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URBAN CHALLENGES AND AIR QUALITY IN SELECTED EUROPEAN CITIES

More than half of the world's population currently resides in urban areas. Therefore, cities must be part of the solution if the increasingly urbanized world is to successfully address environmental challenges such as climate change. Air pollution poses a significant health risk to Europeans. Due to urbanization, population growth, traffic congestion, industrial activities, energy generation, and inadequate urban planning connected to environmental solutions modern cities confront a range of complex challenges concerning air quality. Achieving the zero-pollution vision for 2050 demands further endeavors to diminish air pollution to levels deemed safe for health. This article examines the multifaceted obstacles that modern cities encounter, with a particular emphasis on the critical issue of air quality. The study aims to analyze low-emission solutions aimed at improving the state of air quality in selected European cities. The study assessed changes in the concentrations of NO_2, O_3, PM_{10}, $PM_{2.5}$ and benzo(a)pyrene in chosen European cities between 2013–2022 offering a comparative analysis of air quality challenges and solutions across selected cities. The value of the analysis lies in its ability to draw conclusions from current European urban trends related to air quality improvement and to develop a comprehensive set of recommendations tailored for policymakers.

1. INTRODUCTION

Nowadays, most people in the world live in cities, where one can observe rapid urbanization in recent decades [1]. The global urban population has increased by

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4.6 times from 751 million (30% of the world population) in 1950 to 4.2 billion (55%) in 2018, and the number is projected to reach 6.4 billion (68%) in 2050 [2]. This process leads to increased demand for housing, transportation, and infrastructure, putting pressure on resources and exacerbating environmental issues like air and water pollution. Development projects often have environmental consequences such as habitat destruction, loss of green spaces, and increased carbon emissions [3].

Urbanization often brings about various sources of air pollution such as industrial emissions, vehicular exhaust, and construction activities, among others [4]. The process of urbanization in European metropolitan regions has a considerable impact on air quality. This is primarily due to the escalation of industrial activities, transportation, and energy consumption. The emissions from industrial operations and vehicular traffic include harmful pollutants like particulate matter, nitrogen oxides, and volatile organic compounds, resulting in the formation of localized air pollution hotspots. Moreover, the rising energy demand contributes to the increased burning of fossil fuels, exacerbating the degradation of air quality [5]. As cities expand, the concentration of these pollutants can increase, leading to haze pollution problems and posing serious health risks to residents [6]. Scholars have indeed identified a correlation between city-scale expansion and air pollution [7, 8]. The rapid growth of cities often leads to increased vehicular traffic, industrialization, and energy consumption, all of which contribute to higher levels of air pollution [9]. Additionally, urban sprawl can lead to increased land use change, deforestation, and changes in atmospheric circulation patterns, further exacerbating air quality issues. Therefore, policymakers must implement strict measures to control pollution sources in urban areas [10]. This may include enforcing emission standards for industries and vehicles, promoting sustainable transportation alternatives, investing in green infrastructure, and encouraging energy-efficient practices. By addressing these factors, we can work towards improving urban air quality and ultimately enhancing public health [11].

Balancing economic growth with environmental sustainability is currently a significant challenge for cities [12]. Thus, cities face so many challenges today, but the most important are traffic congestion, air pollution from vehicular emissions, inadequate public transportation infrastructure [11], air and water pollution, waste management issues, and habitat destruction [13, 14]. Air quality remains a significant environmental concern globally [15]. Even in the Nordic regions (Denmark, Finland, Iceland, Norway, and Sweden), known for their relatively clean air, air pollution continues to pose adverse health effects [16]. Therefore, cities face many challenges in terms of constant improvement of air quality, including the implementation of the idea of sustainable development. Nowadays, it is quite a challenge, not only socio-economically, but also the implementation of technological solutions in terms of environmental and health protection aspects [17]. Climate change and carbon emissions are critical matters for humankind at this moment, and environmental-related sustainable development targets are a priority for governments worldwide [18]. There is a need to implement the process of creating a low-emission city model and a pro-environmental solution. At this point, attention

should be paid to low-emission packages used in large urban agglomerations [19]. The paper aims to indicate the multifaceted challenges that modern cities encounter, with a particular emphasis on the critical issue of air quality. Also, the objective of the paper is to explore and propose innovative solutions to address urban challenges, with a specific emphasis on improving air quality.

2. METHODOLOGY

An in-depth analysis of practices in European cities concerning air quality solutions and guidelines outlined in the Zero Pollution Action Plan 2050 was conducted. The study also involves a comprehensive review of existing approaches and policies adopted by selected European cities facing urban challenges, particularly focusing on air quality issues. To facilitate a more comprehensive analysis of city trends, the city practices were categorized into a series of the following sections: green initiatives, strategic solutions, and environmental governance. The conducted analysis was based on air quality report data and practical solutions implemented by leading selected European cities: Berlin, Warsaw, Copenhagen, Amsterdam, Prague and Stockholm in the context of air pollution and good practices in this field. Selected leading cities constitute a reference point for further analysis and presentation of good practices in the area of air protection. Furthermore, the study involved synthesizing findings into actionable insights and recommendations for policymakers. These recommendations aimed to inform future urban planning and environmental policies, emphasizing the importance of integrating sustainable practices and innovative technologies to mitigate air pollution and enhance overall urban air quality.

The subsequent research questions have been formulated to be in line with the aim of the study: What is the current state of air quality in European cities? What are the key factors contributing to good air quality in contemporary urban environments? What innovative practices, technological solutions, environmental and social approaches are employed by leading European cities in terms of ensuring air quality?

To attain the defined objectives and respond to the research questions, the following research methods were employed: analysis of EU strategic documents, reports, projects' outcomes regarding air quality, literature review of national and international academic articles on air pollution, as well as examples of innovative practices in the selected cities in the area of improving air quality. The collected research material facilitated conclusions focused on the following issues:

- identifying the major challenges faced by cities in the area of air quality,
- exploring environmental performance and air quality solutions across the leading EU countries,
- preparation of a package of recommendations and good practices that could be scaled up.

3. AIR QUALITY IN SELECTED EUROPEAN CITIES

Air pollution remains the most significant environmental health hazard in Europe, contributing to cardiovascular and respiratory illnesses that reduce healthy life expectancy and, in severe cases, result in avoidable fatalities. Concentrations above the EU daily limit value for PM10 are seen mainly in some Eastern European countries. In most central and eastern European countries, solid fuels such as coal are widely used for heating households and in some industrial facilities and power plants, which confirms the scale of the air protection issue and the need to implement actions aimed at improving air quality in cities.

According to the statistical data from Europe's air quality status 2023 (https://www.eea.europa.eu/publications/europes-air-quality-status-2023) concentrations of PM10 in 2021 was as follows:

- 21 reporting countries, including 15 EU member states, recorded concentrations above the EU daily limit value of 50 $\mu g/m^3$,
- 11 reporting countries, including 6 EU member states, recorded concentrations above the EU annual limit value of 40 $\mu g/m^3$,
- all 37 reporting countries recorded concentrations above the WHO daily guideline level of 45 $\mu g/m^3$,
- all reporting countries except Iceland registered concentrations above the WHO annual guideline level of 15 $\mu g/m^3$.

The main sources of air pollution in Europe vary across different regions and sectors. Home heating, particularly with solid fuel, is a significant contributor to air pollution, especially in eastern Europe and Italy. This results in extreme air pollution events that have adverse health effects. In northwest Europe, agriculture is the dominant source of pollution due to ammonia emissions from fertilizers and animal waste. Reducing these emissions could lead to decreased fertilizer use and improved air quality. Large industries and power generation plants also contribute to air pollution, despite being subject to inspection and control measures. Similarly, traffic pollution, caused by all vehicles including electric ones, remains a major concern and is not effectively regulated. Shipping is a significant source of particle pollution, especially in coastal areas and ports. Although new regulations have led to better quality marine fuel and the use of scrubbing systems, shipping still has a notable impact on air quality.

The EU identifies seven main air pollutants: ammonia (NH_3), nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter with an aerodynamic diameter lower than 2.5 and 10 μm (PM2.5 and PM10), sulfur oxides (SO_x), tropospheric ozone (O_3) and non-methane volatile organic compounds (NMVOCs). In cities, where 74% of the EU population lives, PM2.5 and ground-level ozone have potentially the most significant effects on human health associated with respiratory and cardiovascular diseases and mortality, compared to other air pollutants [20, 21]. According to the World Health Organization (WHO), an essential contributor to air pollution are particulate emissions

(PM2.5), which are responsible for serious medical problems, especially cardiovascular, pulmonary, and cancer risks [22, 23].

The air quality analysis of leading cities in Europe was based on multi-year annual measurements in Berlin, Warsaw, Copenhagen, Amsterdam, Prague, and Stockholm. Access to the data was provided through the European Environment Agency (EEA). The resource was available at the following link: https://www.eea.europa.eu/data-and-maps/dashboards/air-quality-statistics (Accessed on April 17, 2024). Based on the collected measurement data, concentration charts were created.

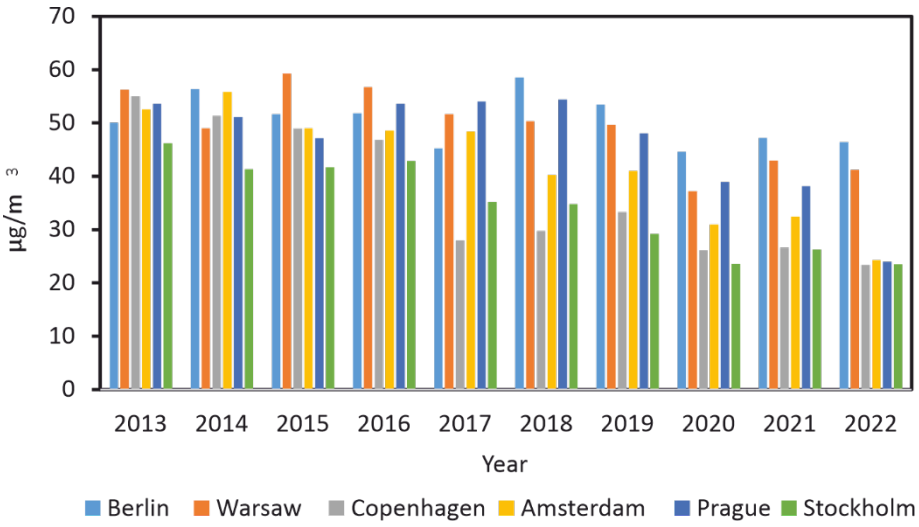

Fig. 1. Nitrogen dioxide concentrations in the selected cities throughout 2013–2022

Figure 1 presents the distribution of nitrogen dioxide concentrations in leading selected cities across Europe over the period from 2013 to 2022. The level of this pollutant varies depending on the level of development of the country in terms of industrialization and the use of environmental protection technologies and solutions. Importantly, nitrogen dioxide emissions into the atmosphere have been reduced over recent years across Europe, and in 2017, a sharp decrease in the level of this pollutant was observed in all surveyed cities, as a result of actions implemented within the European Union.

In Berlin, in 2018, the highest increase in nitrogen dioxide concentration was recorded, likely due to the reactivation of conventional power plants. It is worth noting that such increases can pose a challenge to maintaining low levels of air pollution in the region. However, overall, there has been a positive trend in reducing emissions over the past decade.

Figure 2 presents the concentration of sulfur dioxide in the analyzed cities of Europe. The concentration of sulfur dioxide varies depending on the level of development

of the country, the degree of industrialization, and the environmental protection technologies and solutions employed. The sulfur dioxide concentration values show a significant decrease in Warsaw and Prague over the past ten years, which is considered a positive outcome of actions taken. In other cities, there has been a minimal decrease, attributed to the earlier implementation of solutions aimed at minimizing environmental impact. Sources of sulfur dioxide emissions include fuel combustion processes.

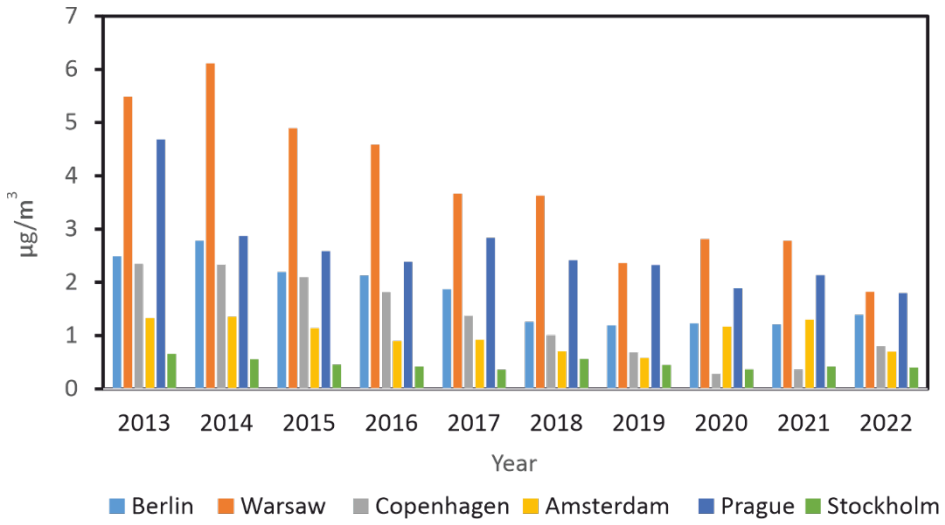

Fig. 2. Sulfur dioxide concentrations in the selected cities throughout 2013–2022

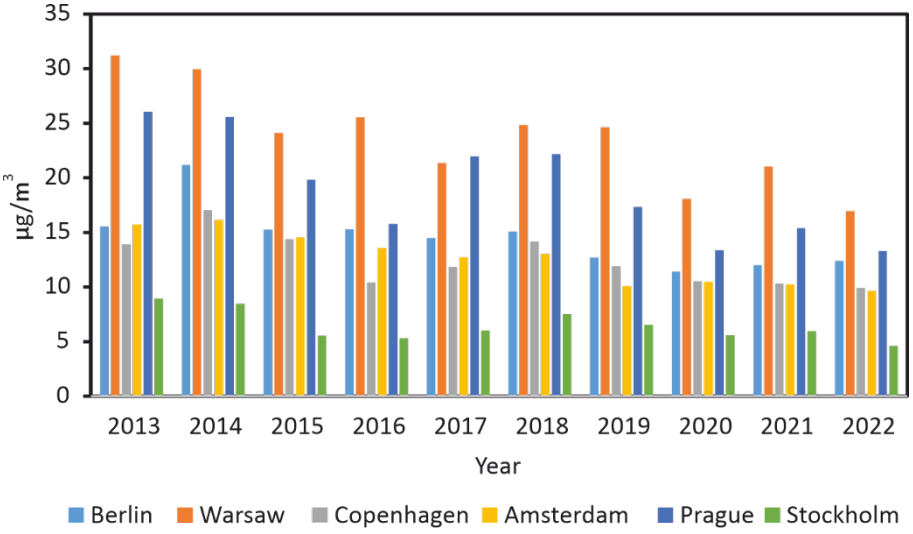

Fig. 3. Particulate matter PM2.5 concentrations in the selected cities throughout 2013–2022

Figure 3 depicts the concentration of PM2.5 particulate matter in the cities of Europe as presented by the authors. The concentrations of this particulate matter vary depending on the level of development of the country, the degree of industrialization, and the environmental protection technologies and solutions employed. PM2.5 is one of the most hazardous air pollutants due to its ability to penetrate deeply into the respiratory systems of humans and animals, potentially causing a range of health problems. Therefore, it is essential to monitor and control the concentration of this particulate matter to safeguard air quality and protect the health of city residents.

Over 10 years from 2013, a significant decrease in PM2.5 particulate matter concentration can be observed in central European cities, while other surveyed cities also show decreases contributing to improved air quality in those regions. This is a positive signal that environmental protection measures and technologies are yielding beneficial effects in combating this harmful pollutant fraction – PM2.5. Nevertheless, the continuation of environmental protection efforts remains critically important to further reduce PM2.5 concentrations and sustain tangible improvements in air quality for all residents of Europe.

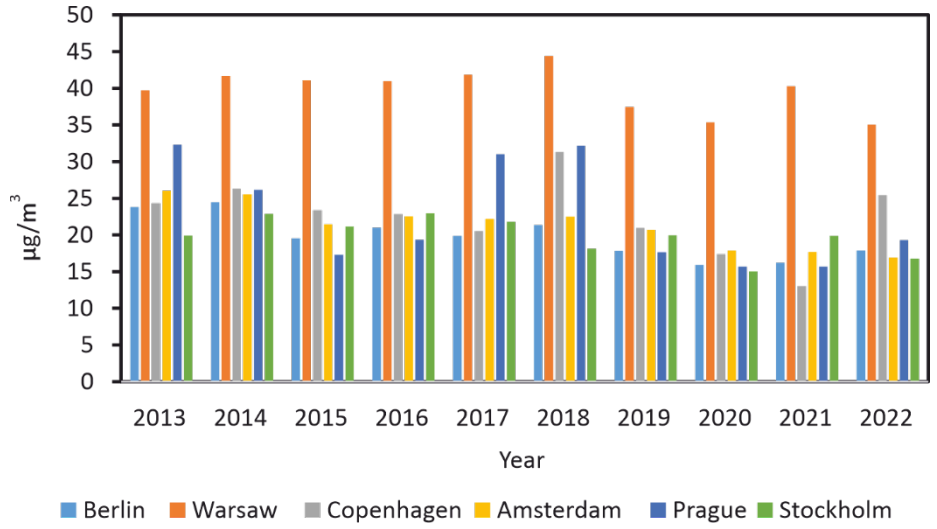

Fig. 4. Particulate matter PM10 concentrations in the selected cities throughout 2013–2022

Figure 4 depicts the concentration of PM10 particulate matter in major cities across Europe. The concentrations of this particulate matter vary depending on the level of development of the country, the degree of industrialization, and the environmental protection technologies and solutions employed.

PM10 particulate matter concentration in Warsaw is significantly higher than in other cities. This difference may stem from the intensity of industrial and transportation

activities, among other factors influencing air pollution emissions. This trend underscores the importance of continuing to implement effective measures aimed at improving air quality and optimizing practices, including fuel transitions and the implementation of modern emission-reducing installations, towards achieving an energy mix. Intensive efforts are being made in Warsaw to maintain the annual concentration of PM10 particulate matter at an acceptable level, which is 40 µg/m^3, to safeguard air quality and protect public health.

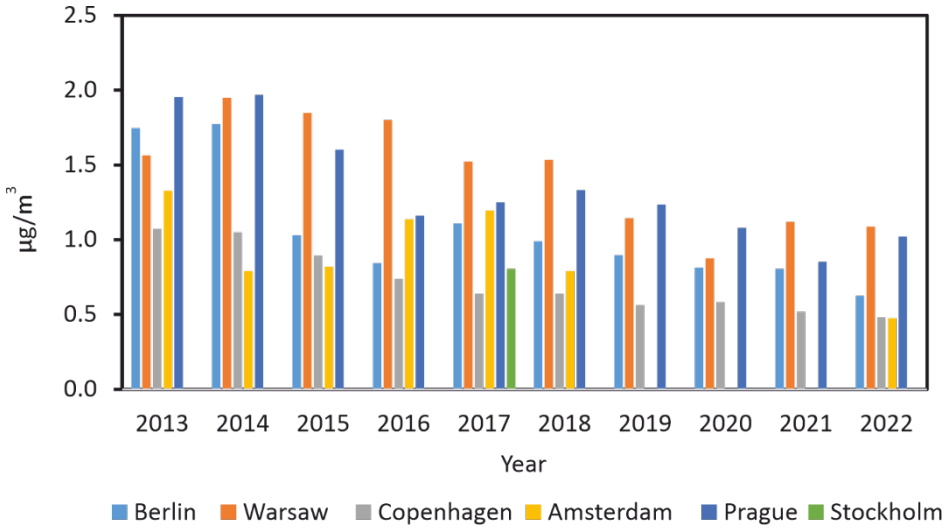

Fig. 5. Variation of benzene concentration in the selected cities throughout 2013–2022

Figure 5 shows benzene concentrations in leading European cities, available at the link: https://www.eea.europa.eu/data-and-maps/dashboards/air-quality-statistics (access date 17.04.2024). Benzene is one of the crucial air pollutants, and its concentration varies depending on the level of development of the country, the degree of industrialization, and the environmental protection technologies and solutions employed. In this case, available data from the platform was analyzed. A positive trend is the significant decrease in emissions of benzene in each country over the past years. This indicates that environmental protection efforts, industrial modernization, and more eco-friendly technological solutions are yielding desired effects in reducing benzene emissions into the atmosphere. The level of benzene concentration does not exceed permissible standards, which is crucial for the health of city residents and environmental protection.

Figure 6 presents the concentration of lead in analyzed cities across Europe. The concentration of lead shows low variability due to generally small values. It is important to emphasize that lead is a toxic substance that can pose serious health risks to humans and the environment, which is why reducing its levels is a critical aspect of environmental protection.

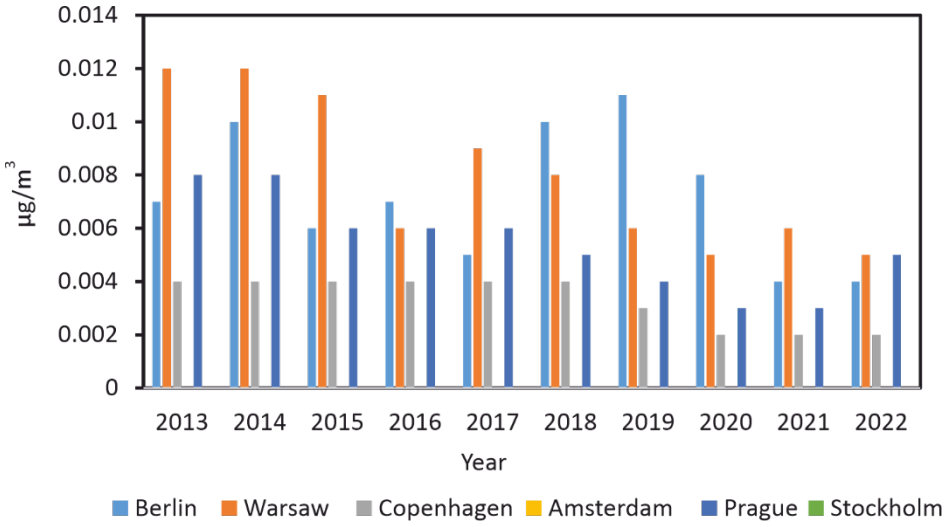

Fig. 6. Lead concentrations in the selected cities throughout 2013–2022

The annual level of lead has decreased in major cities across Europe. This demonstrates the effectiveness of efforts to reduce lead emissions into the atmosphere. The reduction in lead levels may be attributed to the implementation of more stringent regulations, the use of advanced technologies, and changes in industrial and transportation practices. However, despite these positive changes, lead remains a pollutant that requires special attention and monitoring. Efforts to further reduce lead levels should be continued to ensure the health and well-being of city residents and protect the natural environment.

4. GOOD PRACTICES IN IMPROVING AIR QUALITY IN EUROPEAN CITIES

Various initiatives and solutions are being explored and implemented to combat air pollution in European cities. One such approach is the promotion of sustainable transportation alternatives. Investing in public transportation infrastructure, promoting cycling and walking, and incentivizing the use of electric vehicles can significantly reduce vehicular emissions and improve air quality.

Urban planning and design also play a crucial role in addressing air quality challenges. Creating green spaces, implementing green building practices, and adopting sustainable urban development strategies can help mitigate the impact of pollution and enhance air quality. Additionally, measures such as promoting energy efficiency, reducing reliance on fossil fuels, and increasing the use of renewable energy sources contribute to overall air quality improvement.

Based on the analyses conducted, it can be concluded that European cities have consistently been implementing solutions aimed at improving the quality of life and air quality within urban areas. Examples of such initiatives are presented in Table 1.

Table 1

Solutions regarding air quality in selected European cities
(based on the data of the European Environment Agency (EEA))

City	Air quality solutions
Berlin	Berlin's environmental zone, introduced in 2008, aims to improve air quality by substantially cutting nitrogen oxide emissions and particles attributable to traffic. Equipping the city with a modern fleet of buses and public vehicles, as well as their modernization, aimed at reducing pollutant emissions. Financing programs for electric vehicles within commercial transportation. Promoting the retrofitting of commercial vehicles with exhaust gas cleaning systems to reduce nitrogen oxide emissions. Expanding the city's parking management plan to reduce traffic and encourage residents to use public transportation or bicycles. Promoting public transportation, cycling, and walking.
Warsaw	Scores high in environmental governance. The city is enhancing public transportation, energy efficiency in buildings, and green spaces to implement green policies. Investments in modern public transportation, including the purchase of new buses with electric models and expanding tram routes (since 2017). Developing cycling networks while promoting this mode of transportation. Grants for the purchase and installation of solar collectors, heat pumps, photovoltaics, and particularly the replacement of outdated heating systems to reduce air emissions. Expansion of green-blue infrastructure as part of the city's sustainable development plan. Establishment of mobile laboratories for air quality monitoring by the Environmental Protection Division of the City Guard. In 2023 joining the Breathe Life – C40 platform, aimed at tackling toxic air pollution.
Amsterdam	Zero-Emission Mobility in Amsterdam Implementation Agenda 2023–2026: The City of Amsterdam's plans for the transition to cleaner air quality from 2025 onwards include implementing zero-emission zones for vehicles. The air quality action plan addresses transport congestion issues, expands park-and--ride facilities, promotes the adoption of electric vehicles, and pursues other objectives. Introducing emission-free buses, taxis, and municipal ferries in the city center. Implementing an emission-free plan by 2030, requiring all modes of transport throughout the city to be emission-free. Expanding bike paths and promoting cycling as a mode of transportation. Investing in air quality awareness, setting an example as a municipality.
Copenhagen	Development of bike lanes within the capital city to increase the number of residents using this mode of transportation. Construction of a new metro line contributing to the reduction of car usage in transportation. Construction of technologically advanced waste incineration plants with the application of cogeneration energy systems used for heating city buildings. Increased recycling of waste. Investments in wind turbines. Continued reduction in the number of combustion engine vehicles.

Table 1

Solutions regarding air quality in selected European cities
(based on the data of the European Environment Agency (EEA))

Prague	Implementation of the Air Quality Improvement Program (PZKO 2020+), the Territorial Energy Concept, the Climate Plan, and the Sustainable Mobility Plan. Green initiatives, including a new waste management system to boost recycling rates, energy-efficient buildings, and the promotion of green spaces Introduction of emission standards for vehicles corresponding to Euro 6. Promotion of non-grid/grid electrification. A subsidy program offering financial assistance to households for replacing old heating furnaces. Introducing monitoring stations in industrial areas.
Stockholm	To reduce carbon dioxide emissions, subsidies were introduced for replacing diesel buses with electric buses. In 2017, emission requirements for domestic solid fuel boilers were tightened, and new minimum efficiency requirements were introduced. Since 2014, EU limits for PM10 have also been adhered to. In Sweden and other Scandinavian countries, high levels of PM10 are primarily caused by studded winter tyres used during the winter months. As a result, studded tyres have been banned on three of Stockholm's busiest roads. Charges for entering central Stockholm were introduced on a trial basis in 2006 for journeys to the central parts of Stockholm. Expansion of bike paths and promotion of cycling as a mode of transportation. Introduction of green-blue infrastructure as part of sustainable development. Financing programs for electric vehicles within commercial transportation.

Urban air pollution remains a critical concern across Europe, with cities grappling with the challenges of maintaining air quality amidst rapid urbanization and industrial activities. The strategies employed by notable cities offer compelling insights into the multifaceted approach necessary for meaningful improvement. These strategies, ranging from legislative frameworks to innovative sector-specific measures, underscore the complexity of combating air pollution and the imperative for comprehensive, sustained efforts. Examining these efforts and their outcomes reveals the broader implications for public health, environmental sustainability, and socioeconomic equity, emphasizing the importance of continued commitment and innovation in air quality management.

The described best practices in individual cities highlight the need for exchanging experiences and solutions, implementing them on a larger scale throughout Europe and beyond. The requirements of the FIT for 55 package and Europe's pursuit of climate neutrality indicate a realistic goal for the coming years that is achievable.

5. SUMMARY

The air quality issue remains a relevant topic despite years of implementing actions in many urban areas aimed at improving the state of the natural environment, including

air quality. However, challenges still exist. Despite progress, many cities continue to face air pollution challenges, especially with growing traffic volumes, necessitating further investments in preventive measures.

Cities need to invest in efficient public transportation systems, promote active transportation modes like walking and cycling, implement traffic management strategies, and incentivize the use of clean energy vehicles to improve mobility and reduce emissions [24]. Cities must develop climate adaptation and resilience strategies such as improving disaster preparedness, enhancing infrastructure resilience, and reducing greenhouse gas emissions to mitigate the impacts of climate change and build more resilient communities. Cities need to implement pollution control measures, promote waste reduction and recycling, protect natural habitats and green spaces, and invest in sustainable infrastructure to mitigate environmental degradation and safeguard public health [25].

Selected leading cities highlighted in the publication effectively implement corrective actions – best practices – and the measurable outcome of these actions is the improvement in the state of air quality confirmed in environmental reports for cities and data presented on the official websites of the European Environment Agency.

The key factors contributing to good air quality in contemporary urban environments are:

- vehicle emission reduction measures: many cities like Berlin, Warsaw, and Amsterdam are taking actions to reduce vehicle emissions by promoting public transportation; electrifying bus and taxi fleets, and implementing zero-emission zones,
- investments in low-emission transport: expanding cycling infrastructure, promoting bicycles as a mode of transportation, and developing tram and metro networks (e.g., Copenhagen),
- prohibition of detrimental practices such as restrictions on studded tires during winter months (as observed in Stockholm), aimed at mitigating particulate emissions,
- modernization of energy infrastructure: transitioning to renewable energy sources (e.g., investments in wind turbines) and reducing emissions through efficient district heating systems (Copenhagen).

Improvement of the environmental condition through the implementation of the mentioned actions in selected cities in recent years indicates that these measures have rational outcomes in terms of improving residents' quality of life, living standards, and health parameters, for the cities covered in the publication.

The innovative practices, technological solutions, and environmental and social approaches employed by European cities to ensure air quality are as follows:

- transport electrification: implementing zero-emission zones, and promoting electric and hybrid vehicles (e.g., Amsterdam),
- expansion of cycling infrastructure: improving accessibility and safety for cyclists (e.g., Copenhagen, Amsterdam),
- modernization of public transportation: introducing modern, eco-friendly public transportation modes such as electric buses and trams,

- social awareness: investing in education and raising awareness among residents about the impact of emissions on air quality (e.g., Amsterdam),
- air quality monitoring: establishing air quality monitoring stations (e.g., Prague).

Concluding, improving atmospheric air quality in European cities presents a significant challenge that must be implemented with determination, paying particular attention to key actions – best practices such as:

- meeting the requirements of spatial planning in the category of environmental balance,
- improving the functioning of institutional order aimed at achieving urban environmental balance,
- continuing the adopted policy of development of European cities, aiming to implement actions in line with the European Union's strategy for reducing greenhouse gas emissions,
- promoting the directions of adopted actions and future pro-environmental investments aimed at creating a positive image of cities,
- harnessing the existing potential of cities to reduce greenhouse gas emissions,
- implementing the principles of green cities and zero or low-energy buildings by increasing the production of energy and heat from renewable sources, effectively reducing heat demand and greenhouse gas emissions into the atmosphere,
- reducing low emissions by changing the heating system of buildings from fossil fuels, and where possible, connecting buildings to district heating networks or switching to ecological sources of combustion,
- limiting car traffic in the city centers through measures encouraging residents to use public transport and promote cycling and water transport,
- implementing economic tools for users of hybrid and electric vehicles in the form of tax incentives for vehicle use and provision of free parking in all city parking zones, city greening considering the principles of green architecture,
- strengthening the dimension of ecological education and social responsibility of business in the context of sustainable regional development,
- continuously analyzing the internal and external environment to optimize the implementation model of operational actions concerning the socio-economic environment, incorporating the best available techniques and selected proposals of good practices used in other European cities.

By scaling up these strategies, cities can strive towards healthier and more sustainable urban environments, benefitting both current and future generations. Continuous monitoring and adaptation of operational strategies based on the best available techniques and successful practices from other European cities are essential for ongoing progress in urban air quality challenges.

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