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Assessing the Environmental Effects of Road Traffic CO_2 Emissions: A Review

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Abstract:

Road transportation is one of the key contributors to greenhouse emissions globally, especially carbon dioxide (CO_2), which plays a vital role in speeding up climate change. As a result of rapid urbanization with a rise in car ownership, emissions from road traffic have emerged as a critical environmental challenge in many cities around the world. In this study, a systematic literature review on the environmental impacts of road traffic emissions of (CO_2) and the factors affecting these emissions is conducted. The review assesses previous studies based on traffic intensity, vehicle characteristics, fuel types, and operating conditions affecting emission variability. Additionally, it assesses the widely applied emission estimation methods and conventional traffic emissions models, including average speed models, traffic situation models, and modal models. The findings of the analysis show that urban traffic density, vehicle technology, and fuel types are major determinants of emission levels. In addition to (CO_2), other pollutants emitted by road transportation include nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC), and black carbon (BC), which are all major contributors to air quality and human health issues. The review also identifies the importance of policy interventions, technology innovations, and alternative energy sources in addressing transportation emissions. The study concludes that transportation planning, cleaner vehicles, and stricter emission controls are vital for minimizing environmental impacts and paving the way for sustainable transportation systems in cities.

Keywords: Roadway, CO2 emissions, sustainable, transportation, traffic, pollution

1. Introduction

Transportation is a fundamental concept in economic development, enabling the movement of human beings and goods from one place to another [1]. Nevertheless, the rapid increase in urbanization and motorization has led to a notable increase in greenhouse gases, specifically (CO_2), which is perceived to be a contributor to climate change [2]. Road transportation represents one of the largest sources of (CO_2) emissions within the transport sector due to the widespread use of private vehicles and fossil-fuel-based energy systems. As cities continue to expand, traffic congestion, increased travel demand, and inefficient vehicle technologies further intensify environmental pollution and energy consumption [3,4]. In fact, every nation in the globe uses vehicles as a means of obtaining or transferring a variety of items, regardless of their size. People can determine how much gas each vehicle emits by measuring its (CO_2) emissions. This relates to lifestyle choices that could progressively harm the environment, particularly with regard to changing the climate [5,6]. The road network is largely responsible for gas emission. The effort for reducing energy demand as quickly as possible makes the case for transitioning to zero emission much stronger and more obvious [7,8,9]. About one-third of all consumption in the European Union comes from the road and transportation network, making it the biggest consumer. The European Green Deal (EU)[10] set the objective of achieving climate neutrality by 2050 and an ambitious interim target of reducing net greenhouse gases (GHGs) emissions by at least 55% by 2030 relative to 1990 levels. According to the Paris Agreement, this is consistent with the EU's commitment to global climate action [8, 10]. Electric automobiles are frequently thought of as an eco-friendly mode of transportation, the emissions they emit depend on the fuels used in the region where they are utilized. Vehicles that are primarily powered by renewable energy sources may be referred to as "climate-friendly" or "100% ecological" [11]. Certain emission chains, such as production, generating energy and operation, have only been the focus of certain research. Given the complexity and depth of the issue, there is a great demand for an exhaustive study that can assist in evaluating of environmental implications of (CO_2) emissions from different vehicles. This research is a step in that direction [12,13]

Several studies have investigated the environmental impacts of transportation-related emissions and the factors influencing (CO_2) emissions from road traffic. Previous research has focused on individual aspects such as vehicle technology, fuel types, traffic flow characteristics, and emission estimation methods. In addition, numerous emission models have been developed to estimate vehicle emissions under different traffic conditions. Despite these efforts, existing studies often address these aspects separately, and a comprehensive synthesis of the factors influencing road traffic (CO_2) emissions and the estimation models used in urban environments remains limited [14,15]. Thus, it is necessary to carry out a systematic and integrated review of the factors which influence road traffic (CO_2) emissions and the methodologies applied in their estimation. The comprehension of the interrelation between these two concepts is essential in formulating adequate policies and strategies in addressing environmental issues related to transportation activities.

The novelty of this study is in presenting a holistic synthesis of the key factors affecting (CO_2) emission from urban road traffic, as well as presenting and comparing the major emission estimation models applied in transportation studies. Unlike previous studies, which either focus on emission factors or modeling approaches, this study aims to integrate these two aspects to improve the understanding of the underlying mechanisms of traffic emissions. Thus, the objectives of this study are:

1. Identify and analyze the most important factors affecting (CO_2) emissions in road traffic in urban areas.
2. Compare the most used methods and models for calculating emissions in road traffic.
3. Examine the effects of emissions in road traffic, including (CO_2) and other connected pollutants, on the environment.

4. Indicate some possible ways for mitigating emissions in road traffic and promoting sustainable transport solutions.

2 .Methodology

In this study, a systematic literature review approach is employed to analyze the environmental impacts of (CO_2) emissions in road traffic and the methodologies employed for emissions estimation. Systematic review is one of the methodologies employed for analyzing and studying the problem in a transparent, systematic, and reproducible manner.

2.1 Literature Search Strategy

The literature search is conducted using various prominent online journals like Scopus, Web of Science, ScienceDirect, and Google Scholar. The literature search is conducted based on peer-reviewed journals, conference publications, and review articles related to emissions in road traffic and transportation impacts on the environment.

The following keywords are employed in the literature search process: Road traffic (CO_2) emissions, traffic emission models, vehicle emission estimation, transportation carbon emissions, and urban traffic pollution. The literature search is conducted for the period between 2010 and 2025.

2.2 Study Selection Criteria

To ensure the relevance and quality of the studies included in the review, the following criteria were used:

1. Research focused on the issue of (CO_2) emission from the road transportation system.
2. Research dealing with factors affecting the emission from the traffic system.
3. Research discussing the method of estimating the emission from the traffic system or the traffic emission model.
4. Research published in a peer-reviewed journal or scientific conference proceedings.

Studies that are not related to road transport emission or lack sufficient methodological details were excluded

3 .Factors of (CO_2) Emissions in Urban Area

To design the most appropriate strategies to reduce the level of CO_2 emissions due to road traffic, it is crucial to understand the factors that determine the level of these emissions. From the literature, it has been found that there are several significant factors that affect the level of (CO_2) emissions in the urban area. These factors include, intensity of the traffic, characteristics of the vehicles, operational conditions, and environmental factors. However, the level of contribution of these factors differs in various studies due to the differences in the methodologies, geographical area and traffic condition [15,16].

3.1 Intensity of Traffic

The number of trips taken over a particular distance is one of the factors taken into consideration while determining the density of the traffic; therefore, the increase in the activity of the traffic results in the increase of the level of harmful carbon emission. Total emission in the urban roadway is often determined by multiplying of the vehicle traveled distance (VTD) by emission factors (EF), Excessive VTD results in the increase of pollution level [16]. However, it is possible that such reliance on traffic volume as an emission level indicator could be simplistic approach to the complex nature of urban traffic systems. Based on some studies conducted on this topic, it can be argued that aspects concerning the flow of traffic, such as stop-and-go driving or congestions, might be more significant for emissions than the actual number of vehicles on the road. Hence, the role of traffic flow on emissions might be underestimated by emission estimates based on this approach alone [17].

3.2 Types of Vehicles and Energy

The characteristics of vehicles, such as the type of engine, age, size, and type of fuel used, have a significant influence on the level of emissions produced by the vehicles. Studies show that vehicles that are old and have inefficient combustion mechanisms tend to produce higher amounts of emissions compared to newer vehicles that have met the required standards

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on environmental protection. The type of fuel used is also instrumental in determining the environmental effects of transportation systems [18,19]. Another significant factor is the type of energy used, such as electricity and fossil fuels. The vehicle and energy sources must be taken into account in the emission models because electric vehicles have relatively lower environmental consequences [20,21, 22].

3.3 Operating Circumstances

Emissions are also significantly affected by the modes of operation of vehicles, such as accelerating, cruising, decelerating, and idling. Among these, the highest rates of carbon emissions occur during accelerating, while idling, with no speed and constant fuel consumption, has the highest emission factors [23]. The average speed, level of congestion, and density of vehicles also affect the level of emissions. The zones with the highest level of emissions are normally identified as the areas with the highest number of intersections with stop and go traffic [24, 25].

3.4 Alternative Factors

(CO_2) emissions also depend on other environmental and infrastructural factors. Although meteorological factors such as the ambient temperature and altitude have some effects on fuel efficiency and combustion, which in turn affects the level of emissions, the slope of the roadway can also affect the engine load and fuel consumption [26-29].

4. Methods of estimation CO_2 Emissions

The precise calculation of emissions from (CO_2) by road transportation is vital in understanding the impacts on the environment from traffic systems. Various techniques for estimating emissions from traffic systems have been developed, each with different demands in terms of data requirements and computational complexities in spatial or temporal resolution. The techniques can be categorized mainly into two groups: top-down approaches and bottom-up approaches [30,31].

4.1 Top-Down Emission Estimation Methods

In top-down approaches, emission estimation is performed using aggregated data like fuel consumption statistics or energy inventory data for a region. In these approaches, total emissions are calculated based on macro-level data. These approaches are usually employed for emission inventory development. Total emissions are usually calculated by multiplying total fuel consumed by emission factor data for different types of fuels. Since these approaches are based on aggregated data; therefore, they are easy to apply and require minimal traffic-specific data. However, the main limitation of these methods is the lack of detailed information on traffic dynamics, for example, how vehicles move, how congested they are, and how they are operated. Thus, top-down methods are more suitable for performing large-scale emission assessments rather than in-depth analysis of urban traffic dynamics [30].

4.2 Bottom-Up Emission Estimation Methods

Bottom-up approaches use data on traffic activity to compute emissions. They use details such as how far vehicles are traveling, traffic flow, type of vehicles, and driving conditions. Using such detailed data on traffic activity, it is possible to obtain accurate results for local or city-level scales. One widely used bottom-up approach is based on the distance traveled by vehicles, which is referred to as vehicle traveled distance (VTD) and vehicle kilometers traveled (VKT). In this method, the total amount of emissions is calculated by multiplying the distance traveled by the vehicles by the emission factor corresponding to specific vehicles. This method has been widely applied in the field of urban transport and provides a more detailed analysis of the emissions generated by traffic [31].

According to [32], vehicles worldwide can apply an approach that yields in the acquired data. This relates to modern technology, which is becoming more advanced in order to support the development of environmentally friendly vehicles and serve as the foundation for long-distance transportation. Companies and technicians working in the equipment business can be instructed to create fewer vehicles with (CO_2) emissions when this technique is adopted and extended to other vehicle types. This implies they must provide the issue more careful thought.

It is strongly linked to a number of factors, such as the volume of traffic flow, the vehicle's speed, internal components like equipment, the vehicle's age, the engine used, the energy capacity required and expended, and significant vehicle components that affect fuel consumption [30]. In addition, the other source clarified that the vehicle's kilometers can be used as prediction information. Due of the prevalence of transportation use in developing nations, certain Southeast Asian nations can adopt this strategy [33]. Since it has been used for estimating, the method—which uses the kilometers of each vehicle—would be changed to a different policy while maintaining the same strategy. Indonesia offers more than just estimates of (CO_2) emissions. The same variables are included in the district of Tampan, Pekanbaru, Riau, which has its own calculating system [34].

The estimation of (CO_2) emissions, especially in China, also shows that the closer people are to their place of employment, the easier it is for them to get there, and the less gas is released. Actually, the region's (CO_2) emissions have decreased as a result of train access [35]. Additionally, this guarantees that next generations will be able to develop the most recent concepts, theories, and inventions regarding the replacement of fuel which is constantly being utilized in attempt to create a fuel that is easily accessible, renewable, and environmentally friendly.

The USA has developed renewable energy that can withstand the effects of emissions [32]. In this instance, it additionally specifies that in order to lower the gas emissions that take place. Filtering motorized vehicles is one way to achieve this. According to sources that conduct research in Indonesia, this is corroborated by high traffic volumes and shows mapping findings with concentrations of gas emissions [36,37].

In reality, the measurement is used not just in large cities but also in underdeveloped nations with a large number of vehicle users who are hooked and cannot be separated by humans. The MOBILE Software and vehicle traveled distance (VTD) have distinct variables to estimate. When people can accomplish their goals more quickly, all of the tasks may become simpler.

5. Conventional Models of Emissions

Traffic emission models can be broadly divided into two groups: traditional models based on mathematical or physical principles, which are used by government agencies and organizations, and data-driven models, they have recently become more well-liked because of their capacity to adapt to particular data situations and application requirements.

According to Smit's [38] concept, traditional models are further categorized in this study into average speed, traffic scenario, and modal models. Other classification techniques in study include classifying models as white-box, gray-box, and black-box models according to their degree of interpretability, or as macroscopic, mesoscopic, or microscopic based on their application [39]. Even the often-used macro-meso-micro classification is still debatable, and there isn't yet a system of categories that is broadly recognized [40].

5.1 Models of Average Speed Emissions

Based on the average speed of vehicles, average speed emission models calculate overall emissions. Usually, these models are used to evaluate long-term trends and aggregate emissions at the national or urban levels. The Computer Program to Calculate Emissions from Road Transportation (COPERT), Emission Factor (EMFAC), and Mobile Source Emissions Factor (MOBILE) are representative examples.

The European Environment Agency is responsible for monitoring the COPERT tool, which is the official tool used by the EU to calculate vehicle emissions [41]. The tool can be used to calculate vehicle emissions as well as energy consumption by inputting information such as the composition of the vehicle fleet, the total distance traveled, the speed at which the vehicles were moving, and the temperature. The tool identifies three main sources of vehicle emissions as gasoline evaporation, cold starts, and hot engine operation. The emission factors are predicted using regression functions that depend on speed [42].

In California, Air Resources Board (CARB) created the EMFAC model, which is often used to evaluate on-road vehicle emissions. It includes calibration parameters that take into account local environmental elements, vehicle requirements, and operating conditions, and it defines emission factors for a range of speeds (usually at intervals of 5 m/s) [43]. Similar to EMFAC, the MOBILE model was created by the U.S. Environmental Protection Agency (EPA), although it hasn't been upgraded since (2004) and doesn't account for (CO_2) emission predictions [44].

5.2 Models of Traffic Situation

By examining actual vehicle operation patterns, traffic situation models correlate emission factors to particular driving situations [37]. These models usually categorize traffic conditions according to many emission parameters, such as region, road type, speed limit, and level of service [45]. Handbook Emission Factors for Road Transport (HBEFA) is a typical model. The European Commission supports (HBEFA), which is the standard model for analyzing road pollutants. It categorizes emissions according to a number of factors, such as road slopes, vehicle categories, years, contaminants, traffic situations, and emission types [46]. A portion of the emission factor data utilized in the COPERT model is also provided by HBEFA [47].Figure 1 provides a comparative summary of COPERT, EMFAC, MOBILE, and HBEFA in terms of their input requirements, supported vehicle and energy types, road categories, and model versions in order to illustrate the similarities and differences between popular conventional emission models.

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Model	COPERT	EMFAC	MOBILE	HBEFA
Input	Average speed, vehicle fleet composition, vehicle activity, weather condition, etc.	Average speed, vehicle fleet composition, vehicle activity, weather condition, etc.	Average speed, vehicle fleet composition, vehicle activity, weather condition, etc.	Average speed, vehicle fleet composition, vehicle activity, gradient, weather condition, etc.
Spatial Scale	National, Regional, local, link	Regional, project level	National, local	City, project level
Time Scale	Year, month, week, day, hour	Year, season	Year, season, month, day	Year, month, week, day, hour
Vehicle Type	Passenger car, light-duty, heavy-duty, urban buses & coaches, motorcycle	Passenger car, light-duty, heavy-duty, motorcycles, medium-duty, buses, motorcycle	Passenger car, motorcycle, light and heavy-duty truck	Passenger car, light commercial vehicles, heavy-duty truck, urban buses & coaches, motorcycle
Energy Type	Gasoline, diesel, liquefied petroleum gas	Gasoline, diesel, natural gas, electricity	Gasoline, diesel	Gasoline, diesel, electricity
Road Type	Urban, rural & highway	/	highway	Motorway, rural, urban, overall average
Driving Cycle	European Countries	FTP, California Unified Cycle	Different Countries	European Countries
Version	COPERT 5.8 (2024)	EMFAC (2021)	MOBILE 6.2 (2004)	HBEFA 4.2 (2022)

Figure 1. COPERT, EMFAC, MOBILE and HBEFA models comparison. [42,43,44,47]

5.3 Modal Models

By dividing vehicle operation into several modes based on variables including speed, acceleration, and engine revolutions per minute (RPM), modal models calculate vehicle emissions. Each mode is associated with an emission rate function that takes fuel parameters, vehicle type, and technology into consideration. These models are also known as instantaneous speed models since they function at a high temporal resolution (1Hz), allowing per-second prediction of vehicle modes and their corresponding factors related to emissions [48-50]. In addition to numerous microscopic emission models like the Virginia Tech microscopic energy and emission model (VT-Micro) and the Passenger Car and Heavy-Duty Emission Model (PHEM), popular modal models include Motor Vehicle Emission Simulator (MOVES), Comprehensive Modal Emission Model (CMEM), and International Vehicle Emissions (IVE).

The U.S. EPA created the MOVES model, an accurate approach that functions at the macro and micro levels. Vehicle Specific Power (VSP) and vehicle speed categories are used to define vehicle emission rates under various operating modes. The engine's power requirement to overcome all driving obstacles, such as slope resistance, aerodynamic drag, tire resistance, and acceleration resistance, is represented as (VSP) [51-55]. The MOVES model uses the emission performance of traffic flow on a particular road section using distribution of vehicle operating modes. The University of California created the (IVE) model with the intention of simulating motor vehicle emissions in developing nations. It uses engine load (ES) categories and (VSP) to quantify emissions.

The EPA and the National Cooperative Highway Research Program (NCHRP) funded the CMEM model. Acceleration, air/fuel equivalency ratio, fuel rate, speed, road slope, and auxiliary load are among the inputs used by this model. Researchers tested 300 real-world vehicles utilizing dynamometers to gather data for modeling [56-57.] The six primary modules of the CMEM model are in charge of forecasting engine power, speed, air/fuel ratio, fuel consumption, emissions, and catalyst conversion efficiency. Figure 2 summarizes a comparison of the MOVES, IVE, CMEM, PHEM, and VT-Micro models.

Model	MOVES	IVE	CMEM	PHEM	VT-Micro
Input	Vehicle operation mode, vehicle fleet composition, vehicle activity, weather condition, etc.	Vehicle operation mode, vehicle fleet composition, vehicle activity, weather condition, etc.	Physical parameters (engine capacity, vehicle mass, maximum power, torque, etc.)	Speed and gradient profiles of vehicles	Speed profile of vehicles
Spatial Scale	National, Regional, Project level	National, regional, local, link	Vehicle-level	Vehicle-level	Vehicle-level
Time Scale	Hour, day, week, month, year	Hour, day, week, month, year	Real time or instantaneous	Real time or instantaneous	Real time or instantaneous
Vehicle Type	Passenger car, trucks, buses, motorcycle, motorhomes	Bus, truck, small engine, motorcycle	Car, truck	Passenger car, light-duty, heavy-duty, buses, motorcycle	Light duty vehicle and trucks
Energy Type	Gasoline, diesel, CNG, LPG, electricity, ethanol	Gasoline, diesel, NG, ethanol, propane, CNG and LPG	Diesel, gasoline	Diesel, gasoline	Diesel, gasoline
Road type	Rural, Urban	/	/	/	/
Driving Cycle	Different countries	Developing countries	FTP, US06, MEC01	European countries	FTP
Version	MOVES 5.0 (2024)	IVE (2007)	CMEM 3.0 (2005)	Continuously updated	VT-Micro 2.0 (2004)

Figure 2: The comparison of MOVES, IVE, CMEM, PHEM and VT-Micro models [49,50,51,54,55]

5.4 Comparison of Conventional Emission Models

Over time, several conventional models have been developed for estimating road traffic emissions. However, the accuracy of such models depends significantly on the amount and type of data available and the traffic conditions. All the models carry certain advantages and disadvantages that influence its applicability.

5.4.1 Model Accuracy

Microscopic models such as CMEM, PHEM, and VT-Micro are found to be more accurate in estimating emissions because they consider the detailed characteristics of vehicles in motion. The detailed characteristics are based on the acceleration rates, speeds of the vehicles and engine load. However, the accuracy of such models depends on the availability of accurate and detailed traffic data, which is not always possible to obtain such data [17, 24, 56].

In comparison, macroscopic models such as COPERT, EMFAC, and MOBILE using inputs such as average speed of vehicle and fleet composition to estimate emissions. They are less detailed but more commonly used because they require less information and are computationally faster. However, the downside of such an approach is that it does not capture the complexities of traffic in busy urban areas, particularly where there are many stops and starts condition [37, 57].

5.4.2 Model Limitations

Despite their popularity, these traditional emission models are accompanied by some significant disadvantages. In the case of macroscopic models, it is difficult to account for the impact of driving behaviors and traffic congestion on emissions. Consider average speed approaches, for instance; these may underestimate emissions in congested traffic since acceleration and deceleration are not well accounted for [17, 39].

A microscopic approach is more detailed, but it requires a significant volume of input data, including vehicle paths, speed profiles, and engine characteristics. The difficulty and expense of handling such detailed data limit the application of microscopic models to traffic networks with many vehicles. several emission models based on different driving cycles and vehicle fleets in different regions are developed. This makes the emission models less portable from one region to another. Fuel types and vehicle types can have a great impact on the performance of the emission models [47, 57].

5.4.3 Model Applicability

The selection of an appropriate emission model depends to a large extent on the objectives of the study and data availability. When it comes to large-scale emission inventory studies, macroscopic models are generally preferred since these are easily implemented when working with aggregated traffic data. However, in situations where there is a need to offer a balance between model complexity and accuracy, traffic situation or mesoscopic models like HBEFA are useful since they take into account traffic condition without requiring too much data to be available [17].

For in-depth simulation of traffic, microscopic models can be very helpful, especially when the traffic management strategies, eco-driving strategies, and the performance of vehicle technologies have to be tested. These models perform best when the focus is on the simulation of the emissions from particular road segments and vehicles. In general, there isn't a single emission model that is always better. Rather, each model represents a trade-off between accuracy, data requirements, computational complexity, and application; as a result, the particular research objectives and data availability should be taken into consideration when choosing an appropriate model [39,57].

6. Results of the Literature Review

The analysis of the selected studies reveals distinct and consistent patterns in road traffic (CO_2) emissions and factors influencing changes in their levels within cities. The literature can be categorized into two major themes: first, environmental impacts of passenger vehicle emissions, and second, all types of pollutants resulting from urban road transport infrastructure.

6.1 Environmental Impacts of Passenger Vehicle Emissions

The literature identifies that passenger vehicles are always cited as a major source of emissions in urban transportation. As cities are growing at a fast rate and more people are using vehicles for transportation, the amount of (CO_2) emissions from traffic is increasing at a rapid rate. Various studies have emphasized that urban transportation systems play a critical role in determining emission levels due to factors such as travel demand, land-use patterns, and transportation infrastructure.

Earlier studies indicate that the integration of land use and transportation planning can lead to the reduction of emissions caused by traffic. For instance, the strategies include improving public transport, promoting transit-oriented development, and reducing the use of personal vehicles. These strategies are widely accepted as effective measures towards promoting low-carbon urban mobility. For example, many countries have set long-term targets towards mitigating the effects of climate change, particularly on transportation and promoting the sustainability of urban mobility. [58-60] as shown in Table 1.

Table 1. Comparative Environmental Features of the Main Types of Vehicles.

Vehicle Type	**Energy Source**	**CO_2 Emission Level**	**Key Pollutants**	**Environmental Effect**
Gasoline passenger vehicles	Gasoline	High	CO, HC, BC	Major contributor to urban traffic emissions
Diesel vehicles	Diesel fuel	High	NOx, PM, BC	Significant air quality impacts in urban areas
Hybrid vehicles	Gasoline + electric	Medium	Lower CO_2	Improved fuel efficiency and reduced emissions
Battery electric vehicles (BEVs)	Electricity	Low	Minimal direct pollutants	Emissions depend on electricity generation mix

6.2 Road Transportation-Related Pollutants

In addition to (CO_2) emissions, road transportation generates several other pollutants that significantly affect urban air quality. These pollutants include nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC), and black carbon (BC). The reviewed studies indicate that the emission characteristics of these pollutants vary depending on vehicle type, fuel technology, and traffic conditions.

Black carbon emissions are particularly important because of their strong influence on both climate change and air quality. Studies suggest that gasoline-powered passenger vehicles can contribute significantly to (BC) emissions due to incomplete combustion processes. Driving conditions such as acceleration, congestion, and stop-and-go traffic patterns have also been shown to increase the emission rates of several pollutants

Based on the findings by [61], it demonstrates that passenger vehicles notably gasoline-powered vehicles considerably add to (BC) emissions compared to heavy duty vehicles. Therefore, these private vehicles (PV) are crucial in lowering (BC) emissions in metropolitan areas. Furthermore, the results demonstrate that driving circumstances and fuel use are major factors in (BC) emissions.

From the findings, it can be concluded that the emissions from passenger vehicles on different types of roadways are quite different from each other. In an urban area, diesel-powered vehicles emit more (No_x) emissions compared to gasoline-powered vehicles. This occurs because the vehicles keep on starting and stopping. Moreover, gasoline-powered vehicles emit the highest amounts of (CO) and (HC) emissions on highway roads, thus road conditions and vehicle characteristics are two factors that influence the emissions from passenger vehicles [60-62].

6.3 Evolution of Emission Modeling Approaches

The reviewed literature also shows a clear evolution in emission estimation methods over time. Early studies primarily relied on macroscopic emission models based on aggregated traffic parameters such as average vehicle speed and vehicle kilometers traveled (VKT). These models were widely used because they require relatively simple input data and are suitable for large-scale emission inventories.[58]

More recent research has increasingly focused on microscopic and modal emission models that incorporate detailed vehicle operating conditions, including speed, acceleration, and engine load. Models such as MOVES, CMEM, IVE, and PHEM are capable of capturing real-world vehicle dynamics more accurately, which improves the reliability of emission estimates. However, these models also require high-resolution traffic data and greater computational resources. Overall, the literature indicates that emission modeling approaches have gradually shifted toward more detailed and data-intensive techniques in order to better represent the complexity of real-world traffic systems.[59]

7. Discussion

According to this study, the most serious environmental problem with detrimental effects is the increase in (CO_2) emissions from consumption in large cities. In order to avoid air pollution and unfavorable climate impacts, it is essential to reduce emissions from these vehicles.

7.1 Life-Cycle Effects

Life-cycle assessment (LCA) studies indicate that vehicle emissions should also consider upstream processes such as vehicle manufacturing, fuel production, and electricity generation. In the case of electric vehicles (EVs), present an intriguing key reducing pollution with an emphasis on an even more efficient use in terms of energy compared to combustion engine vehicles. This is because (EVs) are driven using electric motors. This enables them to convert electrical energy to kinetic energy, therefore require less energy per mile traveled, although operational emissions are significantly lower than those of conventional internal combustion engine vehicles, their overall environmental performance depends on emissions associated with electricity production and battery manufacturing [63].

There are several regulations in place formed to minimize the emissions from automobiles. These restrictions include the efficiency of fuels and pollution limits to encourage the use of public transit. As stated by [64], the promotion of other modes of transportation, including walking and biking, can effectively reduce the emissions from fast trips, which are often made by private cars. But due to topographic characteristics, the public transit infrastructure varies from the newly industrialized nations.

7.2 Energy Mix Considerations

The effectiveness of emission reduction strategies in transportation is strongly influenced by the energy mix used for electricity generation. In countries where electricity production is dominated by coal-based power plants, the indirect emissions associated with electric vehicles may significantly reduce their environmental benefits. Conversely, in regions with a high share of renewable energy sources, the adoption of EVs can lead to substantial reductions in greenhouse gas emissions [65]. This relationship highlights the importance of integrating transportation policies with energy sector decarbonization strategies. Without simultaneous reductions in the carbon intensity of electricity generation, the potential emission reductions from electrified transportation systems may remain limited [66].

According to [67], the government can benefit if they urge corporations to enhance the fuel economy of their vehicles. This can lead to the development of fuel-efficient vehicles, thereby ensuring the fuel economy standards remain within the comprehensible range that could indirectly reduce emissions. As per previous studies, the application of alternative fuels such as compressed natural gas (CNG) or hydrogen can lead to the reduction of emissions [60]. especially in developing countries, the application of alternative fuel sources can increase sustainability, thereby reducing the emissions associated with the transportation sector.

7.3 Uncertainties in Traffic Emission Estimates

The uncertainty within emission estimation models is one of the main obstacles in transportation emission assessments. Simplified assumptions about vehicle activity, average speed, and emission parameters are the foundation of many widely used models. However, due to factors like traffic congestion, driving habits, weather, and road infrastructure, real-world driving circumstances frequently differ greatly.[17, 24]

For instance, in crowded urban settings where vehicles often accelerate and decelerate, macroscopic models relying on average vehicle speed or aggregated traffic data may underestimate emissions. Microscopic emission models, on the other hand, can increase accuracy but need high-resolution traffic data since they include specific vehicle operating characteristics including acceleration, engine load, and speed changes. It is therefore challenging to acquire accurate emission estimates in complex urban transportation systems due to uncertainty arising from both data availability and model construction [68,69].

7.4 Traffic Emissions Variability by Region

Significant regional variation in road traffic emissions is also shown by the analyzed research. Regional differences in emission levels are caused by differences in fuel regulations, urban planning, transportation strategies, and the structure of the vehicle fleet. For example, compared to cities that mainly rely on older internal combustion engine automobiles, cities with higher percentages of electric vehicles, public transportation, and tougher pollution regulations typically have lower per-vehicle emissions. In the same way, older vehicle fleets, weaker fuel quality regulations, and increased traffic congestion frequently result in greater emission levels in developing countries.[24,68]

The total environmental advantages of alternative vehicle technologies are also influenced by regional variations in energy generation sources. The indirect emissions linked to electric vehicles could reduce their potential environmental benefits in areas where fossil fuels are the primary source of electricity. Conversely, in areas with a higher share of renewable energy sources, vehicle electrification can significantly reduce greenhouse gas emissions.[70]

8. Conclusions

This review examined the main factors influencing (CO_2) emissions in urban road transportation and critically analyzed existing emission estimation methods and conventional emission models. The issue of (CO_2) emissions from various vehicles within the urban areas is also something that should be addressed because these emissions contribute largely to the deterioration of the environment and climate change. To establish a sustainable cities and transport systems, policy initiatives such as the development of green technology and the tracking of emissions regulations play important roles because they raise awareness among people on the utilization of environmentally friendly vehicles. The government can also achieve its goal of zero emissions through the utilization of clean fuel and technologies.

The review also highlights that different emission estimation methods exhibit distinct advantages and limitations depending on their modeling structure and data requirements. Macroscopic models, such as COPERT and EMFAC, are widely used for national and regional emission inventories due to their relatively simple implementation and low data requirements. However, these models often rely on aggregated traffic parameters and may fail to capture detailed driving dynamics in congested urban environments. In contrast, microscopic and modal emission models, including MOVES, CMEM, IVE, PHEM, and VT-Micro, provide more accurate emission estimates by incorporating detailed vehicle operating conditions such as speed, acceleration, and engine load. Despite their higher accuracy, these models require high-resolution vehicle trajectory data and substantial computational resources, which may limit their applicability in large-scale traffic networks.

Recent developments in data-driven and machine learning models have brought in new avenues to enhance the accuracy of emission estimation models. These models are found to have the potential to deal with complex nonlinear relationships between traffic variables and emission output variables. However, at the same time, it is found from the literature that there are some limitations associated with data interpretability and data requirements for using these models.

Based on the analysis of the literature reviewed in this study, some of the gaps in emission estimation models are found to be significant. First, emission models are mostly developed using data specific to a particular region. This creates a limitation in using the models for other regions with different traffic patterns, vehicle fleets, and fuel characteristics.

Second, there is no specific framework to evaluate emission models under a standard condition. This creates a problem in selecting the appropriate emission models for specific applications.

Thirdly, there is still an emerging area of research with regard to integrating emission estimation models with real-time traffic monitoring systems and intelligent transportation systems.

In terms of future work, there is a need to develop a standardized framework of evaluating emission estimation models, as well as improving the transferability of existing emission estimation models to various geographic regions. There is also a need to integrate emission estimation models with other real-time data sources.

Overall, it is believed that in order to support policy decisions and achieve sustainability in urban transportation systems, it is essential to improve the accuracy and applicability of traffic emission models.

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