A Review on Exhaust Emissions from Vehicles

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ABSTRACT

Vehicular emissions are one of the most critical sources of urban air pollution, especially in densely populated cities like Delhi, where rapid urbanization and increasing vehicle numbers exacerbate air quality concerns. These emissions can be categorized into exhaust and non-exhaust sources. Exhaust emissions result from the combustion of fuel and comprise carbon dioxide (CO_2), nitrogen oxides (NO_x), hydrocarbons (HC), and Mobile Source Air Toxics (MSATs) that lead to adverse health effects and environmental degradation. Contributing significantly to the total particulate pollution with non-exhaust emissions are road dust resuspension, tyre wear, and brake wear among others.

Efforts to mitigate vehicular emissions have led to the growth of interest in alternative fuels, particularly Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG), as possible alternatives to traditional petrol and diesel. A series of studies undertaken in European countries showed that vehicles running on LPG and CNG emit lower CO, HC, and CO_2, thus making them environmentally viable alternatives. However, several challenges are identified, including limited fuel infrastructure, vehicle calibration problems, and a need for supportive policies to induce large-scale use.

This study evaluates the impact of fuel types on emissions using emission inventory models and chassis dynamometer testing. The results indicate that while CNG and LPG significantly reduce CO_2 and HC emissions. These measures, when combined, can help create a more effective long-term strategy for reducing vehicular pollution and improving urban air quality.

Key Words: Dynamometer, alternative fuels, emission, fuelling systems.

1. INTRODUCTION

The most important environmental and public health issue concerning air quality is in cities, where vehicular emissions significantly contribute to air pollution. The Air Quality Index (AQI) quantifies pollution levels on the basis of concentration in key pollutants: carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), and carbon dioxide (CO_2) [1]. Poor air quality has been directly associated with very grave respiratory and cardiovascular diseases and negative environmental impacts such as climate change.

Vehicular emissions are divided into two: exhaust emissions and non-exhaust sources. Exhaust emissions occur due to fuel combustion in internal combustion engines, producing pollutants such as CO_2, NO_x and HC. Non-exhaust sources include pollutants from tyre wear, brake wear, and road dust resuspension [2], which heavily impact urban air quality. Traditional fossil fuels like petrol and diesel are major contributors to such emissions that require alternatives for cleaner sources [3,4].

Alternative fuel usage can help in controlling the emissions through vehicles, where using LPG and CNG-based fuels have reduced the level of CO, HC, and CO_2 considerably and thus provide better alternatives to check pollution levels in urban regions as studies suggest European researches [6]. Delhi is one of the most polluted cities in the world but has seen a substantial increase in vehicular emissions despite stricter emission norms and technological advancements. Rising evidence suggests that exhaust and non-exhausts are as important sources for air pollution, and road dust is one of the significant contributing sources to PM pollution. As vehicles continue to multiply, it would be essential to address both the sources of emissions to reduce their base levels for quality improvement [15].

This study is aimed at the assessment of various effects of fuel types on emissions, through chassis dynamometer testing and emission inventory models. The relative contributions of exhaust and non-exhaust emissions are analysed with respect to urban environment. Findings will enable policy decisions, optimize strategies for emission control, and ensure that cleaner and more sustainable transport solutions are used in the fight against air pollution. Some of the major advantages and disadvantages of LPG and CNG fuels are shown in table 1.

Table 1 Major Advantages and Disadvantages of alternative fuels [8]

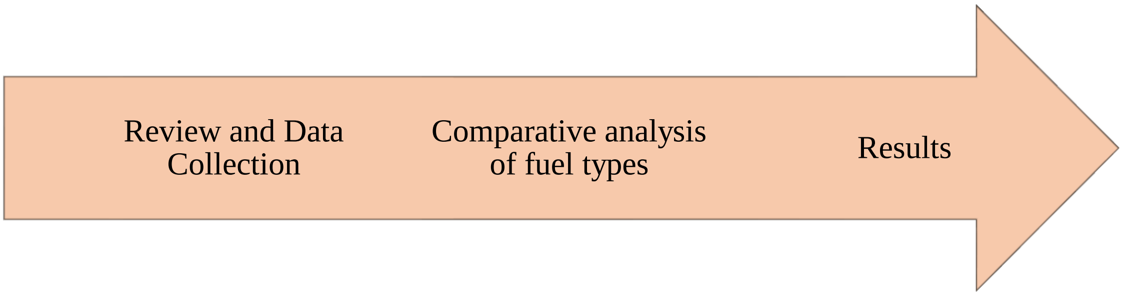
Fuel	Advantages	Disadvantages
Methane	• Very low emissions of ozone-forming hydrocarbons, particulate matter (PM), NO_x emissions, toxic compounds and carbon monoxide. • Can be made from a variety of feedstocks, including renewables. • More fuel efficiency. • Better combustion and starting characteristics than gasoline.	• Higher vehicle cost. • Lower vehicle range. • Less convenient refuelling. • Limited refuelling infrastructure.
Propane	• Cheaper than gasoline today. • Most widely available clean fuel today. • Lower emissions of ozone-forming hydrocarbons and toxic compounds, lower PM emissions. • Excellent fuel, especially for fleet vehicles.	• Cost will rise with demand. • Limited supply. • No energy security or trade balance benefits.

2. METHODOLOGY

This applies a systematic approach in evaluating vehicular emissions, alternative fuels, and their contribution to urban air quality management. It involved a literature review of all data gathered from pre-reviewed journals, government reports, and environmental studies that help in giving an overall view of exhaust and non-exhaust emissions. Studies on primary pollutants, especially carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM10), hydrocarbons (HC), and volatile organic compounds (VOCs), are analysed to provide an overview of the emission trend. Non-exhaust sources that are increasingly considered in urban pollution include road dust resuspension, tire and brake wear, among others [7,9].

A comparative analysis of fuel types was carried out, which included conventional fuels such as petrol and diesel and alternative fuels such as Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG). The emission results obtained from standardized drive cycles, including the European Driving Cycle (ECE, UDC+EUDC) and the New European Driving Cycle (NEDC) [8], were analysed along with real-world emissions data. The variability in emissions under different driving conditions was studied to assess the effectiveness of alternative fuels in reducing overall vehicular pollution.

Further, it reviews the policy frameworks and the technological progresses related to the control of emission. The feasibility of alternative fuels in terms of the fuel infrastructure, vehicle maintenance and calibration are studied. There is also lab-vehicle mismatch, which reveals measures of the regulations and prospects of improvement for strategies of emissions abatement. Using this, the review evaluates comprehensive vehicular emissions and transport solution.



2.1 Vehicle Used

Emissions of CO, HC, NO_x and CO_2 from chassis dynamometer tests on gasoline vehicles running on different fuels were measured at the BOSMAL Automotive R&D Centre in Poland. The experiments carried out in this work were part of a research project focused on the effects of alternative fuels on exhaust emissions from vehicles with both spark-ignition and compression-ignition engines [8, 9].

The aim of this research was to determine the impact of various fuel types, such as petrol, LPG, and CNG, on exhaust emissions, taking into account the environmental and economic benefits of alternative fuels. The study used the ECE (UDC + EUDC) cycle, consistent with EURO II standards, as well as the new vehicle homologation procedure adopted by Directive 98/69/EC, which is referred to as the NEDC drive cycle [8,19].

The test cycle comprised the UDC phase, consisting of four consecutive 195-second segments, followed by the high-speed extra-urban drive cycle (EUDC), lasting 364 seconds. These tests were designed to evaluate the influence of each phase of the ECE or NEDC cycles (195-second segments of the UDC and EUDC phases) on emission. The emissions of all the monitored pollutants were measured in grams per kilometre for the complete cycle or in specific phases [8,22].

The study was based on several models of vehicles, marked A to F, which are commonly encountered in European highways. These vehicles were manufactured in Europe and consisted of gasoline-powered vehicles equipped with one of the following systems: one with a carburettor system and five fitted with SPI and MPI systems, respectively. Every vehicle had a set of both gasoline and LPG-CNG fuelling systems available on it as alternatives. Vehicles A to E were equipped with LPG systems by fitting the specific apparatus onto the petrol fuelling mechanism in place. On the other hand, Vehicle F was constructed as a dual-fuel vehicle. Specifications of the six tested vehicles are summarised in Table 2 [19].

Table 2 Vehicles used in tests

Vehicle type	Engine type	Engine displacement[ccm]	Fuel used	LPG/CNG fuelling system
A	SI carburettor	1600	LPG | Gasoline	mechanically controlled
B	SI SPI	1600	LPG | Gasoline	mechanically controlled
C	SI SPI	1600	LPG | Gasoline	mechanically controlled
D	SI MPI	1200	LPG | Gasoline	electronically controlled
E	SI MPI	1200	LPG | Gasoline	electronically controlled
F	SI MPI	1600	LPG | Gasoline	gas injection

2.2 Exhaust Emissions in Delhi: (2010-2020)

The analysis of exhaust emissions in Delhi from 2010 to 2020 is crucial to the understanding and identification of critical trends and issues in managing urban air quality. Recent data indicate that tailpipe emissions of on-road vehicles continue to be a significant source of atmospheric pollutants during this period [12,17,20]. In 2011, the emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x) and particulate matter (PM_{10}) were measured at approximately 14,119 Gg, 98 Gg, and 5 Gg, respectively. Projections suggest that by 2020, these levels are expected to surge dramatically to about 48,577 Gg for CO_2, 322 Gg for NO_x, and 10 Gg for PM_{10}. In addition, the emissions of carbon monoxide (CO) and hydrocarbons (HC) have increased; 2011 levels were recorded at 275 Gg for CO and 80 Gg for HC while an estimate projects an increase to 485 Gg and 199 Gg for CO and HC, respectively, in 2020 [18,23].
These figures indicate the growing number of vehicles and continued use of older, higher-emission technologies despite regulatory interventions. Targeted measures such as the phasing out of older commercial vehicles and the accelerated adoption of Compressed Natural Gas (CNG) in public transport during the early part of this period contributed to short-term reductions in NO_x and PM_{10} emissions. However, the overall trend indicates that exhaust emissions remain a significant environmental concern.

Different vehicle categories contribute variably: heavy-duty vehicles and buses continue to be prominent sources of NO_x and PM_{10}, while private vehicles, including two-wheelers and cars, are major contributors to CO_2, CO and HC emissions. The persistent rise in CO_2 emissions specifically highlights a larger challenge in managing greenhouse gas outputs in an increasingly booming urban environment [27].
In summary, although some regulatory measures and technology shifts have led to localized improvements, the overall trend in exhaust emissions between 2010 and 2020 underscores the need for continued policy innovation and technology upgrades to mitigate the adverse impacts on public health and the environment [23,24].

3. DISCUSSION

A series of tests was conducted on the chassis dynamometer facility using the vehicles listed in table 2 and results are mentioned below:

3.1 Test Results of Chassis Dynamometer

Each vehicle was alternately fuelled with gasoline, LPG or CNG. Figs. 1-3-5 show CO, HC and NO_x emissions for the first two elementary steps of the UDC (Urban driving cycle) cycle, the following two steps of the UDC, the EUDC (Extra Urban driving cycle) cycle and the complete NEDC cycle for the bi-fuel vehicle (Type F) with SI engine, running with petrol or CNG.

The following is observed, and it indicates that emissions of CO and HC are considerably reduced when CNG is used as compared to gasoline throughout the whole NEDC cycle. Specifically, the full UDC cycle is taken during the initial 195-second phase [8]. During the EUDC phase, emissions of CO are higher for CNG as compared to gasoline. The first 195 seconds of the UDC cycle have the greatest impact on overall emissions throughout the NEDC cycle as they contribute to a significant reduction in CO, HC, and NO_x emissions with CNG [22].

NO_x emissions were comparable for both gasoline and CNG fuels. Figure 7 illustrates CO_2 emissions for both fuel types, and CO_2 emissions are always lower with CNG in all phases of the UDC and NEDC cycles and for the whole NEDC cycle [19,22,8].

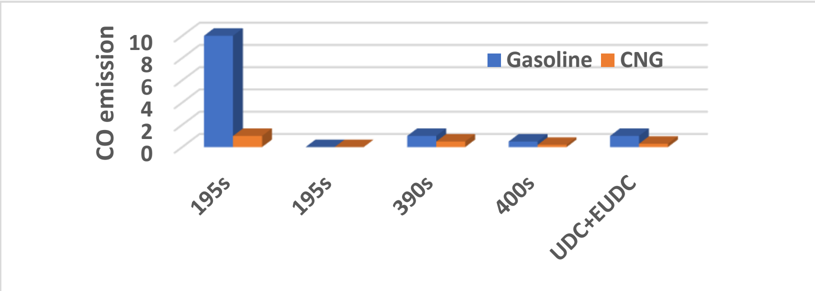


Fig 1 CO emission for vehicle F with petrol and CNG alternatively

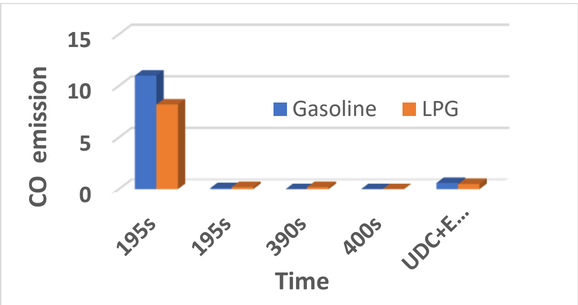


Fig 2 CO emission for vehicle F with Petrol and LPG alternatively

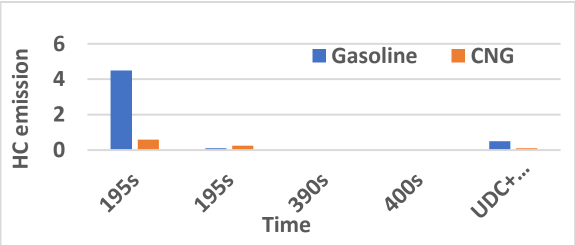


Fig 3 HC emission for vehicle F with petrol and CNG alternatively

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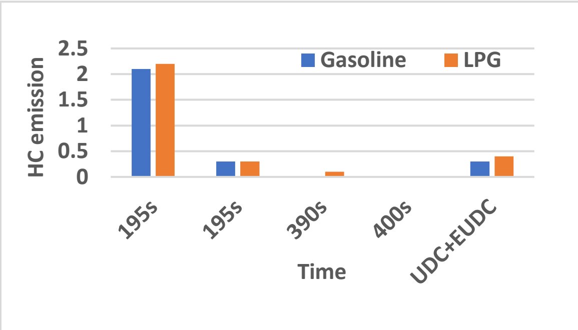

Fig 4 HC emission for vehicle F with petrol and LPG alternatively

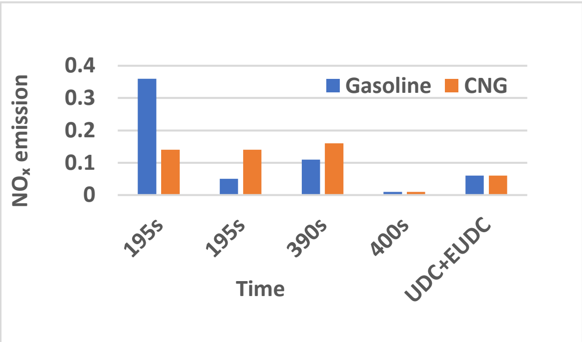

Fig 5 NO_x emission for vehicle F with Petrol and CNG alternatively

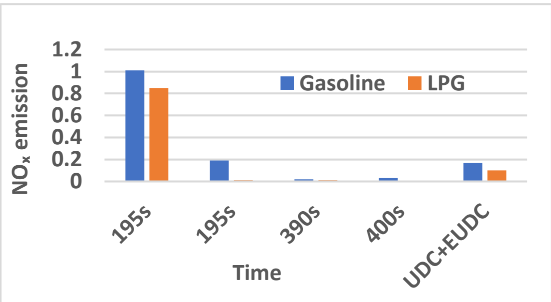

Fig 6 NO_x emission for vehicle F with Petrol and LPG alternatively

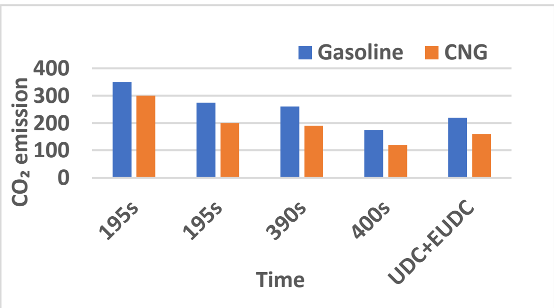

Fig 7 CO_2 emission for vehicle F with petrol and CNG alternatively

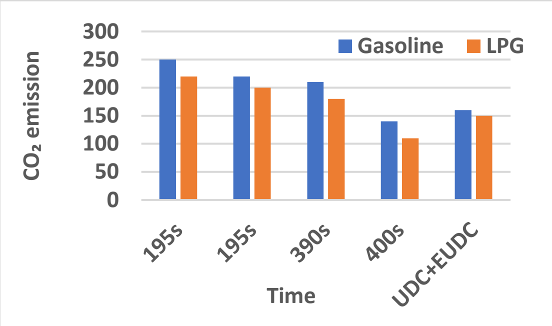

Fig 8 CO_2 emission for vehicle F with petrol and LPG alternatively

3.2 Level of emissions

Fig 9 illustrates the trends in key exhaust emission from Delhi's on road vehicles over the period 2010 to 2020. The graph shows a steady and significant upward trajectory in the levels of emission [5,21,25,23].

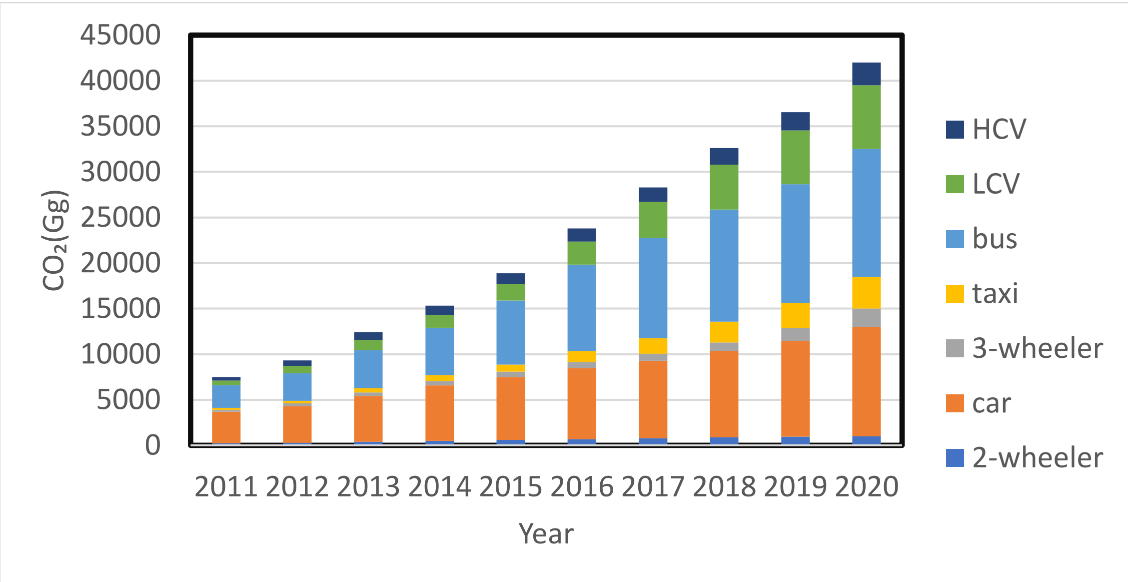

Fig 9 CO_2 emission by each vehicle

4. URBAN AIR QUALITY IMPACTS

Air pollution persists as one of the growing areas of concerns among many rapid, growing urban towns, most largely due to car emissions leading to deteriorated conditions in environments. Studies by various researchers done at Delhi demonstrated how, notwithstanding new cleaner fuels with CNG alongside the de-induction process involving older emitters [30], continued sources of the combined exhausts as well as the non-exhausts prevail dominantly at different levels that define ambient pollution over there in particular [4,5]. Data from 2010 to 2020 show a continuous increase in major pollutants, including CO_2, NO_x, and PM_{10}, primarily due to the growing number of vehicles on the road and the growing role of non-exhaust sources such as road dust, brake, and tire wear. In parallel, experimental research from Europe investigating alternative fuels reveals that although LPG and CNG reduce CO and hydrocarbon (HC) emissions compared to petrol, under specific circumstances they may result in increased NO_x emissions [21,22]. Further studies highlight the gap between laboratory-emulated emission measurements and actual driving conditions, insisting on the use of proper testing procedures that would more closely mimic the city traffic flow [26]. Together, these reports highlight the point that enhancing urban air quality requires a combination of technology, stringent regulations, and maintenance practices to reduce exhaust and non-exhaust emissions effectively.

5. CONCLUSION

It helps to give an overall view regarding vehicular pollution and the potential role of alternative fuels in bringing down environmental damage. The case study on the Delhi vehicular emissions shows that despite major regulatory interventions, which include phasing out older vehicles and adopting cleaner fuel technologies, such as CNG, emissions of key exhaust pollutants (CO_2, NO_x, PM_{10}, CO, and HC) have increased for the last ten years. This is further exacerbated by the increase in non-exhaust sources, such as road dust, brake wear, and tire wear, which are continually deteriorating urban air quality.

The study provides controlled laboratory insights into the performance of alternative fuels in parallel. The study shows that LPG and CNG can reduce carbon monoxide and hydrocarbons emissions significantly compared to petrol. However, it also brings out that at certain operational conditions, especially high-speed or high-load conditions, these fuels lead to elevated nitrogen oxides (NO_x) emissions. This divergence between controlled test results and real-world performance underscores the complexities inherent in fuel technology and vehicle calibration.

Collectively, these studies emphasize that reducing vehicular pollution requires a multifaceted strategy. Effective mitigation must integrate advanced fuel technologies, stringent real-world emission testing, and targeted maintenance practices. Only through such a holistic approach can urban centres achieve sustainable improvements in air quality while addressing both exhaust and non-exhaust emission sources.

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