vehicle Category	NO (t)	VOC (t)	NMVOC (t)
Auto Rickshaw	15.429	30.460	25.686
Tempo	127.203	14.263	11.685
Car	32.540	33.070	24.255
Jeep/Pickup	264.225	17.437	14.435
Small Truck	7533.108	163.012	149.254
Medium Truck	6556.887	175.291	150.459
Heavy Truck	17169.074	512.765	445.675
Micro Bus	1827.668	44.058	36.406
Mini Bus	1648.675	44.198	38.708
Large Bus	12806.965	509.374	456.320
Motorcycle	2363.880	10067.751	8018.533
Total (t)	50345.653	11611.678	9371.415

The possible emission inventory in 2021 if lockdown had not occurred is shown in Table 5.10:

Table: 5.10: Emission inventory for 2021 if lockdown due to covid-19 had not occurred

Vehicle Category	NO (t)	VOC (t)	NMVOC (t)
Auto Rickshaw	15.274	25.991	21.834
Tempo	128.578	13.332	10.644
Car	32.844	30.181	21.235
Jeep/Pickup	287.629	17.760	14.552
Small Truck	8035.725	184.950	169.913
Medium Truck	7044.724	185.497	159.981
Heavy Truck	18306.042	598.893	520.862
Micro Bus	2083.835	51.346	42.449
Mini Bus	1747.353	47.853	41.997
Large Bus	14151.815	497.823	447.981
Motorcycle	2762.202	10260.077	7970.691
Total (t)	54596.021	11913.703	9422.140

Table: 5.10 (continued)

Vehicle Category	CO_2 (t)	CO (t)	CH_4 (t)	NO_X (t)	SO_2 (t)
Auto Rickshaw	56565.578	68.993	4.820	15.688	5.170
Tempo	87437.507	67.835	2.831	199.955	19.353
Car	96329.265	142.093	8.945	33.764	8.803
Jeep/Pickup	244010.957	103.604	3.576	456.935	59.115
Small Truck	2444511.822	1930.821	15.552	10334.418	718.842
Medium Truck	1600369.992	1949.853	25.516	7975.437	470.989
Heavy Truck	2635904.121	5016.001	78.031	20799.598	775.869
Micro Bus	493744.821	620.016	8.897	2375.362	144.885
Mini Bus	253181.148	530.933	5.856	1979.179	74.358
Large Bus	3296072.364	4423.240	49.842	16077.464	970.089
Motorcycle	2315161.696	61630.340	2444.012	2877.294	211.551
Total (t)	13523289.271	76483.728	2647.880	63125.093	3459.026
Vehicle Category	**PM 10 (t)**	**PM 2.5 (t)**	**NO_2 (t)**	**N_2O (t)**	**NH_3 (t)**
Auto Rickshaw	7.192	3.987	0.414	0.550	4.039
Tempo	14.559	9.102	71.377	2.470	3.580
Car	12.581	6.907	0.920	1.358	8.773
Jeep/Pickup	30.499	19.199	169.306	5.568	5.542
Small Truck	656.122	372.944	2298.693	82.329	44.593
Medium Truck	293.965	171.858	930.713	60.825	17.294
Heavy Truck	552.681	390.592	2493.556	53.815	17.636
Micro Bus	101.648	59.382	291.526	10.598	5.583
Mini Bus	45.182	30.781	231.826	2.883	1.842
Large Bus	531.260	339.571	1925.649	91.485	26.511
Motorcycle	587.319	365.706	115.092	71.760	71.760
Total (t)	2833.008	1770.029	8529.072	383.642	207.153

The possible yearly trend of Carbon dioxide gas emission for different vehicle types if lockdown had not occured is shown in Figure 5.8.

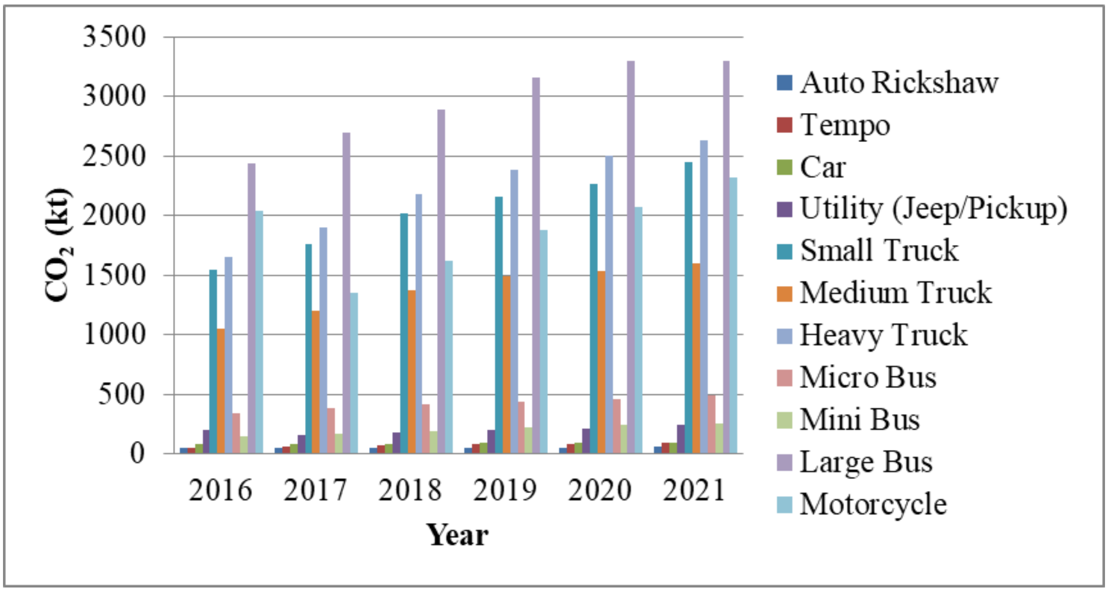

Figure 5.8: Possible yearly trend of CO_2 emission if lockdown had not occurred

The reduction in the vehicular emission of CO_2 due to lockdown is shown in Figure 5.9.

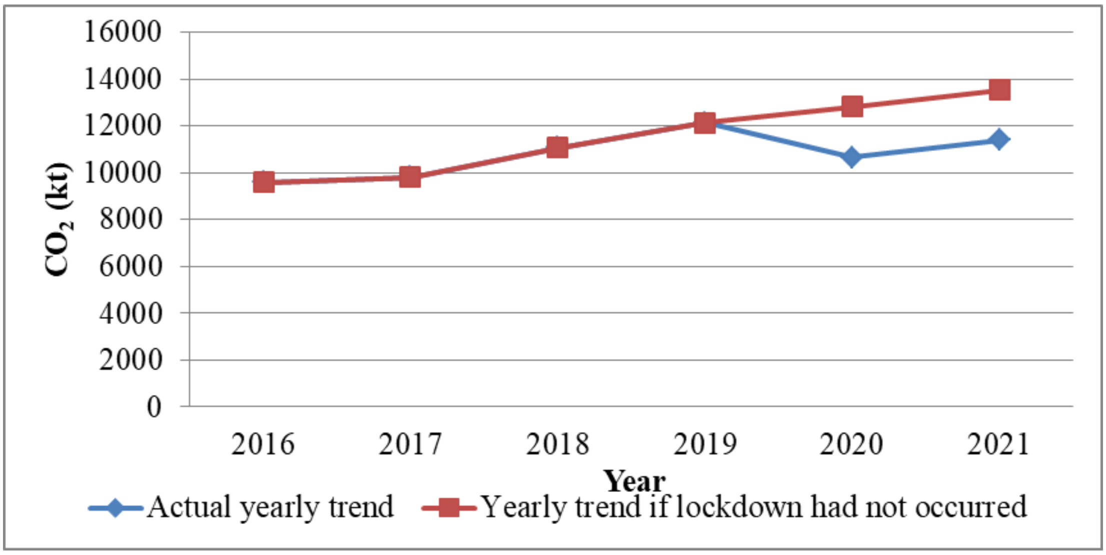

Figure 5.9: Graphical representation of decrease in total CO_2 emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emission of CO_2 was found to be 16.866% less than the expected value in the year 2020 and it was found to be 15.826% less than the expected value in the year 2021.

The possible yearly trend of Carbon monoxide gas emission for different vehicle types if lockdown had not occured is shown in Figure 5.10.

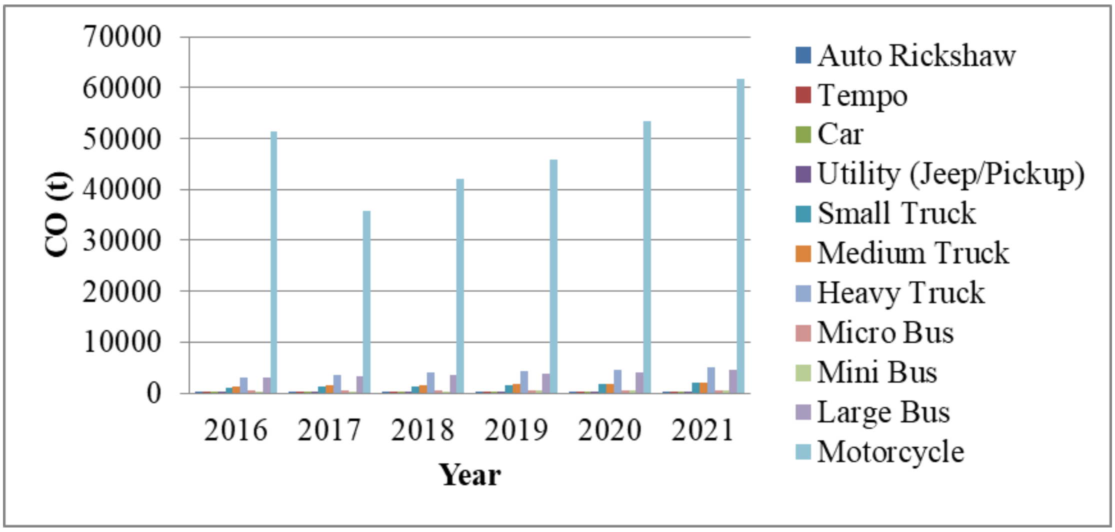

Figure 5.10: Possible yearly trend of CO emission if lockdown had not occurred

The reduction in the vehicular emission of CO due to lockdown is shown in Figure 5.11.

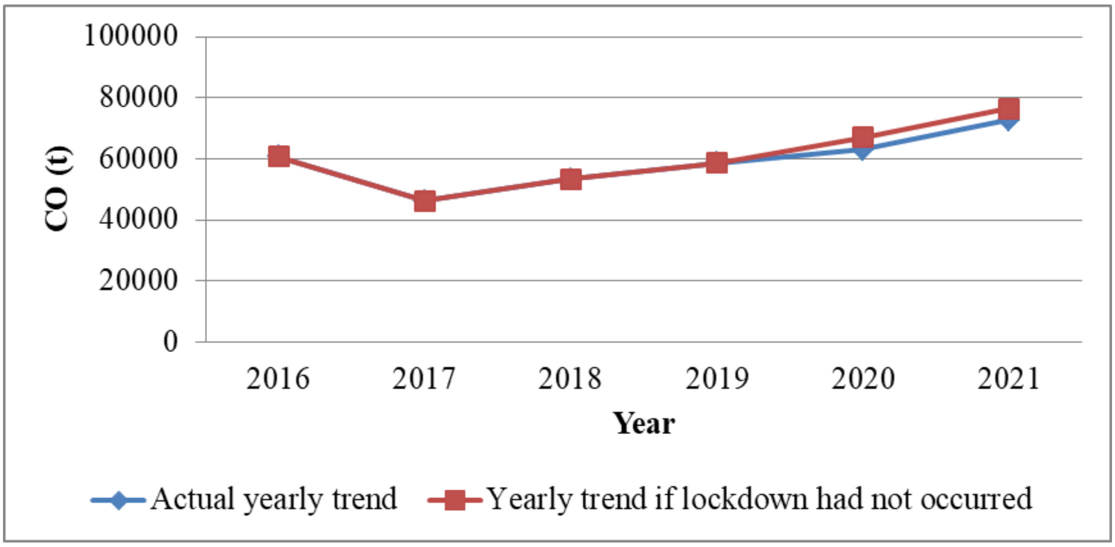

Figure: 5.11: Graphical representation of decrease in total CO emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emissions of Carbon monoxide was found to be 5.798% less than the expected value in the year 2020 and it was found to be 4.788% less than the expected value in the year 2021.

The possible yearly CH_4 emission if lockdown had not occured is shown in Figure 5.12.

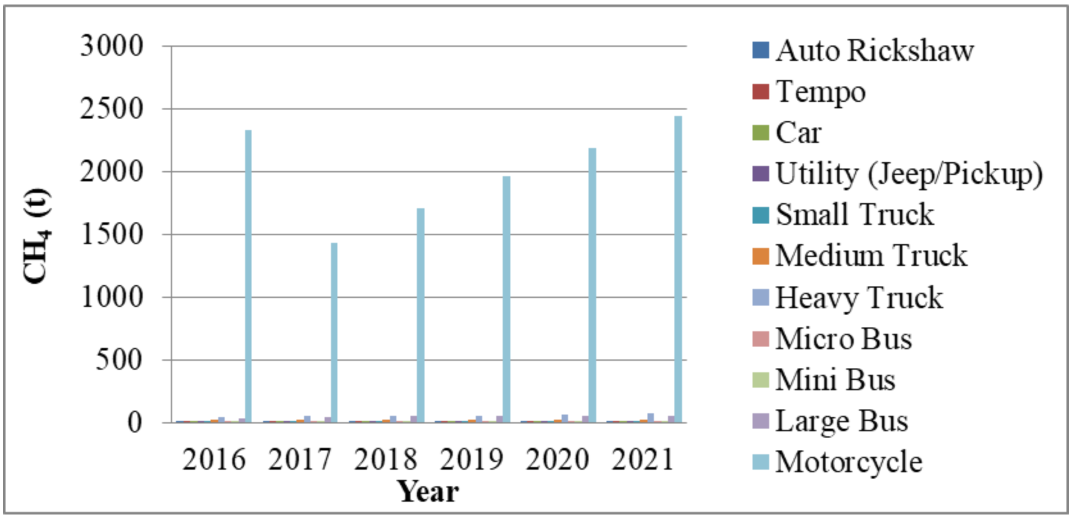

Figure 5.12: Possible yearly trend of CH_4 emission if lockdown had not occurred

The change in the vehicular emission of CH_4 due to lockdown is shown in Figure 5.13.

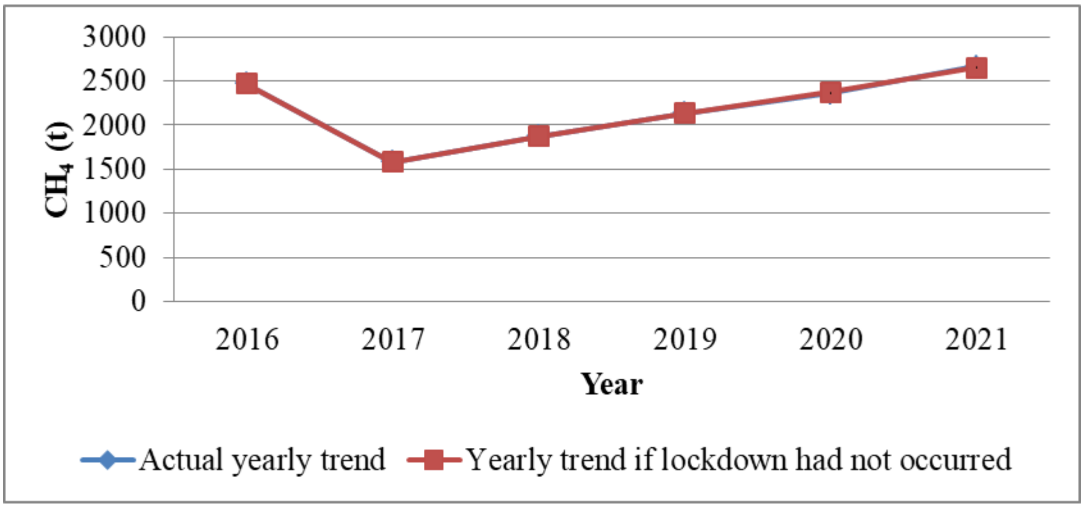

Figure 5.13: Graphical representation of change in total CH_4 emission due to lockdown

The total vehicular emission of Methane was found to have a negligible decrease of 0.798% from the expected value in the year 2020 a negligible increase of 0.512% from the expected value in the year 2021. This could be because no change was assumed for the activity of medium and heavy trucks or motorcycles due to the covid-19 lockdown in Bangladesh as per practical conditions and these vehicles appear to have the greatest contribution to the emission of Methane in Figure 5.11.

The possible yearly trend of Nitrogen Oxides emission for different vehicle types if lockdown had not occured is shown in Figure 5.14.

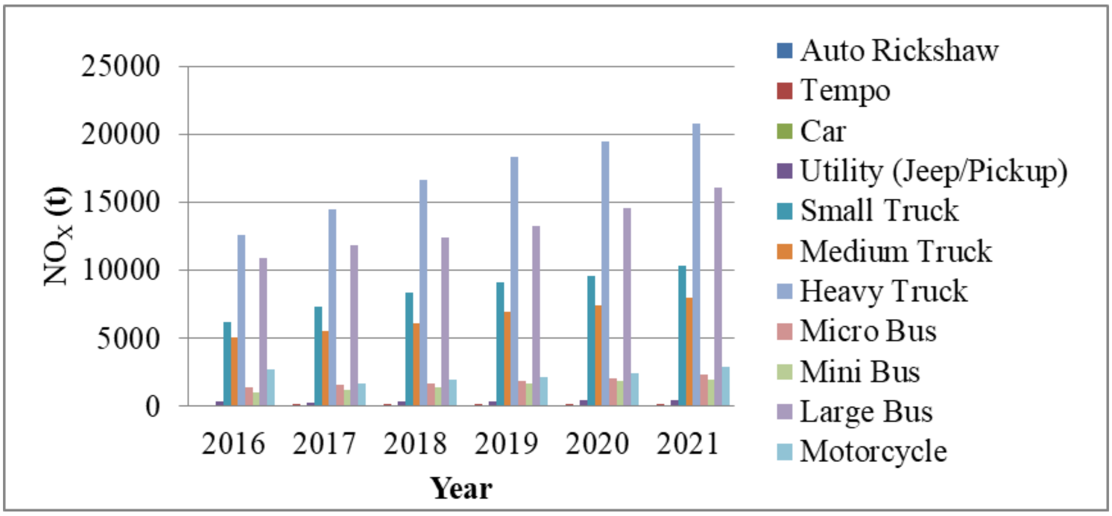

Figure 5.14: Possible yearly trend of NO_X emission if lockdown had not occurred

The reduction in the vehicular emission of NO_X due to lockdown is shown in Figure 5.15.

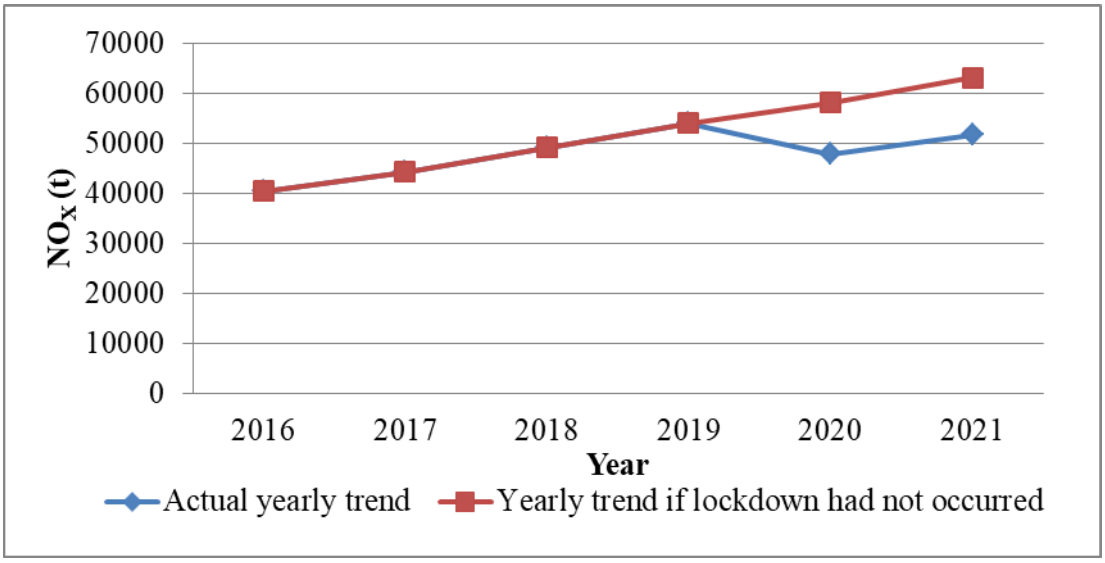

Figure 5.15: Graphical representation of decrease in total NO_X emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emissions of Nitrogen oxides was found to be 17.636% less than the expected in the year 2020 and it was found to be 18.013% less than the expected value in the year 2021.

The possible yearly trend of Sulfur dioxide emission for different vehicle types if lockdown had not occured is shown in Figure 5.16.

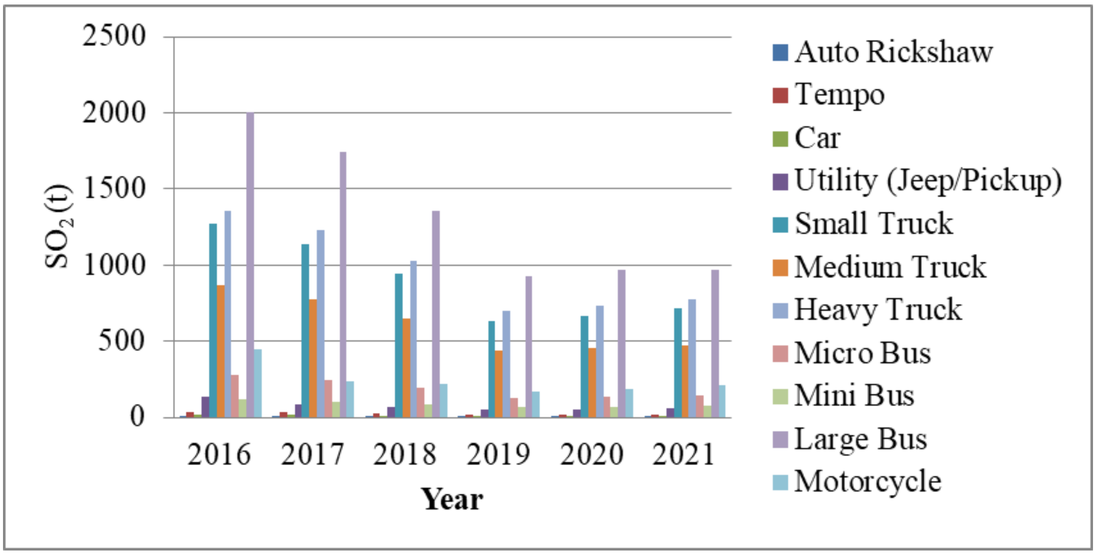

Figure 5.16: Possible yearly trend of SO_2 emission if lockdown had not occurred

The reduction in the vehicular emission of SO_2 due to lockdown is shown in Figure 5.17.

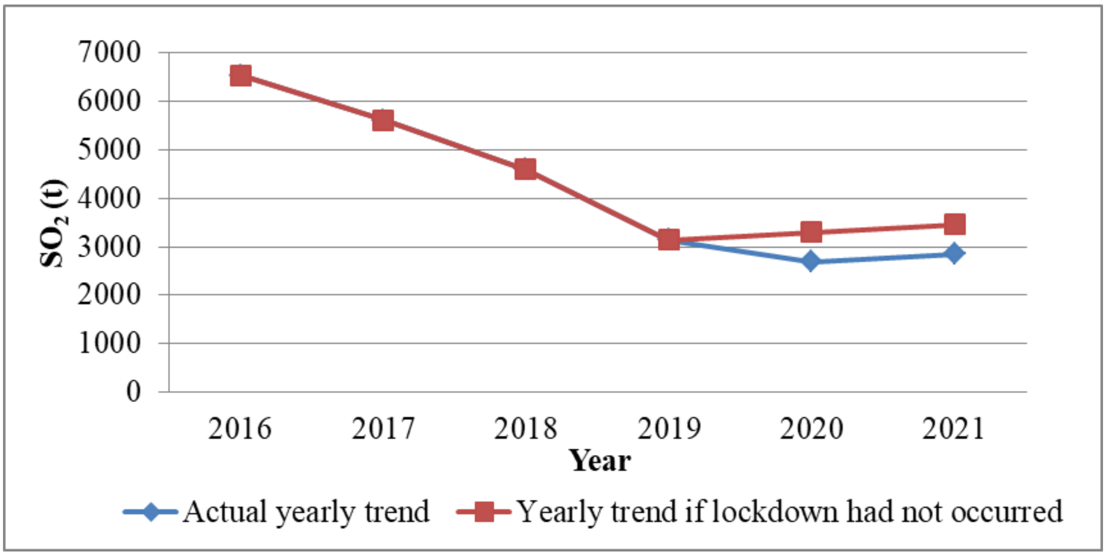

Figure 5.17: Graphical representation of decrease in total SO_2 emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emissions of Sulfur dioxide was found to be 18.643% less than the expected in the year 2020 and it was found to be 17.726% less than the expected value in the year 2021.

The possible yearly PM 10 emission if lockdown had not occured is shown in Figure 5.18.

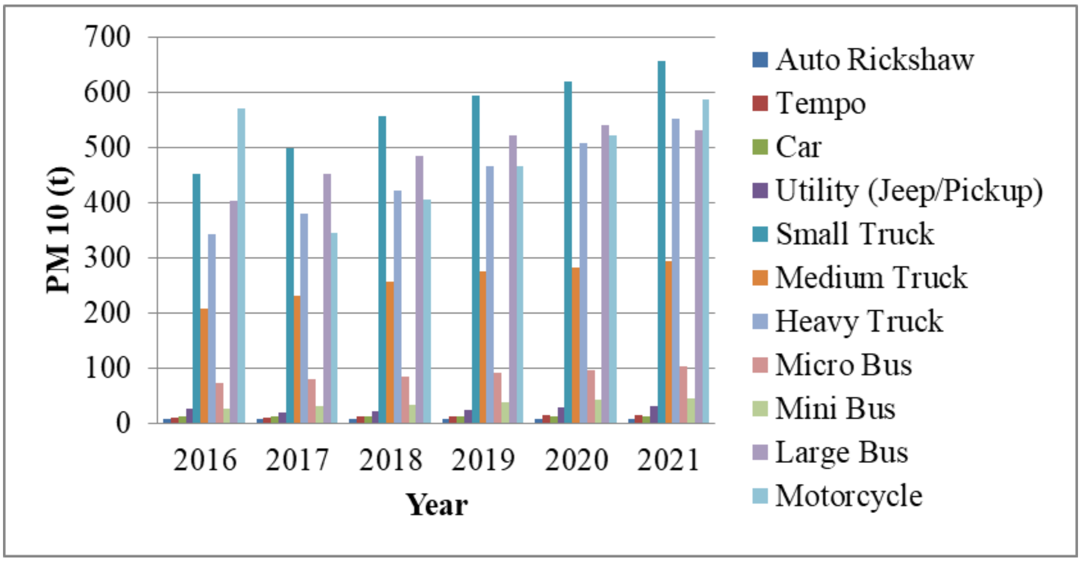

Figure 5.18: Possible yearly trend of PM 10 emission if lockdown had not occurred

The reduction in vehicular emission of PM 10 due to lockdown is shown in Figure 5.19.

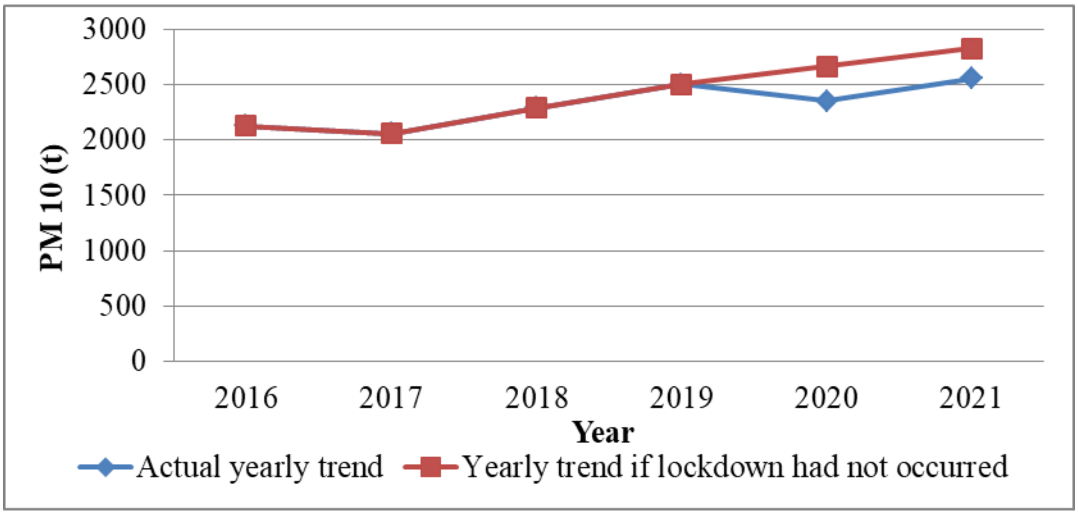

Figure 5.19: Graphical representation of decrease in total PM 10 emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emissions of PM 10 was found to be 11.680% less than the expected in the year 2020 and it was found to be 9.763% less than the expected value in the year 2021.

The possible PM 2.5 emission if lockdown had not occured is shown in Figure 5.20.

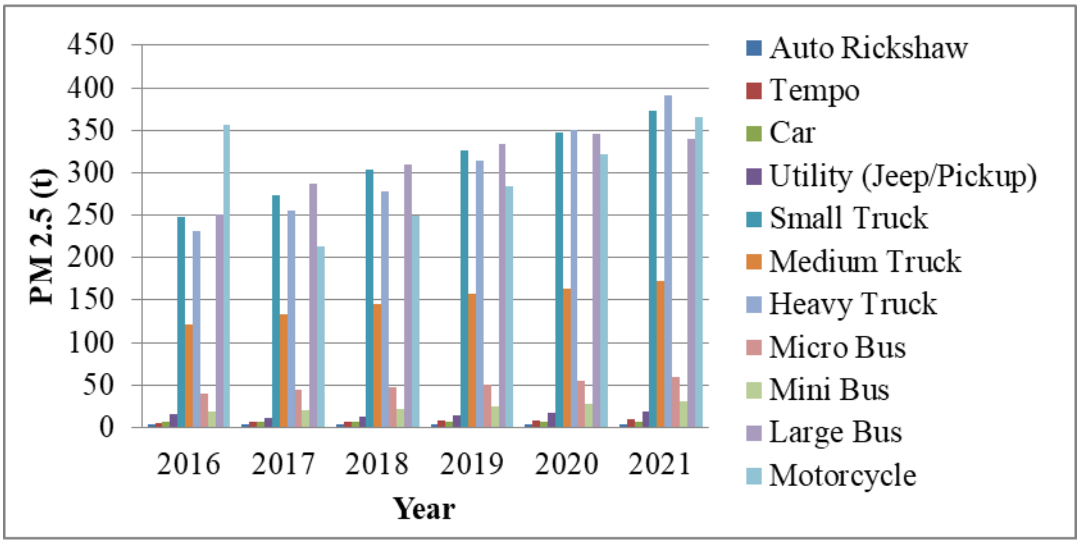

Figure 5.20: Possible yearly trend of PM 2.5 emission if lockdown had not occurred

The reduction in vehicular emission of PM 2.5 due to lockdown is shown in Figure 5.21.

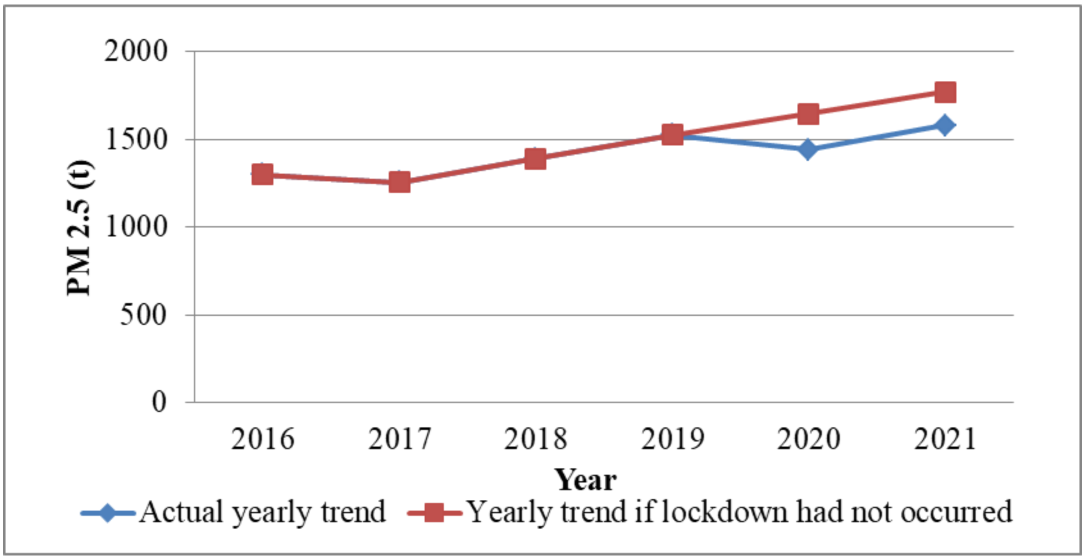

Figure 5.21: Graphical representation of decrease in total PM 2.5 emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emissions of PM 2.5 was found to be 12.511% less than the expected in the year 2020 and it was found to be 10.709% less than the expected value in the year 2021.

The possible yearly trend of Nitrogen dioxide emission for different vehicle types if lockdown had not occured is shown in Figure 5.22.

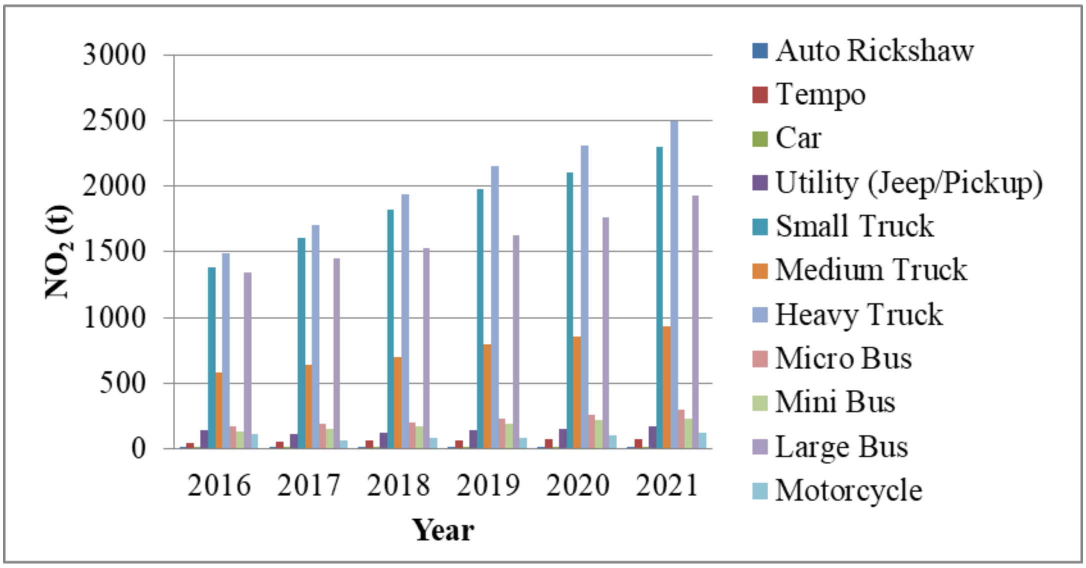

Figure 5.22: Possible yearly trend of NO_2 emission if lockdown had not occurred

The reduction in the vehicular emission of NO_2 due to lockdown is shown in Figure 5.23.

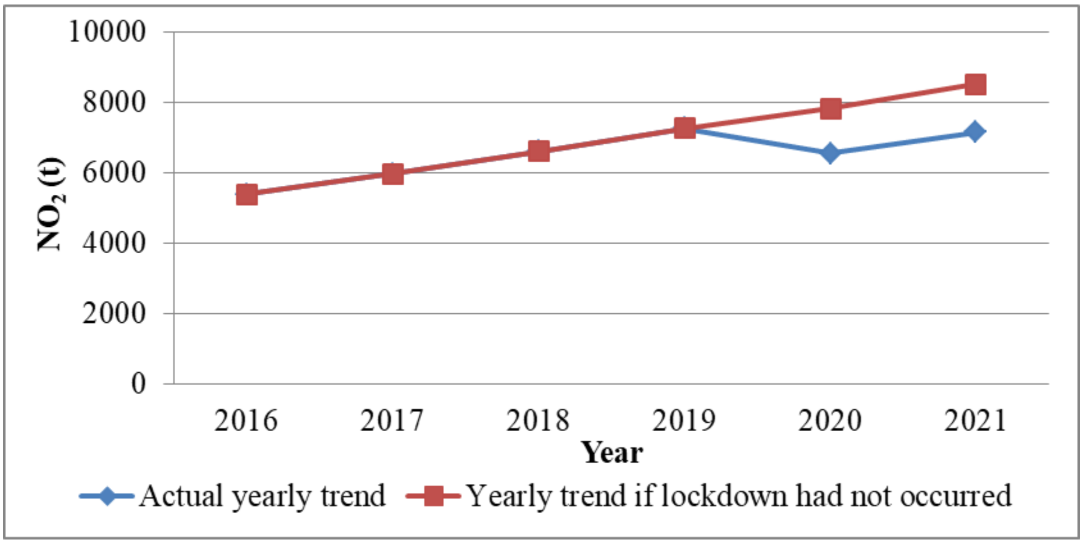

Figure 5.23: Graphical representation of decrease in total NO_2 emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emissions of Nitrogen Dioxide was found to be 16.218% less than the expected in the year 2020 and it was found to be 16.200% less than the expected value in the year 2021.

The possible yearly trend of Nitrous oxide emission for different vehicle types if lockdown had not occured is shown in Figure 5.24.

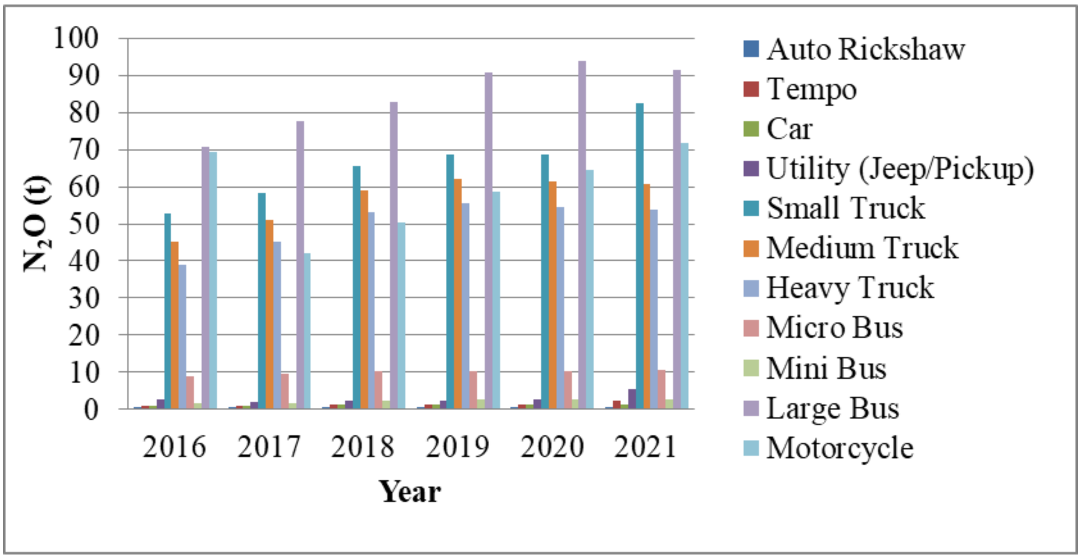

Figure 5.24: Possible yearly trend of N_2O emission if lockdown had not occurred

The reduction in the vehicular emission of N_2O due to lockdown is shown in Figure 5.25.

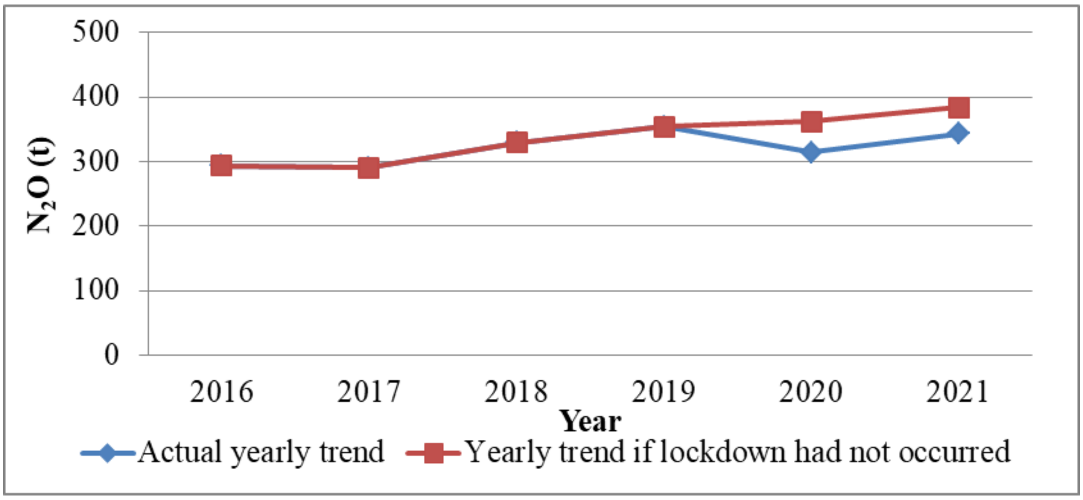

Figure 5.25: Graphical representation of decrease in total N_2O emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emissions of Nitrous oxide gas was found to be 13.073% less than the expected in the year 2020 and it was found to be 10.615% less than the expected value in the year 2021.

The possible yearly trend of Ammonia emission for different vehicle types if lockdown had not occured is shown in Figure 5.26.

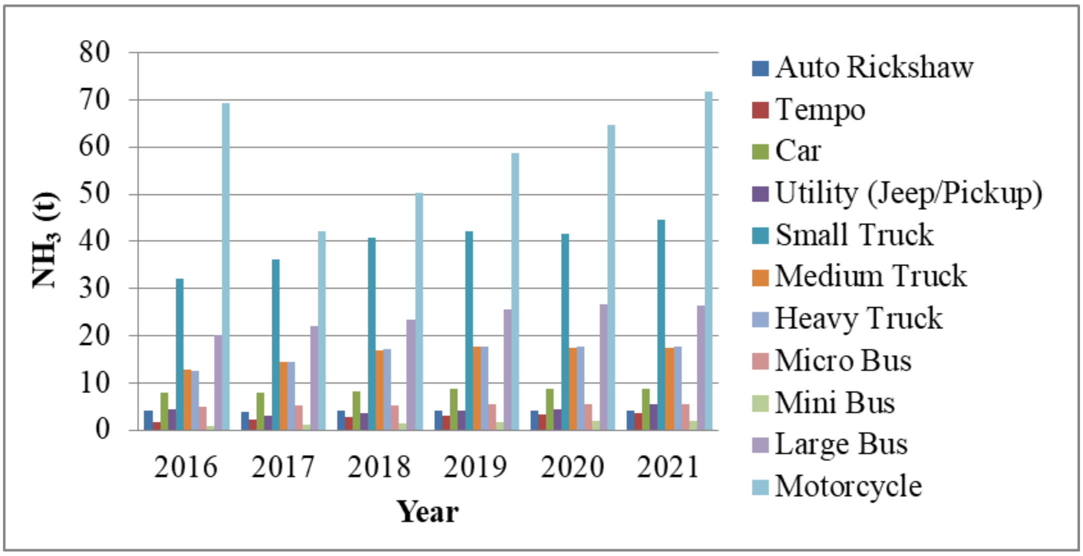

Figure 5.26: Possible yearly trend of NH_3 emission if lockdown had not occurred

The reduction in the vehicular emission of NH_3 due to lockdown is shown in Figure 5.27.

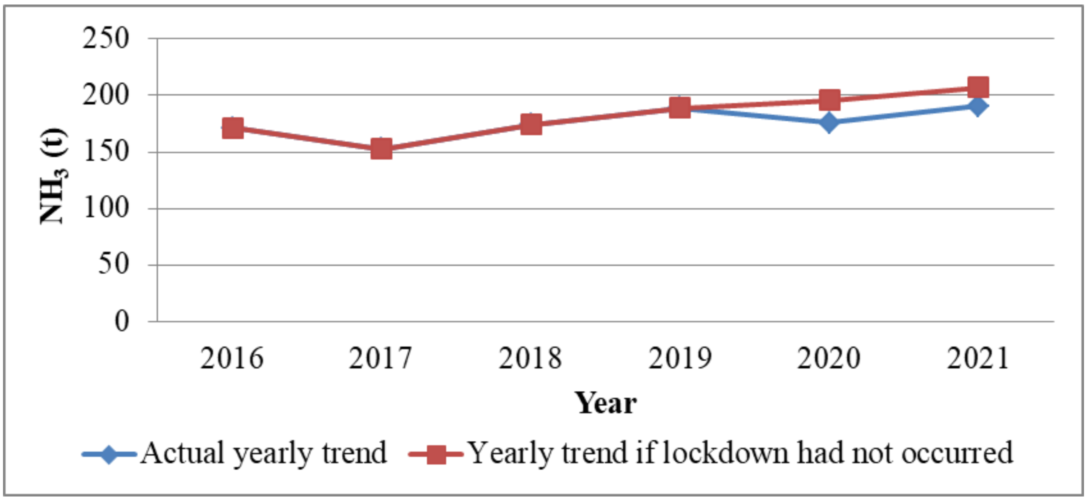

Figure 5.27: Graphical representation of decrease in total NH_3 emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emissions of Ammonia gas was found to be 10.283% less than the expected in the year 2020 and it was found to be 8.1351% less than the expected value in the year 2021.

The possible yearly trend of Nitric oxide emission for different vehicle types if lockdown had not occured is shown in Figure 5.28.

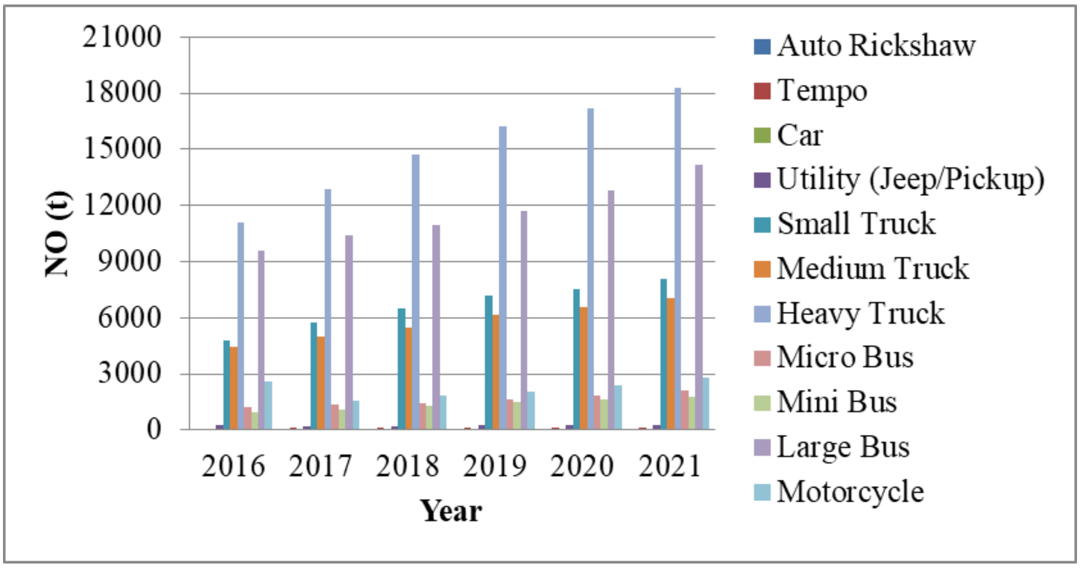

Figure 5.28: Possible yearly trend of NO emission if lockdown had not occurred

The reduction in the vehicular emission of NO due to lockdown is shown in Figure 5.29.

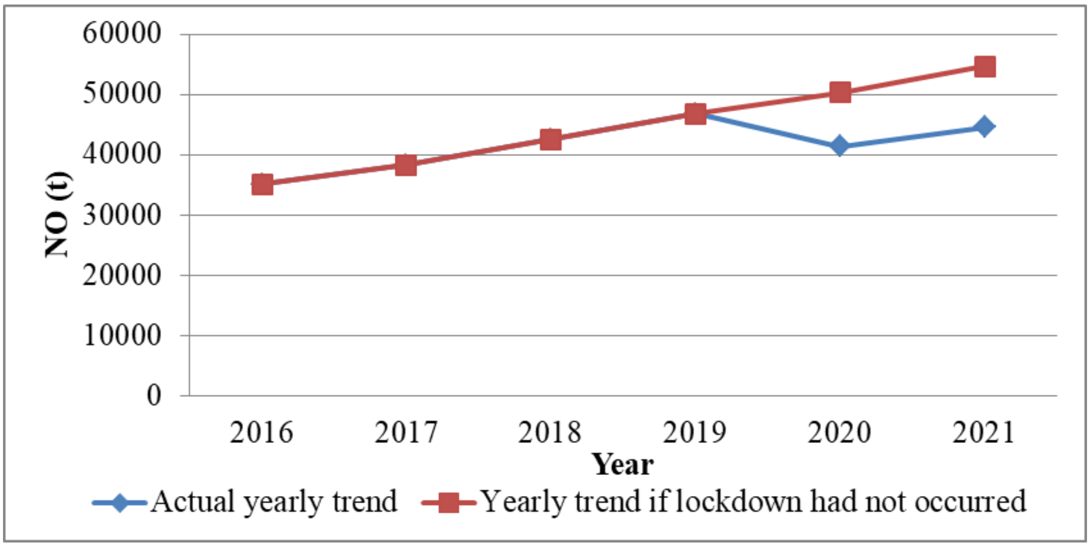

Figure 5.29: Graphical representation of decrease in total NO emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emissions of Nitric oxide gas was found to be 17.856% less than the expected in the year 2020 and it was found to be 18.296% less than the expected value in the year 2021.

The possible yearly trend of the emission of volatile organic compounds for different vehicle types if lockdown had not occured is shown in Figure 5.30.

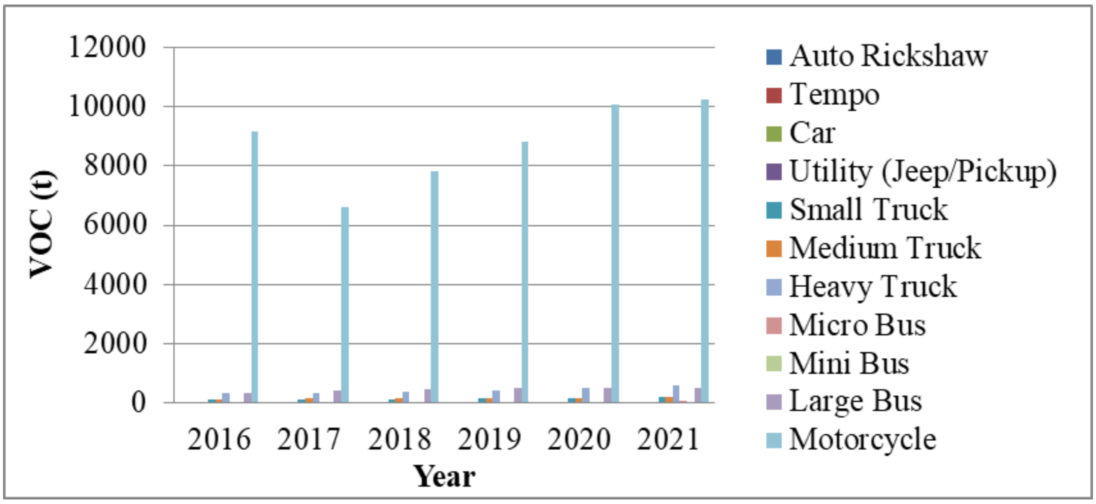

Figure 5.30: Possible yearly trend of VOC emission if lockdown had not occurred

The reduction in vehicular emission of VOC due to lockdown is shown in Figure 5.31.

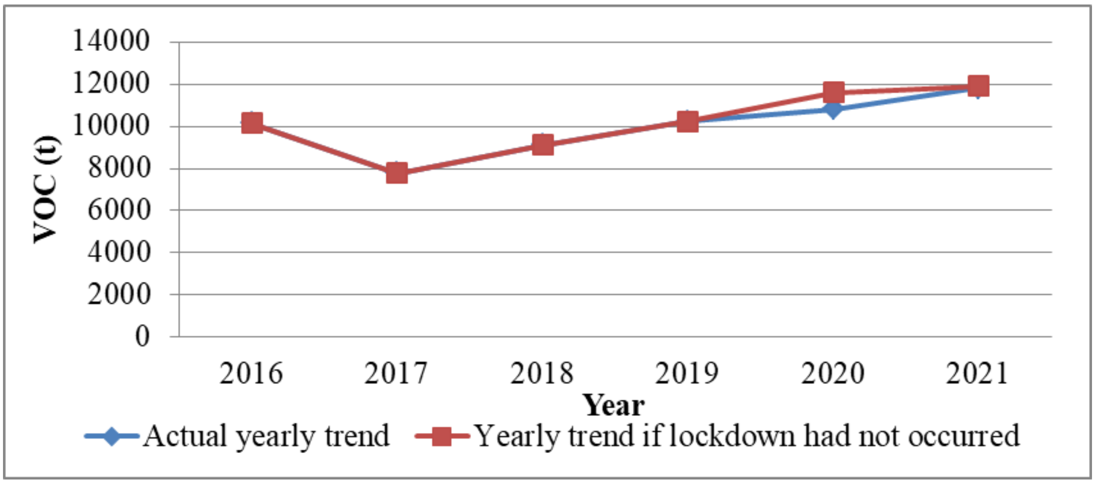

Figure 5.31: Graphical representation of decrease in total VOC emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emissions of Volatile organic compounds was found to be 7.003% less than the expected in the year 2020 and it was found to be only 0.921% less than the expected value in the year 2021. Therefore there was a significant decrease in the emission of VOC in the year 2020 but a negligible change for the year 2021.

The possible yearly trend of the emission of non-methane volatile organic compounds for different vehicle types if lockdown had not occured is shown in Figure 5.32.

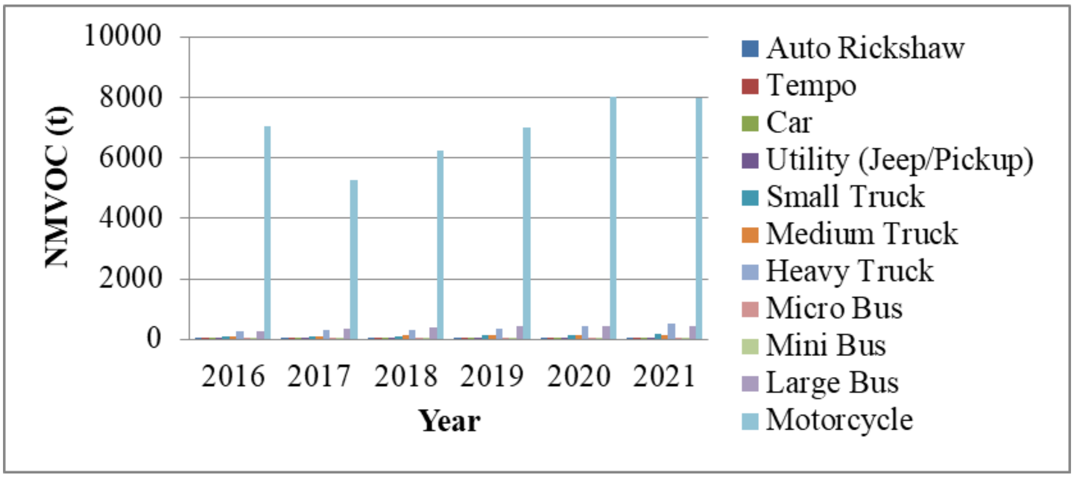

Figure 5.32: Possible yearly trend of NMVOC emission if lockdown had not occurred

The reduction in the emission of NMVOC due to lockdown is shown in Figure 5.33.

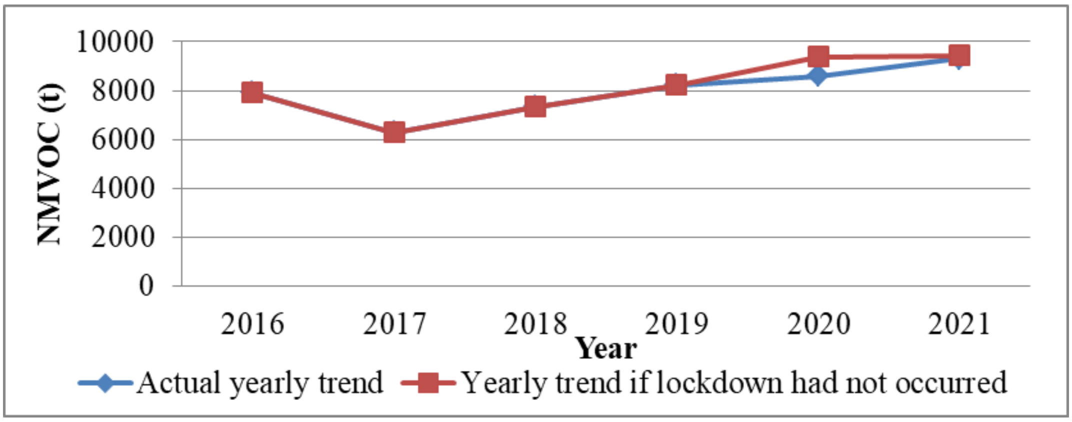

Figure 5.33: Graphical representation of decrease in total NMVOC emission due to lockdown

Thanks to the covid-19 lockdown, the total vehicular emissions of NMVOC was found to be 8.339% less than the expected in the year 2020 and it was found to be only 1.147% less than the expected value in the year 2021.

5.5 Comparative Analysis of Emission Characteristics of Different Types of Vehicles

The percent contribution of CO_2 by different vehicle types is shown in Figure 5.34.

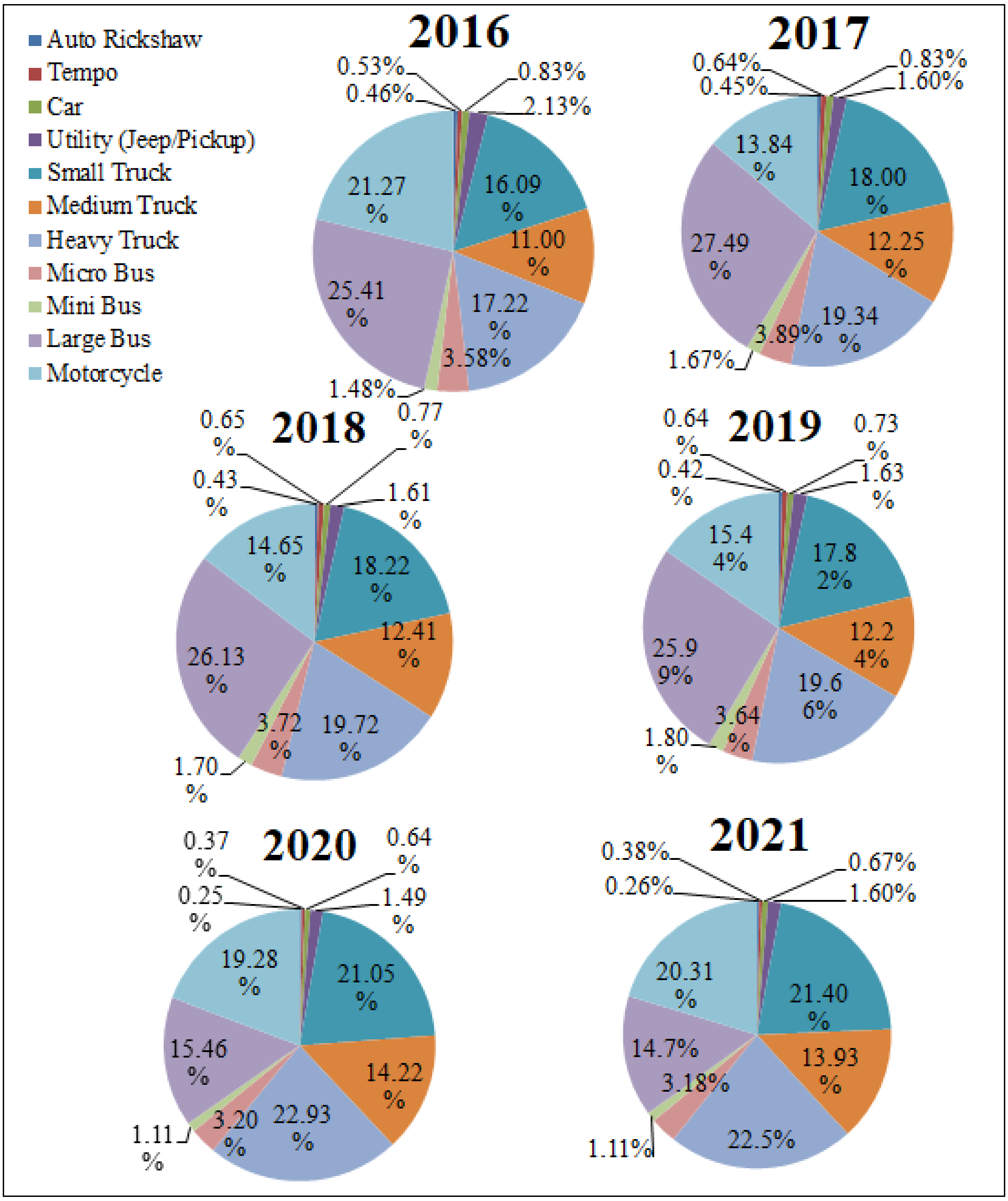

Figure 5.34: Contribution of vehicles to the emission of CO_2 throughout the years

From the year 2016 to 2019, large buses were found to be the biggest contributors to CO_2 emission and during covid-19, heavy trucks emitted the greatest amount of CO_2. And throughout all the years, the vehicles contributing to the most significant quantity of CO_2 emission were large buses, heavy trucks, small trucks and motorcycles.

The percent contribution of CO by different type of vehicles is shown in Figure 5.35.

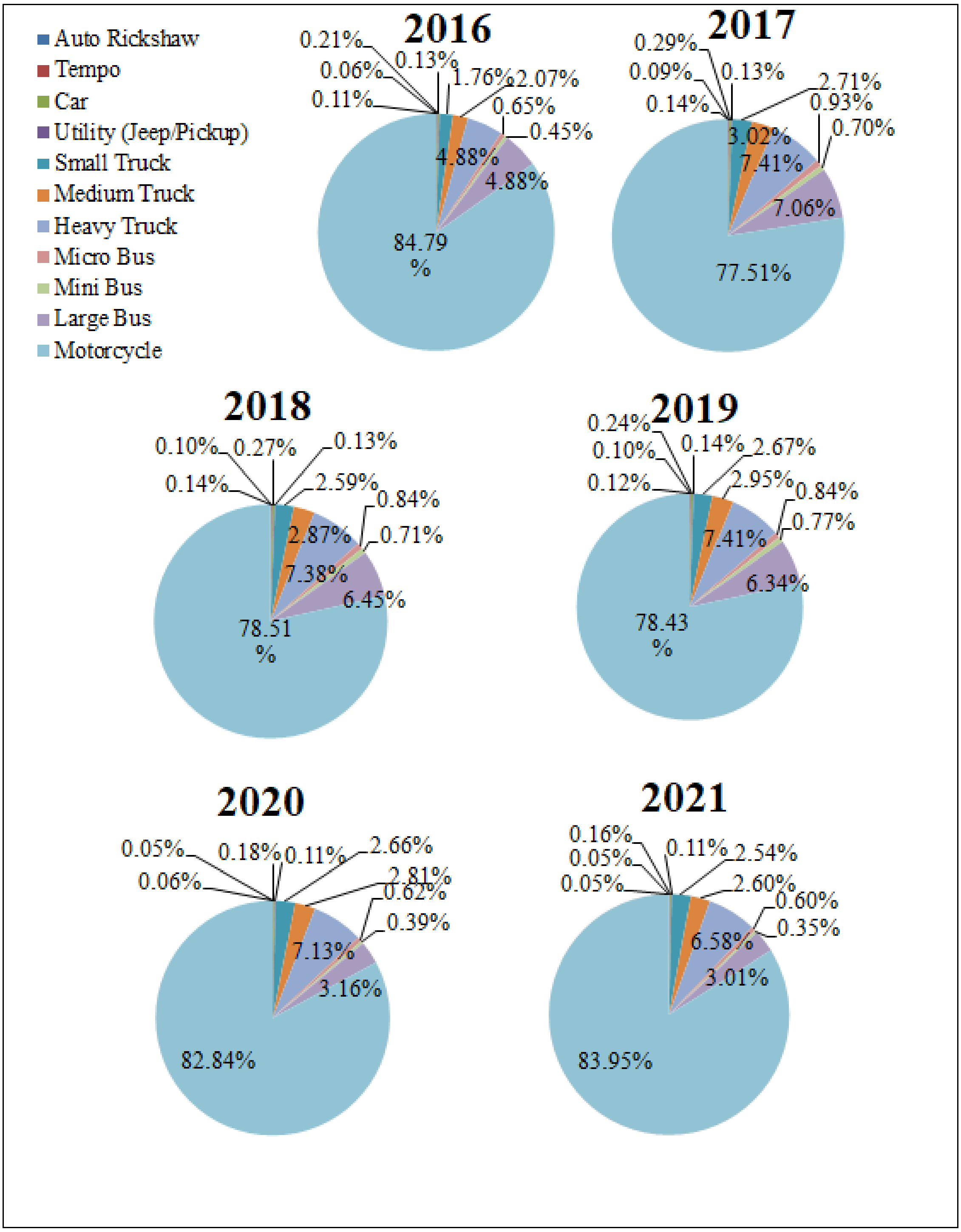

Figure 5.35: Contribution of vehicles to the emission of CO throughout the years

All throughout the years, the biggest contributors to CO emission were found to be motorcycles, heavy trucks, large buses, medium trucks and small trucks in decreasing order. 78% to 85% of CO emission was found to be produced from just Motorcycles. Thus the use of motorcycles is strongly discouraged in order to control the emission of CO.

The percent contribution of CH_4 by different type of vehicles is shown in Figure 5.36.

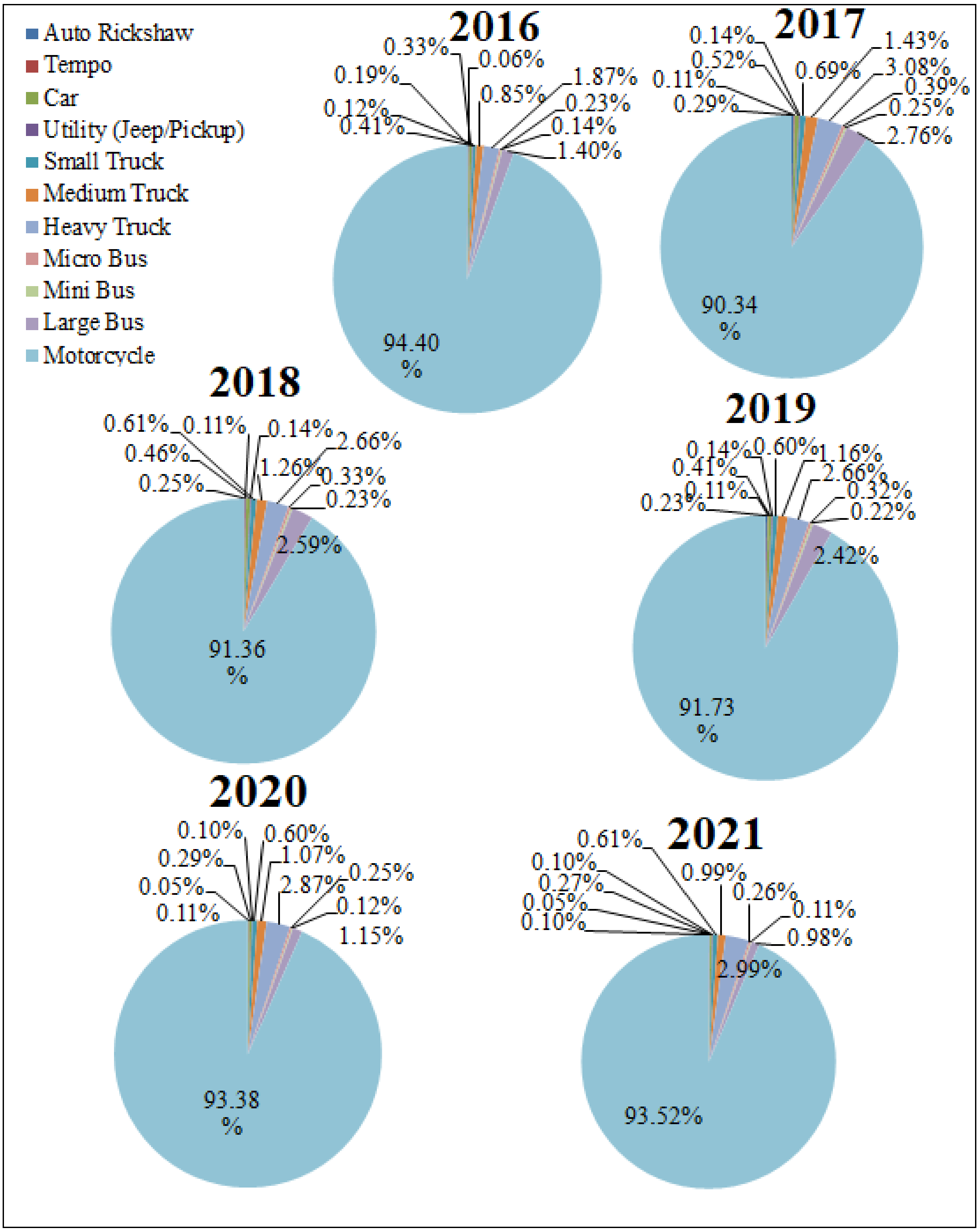

Figure 5.36: Contribution of vehicles to the emission of CH_4 throughout the years

All throughout the years, the biggest contributors to CH_4 emission were found to be motorcycles, heavy trucks, large buses and medium trucks in decreasing order. 90% to 94.4% of CH_4 emission was found to be produced by just motorcycles. Thus the use of motorcycles is strongly discouraged in order to control the emission of CH_4.

The percent contribution of NO_X by different type of vehicles is shown in Figure 5.37.

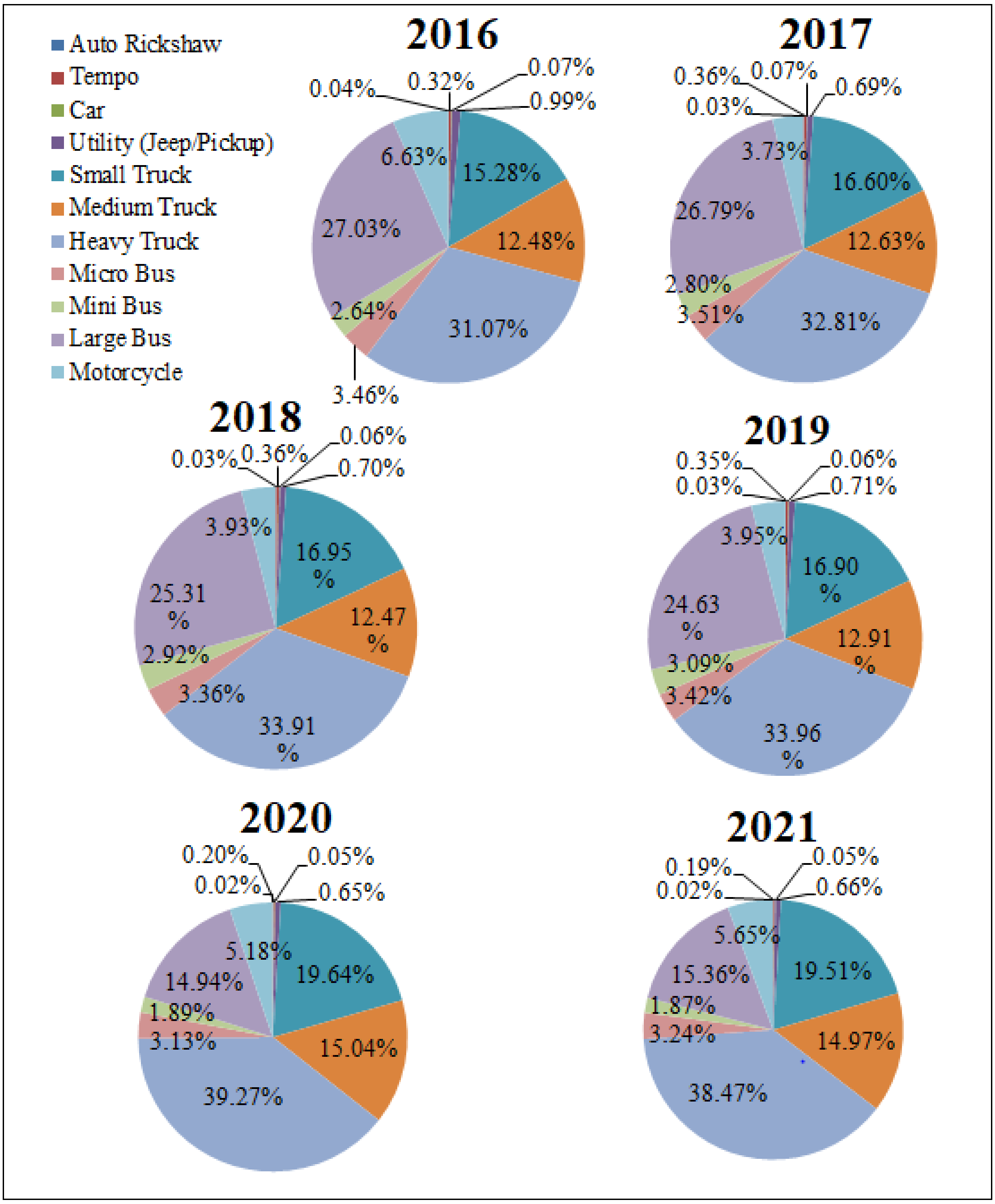

Figure 5.37: Contribution of vehicles to the emission of NO_X throughout the years

All throughout the years, the vehicles contributing to the most significant quantity of NO_X emission were found to be heavy trucks, large buses, small trucks and medium trucks, with heavy trucks being the largest contributor each year. 31.07 to 39.37% of NO_X emission was found to be produced by just heavy trucks.

The percent contribution of SO_2 by different type of vehicles is shown in Figure 5.38.

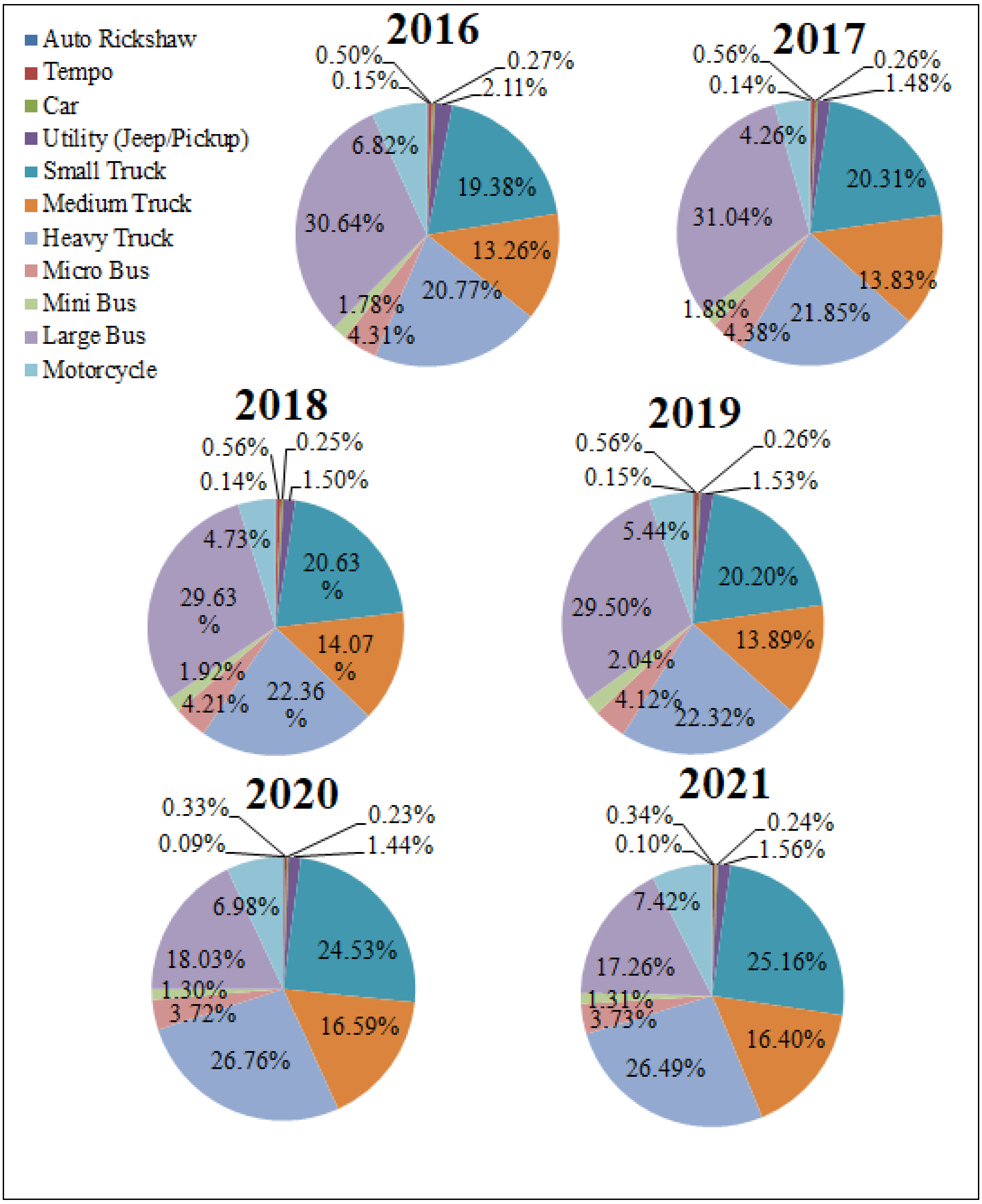

Figure 5.38: Contribution of vehicles to the emission of SO_2 throughout the years

From 2016 to 2019, the greatest contributor to SO_2 emission was found to be large buses but during 2020 and 2021 the largest contributor was heavy trucks, possibly due to restrictions of bus movement during the lockdown. Furthermore, small and medium trucks were also found to produce significant amounts of SO_2 throughout all the years.

The percent contribution of PM 10 by different type of vehicles is shown in Figure 5.39.

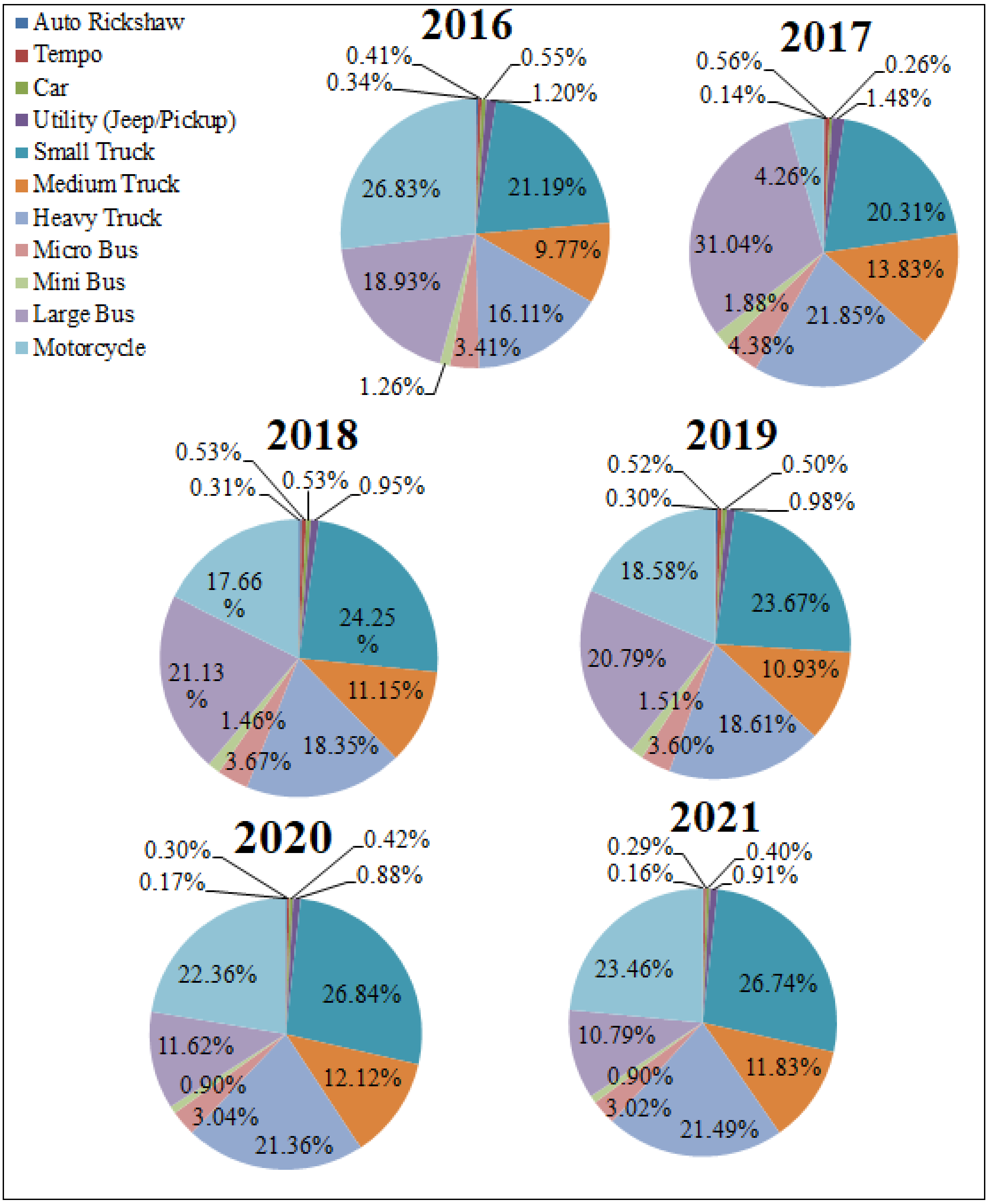

Figure 5.39: Contribution of vehicles to the emission of PM 10 throughout the years

The biggest contributor to the emission of PM 10 in the year 2016 was found to be motorcycles but from the year 2017 to 2021 it was found to be small trucks. Throughout all the years, small trucks, motorcycles, large buses, heavy trucks and medium trucks were all found to produce significant amounts of PM 10 emissions.

The percent contribution of PM 2.5 by different type of vehicles is shown in Figure 5.40.

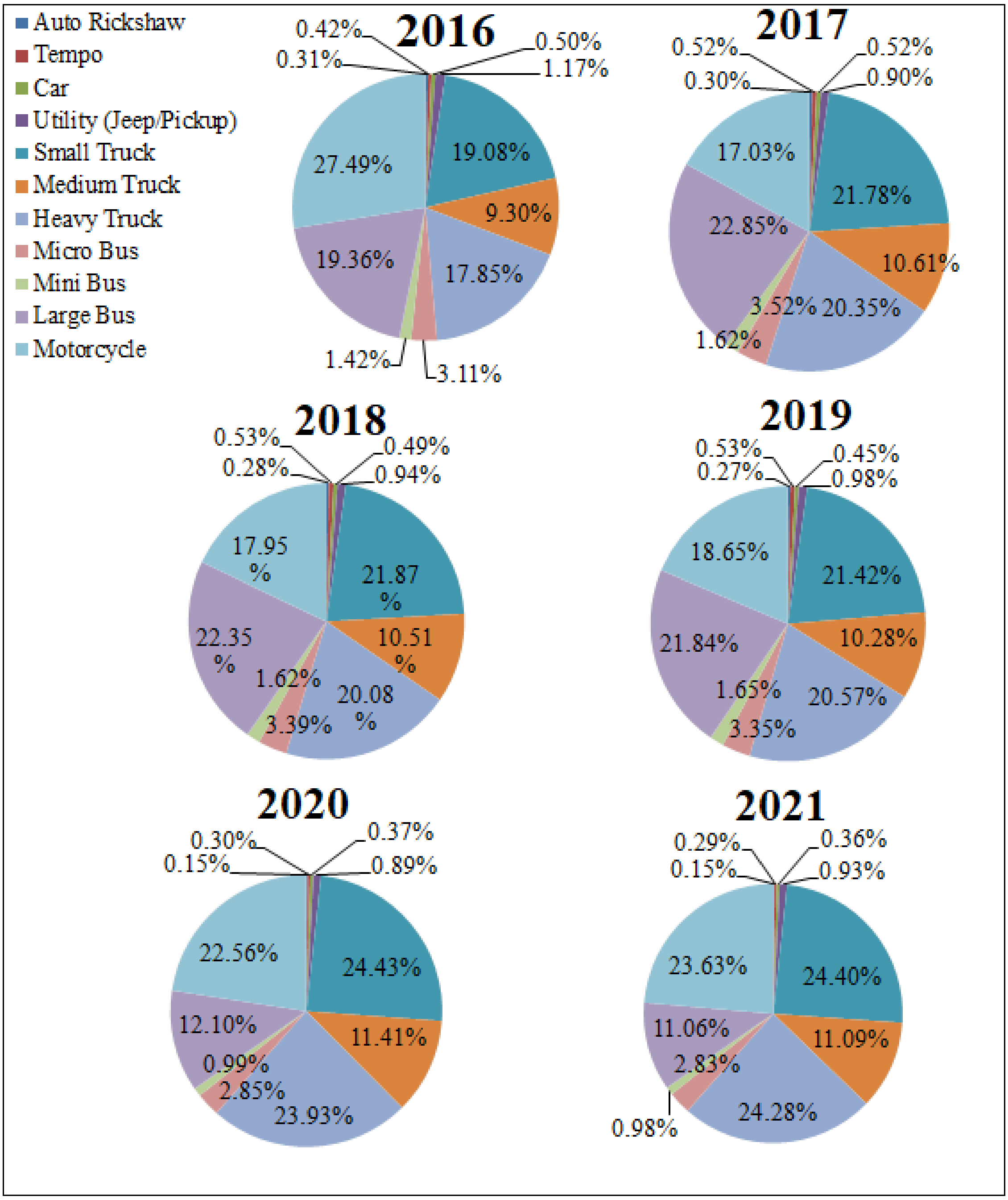

Figure 5.40: Contribution of vehicles to the emission of PM 2.5 throughout the years

The biggest contributor to the emission of PM 2.5 in the year 2016 was found to be motorcycles; from the year 2017 to 2019 it was found to be large buses and from the year 2020 and 2021 it was found to be small trucks. Throughout all the years, heavy trucks and medium trucks were also found to produce significant amounts of PM 2.5 emissions.

The percent contribution of NO_2 by different type of vehicles is shown in Figure 5.41.

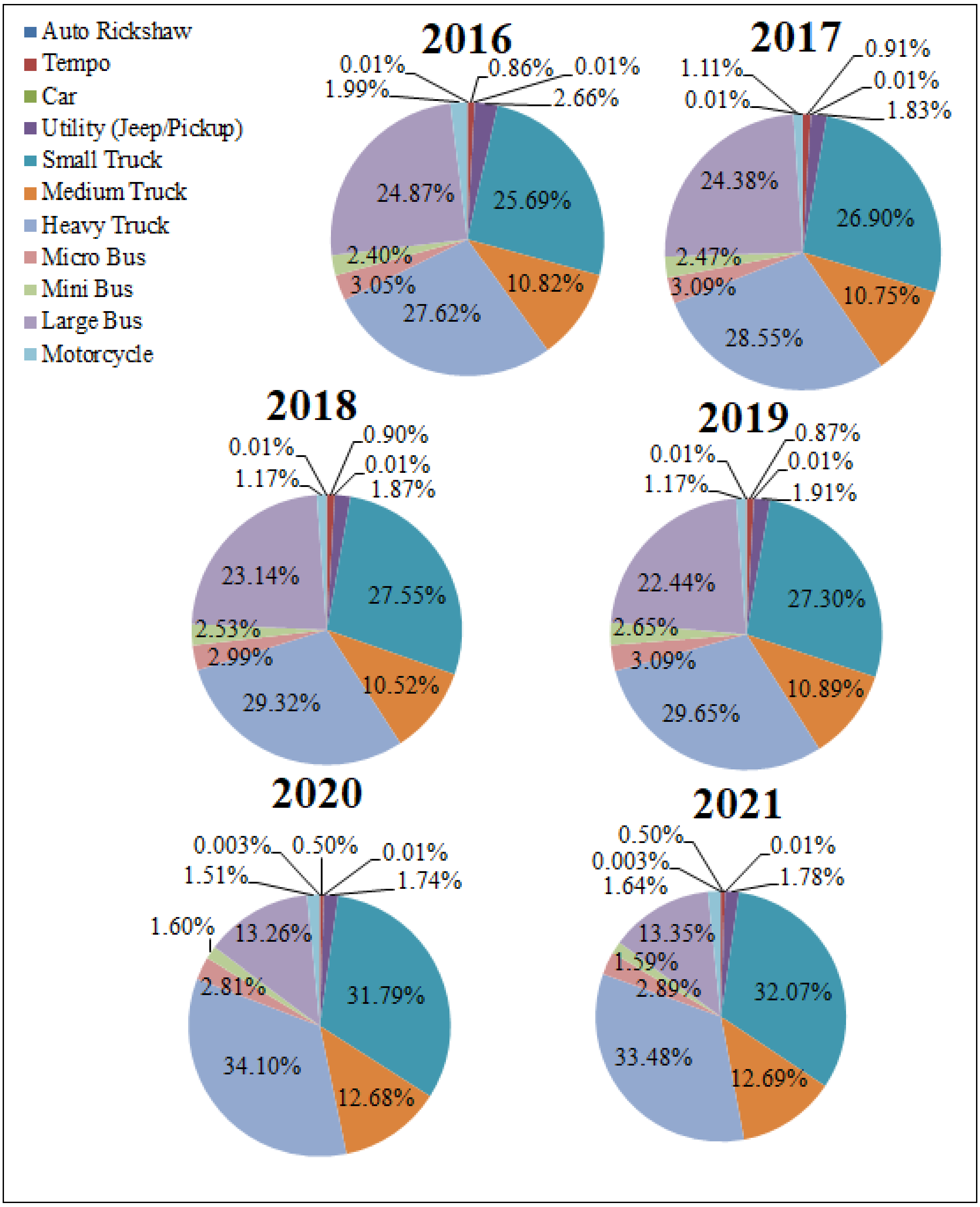

Figure 5.41: Contribution of vehicles to the emission of NO_2 throughout the years

The biggest contributor to the emission of NO_2 in the year 2016 was found to be motorcycles; from the year 2017 to 2019 it was found to be large buses and from the year 2020 and 2021 it was found to be small trucks. Throughout all the years, heavy trucks and medium trucks were also found to produce significant amounts of NO_2 emissions.

The percent contribution of N_2O by different type of vehicles is shown in Figure 5.42.

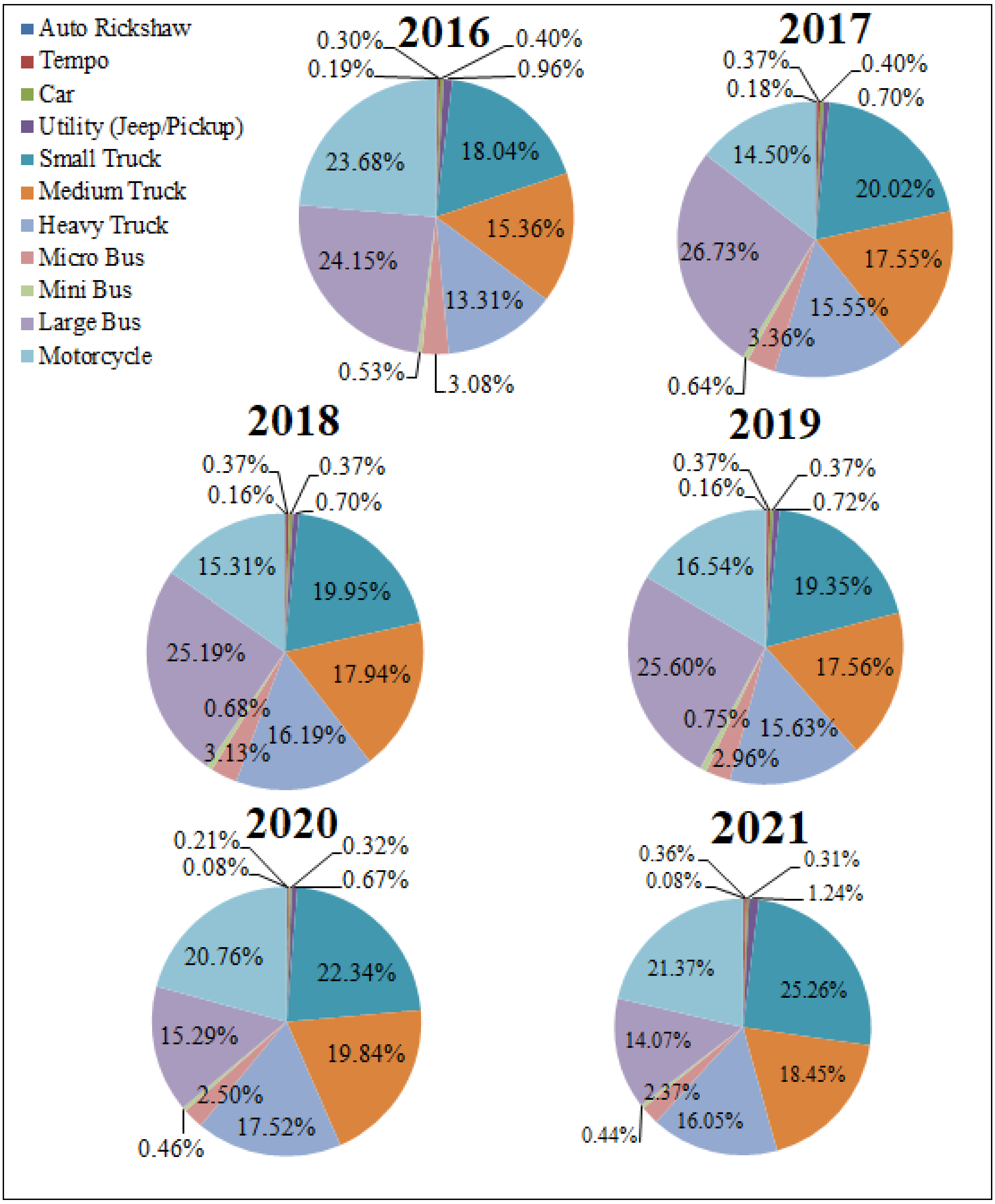

Figure 5.42: Contribution of vehicles to the emission of N_2O throughout the years

From 2016 to 2019, the greatest contributor to N_2O emission was found to be large buses but during 2020 and 2021 the largest contributor was found to be small trucks. Furthermore, motorcycles, medium trucks and heavy trucks were also found to produce significant amounts of N_2O throughout all the years.

The percent contribution of NH_3 by different type of vehicles is shown in Figure 5.43.

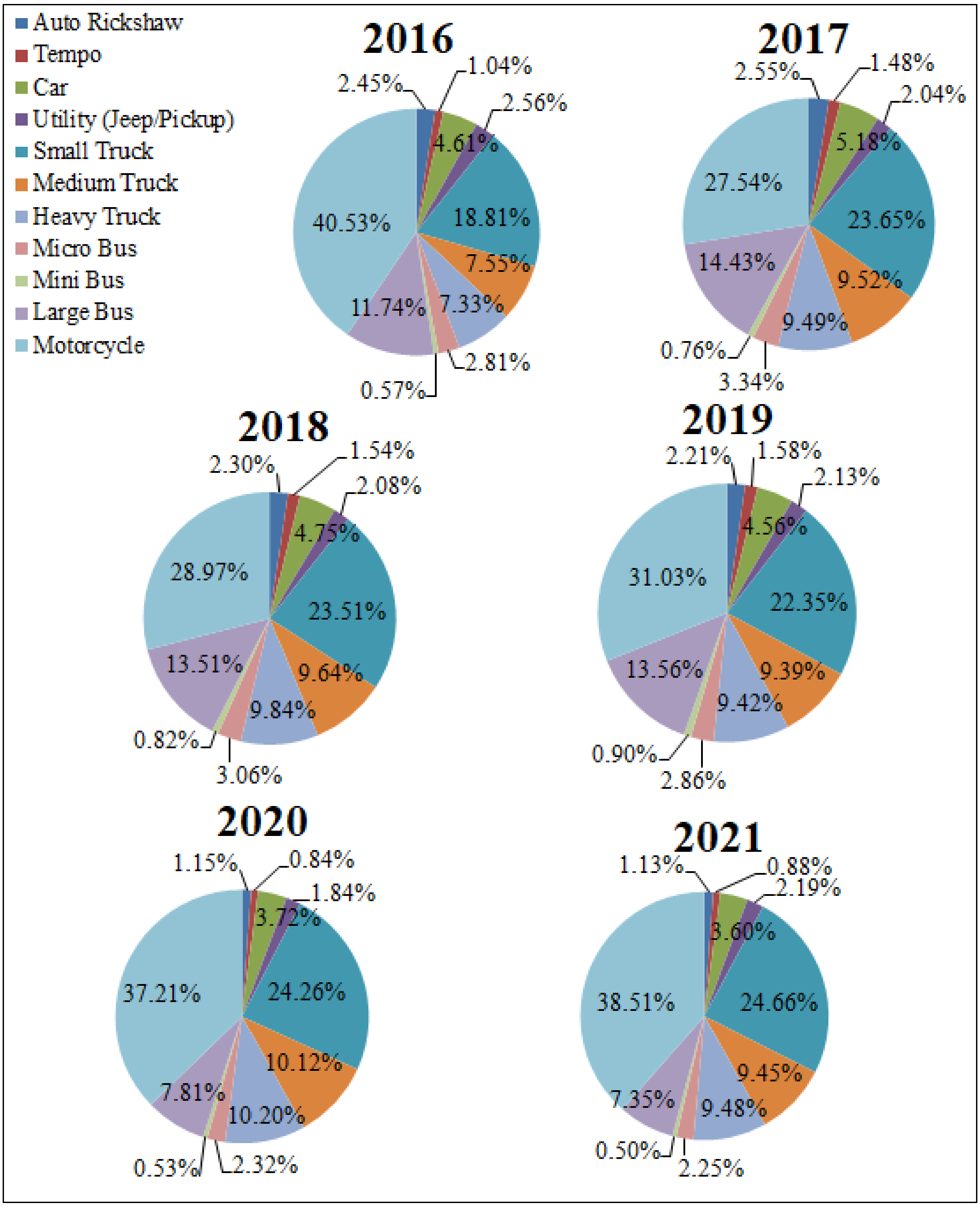

Figure 5.43: Contribution of vehicles to the emission of NH_3 throughout the years

Throughout all the years, the greatest contributors to the emission of NH_3 were found to be motorcycles and small trucks in decreasing order. Furthermore, heavy trucks, medium trucks and large buses were also found to contribute to a significant amount of NH_3 emission. 27.54% to 40.53% of NH_3 were produced by just motorcycles.

The percent contribution of NO by different type of vehicles is shown in Figure 5.44.

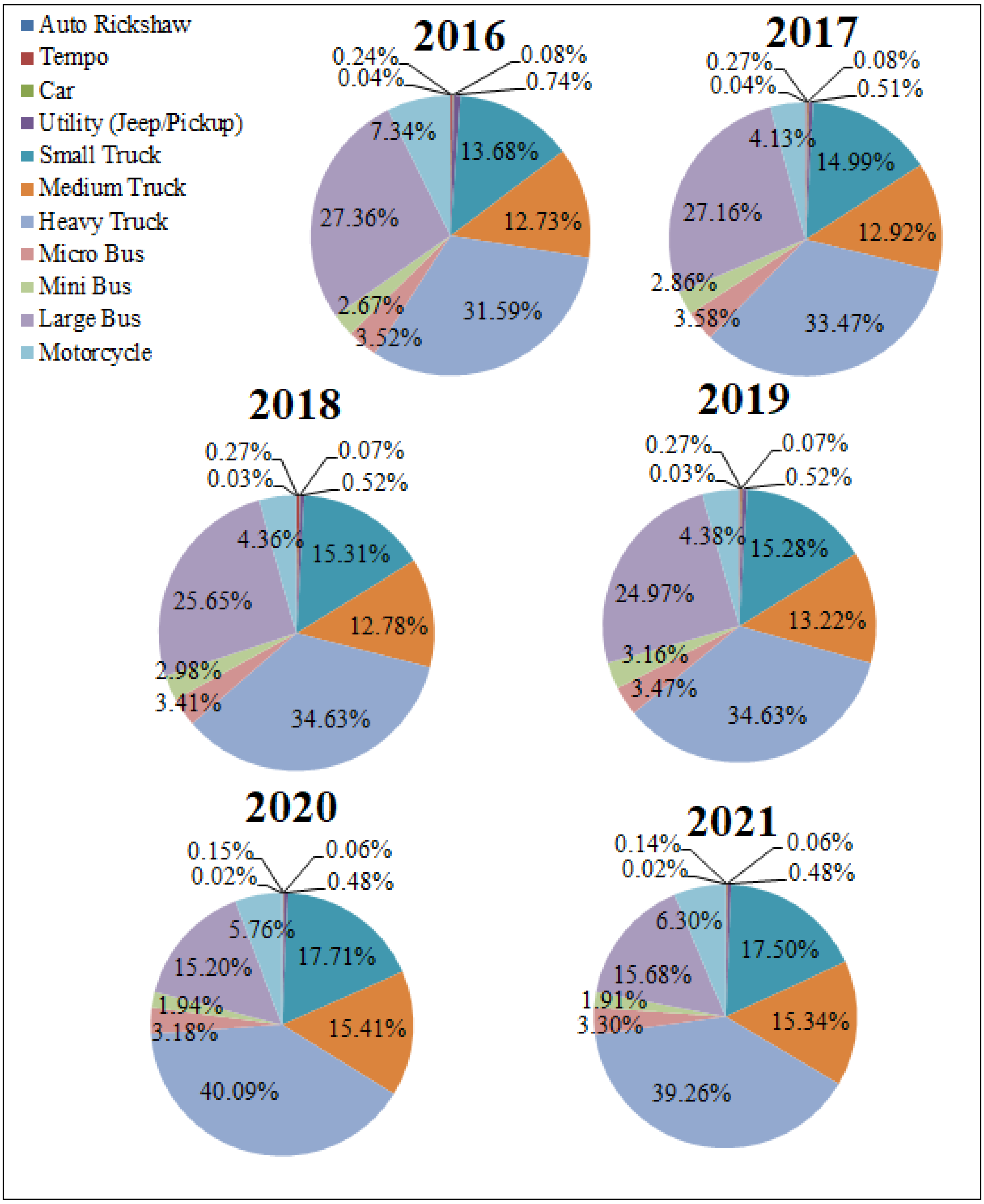

Figure 5.44: Contribution of vehicles to the emission of NO throughout the years

Throughout all the years, the greatest contributor to the emission of NO was found to be heavy trucks. 31.59% to 40.09% of NO emission was found to be produced by just heavy trucks. Furthermore, large buses, small trucks and medium trucks were also found to have significant contribution to the emission of NO.

The percent contribution of VOC by different type of vehicles is shown in Figure 5.45.

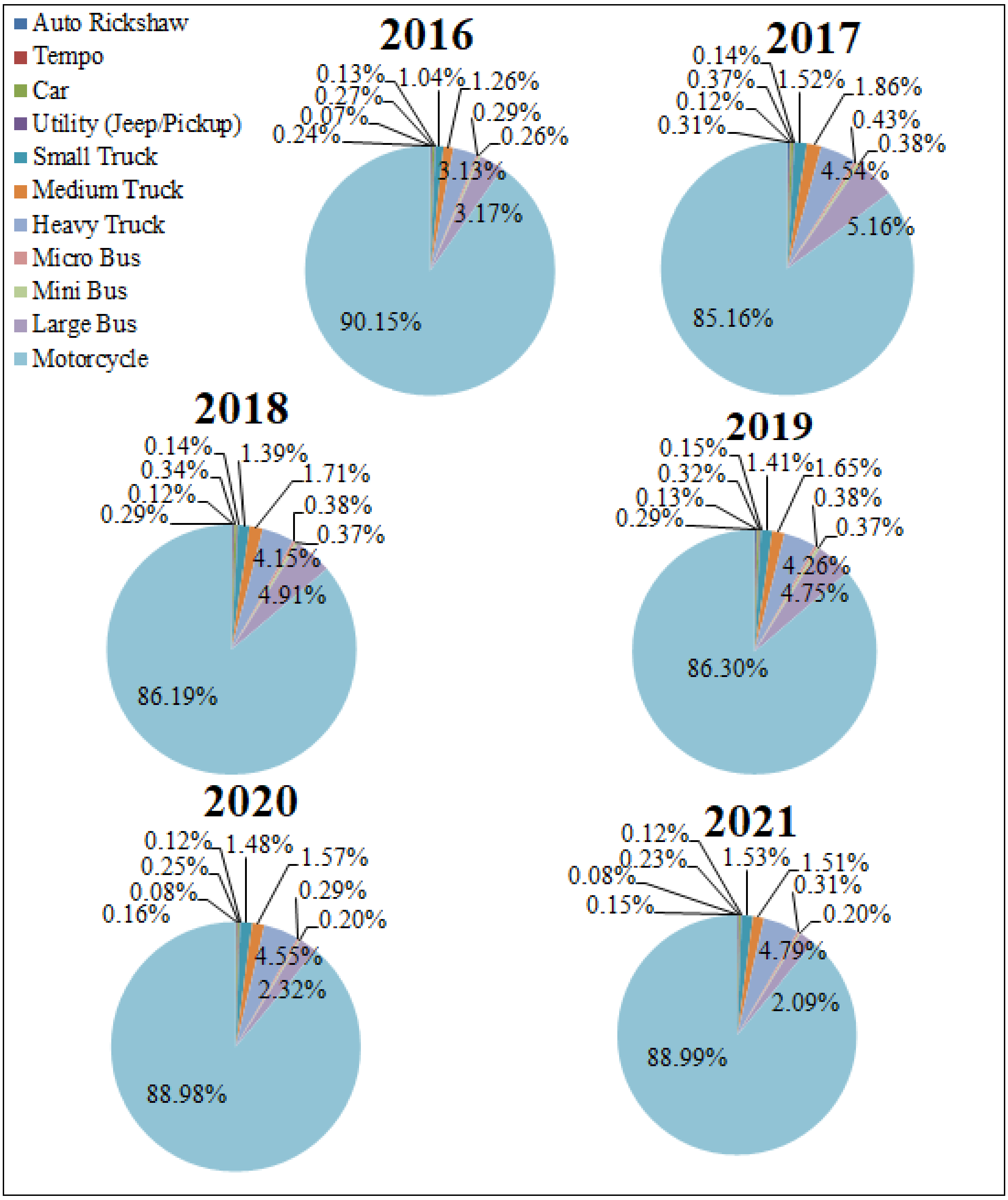

Figure 5.45: Contribution of vehicles to the emission of VOC throughout the years

Throughout all the years, the greatest contributor to the emission of VOC was found to be motorcycles. 85.16% to 90.15% of VOC emission was owed just to motorcycles. Furthermore, large buses, small trucks, medium trucks and heavy trucks were also found to have some contribution to the emission of VOC. Therefore, the use of motorcycles is strongly discouraged in order to control the emission of VOC.

The percent contribution of NMVOC by different vehicle types is shown in Figure 5.46.

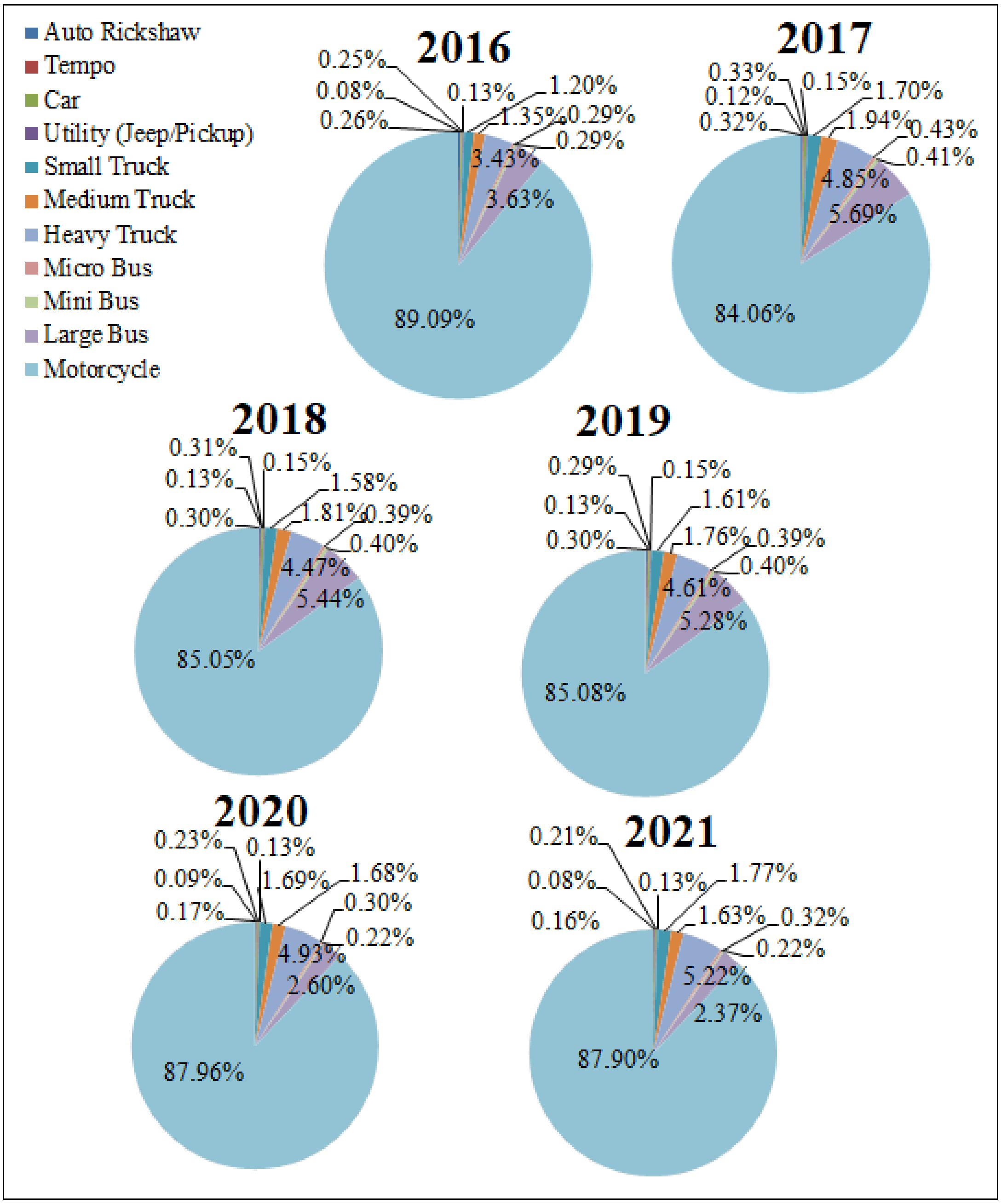

Figure 5.46: Contribution of vehicles to the emission of NMVOC throughout the years

Throughout all the years, the greatest contributor to the emission of NMVOC was found to be motorcycles. 84.06% to 89.09% of NMVOC emission was owed just to motorcycles. Furthermore, large buses, small trucks, medium trucks and heavy trucks were also found to have some contribution to the emission of NMVOC. Thus the use of motorcycles is strongly discouraged in order to control the emission of NMVOC.

5.6 Prediction for the Year 2025

The total quantity of emissions of 13 major pollutants and greenhouse gases found from the predicted analysis of 2025 are shown in Table 5.11.

Table 5.11: Total predicted emissions in 2025

Pollutant/ GHG	Emission (t)	Pollutant/ GHG	Emission (t)
Carbon Dioxide	16651347.992	Nitrogen Dioxide	6746.508
Carbon Monoxide	56491.951	Nitrous Oxide	517.652
Methane	3500.093	Ammonia	283.039
Nitrogen Oxides	51288.845	Nitric oxide	44542.337
Sulfur Dioxide	4133.276	Volatile Organic compounds	10315.505
PM 10	2942.385	Non-methane volatile organic compounds	7457.633
PM 2.5	1657.879		

To provide a clearer picture, the graphical representation of the possible future trends for the emission of CO_2 is shown in Figure 5.47.

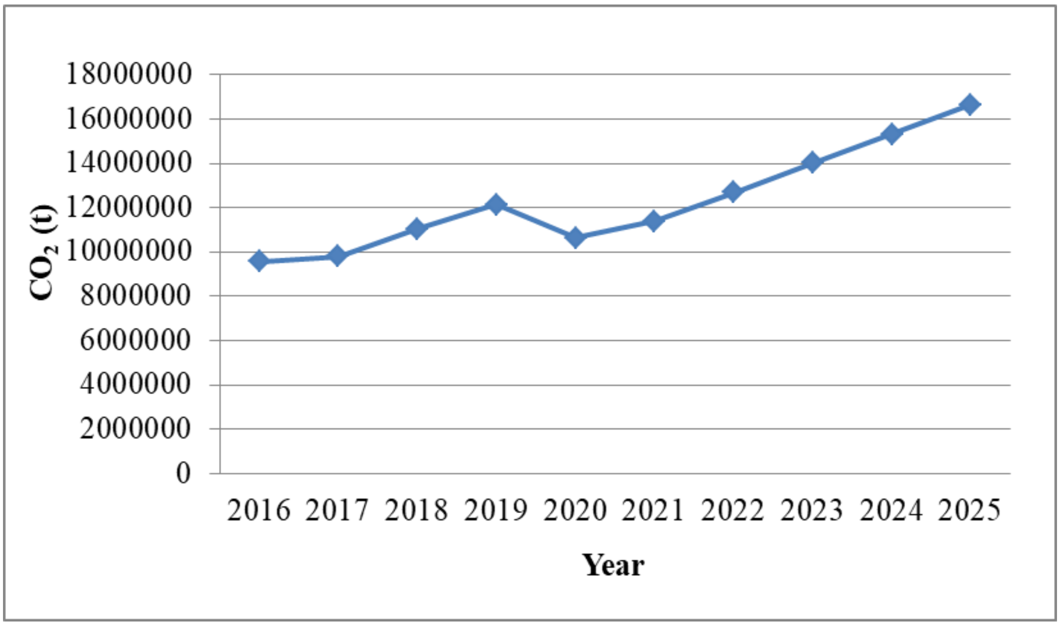

Figure 5.47: Emission of primary GHG Carbon Dioxide throughout the years and predicted emission up to 2025

The graphical representation of the possible future trends for the emission of other major pollutants and GHG's is shown in Figure 5.48.

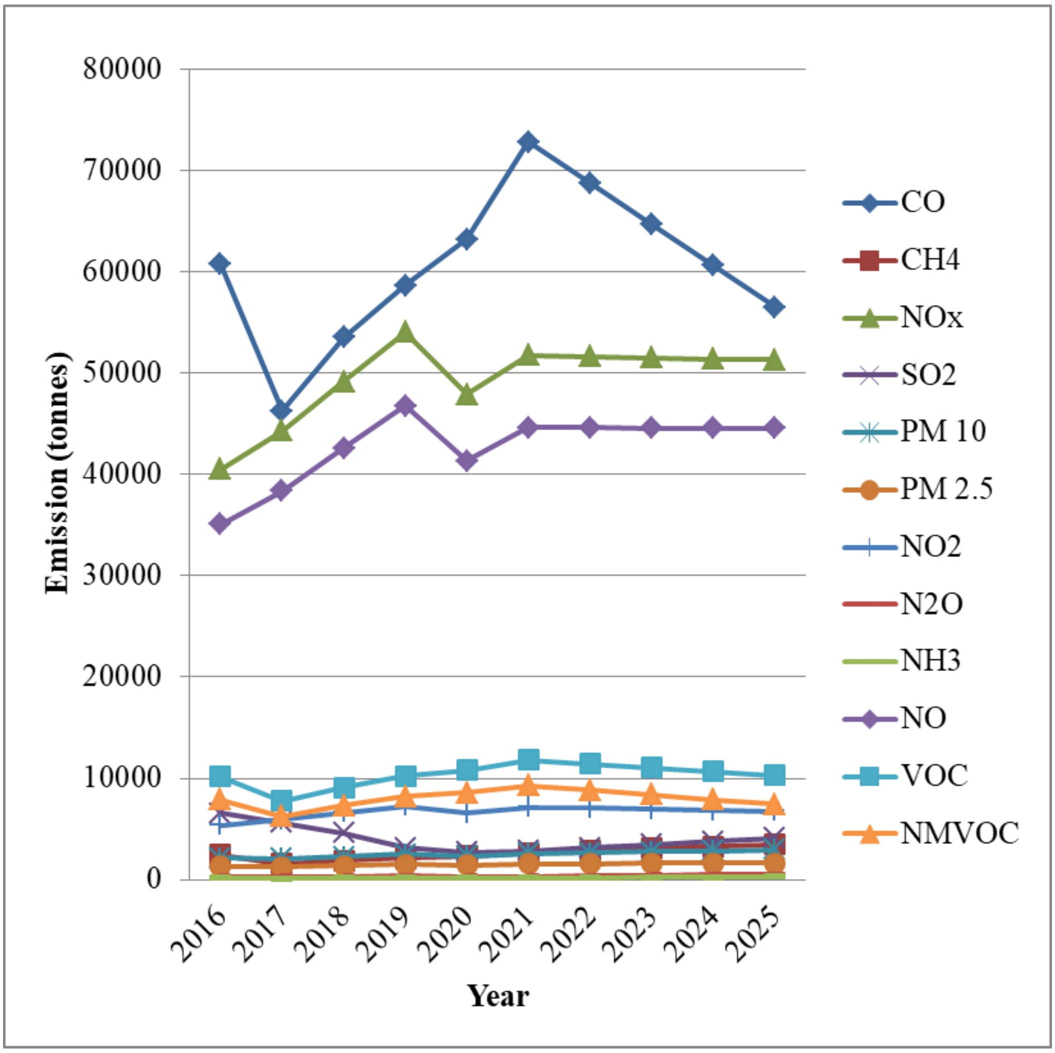

Figure 5.48: Emission of other major pollutants throughout the years and predicted emission up to 2025

The greatest concern for the year 2025 in terms of global warming is the possible increase in the amount of CO_2 emission as it is the primary greenhouse gas and the greatest percentage of vehicular exhaust fumes consist of CO_2. But on the bright side, a decrease in the yearly emission of CO, NO_X, NO_2, NO, VOC and NMVOC can be expected owing to the implementation of newer and improved euro standard vehicles and a decrease in the number of vehicles with older technology.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

The growth rate of registered vehicles is increasing rapidly and the complexity of maintaining proper guidance is getting out of hand. A large number of pollutants are generated from the transport sector and its continuous generation process is hampering people's daily life. The overall study findings and regarding recommendations have been presented in this chapter. This chapter concludes the study by pointing out the weakness inside the system and suggests the policy makers, planners as well as related authorities to take proper action on controlling vehicular emissions. This study used the European software COPERT 5.5 to estimate the vehicular emission of 13 major pollutants in Bangladesh from the year 2016 to 2021 and compared the results of yearly total quantity of primary GHG i.e. CO_2 emission in the transport sector of Bangladesh against a similar study made by World Bank for the years 2016, 2017 and 2018. This research also focuses on the COVID-19 situation and does a qualitative analysis of the lockdown effect on vehicular emission.

Although it seemed to be a devastating impact made by the pandemic, there was a small blessing in disguise, i.e. reduction in the damage caused by vehicular emissions.

The key findings of this study are given below:

- The percentage deviation of CO_2 emissions found using COPERT 5.5 from actual World Bank data was found to be 0.467% for the year 2016, 4.647% for the year 2017 and 2.382% for the year 2018, all of which is below 5%. Therefore the results of this study suggest that COPERT 5.5 may be a suitable emission model for Bangladesh.
- By carrying out analysis for the year 2020 and 2021 two times, once using actual data and again by assuming lockdown did not occur, an average decrease of 16.346% for CO_2, 5.293% for CO, 17.824% for NO_X, 18.184% for SO_2, 10.722% for PM 10, 11.610% for PM 2.5, 16.209% for NO_2, 11.844% for N_2O, 9.209% for NH_3, 18.076% for NO, 3.962% for VOC, and 4.743% for NMVOC was observed for the actual values with respect to the expected values if the lockdown had not occurred.

- From the comparative analysis of emission characteristics of different types of vehicles, it was found that heavy trucks, large buses, medium trucks, small trucks and motorcycles contribute to the greatest amount of emission of pollutants and GHG's. Just heavy trucks produced 31.07 to 39.37% of NOX, 27.62% to 34.10% of NO2, 31.59% to 40.09% of NO. 78% to 85% of CO, 90% to 94.4% of CH_4, 27.54% to 40.53% of NH_3, 85.16% to 90.15% of VOC and 84.06% to 89.09% of NMVOC emission was owed to just motorcycles.
- A set of emission factors for different types of pollutants have been found throughout the analysis and compared with the old emission factor which is used as base emission factor since 2012.

Recommendations

A range of emission factors of different pollutants are found using COPERT 5.5 software for several kinds of vehicle technology and fuel type. These emission factors will help to develop a proper emission inventory for the transport sector. Since emission factors change with vehicle age, the emission factors can be found for different years and they can be used for predicting emission characteristics of vehicles by observing the change in emission factors with time. The emission factors found in this study are preferable for estimating the zonal emission rate from vehicles for Bangladesh.

Since the results of this study suggests that vehicular emission indeed decreased by a significant amount due to the covid-19 lockdown, this paper urges organizations in every sector of Bangladesh who have the capability of maintaining their efficiency through work from home, to continue doing so to prevent the situation to returning to the way it used to be.

Since motorcycles were found to contribute to the emission of scary amounts of CO, CH_4, $NH_{3,}$ VOC and NMVOC, this paper attempts to discourage the use of motorcycles and to aid the public in selecting a less detrimental motorized vehicle if possible. Where it is not feasible to change the type of vehicle being driven, for example trucks being an irreplaceable mode of transport for goods and buses being an irreplaceable mode of public transport, the only possible mitigation measure is for the policy makers to mandate the replacement of heavy trucks, large buses, medium trucks and small trucks with that of improved technology (higher euro standard) in order to produce less emission and thus bring about a deceleration in the inevitable worsening of the air quality of Bangladesh.

Limitations and recommendations for further research

- One major challenge of our study was the lack of recent information regarding current average speed and annual mileage of each type of vehicle, fuel type split and vehicle technology type split in Bangladesh. In order to obtain more accurate results by COPERT 5.5 for recent times, this paper requests the authority to carry out a study of current vehicle activity, fuel type and technology type.
- To successfully establish a suitable vehicular emission model for Bangladesh, researchers are recommended to test out the available emission software created by other countries by purchasing the license for those softwares to determine if the algorithm of any other software suits better for Bangladesh than that of COPERT 5.5.
- Moreover, it is vital to simultaneously check the results of the models by carrying out manual testing of emissions from vehicles in Bangladesh by suitable machines (Ex: PEMS), so this study strongly recommends the authority to invest in these machinery.
- Some default inputs regarding fuel and lubricant characteristics are considered during the analysis as suggested by the COPERT documentation.
- The discrepancy between real life emissions and COPERT results may be due to the fact that some vehicle technologies and fuel types that exist in Bangladesh were not available in COPERT. It is more beneficial if a standard emission model can be developed for Bangladesh for more adequate results of vehicular emission since COPERT is a European model.

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