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Investigating the applicability of COPERT 5.5 emission software in Bangladesh and developing countrywide vehicular emission inventories†

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The primary step to minimizing air pollution effects owing to motorized vehicles in Bangladesh is to establish accurate emission modelling methods. The total yearly amount of the primary greenhouse gas, carbon dioxide (CO_2), emitted in Bangladesh up to 2020 was obtained by the World Bank. The percentage of total CO_2 emissions released from the transport sector in Bangladesh was reportedly 14.2% in 2014 and 15% in 2020; 90% of this was from on-road vehicles. So, approximately 13% of the total amount of CO_2 emissions in Bangladesh during those years found in the World Bank data can be considered to have come from its road transportation. However, Bangladesh still does not have a vehicular emission model of its own, so there is no straightforward method to quantify the harmful gases released by automobiles alone in this country as of yet. The purpose of this research is to fill this gap. This research investigated the applicability of the European emission model Computer Program to Estimate Emissions from Road Traffic Version 5.5 (COPERT 5.5) for Bangladesh. The yearly production of CO_2 from different vehicular classes in Bangladesh from 2016 to 2020 was computed using COPERT 5.5, and estimations from World Bank data were used as a benchmark. The results of this study suggest that COPERT 5.5 emission software may be applicable to Bangladesh. This research also suggested updated emission factors for CO_2 for different vehicle categories yielded by this software and developed countrywide annual vehicular emission inventories of CO_2 and 12 other major pollutants from 2016 to 2020.

Environmental significance

Emissions from vehicles cause severe health effects and function as a blanket over the surface of the earth by trapping infrared radiation from the earth's surface, contributing to climate change. As Bangladesh does not have a vehicular emission model of its own, this study established the applicability of the COPERT model for Bangladesh, which will inspire academics to carry out broad research regarding the national air pollution rate and also pave the way for substantial positive impacts on the air quality in Bangladesh. Governmental departments may find COPERT estimations useful for updating the vehicular emission standards of Bangladesh by imposing new rules related to Euro standards and the fuel quality of vehicles in order to decrease emission levels.

1 Introduction

With Bangladesh being ranked as the country with the worst air quality in the world in 2021,[5] and its capital Dhaka being ranked as the second most polluted city globally,[6] vehicular emissions in Bangladesh have risen to the point that they have become a severe environmental concern with several adverse effects on human health. These poor rankings are attributed to emissions from brick kilns, vehicles, and construction sites.

The Environment Conservation Rules of 1997 established the initial set of ambient air quality guidelines for Bangladesh. Based on a recommendation from the World Bank-funded Air Quality Management Project (AQMP), which assessed the previous guidelines, the Government of Bangladesh replaced the 1997 standards with new ones in July 2005.[7] The updated limit values for the criteria air pollutants are shown in Table 1, where [a] means not to be exceeded more than once per year, [b] means that the objective is attained when the annual arithmetic mean is less than or equal to 50 μg m^{-3}, [c] means that the objective is attained when the expected number of days per calendar year with a 24 hours average of 150 μg m^{-3} is equal to or less than 1, and [d] means that the objective is attained when the expected number of days per calendar year with the maximum hourly average of 0.12 ppm is equal to or less than 1.[8]

The Ministry of Environment, Forests, and Climate Change released a paper titled "Nationally Determined Contributions (NDCs) 2021" that includes the updated greenhouse gas (GHG) emission targets of Bangladesh. 2012 has been taken into consideration as the base year during which 169.05 million tons

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Table 1 National Ambient Air Quality Standards (NAAQS) for Bangladesh[8]

Pollutant	Limit value	Averaging time
Carbon monoxide (CO)	10 mg m^{-3} (9 ppm)	8 hours[a]
	40 mg m^{-3} (35 ppm)	1 hour[a]
Lead (Pb)	0.5 μg m^{-3}	Annual
Nitrogen oxides (NO_X)	100 μg m^{-3} (0.053 ppm)	Annual
Particulate matter 10 μm	50 μg m^{-3}	Annual[b]
or less in diameter (PM_{10})	150 μg m^{-3}	24 hours[c]
Particulate matter 2.5 μm	15 μg m^{-3}	Annual
or less in diameter ($PM_{2.5}$)	65 μg m^{-3}	24 hours
Ozone (O_3)	235 μg m^{-3} (0.12 ppm)	1 hour[d]
	157 μg m^{-3} (0.08 ppm)	8 hours
Sulfur dioxide (SO_2)	80 μg m^{-3} (0.03 ppm)	Annual
	365 μg m^{-3} (0.14 ppm)	24 hours[a]

of CO_2 equivalent ($MtCO_2e$) of GHG emissions were produced, out of which 16.77 million tons came from the transportation sector.[9] Based on the global warming potential (GWP) of the gas, the unit "CO_2e" denotes an amount of a greenhouse gas whose atmospheric influence has been standardized to that of one unit mass of carbon dioxide (CO_2).[10] In the unconditional scenario, the target is to cut GHG emissions in the relevant sectors (transportation being one of the largest contributing sectors) by 89.47 Mt CO_2e (21.85%) below Business As Usual (BAU) in 2030 compared to the base year. This is based on present local-level capabilities and will be financed with internal resources. The conditional emission reduction, which would lower GHG emissions in the same sectors by 27.56 Mt CO_2e (6.73%) below BAU in 2030 compared to the base year, will be executed depending upon foreign finance and technological support.[9]

Around 15% of total emissions are generated from the transportation sector.[3] As the growing economy demands the expansion of motorized transportation, it is reasonable to expect that already high levels of air pollution will only worsen in the future. As Bangladesh is a developing country where new technologies are usually embraced slowly, it lacks the sophisticated machinery needed to carry out manual testing of vehicular fumes. Therefore, it is imperative for us to carry out a quantitative analysis of vehicular emissions as a stepping stone to determining effective strategies to mitigate their harmful effects.

Currently, there is no vehicular emission model tailored for Bangladesh, nor are there any comprehensive air pollutant emission inventories in this country.[11] Moreover, the latest vehicular emission factors that were proposed for Bangladesh are from seven years ago; these factors are area-specific but not country-specific, and they are for vehicles with older technologies, some of which are no longer running in Bangladesh.[12] The deficiency of necessary resources makes it challenging to carry out extensive research regarding vehicular pollution in this country. This study attempts to fill in these gaps. The objective of this study is to prove COPERT to be suitable for this country in order to aid in research regarding the national air pollution rate and pave the way for substantial positive impacts on the air quality in Bangladesh. This paper also aims to provide academic advantages compared to works in the public domain by proposing updated Bangladesh-specific emission factors for CO_2, which are dedicated to vehicles with more up-to-date technologies that are currently running throughout the whole country. Finally, this paper seeks to offer a better understanding of the magnitude of CO_2 emissions released by different types of vehicles running in this country by preparing annual emission inventories and evaluating the contribution of CO_2 emissions by different vehicle types, along with the total magnitude of emissions of 12 other major pollutants throughout the years of analysis.

Various countries throughout the world have developed software-based emission models like the Motor Vehicle Emission Simulator (MOVES),[13] Mobile Source Emission Factor Model Version 6 (MOBILE6),[14] COPERT,[15] Comprehensive Modal Emissions Model (CMEM),[16] International Vehicle Emissions (IVE) Model,[17] *etc.*, which are popular in Europe and America. Bangladesh has adopted European emission standards since 2005.[18] Since N. Kholod suggested that COPERT should be used in countries that have adopted European emission standards,[19] this research utilized the European software COPERT 5.5 to compute vehicular emissions. The algorithms of the aforementioned models either follow a top-down or bottom-up methodology. Using the top-down methodology, yearly emissions for the whole region can be estimated, whereas using the bottom-up methodology, hourly emissions can be estimated by considering individual roads to be separate line sources.[20] Both methodologies are offered by COPERT, but for this study, the top-down methodology was used because the only vehicular activity information that was obtainable for this country was in the Road User Cost (RUC) report, which was the average data for its national or regional highways and Zilla roads, collected by the Roads and Highways Department (RHD) from all seven divisions of Bangladesh.[21]

Emission inventories have been created using previous versions of COPERT in countries outside of Europe, like China,[22,23] South Africa,[24] and Latin America, where the same difficulties have been detected regarding the data compilation presented in this work.[25–27] A study was conducted in Italy using the top-down approach, which primarily focused on estimating local emissions from vehicle transportation.[28] The results were compared to those produced from a geographical decentralization of national surveys using simple surrogate variables defined by vehicle type and driving mode. Another research study based on different emission inventories discussed the methodology of COPERT and MOVES software and detailed the history and current state of vehicular emission simulation in Europe.[20] These studies resulted in the development of a set of computer-based models and methodologies that address all motor vehicle emission concerns of policymakers, organizations, the locomotive industry, and the oil industry. A study in China created the emission inventory of gasoline-fuelled vehicles using Zibo city's complete emission factor method and provided a theoretical background for gasoline vehicle emission control schemes.[29] Another study compared the mechanical measurement of emissions *via* PEMS (Portable Emissions Measurement System) with software-based measurement using

COPERT emission factors by measuring nitrogen oxides and nitrogen dioxide emissions from diesel-fuelled passenger cars equipped with Euro-6 technology.[30] One study used COPERT 4 to calculate atmospheric pollutant emissions associated with road traffic in the North-East region of Romania. They used this tool to assess emissions, specifically in terms of energy consumption and CO_2 equivalent emissions. The software allowed them to model different scenarios, such as the impact of road network conditions on emissions.[31] Although one prior study utilized COPERT in Bangladesh to calculate the decrease in GHG emissions due to the increase in fuel taxes and determine the best possible corrective fuel tax for automobiles in this country,[32] the accuracy of the emissions yielded by COPERT was not checked by comparison with data from another reliable source. Therefore, to the best of our knowledge, the applicability of COPERT software in Bangladesh has not been established yet. Our research is intended to resolve this inquiry. This paper will be one of the first to introduce COPERT to Bangladesh as the remarkable open-source software that estimates nearly accurate vehicular emissions using country-specific data. As our results showed little to no difference from a reliable source of information, government agencies may find COPERT useful for updating Bangladesh's vehicular emission standards. Estimates from COPERT may assist policymakers in imposing new rules related to Euro standards and vehicle fuel quality in order to reduce emissions levels.

2 Methods and materials

All of the data used for this research has been accumulated by the authors from the Department of Environment (DOE) office, the Bangladesh Road Transport Authority (BRTA) office, and several research papers and government reports created by the Roads and Highways Department (RHD).

2.1 Vehicle classification and stock number

The quantity of motorized vehicles that were registered in Bangladesh from 1997 to 2009 was obtained from the Dhaka School of Economics (DScE) data bank,[33] as shown in Table 2:

Table 2 Number of motor vehicles registered in Bangladesh from 1997 to 2009 from DScE[33]

Year	Car	Jeep & micro	Taxi	Bus	Truck	Auto	Bike	Others
1997	8354	1759	14	970	1282	6546	12 080	—
1998	5876	2173	103	883	2733	4403	14 525	—
1999	4986	1223	216	746	2018	2140	16 511	—
2000	4087	1819	580	741	2725	4135	14 614	—
2001	6587	2465	771	1812	2575	603	24 409	—
2002	6757	3038	2233	3054	2377	5469	29 047	—
2003	7045	1804	5020	2015	2795	13 866	21 096	—
2004	5410	2514	540	1479	2583	8974	24 941	2761
2005	6431	3963	515	1144	2791	4877	43 226	2931
2006	8447	5540	275	1261	3065	6898	51 106	3713
2007	11 941	5650	15	1750	2521	10 530	85 131	3734
2008	16 927	6537	9	1649	2609	19 071	93 541	4076
2009	21 461	9027	12	1504	6561	14 902	45 142	6634

The quantity of motorized vehicles that were registered in Bangladesh from up to 2010 to 2021 was obtained from BRTA[34] as shown in Table 3:

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 DScE and BRTA, which gives a negative value for the year 2010 by back calculation. To fix this problem, data for the year 2010 was obtained from a report made by DOE[18] as shown in Table 4:

DScE classified vehicles into 8 categories,[33] BRTA classified them into 20 categories,[34] and the DOE classified them into 9 categories.[18] For greater accuracy, the 20 BRTA classifications were used for this study. So in order to convert the vehicle categories found in DScE and DOE into BRTA categories, we first found which categories were equivalent to which, as found in DScE,[33] which is shown in Table 5:

The combined data from the other two sources was broken down into its subcategories according to the average ratio of the subcategories observed in the years in the BRTA data. For example, jeep and micro (total) found by DScE were broken down into corresponding jeep and microbus by calculating the average ratio of jeeps and microbuses observed in the years in the BRTA data and then breaking down the given number of jeep and micro (total) into the 2 subcategories using the respective ratios.

The average lifespan of a car in Bangladesh is said to be 20 years.[35] Thus, 20 years' data were taken into account for each year of analysis. Since vehicle activity data was collected from the RUC report by RHD, where vehicles were classified into 11 categories,[21] stock numbers were in 20 BRTA categories,[34] and COPERT itself had its own vehicular classifications,[15] the vehicle classifications in COPERT 5.5, which are equivalent to both BRTA and RHD classifications, were determined. The BRTA and RHD equivalent vehicle classifications were obtained from the DScE.[33] Then the characteristics of representative models of the vehicles (the most commonly purchased models in Bangladesh) like axle number, weight, and dimensions from the RUC report[21] were compared with those of the COPERT classifications as described in the guidebook,[15] in order to find the equivalent classifications, as summarized in Table 6:

2.2 Breakdown of stock into fuel type

Since there is no comprehensive study on the percentage of vehicles using different types of fuel for all vehicular categories in Bangladesh, we used the results of a fuel split study carried out by the DOE found in the "Revisions of Vehicular Emission Standards in Bangladesh" to divide the number of each type of vehicle in terms of the type of fuel used,[18] as shown in Table 7:

However, the specific percentage breakdown of vehicles using these different fuels varies over time and is subject to government policies, fuel prices, and environmental initiatives; thus, adjustments were made considering the improvement in the automobile and fuel industries in Bangladesh from the year of the study to the year of this analysis and considering the state of the fuel industry during the years of analysis. For example, cars and taxis running on diesel were not considered to be 0%;

Table 3 Number of motor vehicles registered in Bangladesh from up to 2010 to 2021 from BRTA[34]

Vehicle category	Up to 2010	2011	2012	2013	2014	2015
Ambulance	2486	218	181	240	337	472
Auto rickshaw	110 623	20 406	23 528	15 633	19 828	18 700
Auto tempo	9446	175	626	393	472	1081
Bus	23 385	1753	1438	1104	1486	2378
Cargo van	3363	489	282	686	605	398
Covered van	6022	2480	1511	2347	2950	2442
Delivery van	15 391	1037	802	941	1235	1779
Human hauler	4827	1151	714	385	225	1129
Jeep	28 131	2141	1575	1303	1849	3564
Microbus	62 399	4037	3031	2530	4302	5177
Minibus	23 070	271	246	148	257	320
Motor cycle	755 514	116 534	101 895	85 321	90 401	229 010
Pick up	29 103	10 314	7530	6443	9424	9992
Private passenger car	207 989	12 942	9220	10 456	14 681	21 029
Special purpose vehicle	5022	391	225	228	174	298
Tanker	2606	309	188	218	350	319
Taxicab	35 122	75	170	50	372	83
Tractor	14 648	5195	3494	1885	1521	1689
Truck	65 889	6853	4043	4838	7939	6022
Others	22 332	1265	1062	1064	1580	2059
Vehicle category	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Ambulance	374	493	563	665	788	755
Auto rickshaw	10 656	8852	21 593	29 807	16 724	9158
Auto tempo	1313	1592	609	224	77	25
Bus	3832	3757	2755	3558	2395	1517
Cargo van	1015	1413	1280	4	2	3
Covered van	3399	5201	5728	3070	2023	3800
Delivery van	2220	2420	2105	1523	1170	1436
Human hauler	3443	3393	1418	509	122	52
Jeep	4869	5419	5547	5627	4911	7602
Microbus	5789	5571	4131	3682	2779	4941
Minibus	459	491	436	835	620	392
Motor cycle	315 089	325 876	393 545	401 452	311 016	375 252
Pick up	11 220	13 454	13 060	11 918	10 498	10 897
Private passenger car	20 268	21 952	18 222	16 779	12 403	16 049
Special purpose vehicle	613	994	1334	1179	703	518
Tanker	380	317	527	417	304	248
Taxicab	43	14	159	11	8	0
Tractor	2535	2777	3553	2561	2498	2567
Truck	6605	10 329	12 644	8318	4719	5789
Others	3842	5018	5973	5293	3900	4029

Table 4 Number of vehicles registered in 2010 found from the revision of vehicular emission standards of Bangladesh report by DOE[18]

DOE report category	Motor car	Jeep/station wagon	Taxi	Bus	Minibus	Truck	Auto rickshaw	Motor cycle	Others
2010	19 557	6667	0	1101	142	4543	1362	30 264	12 225

instead, the yearly different fuel split for cars and taxis was taken from a comprehensive fuel split study for private cars carried out in Dhaka city.[36]

2.3 Breakdown of stock into Euro standards

Bangladesh has adopted European emission standards since 2005.[18] However, there is no clear documentation about which emission standard was implemented in which year nationwide because some divisions of Bangladesh are less developed than others, and in reality, different parts of this country have maintained different emission standards simultaneously, so it is difficult to generalize for the entirety of Bangladesh given that the scarce information that can be found on the internet is division-centric. The "Revisions of Vehicular Emission Standards for Bangladesh" report written by the Department of Environment (DOE)[18] mentioned that, compared to Europe,

Table 5 BRTA categories that are equivalent to DScE and DOE report categories[33]

DCsE category	BRTA category	DOE report category
Car	Private car	Motor car
Taxi	Taxicabs	Taxi
Jeep and micro	Jeep	Jeep/station wagon
	Station wagons	
	Microbus	Bus
Bus	Bus	
	Minibus	Minibus
	Human hauler	Others
Others	Special vehicle	
	Delivery van	
	Ambulance	
	Tractor	
	Pick up	
Truck	Truck	Truck
	Tanker	
	Covered van	
	Cargo van	
Auto	Auto rickshaw	Auto rickshaw
	Auto tempo	
Motorcycle	Motorcycle	Motor cycle

there is a lag time of 5 to 15 years for a European emission standard to be implemented in most Asian countries. After comprehensive research in the public domain, database queries, and consultation with experts in the field, this study made the assumption that each Euro standard was implemented in Bangladesh 5 years after being launched in Europe, as mentioned in the DOE report[18] considering the unavailability of the required quality of fuel, the lack of necessary infrastructure, slow technological growth, and poor economic conditions in Bangladesh. Thus, the launching and ending years of production of different Euro-standard engines in Europe, which were collected from the COPERT guidebook,[15] were used to assume those for Bangladesh. Future researchers could benefit from obtaining more in-depth information regarding the Euro standards of vehicles running in Bangladesh in order to enhance the accuracy of the findings of this study.

The launching and ending years of production of different Euro-standard engines in Europe[15] and the corresponding assumed launching and ending years of production of the same Euro standards in Bangladesh are shown in Table 8:

To divide the vehicular stock according to the types of technology available in COPERT 5.5, the number of registered vehicles registered per year in Bangladesh, as shown in Tables 2, 3, and 4, was assumed to have the Euro standard engine that was assumed to be launched in the particular year, as shown in Table 8. The number of vehicles running per year distributed into COPERT 5.5 classifications (category-fuel-segment-Euro standard) and equivalent BRTA and RHD classifications is shown in Table 9:

2.4 Mileage and activity information

The annual kilometres travelled and average speeds of different vehicle categories throughout the years were collected from the RUC report,[21] as shown in Table 10:

Here, the values of annual mileage and speed were found to be reduced in the 2016–2017 study compared to the 2004–2005 study, so the values were assumed to decrease at a uniform rate,

Table 6 The COPERT 5.5 classifications which are equivalent to the 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	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 (standard coaches ≤18 tonnes)
Minibus (diesel fueled)	Minibus	Buses (standard urban buses 15–18 tonnes)
Microbus (diesel fueled)	Microbus	Buses (urban buses midi ≤15 tonnes)
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, <3.5 tonnes)
Tractors and trucks	Small truck	Heavy duty trucks (rigid ≤7.5 tonnes)
Trucks	Medium truck	Heavy duty trucks (rigid 14–20 tonnes)
Tankers and trucks	Heavy truck	Heavy duty trucks (rigid 20–26 tonnes)
Motor cycle	Motorcycle	4 stroke <250 cm^3 motorcycle

Table 7 Percentage of types of fuels used by different vehicular categories[18]

Vehicle category	CNG (%)	Petrol (%)	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

Table 8 Timeline of implementation of different Euro standards in Europe[15] and corresponding assumed timeline of implementation of the same Euro standards in Bangladesh

Vehicle category	Type of fuel	Euro standard	Launching year in Europe	Ending year of production in Europe	Assumed year of launch in Bangladesh	Assumed ending year of production in Bangladesh
Passenger cars	Petrol	1	1992	1996	1997	2001
		2	1996	1999	2001	2004
		3	2000	2004	2005	2009
		4	2005	2009	2010	2014
		5	2011	2014	2016	2019
		6 a/b/c	2014	2016	2019	2021
	Diesel	1	1992	1996	1997	2001
		2	1996	2000	2001	2005
		3	2000	2005	2005	2010
		4	2005	2010	2010	2015
		5	2010	2014	2015	2019
		6 a/b/c	2014	2019	2019	—
	CNG	4	2005	2009	2010	2014
		5	2010	2014	2015	2019
		6 a/b/c	2015	2016	2020	2021
		6 d-temp	2017	2019	2022	2024
Light commercial vehicles	Petrol	1	1993	1997	1998	2002
		2	1997	2001	2002	2006
		3	2001	2006	2006	2011
		4	2006	2010	2011	2015
		5	2011	2015	2016	2020
		6 a/b/c	2016	2017	2021	2022
Light commercial vehicles	Diesel	1	1993	1997	1998	2002
		2	1997	2001	2002	2006
		3	2001	2006	2006	2011
		4	2006	2011	2011	2016
		5	2011	2015	2016	2020
		6 a/b/c	2015	2017	2020	2022
Heavy duty trucks	Diesel	1	1992	1995	1997	2000
		2	1996	2000	2001	2005
		3	2000	2005	2005	2010
		4	2005	2008	2010	2013
		5	2008	2013	2013	2018
		6 a/b/c	2013	2019	2018	—
Motorcycles	Petrol	1	1999	2003	2004	2008
		2	2003	2006	2008	2011
		3	2006	2013	2011	2018
		4	2016	2020	2021	—

and this rate was also used to predict the annual mileage and speed for different vehicles for the following years after 2017. For 2020, the vehicular mileage did decrease[37] but it was assumed that the vehicular speed increased[38] during that year because of the COVID-19 lockdown. Emissions calculated in COPERT 5.5 were found to be most impacted by the annual mileage and average speed data. Since this data is the most accurate for the years 2016 and 2017, as it was directly collected from the RUC report 2016–2017,[21] and since the World Bank data is available up to 2020, results for the years 2016, 2017, 2018, 2019, and 2020 were checked against the World Bank data for examining the applicability of this software for Bangladesh.

For each year of analysis, the number of vehicles registered up to 20 years prior to the year was taken into account.[35] This means that different vehicles running in a particular year with the same COPERT classification had different ages and thus different lifetime mileage values. However, COPERT only allows one lifetime mileage to be assigned to one vehicle class, so it was necessary to calculate the mean age of each vehicle class during a particular year using a frequency table. The lifetime mileage of each vehicle class for the particular year of analysis was then calculated by multiplying its mean age with its annual km travelled, as shown in eqn (1):

$$\text{Lifetime mileage (km)} = \text{mean age using a frequency table} \times \text{annual km travelled} \quad (1)$$

2.5 Fuel characteristics and additional parameters

Fuel characteristics like density and chemical content of petrol and diesel fuels for Dhaka, Chittagong, and the rest of the country were taken from the report on this country's updated vehicular emission standards[18] for 2012 as well as for future years. The minimum value of fuel density and the maximum value of chemical content were considered for the worst-case

Table 9 Number of vehicles per year distributed into BRTA, RHD and COPERT 5.5 classifications (category-fuel-segment-Euro standard)

BRTA classification(s)	RHD classification	COPERT 5.5 classification (category-fuel-segment-Euro standard)	2016 stock	2017 stock
Auto rickshaw	Auto rickshaw	Passenger cars – petrol – mini – Euro 4	1175	1272
		Passenger cars – petrol – mini – Euro 5	2786	3200
		Passenger cars – petrol – mini – Euro 6 a/b/c	3934	3816
Tempo and human hauler	Tempo	Passenger cars – petrol – small – Euro 3	60	74
		Passenger cars – petrol – small – Euro 4	202	235
		Passenger cars – petrol – small – Euro 5	516	562
		Passenger cars – petrol – small – Euro 6 a/b/c	878	1236
Cars and taxicabs	Car	Passenger cars – petrol – medium – Euro 3	1261	1286
		Passenger cars – petrol – medium – Euro 4	1796	1951
		Passenger cars – petrol – medium – Euro 5	3718	3647
		Passenger cars – petrol – medium – Euro 6 a/b/c	3639	4391
Ambulance, jeep and pickup	Jeep/pickup	Passenger cars – petrol – large-SUV-executive – Euro 3	130	148
		Passenger cars – petrol – large-SUV-executive – Euro 4	490	628
		Passenger cars – petrol – large-SUV-executive – Euro 5	1626	1792
		Passenger cars – petrol – large-SUV-executive – Euro 6 a/b/c	2365	2916
Tempo and human hauler	Tempo	Passenger cars – diesel – small – Euro 3	336	410
		Passenger cars – diesel – small – Euro 4	695	714
		Passenger cars – diesel – small – Euro 5	1219	1329
		Passenger cars – diesel – small – Euro 6 a/b/c	2149	2981
Ambulance, jeep and pickup	Jeep/pickup	Passenger cars – diesel – large-SUV-executive – Euro 3	699	794
		Passenger cars – diesel – large-SUV-executive – Euro 4	2219	2798
		Passenger cars – diesel – large-SUV-executive – Euro 5	7126	7875
		Passenger cars – diesel – large-SUV-executive – Euro 6 a/b/c	10 083	11 944
Auto rickshaw	Auto rickshaw	Passenger cars – CNG bifuel – mini – Euro 4	38 102	40 390
		Passenger cars – CNG bifuel – mini – Euro 5	78 822	90 320
		Passenger cars – CNG bifuel – mini – Euro 6 a/b/c	106 159	95 181
Tempo and human hauler	Tempo	Passenger cars – CNG bifuel – small – Euro 4	3333	3539
		Passenger cars – CNG bifuel – small – Euro 5	5089	5641
		Passenger cars – CNG bifuel – small – Euro 6 a/b/c	9668	12 861
Cars and taxicabs	Car	Passenger cars – CNG bifuel – medium – Euro 4	50 520	48 225
		Passenger cars – CNG bifuel – medium – Euro 5	89 325	96 170
		Passenger cars – CNG bifuel – medium – Euro 6 a/b/c	86 485	95 305
Ambulance, jeep and pickup	Jeep/pickup	Passenger cars – CNG bifuel – large-SUV-executive – Euro 4	5365	6982
		Passenger cars – CNG bifuel – large-SUV-executive – Euro 5	33 334	41 409
		Passenger cars – CNG bifuel – large-SUV-executive – Euro 6 a/b/c	59 028	64 678
Cargo van, delivery van and covered van	Small truck	Light commercial vehicles – diesel – N1-II – Euro 3	3735	4096
		Light commercial vehicles – diesel – N1-II – Euro 4	5327	5709
		Light commercial vehicles – diesel – N1-II – Euro 5	13 749	15 246
		Light commercial vehicles – diesel – N1-II – Euro 6 a/b/c	23 197	29 885
Tractors and trucks	Small truck	Heavy duty trucks – diesel – rigid ≤7.5 t – Euro III	2415	2648
		Heavy duty trucks – diesel – rigid ≤7.5 t – Euro IV	4410	5041
		Heavy duty trucks – diesel – rigid ≤7.5 t – Euro V	16 665	20 436
		Heavy duty trucks – diesel – rigid ≤7.5 t – Euro VI A/B/C	21 522	23 150
Trucks	Medium truck	Heavy duty trucks – diesel – rigid 14–20 t – Euro III	2415	2648
		Heavy duty trucks – diesel – rigid 14–20 t – Euro IV	2990	3057
		Heavy duty trucks – diesel – rigid 14–20 t – Euro V	7276	8117
		Heavy duty trucks – diesel – rigid 14–20 t – Euro VI A/B/C	10 398	12 743
Tankers and trucks	Heavy truck	Heavy duty trucks – diesel – rigid 20–26 t – Euro II	2760	3027
		Heavy duty trucks – diesel – rigid 20–26 t – Euro III	3405	3476
		Heavy duty trucks – diesel – rigid 20–26 t – Euro IV	8246	9198
		Heavy duty trucks – diesel – rigid 20–26 t – Euro V	11 853	14 327
Microbus (diesel fueled)	Microbus	Buses – diesel – urban buses midi ≤15 t – Euro III	958	1089
		Buses – diesel – urban buses midi ≤15 t – Euro IV	1804	2106
		Buses – diesel – urban buses midi ≤15 t – Euro V	4100	4132
		Buses – diesel – urban buses midi ≤15 t – Euro VI A/B/C	4541	5272
Minibus (diesel fueled)	Minibus	Buses – diesel – urban buses standard 15–18 t – Euro II	229	324
		Buses – diesel – urban buses standard 15–18 t – Euro III	495	472
		Buses – diesel – urban buses standard 15–18 t – Euro IV	804	852
		Buses – diesel – urban buses standard 15–18 t – Euro V	1141	1485

Table 9 (*Contd.*)

BRTA classification(s)	RHD classification	COPERT 5.5 classification (category-fuel-segment-Euro standard)	2016 stock	2017 stock
Large bus	Large bus	Buses – diesel – coaches standard ≤18 t – Euro III	3299	4635
		Buses – diesel – coaches standard ≤18 t – Euro IV	5826	5026
		Buses – diesel – coaches standard ≤18 t – Euro V	6153	6501
		Buses – diesel – coaches standard ≤18 t – Euro VI A/B/C	10 823	13 391
Minibus and microbus (CNG fueled)	Mini bus	Buses – CNG – urban CNG buses – Euro I	4455	5156
		Buses – CNG – urban CNG buses – Euro II	8031	9108
		Buses – CNG – urban CNG buses – Euro III	17 011	17 074
		Buses – CNG – urban CNG buses – EEV	18 325	20 780
Motor cycle	Motorcycle	L-Category – petrol – motorcycles 4-stroke <250 cm^3 – Euro 1	82 139	99 106
		L-Category – petrol – motorcycles 4-stroke <250 cm^3 – Euro 2	169 506	225 626
		L-Category – petrol – motorcycles 4-stroke <250 cm^3 – Euro 3	429 203	445 998
		L-Category – petrol – motorcycles 4-stroke <250 cm^3 – Euro 4	822 301	1 046 531

BRTA classification(s)	RHD classification	COPERT 5.5 classification (category-fuel-segment-Euro standard)	2018 stock	2019 stock	2020 stock
Auto rickshaw	Auto rickshaw	Passenger cars – petrol – mini – Euro 4	1315	1488	1708
		Passenger cars – petrol – mini – Euro 5	3804	4106	4454
		Passenger cars – petrol – mini – Euro 6 a/b/c	4075	4773	4829
Tempo and human hauler	Tempo	Passenger cars – petrol – small – Euro 3	94	135	167
		Passenger cars – petrol – small – Euro 4	278	323	443
		Passenger cars – petrol – small – Euro 5	579	599	627
		Passenger cars – petrol – small – Euro 6 a/b/c	1590	1839	1897
Cars and taxicabs	Car	Passenger cars – petrol – medium – Euro 3	1529	1585	1705
		Passenger cars – petrol – medium – Euro 4	2186	2845	3496
		Passenger cars – petrol – medium – Euro 5	3418	3189	3200
		Passenger cars – petrol – medium – Euro 6 a/b/c	5022	5340	5110
Ambulance, jeep and pickup	Jeep/pickup	Passenger cars – petrol – large-SUV-executive – Euro 3	143	236	346
		Passenger cars – petrol – large-SUV-executive – Euro 4	805	997	1337
		Passenger cars – petrol – large-SUV-executive – Euro 5	1897	2035	2104
		Passenger cars – petrol – large-SUV-executive – Euro 6 a/b/c	3568	4014	4198
Tempo and human hauler	Tempo	Passenger cars – diesel – small – Euro 3	515	615	664
		Passenger cars – diesel – small – Euro 4	773	849	1049
		Passenger cars – diesel – small – Euro 5	1295	1280	1453
		Passenger cars – diesel – small – Euro 6 a/b/c	3497	3751	3548
Ambulance, jeep and pickup	Jeep/pickup	Passenger cars – diesel – large-SUV-executive – Euro 3	766	1147	1608
		Passenger cars – diesel – large-SUV-executive – Euro 4	3571	4430	5806
		Passenger cars – diesel – large-SUV-executive – Euro 5	8314	8933	9329
		Passenger cars – diesel – large-SUV-executive – Euro 6 a/b/c	14 050	15 355	15 820
Auto rickshaw	Auto rickshaw	Passenger cars – CNG bifuel – mini – Euro 4	27 909	34 299	35 018
		Passenger cars – CNG bifuel – mini – Euro 5	47 045	52 603	65 871
		Passenger cars – CNG bifuel – mini – Euro 6 a/b/c	89 778	95 163	95 589
		Passenger cars – CNG bifuel – mini – Euro 6 d-temp	78 389	88 317	86 518

Table 9 (*Contd.*)

BRTA classification(s)	RHD classification	COPERT 5.5 classification (category-fuel-segment-Euro standard)	2018 stock	2019 stock	2020 stock
Tempo and human hauler	Tempo	Passenger cars – CNG bifuel – small – Euro 4	2615	3009	3141
		Passenger cars – CNG bifuel – small – Euro 5	3232	3467	4069
		Passenger cars – CNG bifuel – small – Euro 6 a/b/c	4869	4681	5582
		Passenger cars – CNG bifuel – small – Euro 6 d-temp	13 036	13 314	11 803
Cars and taxicabs	Car	Passenger cars – CNG bifuel – medium – Euro 4	36 748	37 493	39 709
		Passenger cars – CNG bifuel – medium – Euro 5	48 655	63 595	76 891
		Passenger cars – CNG bifuel – medium – Euro 6 a/b/c	72 488	66 353	66 752
		Passenger cars – CNG bifuel – medium – Euro 6 d-temp	94 100	96 016	87 781
Ambulance, jeep and pickup	Jeep/pickup	Passenger cars – CNG bifuel – large-SUV-executive – Euro 4	3888	5705	7926
		Passenger cars – CNG bifuel – large-SUV-executive – Euro 5	17 406	21 602	28 153
		Passenger cars – CNG bifuel – large-SUV-executive – Euro 6 a/b/c	40 405	43 428	45 459
		Passenger cars – CNG bifuel – large-SUV-executive – Euro 6 d-temp	66 465	72 059	73 934
Cargo van, delivery van and covered van	Small truck	Light commercial vehicles – diesel – N1-II – Euro 3	4116	4549	4833
		Light commercial vehicles – diesel – N1-II – Euro 4	6012	7671	10 999
		Light commercial vehicles – diesel – N1-II – Euro 5	18 064	20 189	20 422
		Light commercial vehicles – diesel – N1-II – Euro 6 a/b/c	35 340	35 395	34 089
Tractors and trucks	Small truck	Heavy duty trucks – diesel – rigid ≤7.5 t – Euro III	2662	3225	3709
		Heavy duty trucks – diesel – rigid ≤7.5 t – Euro IV	5655	7127	10 349
		Heavy duty trucks – diesel – rigid ≤7.5 t – Euro V	22 791	24 585	24 118
		Heavy duty trucks – diesel – rigid ≤7.5 t – Euro VI A/B/C	27 736	29 150	29 643
Trucks	Medium truck	Heavy duty trucks – diesel – rigid 14–20 t – Euro III	2662	2808	2850
		Heavy duty trucks – diesel – rigid 14–20 t – Euro IV	3056	3943	5594
		Heavy duty trucks – diesel – rigid 14–20 t – Euro V	9202	10 477	10 334
		Heavy duty trucks – diesel – rigid 14–20 t – Euro VI A/B/C	15 661	16 035	15 719
Tankers and trucks	Heavy truck	Heavy duty trucks – diesel – rigid 20–26 t – Euro II	3042	3206	3250
		Heavy duty trucks – diesel – rigid 20–26 t – Euro III	3469	4476	6348
		Heavy duty trucks – diesel – rigid 20–26 t – Euro IV	10 422	11 848	11 718
		Heavy duty trucks – diesel – rigid 20–26 t – Euro V	17 554	17 995	17 664
Microbus (diesel fueled)	Microbus	Buses – diesel – urban buses midi ≤15 t – Euro III	1051	1209	1455
		Buses – diesel – urban buses midi ≤15 t – Euro IV	2627	3328	3845
		Buses – diesel – urban buses midi ≤15 t – Euro V	3976	3902	4061
		Buses – diesel – urban buses midi ≤15 t – Euro VI A/B/C	5893	6024	5687

Table 9 (*Contd.*)

BRTA classification(s)	RHD classification	COPERT 5.5 classification (category-fuel-segment-Euro standard)	2018 stock	2019 stock	2020 stock
Minibus (diesel fueled)	Minibus	Buses – diesel – urban buses standard 15–18 t – Euro II	376	436	483
		Buses – diesel – urban buses standard 15–18 t – Euro III	495	534	705
		Buses – diesel – urban buses standard 15–18 t – Euro IV	863	923	920
		Buses – diesel – urban buses standard 15–18 t – Euro V	1914	2388	2624
Large bus	Large bus	Buses – diesel – coaches standard ≤18 t – Euro III	5361	5856	6143
		Buses – diesel – coaches standard ≤18 t – Euro IV	4830	4884	5157
		Buses – diesel – coaches standard ≤18 t – Euro V	6578	7129	8597
		Buses – diesel – coaches standard ≤18 t – Euro VI A/B/C	15 358	17 678	17 813
Minibus and microbus (CNG fueled)	Mini bus	Buses – CNG – urban CNG buses – Euro I	5076	5714	6700
		Buses – CNG – urban CNG buses – Euro II	11 174	14 039	16 018
		Buses – CNG – urban CNG buses – Euro III	16 291	15 938	16 644
		Buses – CNG – urban CNG buses – EEV	22 568	22 667	21 025
Motor cycle	Motorcycle	L-Category – petrol – motorcycles 4-stroke <250 cm^3 – Euro 1	105 677	114 133	142 773
		L-Category – petrol – motorcycles 4-stroke <250 cm^3 – Euro 2	298 110	318 349	363 724
		L-Category – petrol – motorcycles 4-stroke <250 cm^3 – Euro 3	437 807	483 094	623 599
		L-Category – petrol – motorcycles 4-stroke <250 cm^3 – Euro 4	1 355 071	1 666 370	1 748 494

scenario. The maximum monthly Reid vapour pressure at 38 °C was considered to be 10 psi.[18] The most recent average trip length and average trip duration were recorded to be 5.37 km and 15 minutes, respectively.[39] The highest and lowest monthly temperatures and the average humidity recorded per month in Bangladesh for each year of analysis were collected from the national meteorological department[40–42] and from the Time and Date official website.[43]

2.6 COPERT 5.5 output used for this study

COPERT 5.5 calculates the emissions of GHGs and pollutants in kilograms or tonnes for each vehicle category mentioned earlier in this paper, as well as the total emissions for all vehicle categories per year. The software provides estimates for a wide range of emissions, including arsenic (As), black carbon (BC), cadmium (Cd), methane (CH_4), carbon monoxide (CO), carbon

Table 10 Annual mileage and average speed of different vehicles[21]

	2004–2005		2016–2017	
Vehicle category	Annual km driven in 2004–2005 (km)	Average speed in 2004–2005 (km h^{-1})	Annual km driven in 2016–2017 (km)	Average speed in 2016–2017 (km h^{-1})
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

dioxide (CO_2), chromium (Cr), copper (Cu), elemental carbon (EC), mercury (Hg), nitrous oxide (N_2O), ammonia (NH_3), nickel (Ni), non-methane volatile organic compounds (NMVOC), nitrogen monoxide (NO), nitrogen dioxide (NO_2), nitrogen oxides (NO_X), lead (Pb), particulate matter with a diameter of 10 μm or less (PM_{10}), particulate matter with a diameter of 2.5 μm or less ($PM_{2.5}$), total suspended particulate matter (PM TSP), selenium (Se), sulphur dioxide (SO_2), volatile organic compounds (VOC), zinc (Zn), and more. COPERT generates yearly estimates for all of these greenhouse gases and pollutants. So when we carried out the analysis for 2016–2020, we did get the estimates for all of these pollutants. However, the primary focus of this paper is on carbon dioxide (CO_2) emissions because it is the only emission that can be compared with a reliable data source. Unfortunately, sufficient data is not available in the public domain to assess the accuracy of other greenhouse gases and pollutants estimated by COPERT. Additionally, the National Ambient Air Quality Standards (NAAQS) for Bangladesh, as provided in Table 1, use different units for emission limits, making it difficult to directly compare them with COPERT estimations. Therefore, this paper summarizes the total results for 13 major pollutants: CO_2, CO, CH_4, NO_X, SO_2, PM_{10}, $PM_{2.5}$, NO_2, N_2O, NH_3, NO, VOC, and NMVOC, and provides CO_2 estimations by vehicular categories, comparisons with World Bank data, and the latest emission factors for CO_2 for future research.

2.7 Methodological framework of COPERT 5.5

All information regarding the choice of method and algorithm of the software was found in the COPERT 5.5 guidebook published by the EEA (European Environment Agency).[15] COPERT consists of three methodologies: Tier 1, 2, and 3. Tier 1 is adopted if the mileage of vehicles is unavailable, and Tier 2 is adopted if it is available. Tier 3 is used when the average vehicular speed is available in addition to vehicular mileage.[15] The top-down approach (Tier 3 method) was used since Bangladesh had the necessary data from prior years. Using the Tier 3 method, it is possible to calculate emissions for urban roads, rural roads, and highways separately. But for Bangladesh, vehicular activity data for three different types of roads was not available; rather, the average data was collected by conducting field surveys on the National and Regional Highways and Zilla roads throughout all seven divisions of Bangladesh by the RHD,[21] so the total emissions for all types of roads were calculated. The application of the fundamental methodology of COPERT is briefly described in Fig. 1:

As the Tier 3 approach was employed, the total vehicular emissions were computed using eqn (2):

$$\text{Total vehicular emissions} = \text{hot emissions} + \text{cold-start emissions} \quad (2)$$

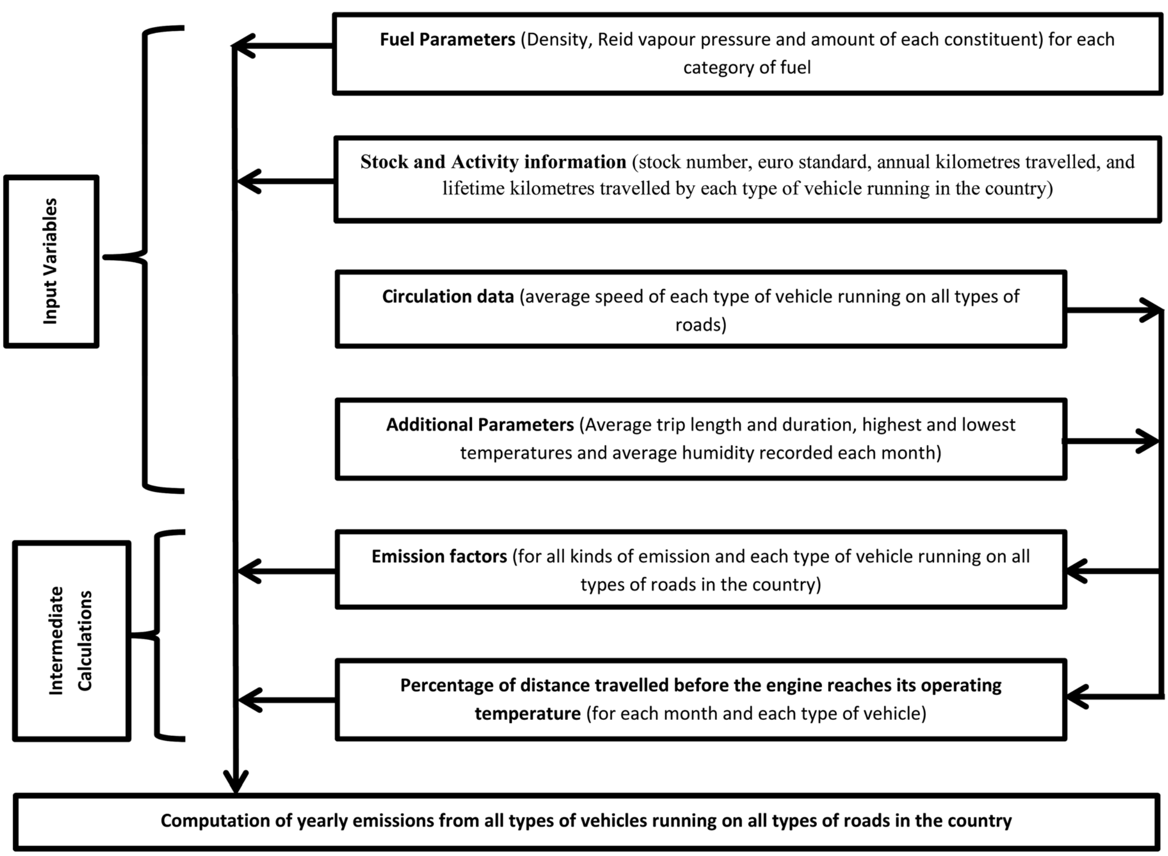

Fig. 1 Application of the fundamental methodology of COPERT.[15]

Here, "hot emissions" refers to the emissions released when the engine runs at its operating temperature. This is calculated using eqn (3):

$$\text{Hot emissions (gm)} = \text{emission factor (gm km}^{-1}) \times \text{quantity of vehicles running} \times \text{km travelled by vehicle (km)} \quad (3)$$

"Cold-start emissions" refer to the toxic gases released when the fuel is just ignited during the starting of the engine. Its calculation is briefly expressed in eqn (4):

$$\text{Cold emissions (gm)} = (\beta \times \text{number of vehicles running} \times \text{cumulative mileage of vehicle (km)} \times \text{emission factor (gm km}^{-1}) \times \text{(emission quotient-1)}) \quad (4)$$

Here, the β parameter is the portion of the distance travelled by the vehicle with the engine still cold, which is influenced by factors like ambient temperatures and the average trip length. The emission quotient is the ratio between the emissions per kilometre when the engine is cold and when it is hot. This is governed by the annual vehicular mileage and the type of pollutant under consideration. The calculation of the β parameter and emission quotient is extensively described in the algorithm given in the guidebook.[15]

For each year's COPERT analysis, different sets of emission factors were generated by using the particular average speeds, average trip lengths, temperatures, and humidity for the particular year of analysis. These coefficients were used by the software to calculate emissions. The emission factors of CO_2 using the data for present times are shown in Table 11. Although Euro 6 emission standards have not been widely adopted in Bangladesh, they have been included because regulations and standards can change over time, and Bangladesh may update their standards to reduce vehicle emissions to improve air quality. Using eqn (3), these emission factors can be utilized to calculate emissions manually. However, for calculation in the present time, a greater percentage of vehicles should be considered to be using older technology compared to newer technology because new emission standards are not fully

Table 11 Emission factors for CO_2 generated by COPERT 5.5 (unit: gm km^{-1})

RHD category	Fuel	Euro standard	CO_2	RHD category	Fuel	Euro standard	CO_2
Auto rickshaw	Petrol	Euro 4	238.558	Utility (jeep/pickup)	CNG bifuel	Euro 6 (a/b/c)	203.576
		Euro 5	238.558			Euro 6d-TEMP	203.565
		Euro 6 (a/b/c)	238.537	Small truck	Diesel	Euro 3	298.734
Tempo	Petrol	Euro 3	223.084			Euro 4	298.734
		Euro 4	237.083			Euro 5	275.197
		Euro 5	237.083			Euro 6 (a/b/c)	275.171
		Euro 6 (a/b/c)	237.062			Euro III	395.098
Car	Petrol	Euro 3	225.722			Euro IV	365.604
		Euro 4	230.053			Euro V	348.045
		Euro 5	230.053			Euro VI (A/B/C)	354.998
		Euro 6 (a/b/c)	230.032	Medium truck	Diesel	Euro III	788.967
Utility (jeep/pickup)	Petrol	Euro 3	315.791			Euro IV	722.907
		Euro 4	381.902			Euro V	719.765
		Euro 5	381.902			Euro VI (A/B/C)	718.705
		Euro 6 (a/b/c)	381.881	Heavy truck	Diesel	Euro II	954.601
Tempo	Diesel	Euro 3	206.959			Euro III	1001.591
		Euro 4	206.959			Euro IV	932.474
		Euro 5	206.959			Euro V	927.315
		Euro 6 (a/b/c)	206.933	Micro bus	Diesel	Euro III	699.299
Utility (jeep/pickup)	Diesel	Euro 3	270.71			Euro IV	646.558
		Euro 4	270.71			Euro V	630.773
		Euro 5	270.71			Euro VI (A/B/C)	643.012
		Euro 6 (a/b/c)	270.684	Mini bus	Diesel	Euro II	999.508
Auto rickshaw	CNG bifuel	Euro 4	267.113			Euro III	1048.697
		Euro 5	267.113			Euro IV	974.015
		Euro 6 (a/b/c)	267.091			Euro V	945.046
		Euro 6d-TEMP	267.081	Large bus	Diesel	Euro III	994.315
Tempo	CNG bifuel	Euro 4	214.239			Euro IV	948.473
		Euro 5	214.239			Euro V	933.114
		Euro 6 (a/b/c)	214.218			Euro VI (A/B/C)	950.801
		Euro 6d-TEMP	214.207	Mini bus	CNG	Euro I	1525.191
Car	CNG bifuel	Euro 4	182.225			Euro II	1415.459
		Euro 5	182.225			Euro III	1250.86
		Euro 6 (a/b/c)	182.204			Enhanced environmentally friendly vehicle (EEV)	1041.496
		Euro 6d-TEMP	182.193	Motorcycle	Petrol	Euro 1	84.124
Utility (jeep/pickup)	CNG bifuel	Euro 4	203.597			Euro 2	76.828
		Euro 5	203.597			Euro 3	63.214
						Euro 4	60.365

implemented 100% across the entire country, *i.e.*, it may take more time for the less developed part of the country to implement new emission standards.

3 Results and discussion

The quantity of total vehicular emissions of 13 major pollutants in tonnes from 2016 to 2019 found by analysis using COPERT 5.5 is given in Table 12:

The total quantity of CO_2 emissions yielded by COPERT 5.5 was 9578085.572 tonnes in 2016, 9794368.498 tonnes in 2017, 11057425.252 tonnes in 2018, 12137029.420 tonnes in 2019, and 10645714.566 tonnes in 2020. The quantity of CO_2 in tonnes released by auto rickshaws, tempos, cars, jeeps/pickups, small trucks, medium trucks, heavy trucks, microbuses, minibuses, large buses, and motorcycles from the years 2016 to 2020 computed by the COPERT 5.5 emission software is illustrated in Fig. 2.

CO_2 emissions were found to increase by 2.26% from 2016 to 2017, 12.90% from 2017 to 2018, 9.76% from 2018 to 2019, and from 2019 to 2020 it was found to decrease by 12.28%. The decrease from 2019 to 2020 was caused by the overall decrease in the number of vehicles registered[34] and the assumed increased vehicular speed[38] during that year because of the COVID-19 lockdown. Large buses, heavy trucks, small trucks, and motorcycles were found to contribute to the most significant quantity of CO_2 emissions from 2016 to 2020, with large buses being the biggest contributors, as shown in Fig. 2. From the World Bank official website, the total annual quantity of CO_2 emissions in Bangladesh was found for the years 1990–2020 (ref. 1) and the percentage of CO_2 emissions by the transport sector with respect to total fuel combustion in Bangladesh was found for the years 1971 to 2014.[2] The World Bank collected data regarding CO_2 emissions in Bangladesh from Climate Watch: Historical GHG Emissions in Washington, DC: World Resources Institute. Climate Watch collected GHG emissions from the transportation sector from the International Energy Agency (IEA).[44] The data sources and methodologies used are described on the Climate Watch website.[45] The percentage of CO_2 emissions by the transport sector in Bangladesh was reportedly 14.2% in 2014 (ref. 2) and 15% in 2020.[3] Therefore, the percentage of CO_2 emissions by the transport sector in Bangladesh was assumed to be between 14.2% and 15% of the total for the years 2016, 2017, 2018, 2019, and 2020. However, in order to determine the amount of CO_2 emitted by on-road

Table 12 COPERT 5.5 estimation of total vehicular emissions of 13 major pollutants in tonnes from the year 2016 to 2020

Pollutant name	2016	2017	2018	2019	2020
Carbon dioxide, CO_2 (t)	9578085.572	9794368.498	11057425.252	12137029.420	10645714.566
Carbon monoxide, CO (t)	60725.733	46283.221	53516.145	58650.085	63173.052
Methane, CH_4 (t)	2467.320	1579.135	1871.868	2135.419	2360.620
Nitrogen oxides, NO_X (t)	40476.589	44303.729	49189.194	54027.801	47914.282
Sulphur dioxide, SO_2 (t)	6545.365	5615.712	4592.637	3147.054	2685.699
Particulate matter 10 µm or less in diameter, PM_{10} (t)	2128.136	2060.452	2291.114	2506.291	2356.354
Particulate matter 2.5 µm or less in diameter, $PM_{2.5}$ (t)	1297.125	1255.524	1388.081	1526.293	1440.633
Nitrogen dioxide, NO_2 (t)	5382.343	5963.306	6607.738	7260.564	6558.400
Nitrous oxide, N_2O (t)	293.098	290.245	329.013	354.185	314.625
Ammonia, NH_3 (t)	171.197	152.833	173.846	188.829	175.543
Nitrogen monoxide, NO (t)	35094.246	38340.423	42581.456	46767.237	41355.882
Volatile organic compound, VOC (t)	10148.197	7766.205	9101.781	10234.170	10798.480
Non-methane volatile organic compound, NMVOC (t)	7915.279	6277.716	7329.793	8214.324	8589.907

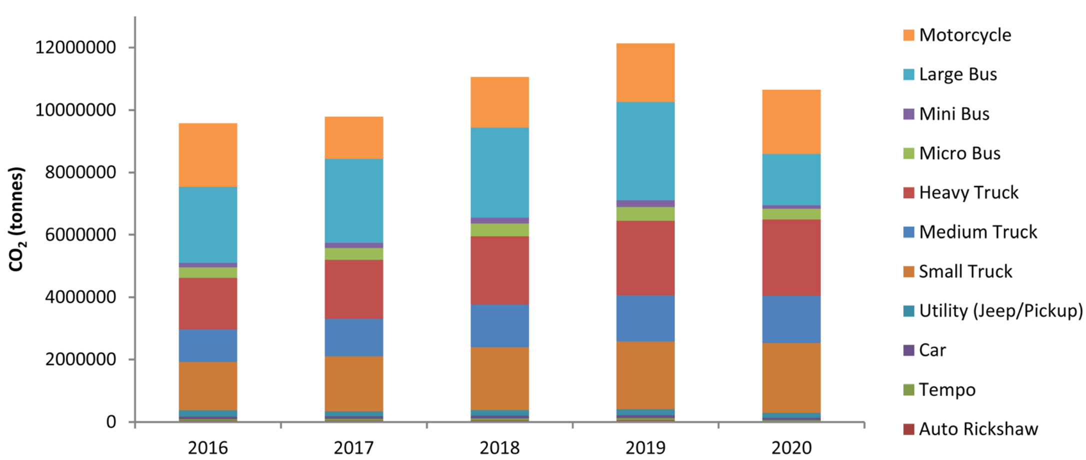

Fig. 2 Vehicular emission inventories of CO_2 from the year 2016 to 2020 in Bangladesh.

Table 13 Comparison between COPERT 5.5 results and estimations using World Bank data

Year	Total CO_2 emissions in Bangladesh from the World Bank[1] (tonnes)	Range of CO_2 emissions from on-road vehicles in Bangladesh (13% of total) (tonnes)	COPERT 5.5 output (tonnes)	Percentage deviation (%)
2016	81 129 000	10 546 770	9578085.572	9
2017	87 658 000	11 395 540	9794368.498	14
2018	95 945 000	12 472 850	11057425.25	11
2019	92 645 000	12 043 850	12137029.42	−1
2020	85 493 000	11 114 090	10645714.57	4

vehicles only, 10% of the amount of emissions from the transport sector was further deducted (7% from shipping and 3% from rail and aviation).[4] So the total amount of CO_2 emissions for a particular year calculated by COPERT 5.5 was checked against 13% (approximately 90% of the average between 14.2% and 15%) of the total CO_2 emission data from the World Bank for that particular year. The comparison between the results obtained from COPERT 5.5 and the values of CO_2 emissions from on-road vehicles in Bangladesh estimated from the World Bank data is summarized in Table 13:

4 Conclusions

The percentage deviation of CO_2 emissions found using COPERT 5.5 from estimations using World Bank data was found to be approximately 9% for the year 2016, about 14% for the year 2017, about 11% for the year 2018, about −1% for the year 2019, and about 4% for the year 2020, all of which are below 15%. Therefore, the results of this study suggest that COPERT 5.5 may be a suitable emission model for Bangladesh.

This study established the applicability of the COPERT model for Bangladesh, which will inspire academics to carry out broad research work by making the most of this software. This is vital for a country like Bangladesh, where it is essential to impose new rules related to vehicular emission standards and also to raise public awareness regarding the emission crisis. This study also appeals to the automotive industries of a developing country like Bangladesh to focus on quality over quantity, *i.e.*, to shift towards cleaner technology.

From the comparative analysis of the emission characteristics of different types of vehicles, it was found that large buses, heavy trucks, small trucks, and motorcycles contributed to the most significant quantity of CO_2 emissions. Thus, this paper attempts to discourage the use of the aforementioned vehicles and possibly aid the public in selecting a motorized vehicle that is less detrimental to the environment. Apart from the obvious benefits of the decrease in traffic congestion, like the decrease in travel time, it acts as an emission control measure in and of itself. If 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 policymakers to mandate the replacement of heavy trucks, large buses, medium trucks, and small trucks with those of improved technology (a higher Euro standard) in order to produce fewer emissions and thus bring about a deceleration in the inevitable worsening of the air quality in Bangladesh.

One major challenge of our study was the lack of updated information regarding the 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 from COPERT 5.5 for present times, it is important that the government carry out a study of current vehicle activity, fuel type, and technology type. Moreover, it is vital to simultaneously check the results of the models by carrying out manual testing of emissions from vehicles in Bangladesh using suitable machines (ex: PEMS), so this study strongly appeals to the authority to invest in this machinery. To successfully establish a suitable vehicular emission model for Bangladesh, researchers are recommended to test out further available emission software developed by other countries to determine if the algorithm of any other software suits Bangladesh better than that of COPERT 5.5 and ultimately develop an emission model specifically for Bangladesh.

Author contributions

All authors confirm equal contributions to the paper in the study conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, supervision, validation, visualization, roles/writing – original draft, writing – review & editing of the study.

Conflicts of interest

There are no conflicts to declare.

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