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VEHICLE EXHAUST EMISSIONS AND THEIR ENVIRONMENTAL IMPACTS

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Abstract

Road transport is an essential part of modern mobility, yet combustion-powered vehicles remain an important source of urban air pollution. This paper reviews the principal pollutants associated with vehicle exhaust and discusses their environmental and health implications. Carbon monoxide, nitrogen oxides, volatile organic compounds, sulfur dioxide, carbon dioxide and particulate matter are considered because of their different mechanisms of action. Carbon monoxide reduces the capacity of blood to transport oxygen; nitrogen oxides and volatile organic compounds contribute to ground-level ozone and photochemical smog; particulate matter penetrates the respiratory system; and carbon dioxide contributes to climate change. The review also considers indirect impacts on vegetation, soils and surface waters. The analysis shows that reducing transport-related pollution requires coordinated measures rather than a single technical solution. Effective approaches include stricter emission inspection, cleaner fuels, improved traffic management, reliable public transport, active mobility and a gradual transition to low- and zero-emission vehicles. These measures are especially relevant for rapidly growing urban areas, where vehicle use, congestion and population exposure occur simultaneously.

Keywords: vehicle emissions; air pollution; particulate matter; nitrogen oxides; public health; sustainable transport.



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1. Introduction

Motor vehicles support economic activity and personal mobility, but their environmental costs are concentrated in densely populated areas. Exhaust emissions are released close to people, buildings and roadside vegetation, while traffic congestion can increase exposure by extending the time that vehicles operate under inefficient conditions. Consequently, transport-related air pollution is both an environmental and a public-health problem.

Fuel combustion in cars, buses and trucks releases a complex mixture of gases and particles. The United States Environmental Protection Agency identifies nitrogen oxides, carbon monoxide, non-methane organic gases and particulate matter among the pollutants emitted by fuel-burning vehicles [1]. The World Health Organization also identifies particulate matter, carbon monoxide, nitrogen dioxide and sulfur dioxide as pollutants of major public-health concern [2].

According to the World Health Organization, ambient air pollution caused an estimated 4.2 million premature deaths worldwide in 2019 [2]. This figure reflects the overall burden of ambient air pollution from all sources; it should not be interpreted as vehicle-specific mortality. Nevertheless, road transport remains an important and controllable source of urban exposure to air pollutants.

The purpose of this paper is to summarize the main components of vehicle exhaust, explain their effects on the environment, human health and vegetation, and outline practical measures for reducing transport-related pollution. The paper is a narrative review based on official international sources and does not report a new experimental study.

2. The Main Part

2.1. Main pollutants in vehicle exhaust. The composition of exhaust depends on fuel type, engine condition, vehicle age, driving cycle and the presence and



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effectiveness of emission-control equipment. Carbon monoxide (CO) is produced when fuel is incompletely combusted. Nitrogen oxides (NO_x), including nitrogen dioxide (NO₂), are formed at high combustion temperatures. Hydrocarbons and volatile organic compounds can be emitted when fuel does not burn completely or evaporates from the fuel system. Diesel engines and other combustion sources can also emit fine particulate matter (PM), while fuel sulfur content affects sulfur oxide emissions.

The principal vehicle-related pollutants and their primary impacts are summarized in Table 1.

Table 1. Principal vehicle-related pollutants and their primary impacts

Pollutant	Main vehicle-related origin	Primary environmental or health effect
CO	Incomplete fuel combustion	Reduces oxygen transport in blood [1, 2]
NO _x and NO ₂	High-temperature combustion	Contributes to ozone, smog and respiratory effects [1, 4]
VOCs	Incomplete combustion and fuel evaporation	React with NO _x to form ground-level ozone [1]
PM	Diesel exhaust, tyre and brake wear, road dust	Can penetrate deep into the respiratory system [2, 3]
SO ₂	Sulfur-containing fuel combustion	Contributes to acidifying air pollution [2]

These pollutants do not act independently. Nitrogen oxides and volatile organic compounds participate in atmospheric reactions that form ground-level ozone and smog. Fine particles can remain suspended in the air and can be transported beyond the road corridor. In addition to tailpipe emissions, road transport produces non-exhaust particles from tyre and brake wear, as well as resuspended road dust [3]. Therefore, replacing an internal-combustion vehicle with a cleaner



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powertrain reduces tailpipe emissions but does not entirely remove the need for road-dust and traffic-management policies.

2.2. Environmental effects. Vehicle emissions degrade local air quality and can influence regional atmospheric processes. NO_x and volatile organic compounds contribute to photochemical smog, which reduces visibility and can damage vegetation. Sulfur dioxide and nitrogen compounds may contribute to acid deposition after atmospheric transformation. Acidifying deposition can alter soil chemistry and affect freshwater ecosystems. Carbon dioxide differs from these local pollutants because its primary effect is global: it accumulates in the atmosphere and contributes to climate change.

Vegetation is sensitive to air pollution because leaves are directly exposed to the atmosphere. Ozone and particulate deposition can interfere with plant physiological processes, while acidifying pollutants may affect soil nutrients and root systems. The effects are influenced by pollutant concentration, duration of exposure, weather conditions and plant species. For this reason, urban roadside greenery should be regarded as an additional protective measure, not as a substitute for emissions prevention at the source.

2.3. Effects on human health. The health burden of air pollution is closely related to pollutant size, concentration and exposure duration. Fine particles are particularly important because they can reach deep parts of the respiratory system. The WHO links ambient air pollution with respiratory diseases, cardiovascular disease, stroke and lung cancer, and notes that fine particulate matter presents a substantial health risk [2]. NO₂ is also important in traffic corridors; it is produced from fuel combustion and contributes to ozone and fine-particle pollution [4].



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CO is a colorless and odorless toxic gas that affects oxygen transport in the body. Its effects are especially concerning in enclosed or poorly ventilated locations and for sensitive groups. Children, older people, people with respiratory or cardiovascular disease, and workers who spend long periods near busy roads may experience greater risks. Reducing exposure therefore requires not only cleaner vehicles but also urban design decisions that separate heavy traffic from schools, hospitals and residential areas whenever possible.

2.4. Measures for reducing transport-related pollution. A practical emissions-reduction strategy combines technological, regulatory and behavioral measures. Regular technical inspection can identify vehicles with defective engines or emission-control systems. Fuel-quality standards, low-sulfur fuels and appropriate maintenance support lower pollutant emissions. Traffic measures, including coordinated signal timing, removal of bottlenecks and freight-routing management, can reduce unnecessary idling and stop-and-go driving.

Public transport, walking and cycling can reduce the number of individual car trips when these options are safe, reliable and convenient. Electrification is another important direction because battery-electric vehicles have no tailpipe emissions during operation. In 2024, global electric-car sales exceeded 17 million units and accounted for more than 20% of total car sales [5]. However, the environmental benefit of electrification is greatest when electricity generation also becomes cleaner and when non-exhaust emissions are addressed through vehicle design, speed management and street cleaning.

3. Conclusion

Vehicle exhaust emissions are a significant source of urban air pollution and can affect atmospheric quality, human health, vegetation, soils and water systems.



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The most relevant pollutants include CO, NO_x, volatile organic compounds, SO₂ and particulate matter, while CO₂ links road transport to climate change. Their impacts arise through different mechanisms, so the response must be integrated. Priority measures include vehicle inspection and maintenance, cleaner fuels, traffic management, high-quality public transport, active mobility and the gradual adoption of low- and zero-emission vehicles. Such a combined approach can reduce exposure near roads and support healthier, more sustainable cities.

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