# ANALYSIS OF $PM_{2.5}$ LEVELS IN ROMANIA (2019-2024): A COMPARATIVE ANALYSIS WITH GLOBAL TRENDS AND THE IMPACT OF SEASONS

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*This paper analyzes $PM_{2.5}$ emissions in Romania (2019-2024), comparing them globally to identify high-risk areas. The study proposes solutions including nature-based air purification utilizing plants, optimized traffic flow to reduce congestion, and the implementation of smoke filters for $PM_{2.5}$ capture. The research highlights the importance of these strategies. Furthermore, the analysis underscores the significance of implementing targeted environmental policies to mitigate $PM_{2.5}$ pollution and improve air quality for the protection of public health.*

**Keywords:** Air pollution; $PM_{2.5}$ Emissions; environmental pollution; health risk.

## 1. Introduction

Air pollution represents a significant problem, with negative social, psychological, economic, environmental and other detrimental effects.[1, 2] Although research suggests a global decline in air pollutant concentrations, the pattern of air pollutant concentrations differs considerably by region. Accordingly, many locations worldwide reveal an upward trend in pollution levels, most particularly in the developed and underdeveloped countries.[1, 3-5] Air pollution is one of the most significant environmental risks for children's health. In 2019, 99% of the global population inhabited regions where the air quality levels established by the World Health Organization (WHO) were not upheld.[6] This paper analyzes $PM_{2.5}$ emission levels, focusing on Romania, comparing them globally to highlight high-risk regions and propose effective mitigation strategies.

Air pollution concerns are becoming more alarming in the global context of climate change, because temperature growth constitutes a crucial factor in the

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intensification of air pollution phenomena.[7] In addition, meteorological variables such as temperature, relative humidity and wind speed have the ability to both positively and negatively influence concentrations of airborne particulate matter atmospheric concentrations.[1, 7] The chemical composition of particulate matter (PM) varies based on its source, including nitrates, sulfates, elemental and organic carbon, organic compounds (such as polycyclic aromatic hydrocarbons), biological compounds, and metals. Understanding and determining the chemical composition of PM is crucial for reducing pollution. Over time, PM can settle on soil surfaces, bodies of water, or higher plants, including their roots and leaves, which can lead to negative impacts on ecosystems and harm their biodiversity.[8]

Air pollution from particulate matter (PM), which consists of a mixture of solid and liquid particles suspended in the atmosphere, is a key indicator of global air quality. Several studies have demonstrated significant associations with a wider range of associated adverse health impacts, in particular respiratory and cardiovascular disorders as well as DNA damage, correlated with pollution levels.[8, 9] Fine particles are more toxic by virtue of their ability to penetrate more deeply into the respiratory tract, causing more pathophysiological damages than the coarse particles. Exposure to $PM_{2.5}$ can also contribute to physiological changes in respiratory cells, with implications for lung health and the development of respiratory diseases.[10] The chemical composition of PM is extremely variable and is influenced directly by primary emissions, such as industrial activities and transportation, as well as secondary atmospheric pathways. $PM_{2.5}$ in industrial areas has higher toxicity than in urban areas do, presumably because of the differences in particle concentration and chemical composition. Atmospheric transport of PM and its interactions with other particles or pollutants can modify the primary chemical composition, species composition and biological properties, including responsiveness. In addition to urban pollution sources such as transportation, the industrial sector, including iron and steel manufacturing, petroleum and petrochemical plants, cement production and related activities, also represents a major contributor to air pollution and PM emissions.[11]

$PM_{2.5}$ are ultrafine inhalable particles with a diameter of 2.5 micrometers [12, 13], that are small enough to be inhaled and so penetrate deep into the respiratory system. The World Health Organization (WHO) estimates more than seven million people worldwide each year die from the diseases connected with fine particulate matter pollution $PM_{2.5}$ .[14] The compound effects of outdoor air pollution and indoor air pollution in households are linked to an estimated 6.7 million premature deaths annually. It is currently estimated that (outdoor) ambient air pollution has accounted for 4.2 million premature deaths on a global estimate in 2019, with a majority of these dying in low- and low-middle-income countries.[6]

This paper has performed a detailed analysis of $PM_{2.5}$ emission levels, focusing on the Romanian situation in the period 2019-2024. The study includes a comparative analysis of $PM_{2.5}$ emissions in Romania and worldwide for the year 2024, identifying cities and regions with significant public health risks associated with $PM_{2.5}$ emissions.

## 2. Methodology

This report used data from the monitoring stations of the National Air Quality Monitoring Network (RNMCA), which has currently 152 stations permanently monitoring air

quality parameters in Romania. To identify the main sources of $PM_{2.5}$ emissions, the information included in the Annual Report on the State of the Environment in Romania for the Year 2023, published by the National Agency for Environmental Protection, was referred on. The data from the World Air Quality Report 2023, providing a global review of air quality data for the year 2023, which summarizes $PM_{2.5}$ data from 7,812 cities in 134 countries, regions and territories, provided comparative analysis. This analyzed the effects of $PM_{2.5}$ emissions on human health and the environment, underlining the importance of specific actions and environmental policies to mitigate the negative impacts. $PM_{2.5}$ airborne suspended particulate are particulate matter which passes a size-selective port as defined by the standard reference method for the sampling and measurement of $PM_{2.5}$; SR EN 14907, with a 50% screening efficiency for an aero-dynamic diameter of 2.5 microns. In agglomerations and zones across the country, the competent authorities are required to adopt the appropriate actions to achieve the annual mean outdoor concentrations of $PM_{2.5}$ not exceeding the limit value of 25 $\mu g/m^3$.[13]

The website for downloading the data collected by the quality monitoring stations is owned and maintained by the Government of Romania, to facilitate the free accessibility to the population. The collected data from the monitoring stations mentioned above was realized for the interval January 1, 2019, 00:00 - January 1, 2025, 00:00. The annual daily average values of $PM_{2.5}$ ($\mu g/m^3$) collected by air quality monitoring stations in different regions of Romania provides a perspective on air quality and its variations in the country. Insufficient $PM_{2.5}$ reference method data, restricts, limitations, limits the potential to perform a comprehensive screening analysis. Despite the existence of multiple $PM_{2.5}$ monitoring stations in Romania, many of them have incomplete data, measuring only at certain time intervals, which does not allow these values to be included in the calculation of the annual average.

## 3. Results and discussion

Fig. 1 illustrates the annual average concentrations of $PM_{2.5}$ particulate matter in the air from 2019-2024.

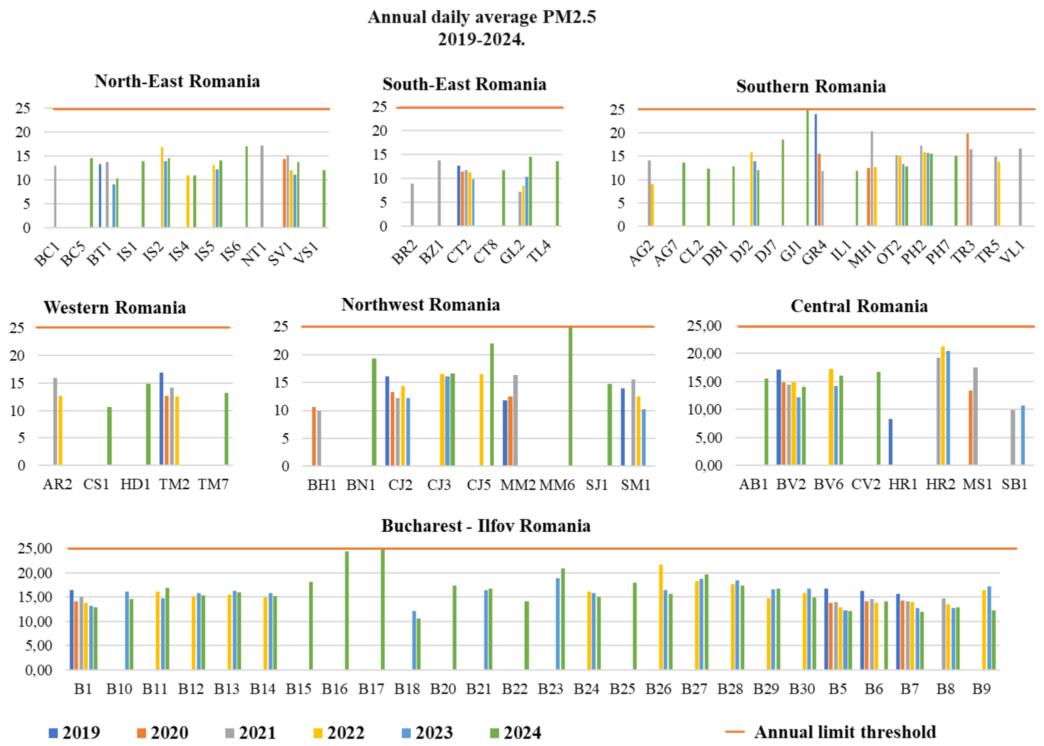
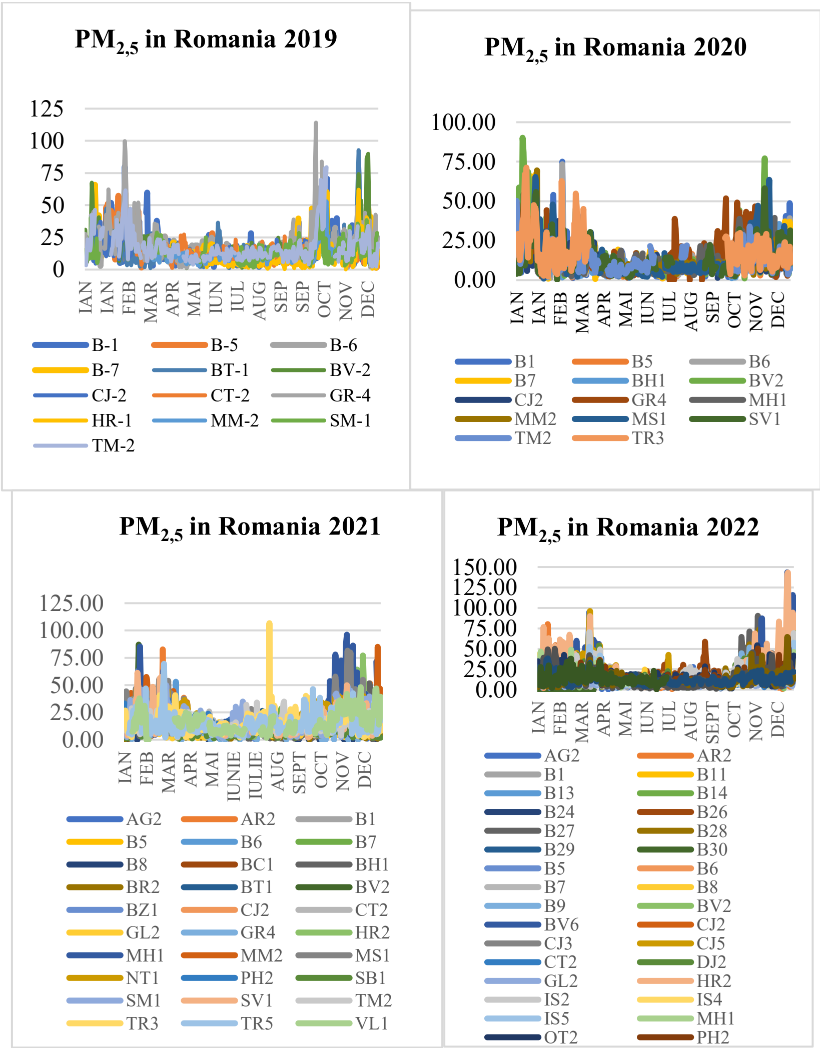



Fig. 1. $PM_{2.5}$ particulate matter - Annual average values in Romania, 2019-2024 [15]

By analyzing the plot values, we notice that the annual daily average $PM_{2.5}$ concentration for the county with sufficient data available for the period 2019-2024 has exceeded the annual limit of 25 μg/m³ only twice. Both exceedances have occurred in 2019, respectively at the monitoring station MM6, located in Sighetu Marmatiei, which registered a measured value of 30.60 μg/m³, and at the monitoring station B17, situated in Bucharest, sector 3, which registered a monitored value of 25.24 μg/m³. The data in the figure also indicates a slightly declining trend in the $PM_{2.5}$ concentrations, which might point towards a potential improvement in air quality. However, the significant annual variability highlights the influence of different meteorological conditions, industrial activities and the implemented pollution control efficiency.

The notable discrepancies between the measured values from the monitoring stations reveal that the pollution sources and local conditions are affecting air quality in different ways across the country. Some stations have shown a declining tendency in $PM_{2.5}$ concentrations over time while other stations report an upward trend or fluctuating irregularly. Such variations may be associated with industrial activity adjustments, traffic fluctuations, meteorological conditions, and the efficiency of pollution management and implementation.



PM2,5 in Romania 2019
125
100
75
50
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IAN IAN FEB MAR APR MAI IUN IUL AUG SEP SEP OCT NOV DEC
B-1 B-5 B-6
B-7 BT-1 BV-2
CJ-2 CT-2 GR-4
HR-1 MM-2 SM-1
TM-2
PM2,5 in Romania 2020
100.00
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IAN IAN FEB MAR APR MAI IUN IUL AUG SEP OCT NOV DEC
B1 B5 B6
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CJ2 GR4 MH1
MM2 MS1 SV1
TM2 TR3
PM2,5 in Romania 2021
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IAN FEB MAR APR MAI IUNIE IULIE AUG SEPT OCT NOV DEC
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BR2 BT1 BV2
BZ1 CJ2 CT2
GL2 GR4 HR2
MH1 MM2 MS1
NT1 PH2 SB1
SM1 SV1 TM2
TR3 TR5 VL1
PM2,5 in Romania 2022
150.00
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IAN FEB MAR APR MAI IUN IUL AUG SEPT OCT NOV DEC
AG2 AR2
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B13 B14
B24 B26
B27 B28
B29 B30
B5 B6
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IS5 MH1
OT2 PH2

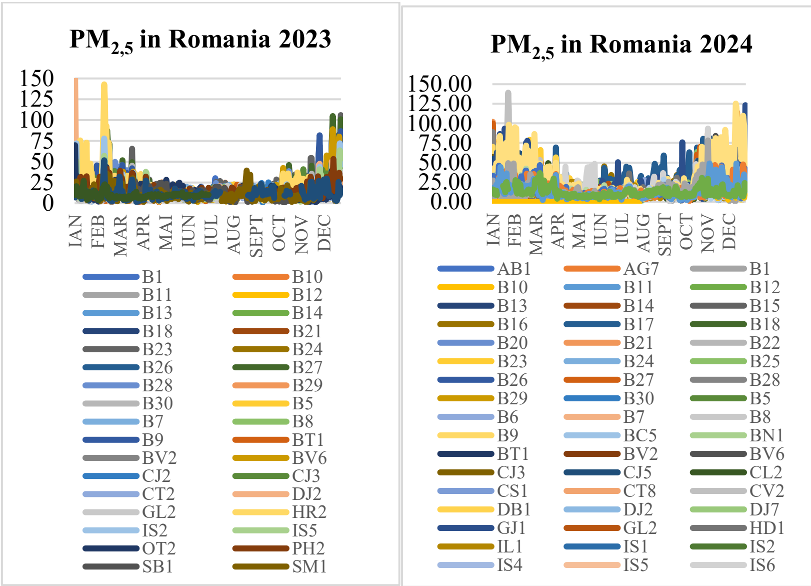


Fig. 2. Romania $PM_{2.5}$ - Month average concentration graph representation by year. [15]

Analyzing Fig. 2, which depicts the daily average concentration values for each year, a clear trend can be noticed, with the highest $PM_{2.5}$ concentrations during the cooler part of the year (October-March) and the lowest values during the warmer months (April-September), with these phenomena being repeated each year between 2019 and 2024. All the graphs indicate a general trend of $PM_{2.5}$ increasing in the cooler months and decreasing in the warmer months, mainly attributed to the enhanced warming activities in the cold season and more efficient pollutant dispersion in the warmer season.

The intensity and occurrence of peak pollution occurrences fluctuate from one year to the next, with 2019 and 2021 seeming to have more intense peaks in comparison with 2020. It is possible that the 2020 levels have been influenced by the COVID-19 pandemic restrictions, which temporarily led to a temporary decline in industrial activity and traffic. However, more detailed analysis is required to evaluate the actual pandemic impacts on air quality.

The graphs point out that the levels of $PM_{2.5}$ significantly fluctuate in different areas of Romania, some regions consistently record consistently high levels of pollution compared to others. Potential factors influencing $PM_{2.5}$ levels include: heating sources such as domestic heating, in particular the use of solid fuels including wood and coal, which represent a major contributor to $PM_{2.5}$ pollution, and the presence of pollutants such as $PM_{2.5}$ emissions during the cold season; industrial emissions, potentially releasing substantial levels of $PM_{2.5}$; vehicle emissions, particularly in urban areas; temperature inversions and stagnant air, which can hold pollutants near the ground, causing high levels of $PM_{2.5}$; some farming activities which also may contribute to $PM_{2.5}$ pollution.

The percentage calculations of the exceeding values of the maximum allowable concentration of 25 µg/m³ for the daily average in Romania in the monitored period 2019-2024 indicated that only 13% of the measured exceedances were above the limit. However, it is important to mention that during the mentioned interval there were many missing data reporting periods, potentially affecting the performance of these results.

By processing $PM_{2.5}$ concentration values from the 2024 World Air Quality Report, which assesses the global state of air quality, we can extract collected data from 8,954 cities in 138 countries, regions and territories from over 40,000 regulated air quality monitoring stations and low-cost sensors. Through this processing, we can output a chart showing the variation in $PM_{2.5}$ concentration between 2019-2024. We can also determine a ranked table based on collected and processed measurements for the year 2024, offering insights into the global air quality trends and trends.[16]

In the graph presented in Fig. 3 we clearly observe that, in the ranking based on the collected air quality monitoring stations values in 2024, Romania is placed in an intermediary position on the global air pollution index, on the 66th position with a concentration of 15.3 µg/m³. Based on a previous report for the year 2023, Romania is placed at 67th position in the same ranking, with a lower value of 15.7 µg/m³, which indicates a relative more balanced situation, which suggests that the implemented measures for reducing this pollution achieved a positive impact. The data suggests a modest declining tendency in $PM_{2.5}$ concentrations in recent years, with a significant improvement in air quality, based on the reported values between 2019-2024. The concentration of 15.3 µg/m³ in 2024 is considerably weaker in comparison with values from previous years, such as 18.6 µg/m³ in 2018 and 18.3 µg/m³ in 2019. This trend underlines the ongoing necessity to pursue and strengthen environmental protection efforts to maintain and continue to improve air quality in Romania to the public health and environmental benefit.

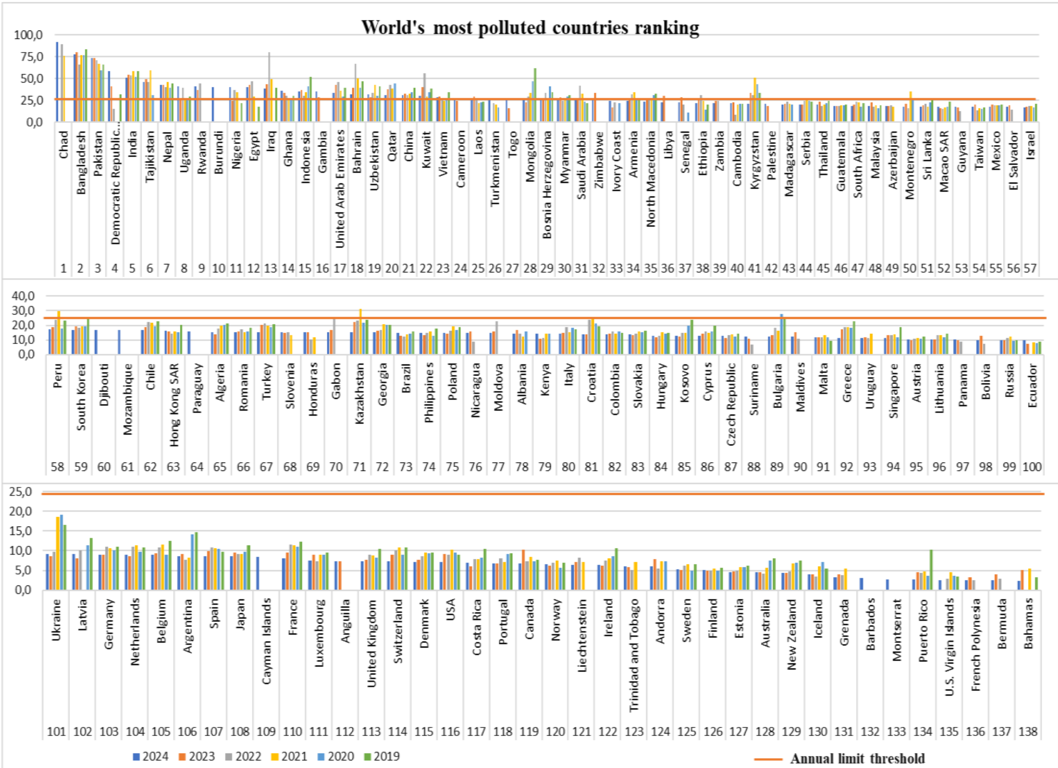


Fig. 3. The most polluted countries and regions ranked based on the average annual concentration of $PM_{2.5}$ (µg/m³) in 2024 and the concentration values from the period 2019-2024.[16]

The 2024-year ranking placed in first place Chad, a country located in the center of Africa, with an economy based mainly on agriculture and an oil resource which has become more important in recent years.[17] In 2024, the $PM_{2.5}$ concentration in Chad was 91.8 µg/m³, having a population of about 17,179,740 inhabitants.[16] Second in the poll rankings is Bangladesh, a country located in South Asia, which is characterized by an exceedingly dense population and has an economy characterized by strong population growth in recent decades, particularly due to a well-developed textile sector.[18] In 2024, the $PM_{2.5}$ concentration in Bangladesh was 78 µg/m³, corresponding population of approximately 169,356,251.[16] Third in the ranking is Pakistan, a southwest Asian located country with a diversified economy, including agriculture, industry and manufacturing as well as services.[19] In 2024, the $PM_{2.5}$ concentration in Pakistan was 73.7 µg/m³, representing a population of approximately 231,402,117.

The present classification provides a perspective on global trends in air pollution by comparing pollution levels in Romania to those in other countries and regions. It also illustrates the necessity for coordinated global action to mitigate air pollution and protect people's health. Air pollution is a trans-boundary concern and addressing it demands common efforts from all nations.

South and East Asia are experiencing the biggest air pollution globally problems. Bangladesh, Pakistan and India have significantly high average $PM_{2.5}$ concentrations.

In Eastern Europe, such as Bosnia and Herzegovina, Northern Macedonia and Serbia have more $PM_{2.5}$ concentrations compared to Romania. Western European countries, such as Germany, France and the UK, have below average $PM_{2.5}$ concentrations, because of more stringent regulation, investments in clean technologies and improved infrastructure.

The United States and Canada have a lower $PM_{2.5}$ concentration compared to Romania, due to strict regulations, clean technologies and advanced infrastructure.

The situation varies considerably in Latin America. Countries such as Guatemala and Peru report higher $PM_{2.5}$ concentrations than Romania, while others like the Bahamas and Bermuda have much cleaner air.

Located in eastern Europe, Romania has a temperate continental climate with considerable seasonal variations. Cold winters may lead to increased consumption of heating fuels, which contributes to pollution. With a population of around 19 million, Romania has a moderate population density, which can affect pollution levels in urban areas.

In summary Romania is facing significant air quality challenges but is better placed than many countries in South and East Asia. Compared to Western Europe and North America, considerable potential for improvement exists.

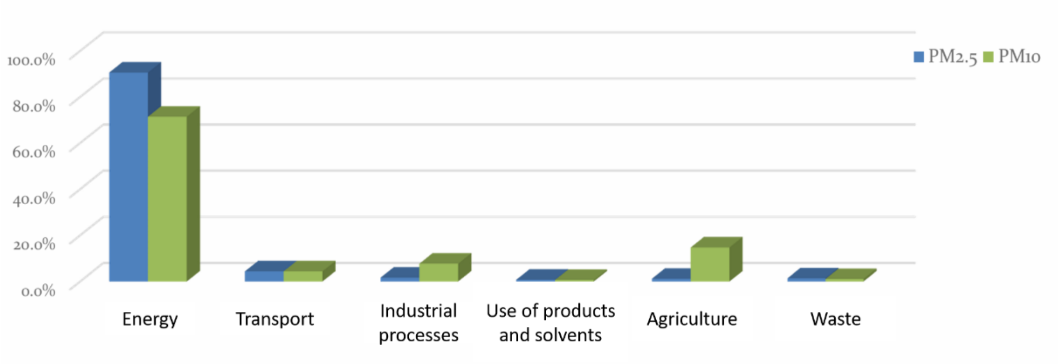


Fig. 4. National contribution of activity sectors in 2022 for $PM_{2.5}$ and $PM_{10}$ emissions of primary airborne particulate matter.[20]

By comparing the values shown in the above graph, it can be observed that the energy sector contributes significantly to the emissions of primary airborne particulate matter, with a percentage of 90.6% for $PM_{2.5}$ and 71.4% for $PM_{10}$. This dominance is mainly determined by particulate matter emissions from residential heating activities, highlighting the considerable impact of this sector on air quality.[20]

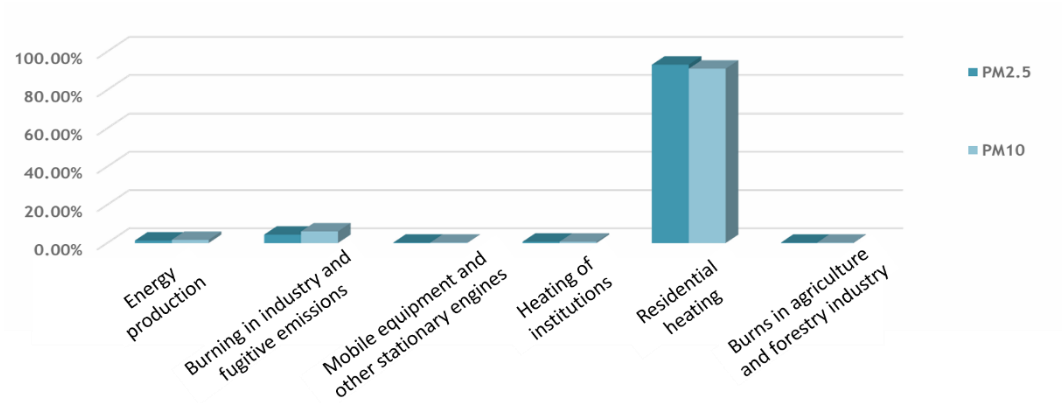


Fig. 5. Sub-sector activity contributions to primary particulate matter $PM_{2.5}$ and $PM_{10}$ emissions for 2022 in the Energy sector [20]

The peak share of emissions from the energy sector of both $PM_{2.5}$ and $PM_{10}$ particulate matter is mainly dominated by residential heating, which accounts for more than 90% of total emissions. $PM_{2.5}$ emissions from the energy sector contribute 90.6% of total national PM emissions, while $PM_{10}$ emissions amount to 71.4%. These data outline the significant impact of residential heating on air quality and emphasize the desirability of implementing effective pollution control measures in this sector to minimize emissions and improve air quality.[20]. This correlation is also evident in the presented results in Fig. 4, which illustrates the daily average $PM_{2.5}$ concentration per year. The graphs reveal a clear trend of rising $PM_{2.5}$ concentrations during the colder season of the year as compared to lower values in the warmer months, and this phenomenon is repeated on an annual average between 2019 and 2024. This suggests that mitigation measures to reduce emissions during the cold season, particularly for residential heating, might contribute substantially to air quality improvements.

A natural air purification solution like Phyto purification might be utilizing plants' natural ability to absorb and retain air pollutants such as fine particulate matter and polycyclic aromatic hydrocarbons. Urban forests have an ecological function of purifying the atmosphere, which is effective in lowering ambient $PM_{2.5}$ concentrations. The studies revealed a favorable effect of the presence of the trichomes, i.e. the fine parts on the leaf surface, on the settling rate of $PM_{2.5}$. This implies that leaves with a higher number of trichomes may contribute to the capture and sequestration of fine particles from the air. Action on reducing anthropogenic sources of primary and secondary aerosols has generally proved very expensive and controlling natural sources of pollution such as windborne dust, sea salt and secondary particle formations from the biogenic precursor organic gases are often difficult or sometimes impossible. This method represents an innovative approach for using plants in nature-based solutions for air pollution control, in which different species compositions have the potential to enhance environmental functions such as carbon sequestration and pollution filtration.[22-26]

A second solution might involve the implementation and optimization of traffic congestion management junctions. These are being designed to improve traffic flow and reduce congestion by making it convenient to switch directions without having vehicles stop. The main purpose of interchanges is to optimize traffic flow congestion by minimizing unnecessary waiting times and improving road safety. They may also affect pollutant emissions by reducing congestion and the travel time of these vehicles.[27]

A very relevant and current technical solution, in the present context of the increasing levels of $PM_{2.5}$ pollutants in the cold season, is the use of methods for separating and capturing these particles using smoke filters. These filters are capable of high efficiency in capturing $PM_{2.5}$, with reported removal rates of more than 90% for fine particles. The efficiency of these filters also depends on the variety of used materials as well as their granularities, which suggests that the proper filter material selection is crucial for minimizing $PM_{2.5}$ emissions, and the implementation of these solutions can significantly contribute to improve air quality and to protect public health.[28] Ongoing monitoring of air quality is vital to assess the efficacy of environmental policies and identify areas of persistent pollution concerns. In this context, the authorities should design and implement pollution control measures adapted to the specificities of individual regions, including the setting of stringent industrial emission regulations and the encouragement of environmentally friendly transport solutions, to achieve more effective air quality management.

## 4. Conclusions

The global trend in primary particulate matter emissions at national level during 2018-2022 has been upward. This assessment suggests that despite efforts to reduce pollution, primary particulate matter emissions have been increasing substantially, which raises serious concerns about the impact on public health and air quality. It is imperative to investigate the sources of this growth and to implement efficient measures to effectively reverse this development.

According to a published report by the Ecopolis Center for Sustainable Policies, for the years 2021-2022, the annual average limit of 25 $\mu g/m^3$ is not exceeded at the national level, but it is reported that collected data from the 27 monitoring sensors of the AerLive. ro platform, located near schools in Bucharest, indicates significant exceedances of the limit values for air pollutants, in particular $PM_{10}$ and $PM_{2.5}$, with daily averages of up to 150 $\mu g/m^3$ at G. Călinescu School, six times exceeding the annual limit of 25 $\mu g/m^3$ for $PM_{2.5}$. In this context, the alarming exceedances at most stations, such as the ones on Calea Giulesti and G. Călinescu

School, emphasize a high risk for the children's health, and other vulnerable citizens of the Capital who are constantly exposed to the polluted air, requiring prompt corrective measures from the competent authorities.

Public education on the health impacts of air pollution and the measures that can be taken by the population to reduce their exposure to $PM_{2.5}$ is very important. This analysis provides a solid basis for future investigations and for the further development of effective policies for improving air quality in Romania. Considering regional variations and different trends, there is no one single solution to continue the improvement of air quality in Romania.

Implementing policies and investments that support greener transport, energy efficiency in housing, sustainable energy production, responsible industrial development and more efficient municipal waste management could strongly reduce the main sources of ambient air pollution. Also ensuring household access to clean energy could significantly limit ambient air pollution in some regions.

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