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Research Article

Air Pollution and Health Effects in Developing Countries, Case Study: Serbia

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Abstract

The primary driver of atmospheric pollution is humanity's demand for energy. Consequently, traffic and industry—particularly the energy sector—are considered the dominant sources of air pollution. Intensive motorized traffic significantly contributes to increased vehicular emissions, negatively impacting the atmosphere and all the environment. A range of negative effects of air pollution is observed, particularly in the urban environment, where one of the most considerable is the impact on human health. Air pollution affects all living organisms, leading to various health issues, including respiratory and cardiovascular diseases, allergic reactions, and even death. Due to urbanization, the prevalence of respiratory conditions, such as allergic asthma, chronic obstructive bronchitis, and chronic obstructive pulmonary disease, is increasing. Literature data shows that the emission of air pollutants (e.g. particulate matter, sulfur or nitrogen oxides) in developing countries, like Serbia, is higher than in industrialized ones. The study deals with the analysis of the health data and air pollutants emission data related to the energy sector and road traffic in Serbia, establishing the dynamic change trend in the period 2012-2022. Trend change dynamics were followed for the main air pollutants like black carbon, particulate matter, nitrogen dioxide, Sulphur dioxide, carbon monoxide, ammonia, and non-methane volatile organic compounds. The analysis showed the positive trend changes in the dominant air pollutants emission relevant for the observed industry sectors, during the 11 years. The emission rate of NO_2 from road transport in the period 2012 - 2022 shows a positive trend of change, and the share of NO_2 in total emission increased from 19.87% to 41.06%. Also, share of black carbon and various particulate matter in total national emission increased. Regarding the coal-power plant as a dominant energy source and a primary source of SO_2 emissions in Serbia, its emission rate fluctuated during the observed period. Nevertheless, its contribution to the total national emissions increased from 90.30% in 2012 to 95.56% in 2022. Regarding the results, future monitoring of the air pollutants emission level and implementing measures to improve the air quality in Serbia should be of high importance. Therefore, investment towards green transition and traffic planning, including the number and types of vehicles within urban areas, as a critical factor in mitigating air pollution levels, should be a priority. Furthermore, policies related to reducing air pollution emission from diverse sources should be harmonized with the European Union's regulatory framework to ensure alignment with empirical outcomes.

Keywords

Air Quality, Air Pollution, Urban Environment, Health Effects, Road Transport, Public Power

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1. Introduction

The growth of the population around the world and the increase of living standards globally affects the quality of the environment, increasing its contamination.

The changes in a complex mixture of gases and particles in the air, constantly varies in composition and origin over time and distance, are described as air pollution. Currently, about 70.000 particles in the air are known to have the potential negative effect. Air pollution is one of the major health issues facing people in the European Union (EU). Different countries have various levels of air pollution depending on their level of industrialization. In 2020, emissions of all key air pollutants in the 27 Member States of the EU (EU-27) continued to decline maintaining a change trend since 2005, even though the noticed increase in gross domestic product over the same period [1]. Additionally, the linkage between social and economic factors and air pollution has been confirmed. Highways and other polluting infrastructure, such as industries and power plants, have historically been situated close to low-income neighborhoods and communities, resulting that the residents of these areas have been disproportionately affected by the pollution.

Air pollution affects all living beings, causing diseases, allergic responses, and even death. The prevalence of respiratory system conditions, such as allergic asthma, chronic obstructive bronchitis, and chronic obstructive pulmonary disease, is rising as a result of urban living. According to the European Environmental Agency (EEA) latest estimation, at least 238.000 premature deaths in the EU in 2020 were a result of exposure to the higher rate of the air pollutants, especially particulate matter ($PM_{2.5}$ and PM_{10}) [2]. Additionally, air pollution has a negative effect on the natural environment (like ozone degradation, destruction of fragile ecosystems, climate change, biodiversity, etc.) or the built environment (e.g. acid rain).

The European Union has a comprehensive clean air policy built on three pillars to cope with the air pollution problem. To achieve the goal of zero pollution by 2050, the EU members should lower emissions of air pollutants, establish criteria for ambient air quality and determine the emission guidelines for major sources of pollution. In the UN 2030 Agenda for Sustainable Development, several Sustainable Development Goals (SDGs) emphasize the significance of lowering air pollution. The Health and Well-Being Goal (SDG 3) should guarantee healthy lives and advance well-being for all individuals and generations. The literature data shows that almost a quarter of the world's energy-related greenhouse gas emissions originate from transport, indicating also the relation with Climate Action Goal (SDG 13) and emphasizing the significance of the relationship between mobility and air quality. The Sustainable Cities and Communities Goal (SDG 11) focuses on the environment and quality of life in urban areas, where urban settlements must satisfy environmental requirements after the ecological transition phase.

2. Urban Air Quality and Health

Millions of people around the world are affected by air pollution, a serious environmental and public health concern. Air pollutants like nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), ground-level ozone, and particulate matter are the pollutants that have the most adverse effects on human health. Particulate matter, as one of the most harmful ones, comes from a variety of sources, coal-power plants, traffic, household burning solid fuel, and other activities, but also it can be a result of the interaction of gaseous pollutants in the air (e.g., nitrogen or Sulphur oxides). Nitrogen oxide emissions are linked to both mobile and stationary industrial sources, as they result from fuel combustion at elevated temperatures, which also produces various other combustion byproducts. Coal-fired power plants and other coal-burning facilities are the most numerous types of SO_2 anthropogenic emission point sources seen by Ozone Monitoring Instrument satellite sensor (OMI) [3].

Exposure to high levels of air pollutants, such as fine particulate matter ($PM_{2.5}$), nitrogen oxides (NO_x), and ozone, is linked to a range of respiratory and cardiovascular diseases, leading to increased mortality and morbidity. Air pollution is the second largest cause of death for children under five and can lead to the development of deadly diseases in 8.1 million people globally [4]. Vulnerable populations, particularly children, the elderly, and those with pre-existing health conditions, are disproportionately affected by poor air quality.

Air pollution is a major issue, particularly in developing countries, driven by a variety of human processes and activities. The energy sector, road transport, traffic, agriculture, etc., are the main causes of air pollution in developing countries like Serbia. This study will point out the relation of air pollution to the energy sector and road traffic in the period 2012-2022, and its impact on human health.

2.1. Urban Air Quality and Road Traffic

Emission of air pollutants from road traffic in urban areas is a growing concern globally, particularly in developing countries. The relationship between road transport and air pollution is complex, shaped by a combination of factors such as economic development, technological advancements, vehicle fleet composition, fuel quality, and regulatory enforcement. Factors that contribute to transport emissions:

1. Emissions from road traffic;
2. Emissions per unit of fuel;
3. Total requested transport services;
4. Fuel consumption per unit of transport service [2].

Road transport is considered as one of the largest consumers of energy and globally shows the highest growth rate of energy consumption in all sectors [5].

In many developing countries, the vehicle fleet is characterized by older, less efficient vehicles that are not subject to stringent emission standards. Additionally, the growing number of motor vehicles in these regions often outpaces the development of adequate infrastructure, leading to increased congestion, traffic emissions, and the proliferation of informal and poorly maintained vehicles. The unsatisfactory quality of fuels, particularly high sulfur content in diesel and gasoline, further aggravates the air pollution levels in many cities. In the European Union, it was found that urban transport is responsible for 40% of SO_2 emissions, and also, about 70% of other pollutants come from road traffic [6, 7]. Therefore, it is considered that the emissions of air pollutants from road transport in developing countries have serious public health implications.

2.2. Air Pollution Related to the Coal-powered Power Plant

The energy sector is also one of the significant sources of air pollution. Although there are few coal-powered power plants in Europe anymore, they still contribute to the air pollution. These power plants operate in Ukraine, Turkey, and the countries of the Western Balkans. Recent data show that the majority of PM_{10} pollution from coal power generation originates from plants in Ukraine, while almost a quarter of SO_2 emissions in Europe, coming from coal power in Turkey, Serbia, Bosnia & Herzegovina, Ukraine and North Macedonia [8]. The same study shows that Turkey takes the lead in NO_x pollution from coal power with a 20% share.

The energy sector in Serbia contributes significantly to the air pollution, particularly the $PM_{2.5}$ concentration. In 2024, 61.8% of electricity in Serbia was generated from coal and almost exclusively from low-efficiency power plants burning lignite, a low-quality coal [9].

3. Air Pollution in Serbia – Causes and Consequences

The main causes of man-made air pollution are emissions from electricity generation in general (particularly from coal-fired power plants), road traffic, household solid fuel combustion, manufacturing byproducts, etc.

Regarding the available data, air pollution in the Western Balkans countries affects human health in practically every location where measurements are made, with annual costs totaling billions of euros [10]. In developing countries ambient quantities of particulate matter (atmospheric aerosol particles, or PM), as one of the most harmful air pollutants, are several times higher compared to industrialized ones [4]. EEA data shows that mortality related to the air pollution in Serbia presents a reason of concern. The number of premature deaths related to air pollution in Serbia in 2024, is presented in Table 1 [11].

Table 1. *The number of attributable deaths to the air pollution in Serbia in 2024 [11].*

Pollutant / Country	Population weighted annual mean ($PM_{2.5}$)	Attributable deaths ($PM_{2.5}$)	Population weighted annual mean (NO_2)	Attributable deaths (NO_2)
Serbia	19.100	10 800	16.200	1 430
EU-27	11.400	239 000	14.100	66 000

Exposure to higher concentrations of $PM_{2.5}$ than recommended by the WHO (World Health Organization) may be associated with ischemic heart disease, lung cancer, chronic obstructive pulmonary disease (COPD), lower respiratory tract infections (e.g. pneumonia), stroke, type 2 diabetes, etc. Table 2 presents the number of deaths caused by diseases related to air pollution in Serbia in 2021 [12].

Table 2. *The number of deaths caused by respiratory diseases in Serbia in 2021 [12].*

	Diseases	No. of deaths per 100 000 population
1	Ischemic heart disease	285.08
2	Stroke	221.67
3	Trachea, bronchus, lung cancers	74.33
4	Lower respiratory infections	60.94
5	Diabetes mellitus	49.84
6	COPD	41.29

	Diseases	No. of deaths per 100 000 population
7	Hypertensive heart disease	37.34

4. Materials & Methods

In this study, data of air pollutant emissions are based on officially declared emissions and used in models of EMEP (the Cooperative Program for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe) [13].

This study seeks to examine the relation of road transport and energy sector with air pollution in developing countries like Serbia, focusing on the types and quantities of the emitted air pollutants, the factors influencing emissions and the public health. The analysis examines the total emission of air pollutant with special attention on data from the road transport sector and the public power sector, spanning the period from 2012 to 2022. The road transport sector encompasses air pollutant emissions from various sources, including passenger cars, light-duty vehicles, heavy-duty vehicles, buses, mopeds, motorcycles, gasoline evaporation, as well as wear from automobile tires and brakes and road abrasion. Emissions from the public power sector are primarily derived from the production of electricity and heat for public consumption.

Regarding the air pollutant types, the analysis includes the emission of: black carbon (BC), particulate matter ($PM_{2.5}$, PM_{10}, PM coarse). PM coarse refers to particles that have an aerodynamic diameter ranging from 2.5 to 10µm ($PM_{2.5-10}$), which distinguishes them from the fine airborne particulate matter ($PM_{2.5}$) and ultra-fine particles ($PM_{0.1}$). Also, analysis includes the emission of gaseous air pollutants like CO, NH_3, non-methane volatile organic compounds (NMVOC), NO_x (as NO_2) and SO_x (as SO_2).

5. Results

The results of the air pollutants emission in Serbia vary over the years Figures 1 and 2.

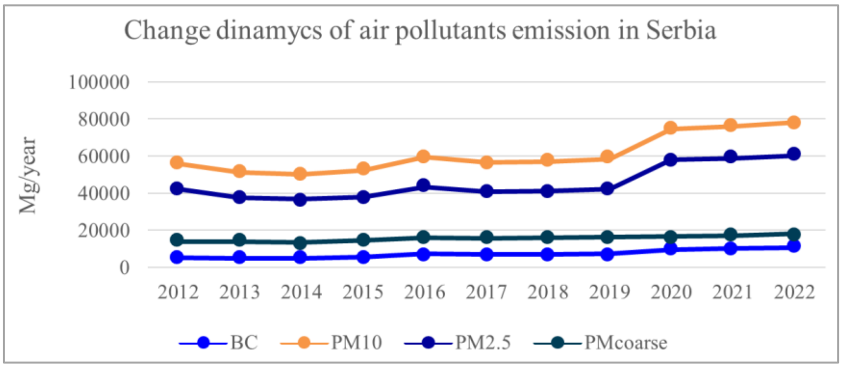

Figure 1. *Total emission of BC, PM_{10}, $PM_{2.5}$ and PM coarse in Serbia during period 2012-2022.*

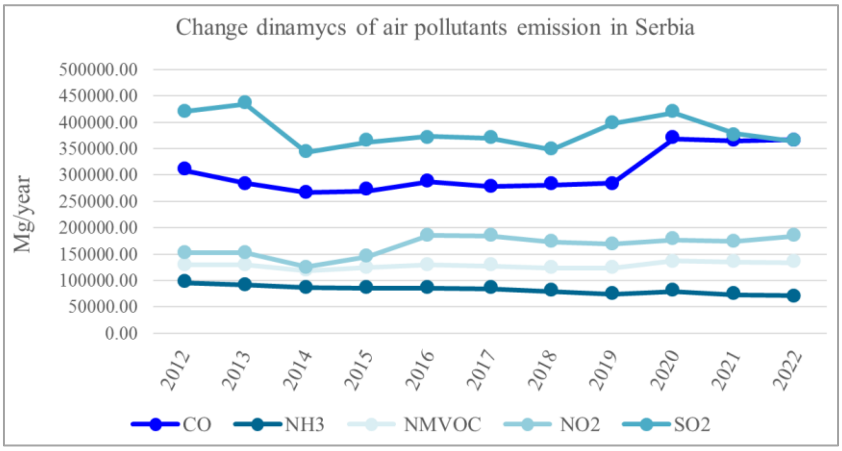

Figure 2. *Total emission of CO, NH_3, NMVOC, NO_2, and SO_2 in Serbia during period 2012-2022.*

The analysis of the obtained data indicates that over the 11 years, the emission rates of various pollutants show distinct variations. Notably, emissions of particulate matter and black carbon demonstrate a positive trend, with a consistent increase in emissions throughout the period.

Regarding the emission data of other air pollutants, NO_2 and CO exhibit a positive trend throughout the analyzed period, while pollutants such as NMVOC, NH_3, and SO_2 show a decline in emission rates.

5.1. Road Transport Related Air Pollutant Emission in Serbia

Results of air pollutants emission coming from the road transport industry sector are presented in Figures 3 and 4.

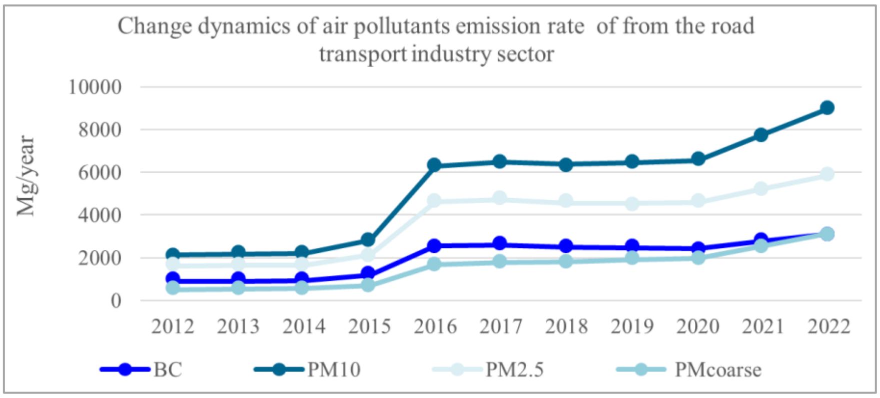

Figure 3. *Emission of BC, PM_{10}, $PM_{2.5}$, and PM coarse from the road transport sector in Serbia during period 2012-2022.*

A positive trend of air pollutants emission from road transport during the 11-year period is noticed, regarding the particulate matter and black carbon from 2015 follow the similar pattern of changes as the total emission in Serbia.

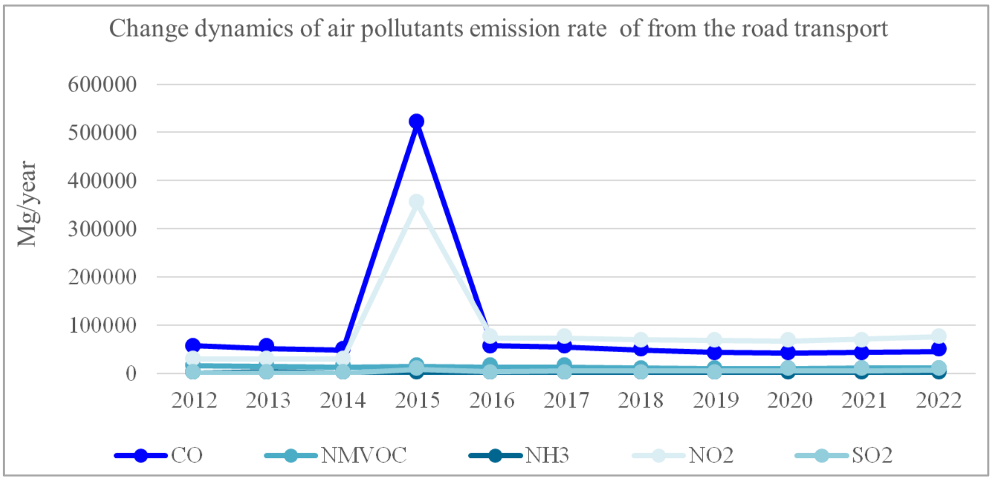

Figure 4. *Emission of CO, NMVOC, NH_3, NO_2, and SO_2 in Serbia from the road transport during period 2012-2022.*

Slightly increment of CO, NH_3, NO_2 and SO_2 emission rate can be noticed from 2016 to 2022, but CO and NO_2 show higher emission rate from 2014 to 2016. The emission rate of NMVOC from road transport is similar to that of NH_3.

From 2016 to 2022, the emission rates of CO, NH_3, NO_2, and SO_2 slightly increased. However, CO and NO_2 exhibited higher emission rates during the period from 2014 to 2016.

5.2. Public Power Related Air Pollutant Emission in Serbia

Figures 5 and 6 show the results of air pollution emissions from the public power industry sector.

The emission rate of BC and PM from the public power shows a slightly positive trend in change dynamics over the observed period. In contrast, the change dynamics of PM coarse emissions show a modest negative trend.

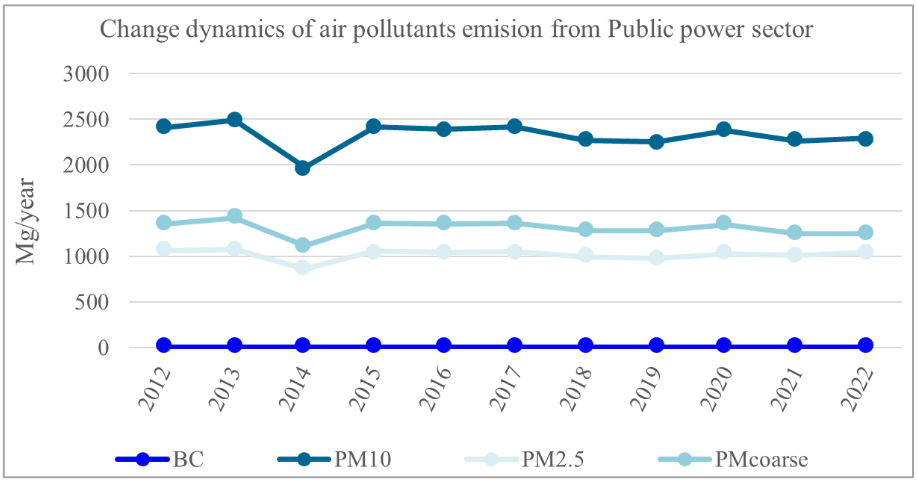

Figure 5. *Emission of BC, PM_{10}, $PM_{2.5}$, and PM coarse from the public power industry sector in Serbia during period 2012-2022.*

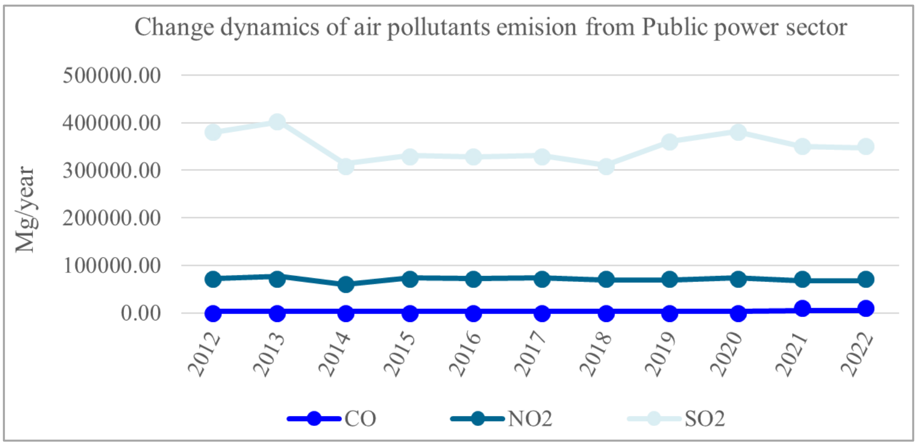

Figure 6. *Emission of CO, NO_2, and SO_2, from the public power industry sector in Serbia during period 2012-2022.*

The emission rates of SO_2 and NO_2 during the observed period show a slight decrease starting from 2021, compared to the CO rate. Regarding the other pollutant emission rate, there is no data for NH_3, and the emission NMVOC is in the range 404.88 to 487.63 Mg/year.

6. Discussion

Air pollution is considered as one of the most prominent problems in developing countries, influenced by electricity production and the rapid expansion of road transport systems.

In the European Union, the implementation of policies linked to the reduction of transport-related air pollution across various modes of transportation has resulted in a significant decrease of the air pollutants emission rate.

From 1990 to 2022, emissions of nitrogen oxides (NO_x) from transport across the EU-27 decreased by 51%, Sulphur oxides (expressed as SO_2) by 82%, carbon monoxide (CO) by 90%, methane (CH_4) and NMVOCs by 76% and 91% respectively. In the same time frame, transport emissions of particulate matter (including non-exhaust emissions) with particle diameter of 10µm/2.5µm or less ($PM_{10/2.5}$) decreased by 46%/58%, respectively [14].

According to the data analyzed in this study, there is a distinct trend in the emission of air pollutants in Serbia. The emission rate of NO_x (as NO_2) from road transport in the period 2012 - 2022 shows a positive trend of change, and the share of NO_2 in total emission increased from 19.87% to 41.06%. Also, share of BC and various PM in total national emission increased. The share of BC emission increased from 17.52% in 2012 to 30.05% in 2022, PM_{10} from 3.83% in 2012 to 11.50% in 2022, PM2.5 from 3.85% in 2012 to 9.74% in 2022 and PM coarse from 3.76% in 2012 to 17.37% in 2022.

The implementation of more stringent policies in Serbia aimed at reducing traffic-related air pollution would contribute to a significant improvement in air quality. Also, regarding the relevant literature data can be concluded that effective traffic planning and enhancement of the current urban conditions towards sustainability are crucial for reducing air pollutants emission [15].

Regarding the energy industry, it was responsible for 14% of all NO_x emissions and 44% of all SO_2 emissions in 2018, according to OECD Air Emissions Data [16]. Also, according to EEA data, the production of heat and electricity accounts for 16% of NO_x emissions and 54% of SO_2 emissions [8].

The data analysis in this study indicates that the energy sector is also a primary source of SO_2 emissions in Serbia. Coal-power plant is dominant energy source in Serbia. Although its emission rate fluctuated during the observed period, its contribution to the total national emissions increased from 90.30% in 2012 to 95.56% in 2022. The Republic of Serbia has made significant investments, some are still ongoing, in coal power plants to reduce air pollutant emissions and extend their operational lifespan. Therefore, monitoring of key air pollutants should remain a primary focus in the forthcoming period. Emission rate from the of other air pollutants included into analysis, except NO_2, have no so significant contributions to the total national emission. Except that the contribution of NO_2 slightly increased from 17.17% in 2012 to 18.65% in 2022. Considering the emission share of BC and various PM, it is observed a declining trend in total emission from 2012 to 2022 in Serbia.

According to WHO data [12], mortality rate due to air pollution in Serbia declines for 28.7 deaths per 100 000 population in 2019, according to the indicator age-standardized mortality rate attributed to household and ambient air pollution. Although the number of premature deaths associated with air pollution remains high, it is crucial to consider it seriously, particularly in light of future trends in air pollution emissions.

7. Conclusions

Air pollution related to road traffic is a growing challenge for many developing countries.

Regarding the literature data, one of the possible methods to decrease emission from road transport is to direct and improve urban conditions towards sustainability. The numerous studies show that many characteristics, including fleet speed, deceleration and acceleration rate, queuing time during idle periods at red signals, queue length, traffic flow rate, and ambient conditions, have a substantial impact on vehicle exhaust emissions. Therefore, traffic planning, together with the number and types of vehicles in the urban area, has an important role in decreasing the air pollution rate. Also, the policies related to the air pollution from different sources should be aligned with the EU regulatory framework, since the noticed results.

Air pollution related to the energy sector, particularly from coal-fired power plants, remains a significant environmental and public health challenge, especially for the people living in the neighboring areas. Adopting cleaner technologies, such as carbon capture and storage (CCS), transitioning to renewable energy sources, and implementing stringent emission standards are essential measures for reducing the environmental and health impacts of coal power electricity generation. Given the ongoing challenges of coal-based energy production, a concerted effort is required to accelerate the shift toward more sustainable and cleaner energy alternatives to safeguard public health and the environment.

Adopting a comprehensive approach related to reducing air pollutants emission rates, developing countries can mitigate the adverse effects of traffic and energy sector-related air pollution, to improve public health, and contribute to global efforts to combat climate change.

Abbreviations

EU	European Union
EU-27	27 Member States of the EU
EEA	European Environmental Agency
$PM_{2.5}$	Fine Airborne Particulate Matter Whith Aerodynamic Diameter 2.5 µm
PM_{10}	Airborne Particulate Matter with Aerodynamic Diameter 10µm
SDG	Sustainable Development Goals
WHO	World Health Organization
COPD	Chronic Obstructive Pulmonary Disease
EMEP	The Cooperative Program for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe
BC	Black Carbon
NMVOC	Non-Methane Volatile Organic Compounds
OECD	Organization for Economic Co-operation and Development

Author Contributions

Jovana Dzoljic: Conceptualization, Data curation, Investigation, Methodology, Resources, Writing – original draft

Vladimir Popovic: Data curation, Supervision, Validation, Writing – review & editing

Vojislav Stojanovic: Resources, Data curation

Data Availability Statement

1. The EMEP/CEIP 2024 data that support the findings of this study can be found at: https://www.ceip.at/webdab-emission-database/emissions-as-used-in-emep-models
2. The WHO data that support the findings of this study can be found at: https://data.who.int/countries/688.
3. The OECD data that support findings in this study can be found at: https://data-explorer.oecd.org.

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Conflicts of Interest

The authors declare no conflicts of interest.

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