Marzena HAJDUK-STELMACHOWICZ • Paulina BEŁCH • Elżbieta SZCZYGIEŁ • Barbara FURA • Michał Piotr FRANKIEWICZ

IMPACT OF COVID-19 PANDEMIC ON THE AIR QUALITY OF POLISH CITIES – CHALLENGES FOR MANAGERS

Marzena **Hajduk-Stelmachowicz** (ORCID: 0000-0003-4945-7207) – *Rzeszów University of Technology*
Paulina **Bełch** (ORCID: 0000-0002-6877-2870) – *Rzeszów University of Technology*
Elżbieta **Szczygieł** (ORCID: 0000-0002-8804-1071) – *University of The National Education Commission in Kraków*
Barbara **Fura** (ORCID: 0000-0002-9601-6634) – *University of Rzeszów*
Michał Piotr **Frankiewicz** (ORCID: 0009-0001-1823-9365) – *Rzeszów University of Technology*

Correspondence address:
Ćwiklińskiej Street 2, 35-601 Rzeszów, Poland
e-mail: bfura@ur.edu.pl

ABSTRACT: This article aimed to investigate the coronavirus pandemic's impact on air quality in Poland. The study used data from 2015–2023 from measurement stations located in five large Polish cities with different geographical locations. The data concerned particulate matter (PM2.5, PM10) and nitrogen oxides (NOx). On the basis of the statistical analyses performed, a decrease in the amount of all types of pollutants was found in 2020, with a reduction in the concentration of NOx being statistically significant only for two of the three cities studied (Kraków and Wrocław). It was concluded that the restrictions introduced in relation to the SARS-CoV-2 virus may have contributed to an improvement in air quality in Polish cities compared to previous years.

KEYWORDS: COVID-19, quality of life, green deal, green economy, sustainable development

Introduction

The definition of air pollution refers in the literature to the presence of solid, liquid, and gaseous substances in a given stratum of the atmosphere in quantities that are not only a nuisance to humans or hurt their health but are also harmful to flora and fauna, water, soil, and climate (Treder, 2017).

In addition to natural sources of air pollution (which refers to such natural processes as forest fires, volcanic eruptions, and dust storms, among others), anthropogenic pollution, which is the result of human activity, is of increasing concern (Treder, 2017). There is a growing body of scholars from a variety of scientific disciplines engaged in multidimensional research addressing environmental issues (Dardanoni & Guerriero, 2021; Han & Li, 2021; Wang & Lei, 2021), circular economics (Trollman et al., 2020; Ibn-Mohammed et al., 2021), ecological economics (Liang, 2020; Wang et al., 2021; Xu, 2021), sustainability (Khokhobaia, 2017; Bonnet et al., 2021; Degai & Petrov, 2021; Linnerud et al., 2021; Stec et al., 2024; Burchard-Dziubińska, 2019), environmental management (Turoń et al., 2020; Sulich et al., 2021), environmental management systems (Matuszak-Flejszman et al., 2019). In the context of achieving strategic economic, ecological, and social objectives, multidimensional quality of life management is of great importance. This is because it influences how people function in their private and professional lives. The quality of life is particularly affected by air quality. It refers to the chemical composition of the air at a height of approximately 2 m above ground level and, in particular, takes into account the content of chemical compounds in the air that are harmful to living organisms (IMGW-PIB, 2021; Poskrobko & Poskrobko, 2012). The legal basis for air quality monitoring in Poland is the Act of 27 April 2001 – Environmental Protection Law (Obwieszczenie, 2020). The levels of pollutant concentrations in the air directly correlate to the amount of pollutants emitted into the atmosphere and the current meteorological conditions in the area. By the Regulation of the Minister of the Environment of 24 August 2012 (Rozporządzenie, 2012) on the levels of certain substances in the air and the Ordinance of the Minister of Environment of 8 October 2019 amending the Ordinance on the levels of certain substances in the air (Rozporządzenie, 2019), the following are defined, inter alia: permissible levels of pollutants in the air due to the human health and plants protection.

The air in Poland is among the most polluted compared to the rest of the European Union (EU) countries (Adamkiewicz & Matyasiak, 2019; EEA, 2020). It poses a real threat to residents of both large and small cities, as the negative impact of air pollution on human health and life is now well documented and confirmed by numerous studies (e.g. Burchard-Dziubińska, 2019; Kampa & Castanas, 2008; Almetwally et al., 2020; Grzywa-Celińska et al., 2020; Ivanova, 2020; Raju et al., 2020; Viegi et al., 2020; Kim et al., 2020; Hu & Guo, 2021; Kim, 2021; Owczarek et al., 2024).

Breathing air with high concentrations of particulate matter PM2.5 and PM10, sulphur and nitrogen oxides (NO_x), as well as ozone and carbon monoxide, is associated with, among other things, disease entities such as asthma, bronchopneumonia, obstructive pulmonary disease, ischaemic stroke, peripheral atherosclerosis, heart failure, ischaemic heart disease, hypertension, cardiac arrhythmias or thromboembolic complications (Tobías et al., 2015). Air pollution may influence the aetiology of mental disorders. Recent ongoing research is looking at the short- and long-term effects of PM2.5, PM10 and NO_2 on the development of psychiatric disorders. Findings indicate that short-term exposure to NO_2 was associated with an increased likelihood of depression. Associations of elevated ozone and PM10 levels with depression and anxiety were also observed (Fan et al., 2020; Zhao et al., 2020).

Characteristics of selected air pollutants

Particulate matter (PM) PM2.5 and PM10 are the main and most dangerous components of smog (Hassan et al., 2021). PM2.5 contains particles smaller than 2.5 micrometres in diameter (Zimny, 2017). It is emitted into the atmosphere in two ways: 1) as a primary pollutant (resulting from both human-made and natural processes); 2) as a secondary pollutant, resulting from the transformation of sulphur dioxide, nitrogen dioxide, ammonia, volatile organic compounds and persistent organic compounds. It can be transported up to 2,500 km, and sedimentation and precipitation do not remove it from the atmosphere. It can remain in the air for many weeks. The small diameter of the particles

DOI: 10.34659/eis.2024.90.3.784

means that they readily enter the lungs and bloodstream. According to the WHO, long-term exposure to PM2.5 contributes to reduced average life length (Adamkiewicz & Matyasiak, 2019). PM10 contains particles smaller than 10 micrometres in diameter (Zimny, 2017), which can reach the upper respiratory tract and lungs. They persist in the atmosphere for several hours (Lis & Ujma, 2016). Their excessive concentrations in the air are harmful to human health and can cause serious respiratory diseases (e.g. asthma attacks, respiratory failure), allergic reactions, lower immunity, and increase the incidence of cancer, which undoubtedly have a social cost. These costs can be analysed in several ways. We can analyse these costs from many angles. From a macroeconomic perspective e.g. costs of sick leave, rehabilitation, and treatment (also sanatorium treatment), expenses for early retirement. From a microeconomic perspective, e.g., the lack of an optimal level of efficiency of employees and processes or the disruption affecting broader social life is included in the work-life balance concept. According to current WHO standards, the permissible 24-hour average concentrations of PM10 and PM2.5 are 50 $\mu g/m^3$ and 25 $\mu g/m^3$ respectively. However, the limit values for inter-annual concentrations of these PM are 20 $\mu g/m^3$ and 10 $\mu g/m^3$, respectively, while in Poland, these values are raised to 40 $\mu g/m^3$ for PM10 and 20 $\mu g/m^3$ for PM2.5. The 24-hour average PM10 level set by the WHO can be exceeded for a maximum of 35 days per year. Concentrations of PM in Poland are sometimes more than five times higher than the permissible standards, and WHO's rankings of the most polluted cities in Europe indicate very poor air quality in Poland (WHO, 2018a). The Barcelona Institute for Global Health has published a ranking of cities with the highest mortality rates due to high concentrations of PM2.5 and nitrogen dioxide in the air. A total of 1,000 cities from 31 European countries (858 urban centres) were surveyed. Cities from Italy, the Czech Republic, and Poland rank in the top ten. It is very worrying that, apart from the Silesian Metropolis (in fifth place), another 15 Polish cities (Jastrzębie-Zdrój, Rybnik, Żory, Radom, Warszawa, Kraków, Łódź, Lublin, Opole, Bielsko-Biała, Zgierz, Kielce, Tomaszów Mazowiecki, Częstochowa, and Piotrków Trybunalski) were listed among the first 50. A total of 61 Polish cities were listed in the ranking. The results of the study suggest that reducing PM2.5 levels could prevent up to 125,000 deaths in European cities each year[1]. The long-term exposure of Warszawa residents to elevated concentrations of PM in 2014 contributed to the occurrence of 2,826 premature deaths of people of productive age (over 30 years of age) and a significant increase in the number of illnesses. The total health costs resulting from this were estimated at between €2.13 billion and €6.43 billion.

The occurrence of PM in the air is caused to a significant extent by human activity. The main sources of PM10 emissions are individual heating of buildings (88.21%); vehicle traffic (5.77%), secondary emissions of particulate pollutants from road and street surfaces (2.98%), industry (1.84%), transboundary influx (1.17%) and non-anthropogenic sources (0.03%)[2]. PM2.5 emissions, on the other hand, are mainly responsible for household combustion (41.06%), road transport (12.95%) and combustion processes in the energy production and transformation sector (10.33%) (Wiech, 2018).

Nitrogen oxides (mainly NO and NO_2) are highly toxic. In Poland, the number of deaths attributed to long-term exposure to NO_2 is estimated at 1,900 per year (EEA, 2020). The source of nitrogen oxide (NO_x) emissions is mainly road transport (37%), so the problem of high concentrations of this pollutant occurs mainly in large cities. The second major source of emissions is combustion processes in the energy production and transformation sector (21%), in addition to non-industrial combustion processes (so-called low emissions related to building heating) (10.7%), other vehicles and appliances (10.5%), industrial combustion processes (9.1), agriculture (8%) and others (Adamkiewicz & Matyasiak, 2019). The permissible hourly average concentration of NO_2 in the air is 200 $\mu g/m^3$ (which can be exceeded only 18 times in a year), while the mid-year limit is 40 $\mu g/m^3$ (WHO, 2018a).

1 Barcelona Institute for Global Health. (2021). Is Global Ranking of Cities. https://isglobalranking.org/

2 Data source: Ministry of the Environment. (2015). National Air Protection Programme to 2020 (with an outlook to 2030).

DOI: 10.34659/eis.2024.90.3.784

Economic aspects of air pollution

Losses caused by environmental pollution affect all segments of the national economy. These include industry, agriculture, forestry, water management, and population health (Augusewicz et al., 2012; Miao et al., 2017; Jaafar et al., 2018; Kumar et al., 2018; Zhou et al., 2018; Xie et al., 2019; Chantret et al., 2020; Fu et al., 2020; Von Schneidemesser et al., 2020; India State-Level Disease Burden Initiative Air Pollution Collaborators, 2021).

Breathing polluted air has negative health effects – it contributes to diseases and their symptoms, which are not only related to the respiratory or cardiovascular system. No doubt, breathing polluted air means a poorer quality of life (private and professional) and that leads to premature deaths. According to calculations by the European Environment Agency (EEA) in 2018 – made on the basis of actual measurement and epidemiological data – most deaths are attributed to excessive concentrations of PM2.5. It is estimated that in Poland - due to high concentrations of this type of dust - more than 46,000 people die prematurely. For 41 European countries, the number of deaths due to PM2.5 outdoor air pollution is estimated at 417,000 deaths (EEA, 2020; Adamkiewicz & Matyasiak, 2019).

According to the Organisation for Economic Co-operation and Development (OECD), urban air pollution levels are expected to become the leading environmental cause of mortality worldwide by 2050 (OECD, 2001; Treder, 2017). This fact has an important economic dimension as it generates external health costs, estimated in Poland at PLN 111 billion per year (i.e. approximately EUR 24.5 billion[3]). The external cost to the countries of the Union due to premature deaths between 2018 and 2025 is estimated at €475 billion, equivalent to 2.9 percent of the average annual GDP. Using innovative transport and heating technologies in the EU, external health costs could be reduced by EUR 183 billion between 2018 and 2025, equivalent to 1.2 percent of the projected GDP in the 28 EU Member States in 2018 (Deloitte, 2018).

The aim of this study, research hypotheses

While humanity has faced epidemic threats in the 21st century, these have been localised and have not extended to the global population and economies. Therefore, lacking previous experience with the multifaceted challenges of managing global change in the face of the COVID-19 pandemic, it is necessary to determine what short- and long-term positive and negative effects/consequences will be brought about by, among other things, the various regulatory restrictions put in place to limit the spread of the SARS-CoV-2 virus. Although studies are being conducted on the environmental impact of COVID-19, they are so limited in scope and duration that it is difficult to draw firm conclusions. Further and more extensive research in this area is needed. The impact of COVID-19 pandemic-related restrictions on the environment, e.g. on air quality in Poland and worldwide, remains a research gap.

The state of the global epidemic caused by the SARS-CoV-2 virus is forcing significant changes in the way and intensity of society and work in the lower-emitting sectors of the economy. As the state of air quality is closely linked to human economic activity (both in terms of environmental protection, ecological economics, and pro-environmental management), the following **research question** was posed: did the COVID-19 pandemic-related restrictions affect the concentrations of selected air pollutants (PM and NO_x) and thus contribute to an improvement in air quality in selected large Polish cities?

The following **research hypotheses** were adopted:

- **H1)** COVID-19 pandemic-related restrictions affected the concentrations of selected air pollutants (i.e. PM2.5 and PM10) and contributed to an improvement in air quality in large Polish cities, i.e. Białystok, Gdańsk, Kraków, Łódź and Wrocław.
- **H2)** Constraints related to the COVID-19 pandemic affected the concentrations of selected air pollutants (i.e. NO_x in large Polish cities, i.e. Kraków, Łódź and Wrocław).

The topic raised is very important, also from another perspective. According to recent scientific reports relating to the results of studies conducted in Wuhan and XiaoGan, air quality was closely

[3] In order to convert the value in euro, the exchange rate of the zloty of 07.07.2021 was adopted at 4.5197.

linked to COVID-19 transmission. It was found that PM2.5 and NO_2 strongly promoted COVID-19 transmission (Li et al., 2020). Another study from India showed an average of about 40% improvement in the air quality index, driven by reductions of 40% in PM10, 44% in PM2.5, 51% in NO_2, and 21% in SO_2 during the lockdown period (Sekar et al., 2023). In 2020, Dublin experienced an average 28% reduction in the medium level of NO_2 and an improvement of 27.7% in AQI (air quality index) compared to 2019 during the lockdown (27 March–5 June) (Kumar et al., 2018). In the years 2020–2021, during the COVID-19 pandemic, the average annual concentrations of NO_x, PM2.5, and PM10, respectively, decreased by about 19%, about 19%, and about 18% in Warszawa and about 16%, about 22%, and about 2% in Kraków, compared to 2019 before the pandemic (Górka-Kostrubiec & Dudzisz, 2023). Other research conducted in six large Polish cities also demonstrated the reduction of pollutants (PM10, PM2,5, NO_2, SO_2) in the period of lockdown as compared to the same periods (March, April, May) in 2018 and 2019 (Finonchyk et al., 2021). However, Fu et al. (2020) found only a slight improvement in air quality during the lockdown caused by the COVID-19 pandemic in five cities in northern China. In their view, the unfavourable meteorology has resulted in a slight improvement in air quality. These contradictory results available in the literature mean that further research is still necessary on the relationship between the economic downturn triggered by the COVID-19 pandemic and air quality.

What is particularly important is the observation of the magnitude of air pollutants (PM10, PM2.5, NO_x) in Polish cities not only during the pandemic period but also immediately after its end. This article fills in this research gap by providing the results of the studied phenomenon in the pre-pandemic period (2015-2019), during the pandemic period (2020-2021), and after the end of the pandemic (2022-2023). In particular, it is important to analyse the consequences (including the area of decision-making) caused by the COVID-19 pandemic. Further research is needed to identify action strategies that the cities analysed can take in the context of pro-environmental local governance.

Material and methods

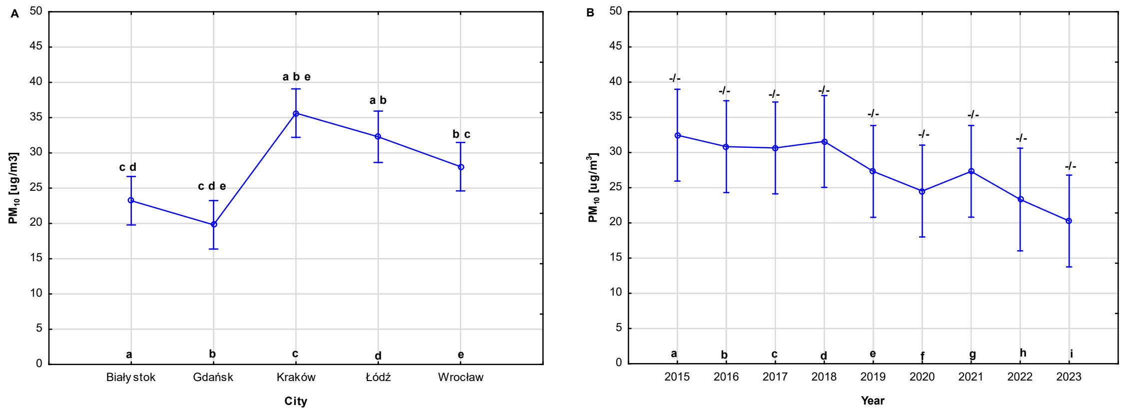
The desk research method was used in this study. In addition, secondary data obtained from the Measurement Data Bank of the Chief Inspectorate for Environmental Protection (Główny Inspektorat Ochrony Środowiska - GIOŚ), collected as part of the State Environmental Monitoring (GIOŚ, 2024), were analysed. Concentrations of PM2.5 and PM10 in five large Polish cities: Białystok, Gdańsk, Kraków, Łódź and Wrocław were compared for the years 2015–2023, as well as concentrations of NO_x in Kraków, Łódź and Wrocław, also for the years 2015–2023. Due to the limited availability of statistical data, analyses of nitrogen oxide concentrations were performed only for three cities. The study was based on automatically recorded data with a one-hour averaging time.

The significance of differences between the concentrations of PM and NO_x (dependent variables) in the years and cities under study (independent variables) was tested using a one-factor analysis of variance (ANOVA). When the ANOVA showed that there were significant differences in the values of the parameters studied, a Tukey post-hoc test was performed to determine between which cities and years these values were significantly different. All statistical analyses were performed using Statistica 13.1 (StatSoft, Inc).

Results

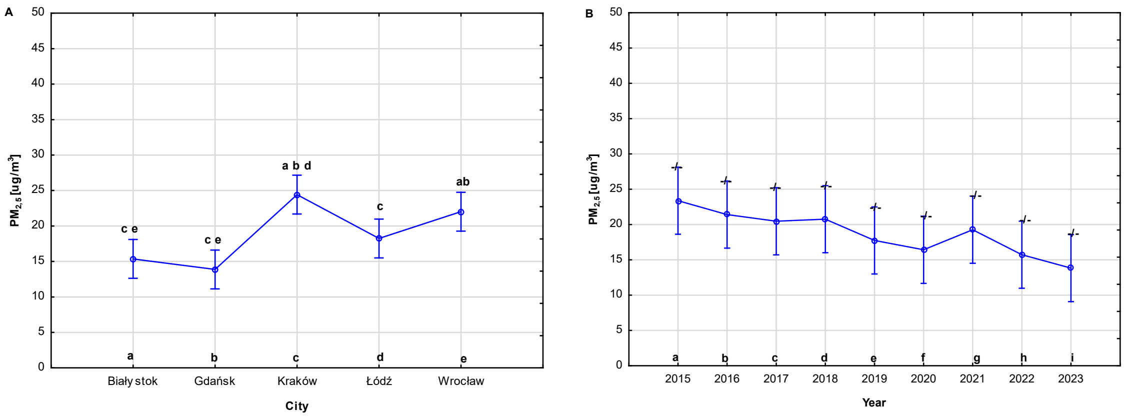
The visualisation of the obtained results is presented in four figures and included in the next part of the work. Figure 1 illustrates the issue of PM10 in the air. Part A shows the average dust concentration in each of the cities studied over the period 2015-2023, while Part B shows the average concentration for all the cities studied separately for each year. Analysis of the results presented in Part A showed that the amount of PM10 dust was statistically significantly higher in Kraków and Łódź than in Białystok and Gdańsk. In addition, the content of this dust was significantly lower in Wrocław than in Kraków but higher than in Gdańsk. In the analysis of Part B, no statistically significant differences were observed in PM 10 dust levels between 2015 and 2023.

DOI: 10.34659/eis.2024.90.3.784



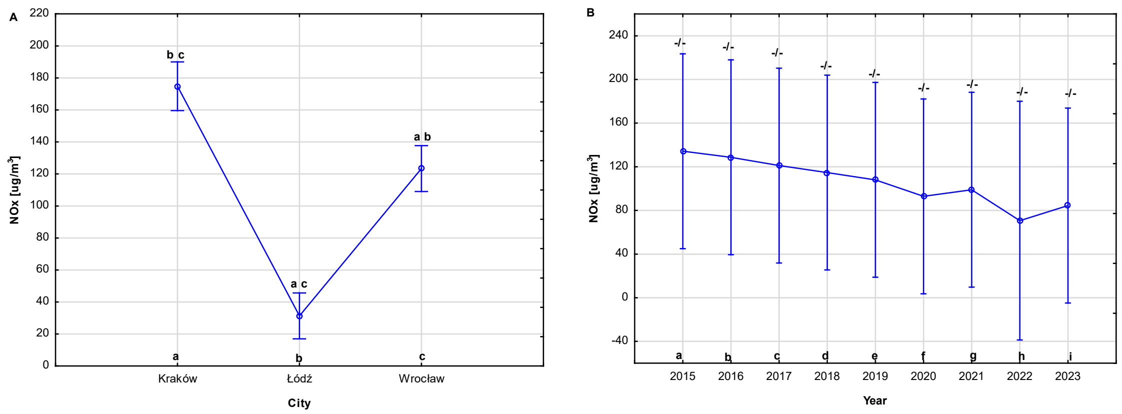
Notes: A – differences in average (for nine years) dust concentrations between cities.
B – differences in average (for the five cities) dust concentrations between years.
The graphs show the means and 0.95 confidence intervals. Individual years are marked with letters. Letters above the mean indicate a significant difference between the means of the years in question. The sign -/- indicates no significant differences between the averages.

Figure 1. Changes in PM10 concentrations between 2015 and 2023, in five selected Polish cities



Notes: as in Figure 1.

Figure 2. Changes in PM2.5 concentrations between 2015 and 2023, in five selected Polish cities



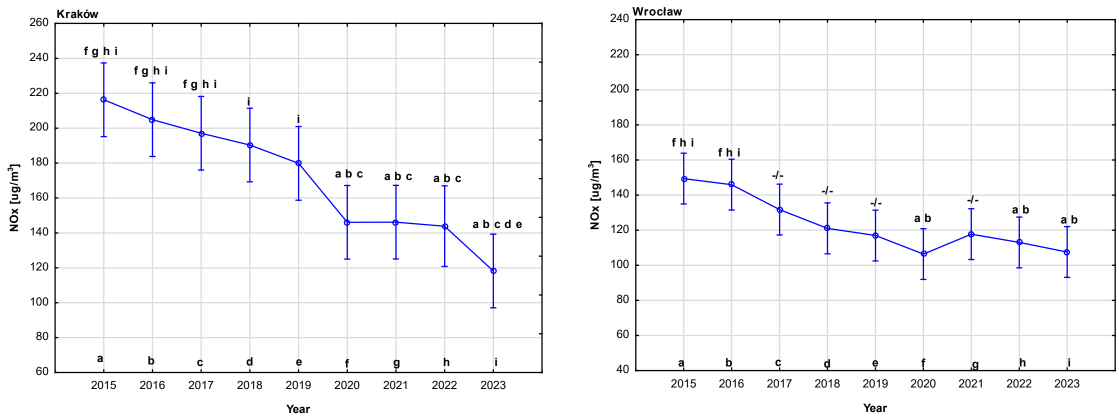
Notes: as in Figure 1.

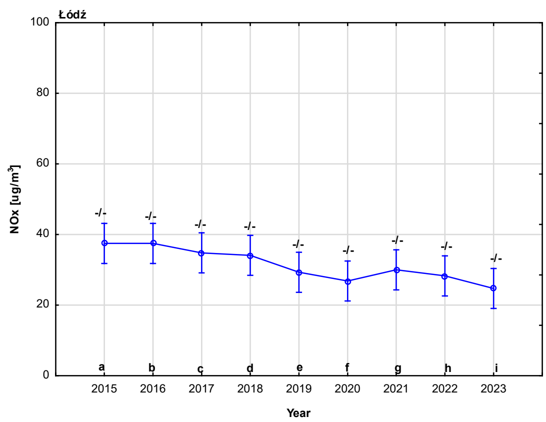
Figure 3. Changes in NOx concentrations between 2015 and 2023, in three selected Polish cities

Figure 2 illustrates the PM2.5 concentrations. As with the previous figure, Part A shows the statistics between cities, while Part B shows the statistics between years. The analysis of Part A showed significantly higher PM2.5 concentrations in Kraków compared to Białystok, Gdańsk, and Łódź, as well as significantly higher concentrations in Wrocław than in Białystok and Gdańsk. In the analysis of Part B, no statistically significant differences were observed in PM 2,5 dust levels between 2015 and 2023 (Figure 2B).

Figure 3 visualises the concentrations of NO_x in Kraków, Łódź and Wrocław. Again, part A shows changes between cities, and part B shows changes between years. For part A, the analysis of variance showed significant differences between all the cities studied ($F(2,23) = 104{,}98$, $p<0.001$). The highest concentrations of NO_x were found in Kraków and the lowest in Łódź. However, no significant differences were found between years (ANOVA, $F(9,17) = 0{,}22$, $p>0.05$).

The analysis of NO_x concentrations in the air is also presented in Figure 4, which is divided into three parts containing the graphs made using data for one city for 2015–2023. In the case of Krakow, ANOVA analysis of differences in relation to 2020 (the year the pandemic started) showed statistically significant results for 2015-2017. In the case of Wrocław, significant differences were observed between the year 2020 and the period of 2015-2016. In the case of Łódź, there were no significant differences in NO_x concentrations between years.





Notes: as in Figure 1.

Figure 4. Changes in NO_x concentrations between 2015 and 2023, in three selected Polish cities

Discussion

Between 1990 and 2004, i.e. from the beginning of the system transformation until Poland acceded to the EU, there was a significant reduction in air pollutant emissions by 45% on average (Poskrobko & Poskrobko, 2012). However, since 2005, the rate of improvement in air quality has been insufficient in the light of achieving at least climate policy objectives. Relatively new international standards for a systems approach to environmental management (such as ISO 14001, EMAS, or ISO 50001) are not yet fully delivering the expected results. This is due to: 1) the optional nature of standardisation, the lack of sufficient knowledge/experience on the subject of effective environ-

DOI: 10.34659/eis.2024.90.3.784

mental management (not only among employees, but also among managers, representatives of the administration, and those responsible for education), 2) the relatively low implementation rate of the systems, 3) the lack of sufficient incentives for their operation (tax, insurance, etc.) 4) and, above all, from the extremely different approach to the issue of eco-innovative competitive advantage not only at the level of the organisation but also at the level of the country (Czajkowska et al., 2018). As a result, the current condition of air quality in Poland is still unsatisfactory and is the result of years of neglect (Kleczkowski, 2020; Zgłobicki & Baran-Zgłobicka, 2024). Although many relatively comprehensive remedial works on air protection were initiated by the government side between 2015 and 2018, they still do not stand at a sufficiently high level of progress. Air pollution emitted by industry and energy has been significantly reduced as requirements for this sector have been introduced at the level of EU legislation (Dyrektywa, 2015; Decyzja, 2017; Rozporządzenie, 2018). What is missing, however, are key legal solutions to reduce the use of the most air-harmful cars.

Communication between the government and local authorities is also a problem. Local authorities often find it difficult to obtain the necessary resources to implement programmes to improve air quality, as the reports of the Supreme Audit Office demonstrate. A remedial programme in this area requires sustainability, systematicity and a long-term approach (Najwyższa Izba Kontroli, 2018; Wiech, 2018). Significant financial support from society is needed, as the challenge in the fight against smog in Poland is the so-called fuel poverty. The lack of adequate means to ensure thermal comfort in an inhabited dwelling often translates into the use of low-quality fuels, which has a negative impact on air quality. Energy-poor people are unable to invest in high-quality furnaces or boilers. In addition, there is the issue of the toxicity of cheaper fuels used to heat these modern furnaces. Reservations are raised even by way of pellet packaging in environmentally harmful plastic bags. The problem with the quality of pellets is due, among other things, to the lack of standards and independent and reliable certification confirming the product's environmentally friendly nature. The Polish government has defined standards for coal to be burned in household furnaces but has not implemented such regulations for pellets. The European standard EN 14961, whose Polish equivalent is EN 1496, is of voluntary nature. The challenges of counterfeit pellets contaminated with harmful resins (containing, among other things, post-production waste from furniture factories, e.g. plywood and ground MDF boards) have been signalled to local authorities and the Ministry of Climate by organisations associating producers and consumers.

The mere decision to implement a new pro-environmental local government policy (expressed, among other things, in investments in boilers and furnaces) does not solve the problem of energy efficiency. Simply replacing furnaces/boilers in buildings built in the 1980s or older will not change the energy demand. This raises the challenge of thermal modernisation. In this type of building, furnaces and boilers have to be oversized due to the low thermal efficiency of the buildings. In the analysed infrastructure, there is often no effective heating system (due to the deficit of repairs). There are many elements of outdated construction and inadequate materials. Much more fuel is needed to heat these types of buildings due to thermal bridges (e.g. leaky windows) through which heat is lost. It is, therefore, clear that different strategies need to be developed for old cities such as Kraków or Wrocław and others for cities where new construction predominates.

In turn, high exhaust emission is the result not only of the increasing number of cars but also of their quality. According to data from the European Automobile Manufacturers' Association (2021), Poles drive some of the oldest cars in Europe. The average age of vehicles is 14.1 years. In comparison, the country with the youngest cars is Luxembourg, where the average is 6.5 years. By contrast, the European average is 11.5 years. The age of cars translates into their emissions performance (Chen & Borken-Kleefeld, 2016). Old vehicles have dominated the structure of passenger cars in Poland for more than a dozen years. According to CSO studies, the share of cars older than 10 years in 2005, 2009, 2010 and 2011 increased cyclically and amounted to 61%, 69.8%, 72.3% and 73.1%, respectively. Data from 2019, on the other hand, shows that 74.5% of passenger cars registered in Poland are 12 years old or older, with the noteworthy fact that 15.7% of cars are 31 years old or older. The number of all cars registered in Poland is also increasing year to year. In 2005, there were 323 cars per 1,000 people. In the following years, the number increased rapidly, reaching 432 in 2009, 470 in 2011, 610 in 2018, and 635 in 2019 (Statistics Poland, 2011, 2013, 2021).

In this case, there is an opportunity for improvement, as there are several regulations in EU countries that set emission limits for diesel and petrol vehicles. The tightening of the standards for PM

DOI: 10.34659/eis.2024.90.3.784

emitted from a diesel car has changed the limit from 0.14 to 0.005 g/km; while the emission value for NO_x for diesel engines was initially set at 0.50 g/km (EURO 3 standard) and has been changed to 0.080 g/km (EURO 6) (Sówka, 2017). There is some debate about the negative impact of DPF firing on air quality.

A positive aspect, however, is that awareness of the problem of air pollution has increased significantly in Poland over the past five years. There has also been another amendment to the Renewable Energy Sources Act of 20 February 2015 (Ustawa, 2015), introducing many highly anticipated changes (Ustawa, 2020).

Some authors note that the COVID-19-induced reduction in economic activity has had a positive impact on improving air quality in many cities around the world. The pandemic may have impacted reduced pollution levels in 2020 in Poland, particularly nitrogen dioxide, due to the introduced lockdown and associated restrictions on the ability to travel (UN Global Compact, 2022). In addition, there are reports that pandemic-related restrictions have had a downward effect on water pollution levels (Saadat et al., 2020; Selvam et al., 2020; Yunus et al., 2020).

Recent studies show that the relationship between coronavirus and air pollution is ambiguous (Linder-Cendrowska et al., 2022). Admittedly, reduced human activity can reduce emissions of certain types of pollution, mainly from motorisation and industry. However, the contribution of low emissions, i.e. pollutants mainly from individual heating of buildings, continues to increase, which, according to the researchers, may contribute to a more severe course of coronavirus infection. During the Hot Topic session at the EAACI Digital Congress 2020, Prof. Gennaro D'Amato (Naples, Italy) presented findings showing that air pollution may affect the COVID-19 pandemic by increasing susceptibility to SARS-CoV-2. In particular, exposure to PM2.5 particles can significantly enhance virus-induced pneumonia and exacerbate the course of comorbidities such as chronic obstructive pulmonary disease (D'Amato & Akdis, 2020).

The results presented in this paper show that there are significant differences in the concentrations of the pollutants studied between the selected cities. In each case, the levels of PM and NO_x are highest in Kraków, the city with the most polluted air in Poland, according to many reports. High concentrations of PM were also found in Łódź and Wrocław. However, as far as the concentration of NO_x is concerned, the lowest was observed in Łódź. Differences in pollution concentrations between cities are not the result of a pandemic. Rather, they are the consequence of problems in implementing programs to improve air quality or individual circumstances such as industry, unfavourable city location, incoming emissions, or the building up of air corridors. Statistically significant differences in PM10 concentrations between non-urban and suburban areas, as well as between non-urban and urban areas in Poland, were confirmed by the results of other studies in 2023 (Tomala, 2023).

Although, according to the results of the analysis, the amount of air pollution has decreased in all Polish cities studied over the last nine years (2015-2023), these results should be interpreted with great care. It should be considered that air quality in Poland has been improving slightly but steadily (GIOŚ, 2024). The drop in PM and NO_x may, therefore, not be entirely related to the coronavirus pandemic but merely to a continuation of the downward trend that has been observed in Poland for several years.

The circumstances of the pandemic have intensified worldwide scientific research, addressing not only the COVID-19 diagnosis but also the effects of the socioeconomic downturn. Many of these studies address the impact of the pandemic on air quality. For example, a study was conducted comparing PM2.5 air concentrations before and during a pandemic outbreak in fifty capital cities from around the world. The results proved inconclusive. Taking the global average, the dust content in the air fell by 12%. However, when considering only European capitals, a decrease in PM2.5 was recorded in only half of them. In addition, the data used for these analyses came from very short time frames and the study itself was carried out just after the announcement of the global pandemic. This means that the main influence on the results may have been the type of measures taken by the authorities of the country in question to reduce the amount of infection, which involved restrictions on movement, and therefore also reduced car traffic or halted factory operations. The coronavirus-related restrictions put in place varied considerably from place to place around the world. In some countries, a complete ban on movement has been introduced, while in other countries, in turn, no official restrictions have been introduced (Rodríguez-Urrego & Rodríguez-Urrego, 2020).

DOI: 10.34659/eis.2024.90.3.784

A similar study was carried out in detail for the epicentre of the coronavirus, the city of Wuhan in China. A period of one month after the outbreak of the pandemic was chosen for the study. Air pollution data from this period was compared with corresponding periods in the five preceding years. In addition to PM2.5, PM10, SO_2, NO_2, CO, and O_3 pollutants were also analysed. The study showed that after the coronavirus restrictions came into effect, average air quality, as defined by the AQI improved by up to 37%, and this improvement was greater the higher the population density of the urban area. Interestingly, even though the winter months were studied, there was a large increase in ozone after the end of the city closure compared to the time before the blockade. The increase was as much as 116.6%. The highest amounts of ozone near the Earth's surface are usually recorded when the air temperature is high, so observing such a large increase in winter brings with it the need for further research to determine the cause of this phenomenon (Lian et al., 2020). Perhaps this is the result of intensified ozone treatments to decontaminate elements likely to come into contact with the COVID-19 coronavirus.

The next major city to be meticulously analysed was New York. The study covered PM2.5 pollution and NO_x. A comparison was made between the first 17 weeks of 2020 and the corresponding periods in the five previous years. There was a decrease in both PM and NO_x concentrations. Analysing the data as a whole, however, it was concluded that the decline in pollution levels was nevertheless similar to the declines experienced in New York City in recent years. In this case, the correlation between the pandemic outbreak and city closures and improvements in air quality may have been coincidental (Zangari et al., 2020).

The results of a WHO (World Health Organisation) study from 25 EU cities indicate that life expectancy in the most polluted cities could increase by up to around 22 months if long-term PM2.5 concentrations were reduced to annual levels according to WHO guidelines (WHO, 2018b). This is, unfortunately, a very difficult task, as studies show that even the global pandemic and the associated deceleration of social and economic life have not contributed significantly to the decrease in PM emissions.

Conclusions

The restrictions put in place following the outbreak of the SARS-CoV-2 virus pandemic have contributed to a sudden change in people's lifestyles. Many people have decided to implement the Slow Life concept in their lives. The real estate market has seen a boom due to a change in household purchase preferences (larger flats) and a migration trend from large cities to the countryside. The need for isolation, downtime caused by, among other things, lockdown decisions, changes in labour laws, learning and working remotely, improvements in digital competencies, and the implementation and rapid spread of affordable e-commerce, e-government, e-medicine, e-schooling solutions have influenced changes in the perception of quality of life issues. Among the challenges to: 1) improving the quality of life in the sphere of improving air quality, 2) issues of legislative gaps, the problem of energy poverty, 3) the problem of low energy efficiency, 4) the lack of sufficient awareness and knowledge of the risks of action taken by both households and other economic actors, 5) and the lack of coherence in the implementation of environmental policies at national and international levels were identified. It is a very interesting set of issues not only for anthropologists but for a wide and interdisciplinary group of specialists in the fields of social sciences, engineering and technology, natural sciences, humanities, medical sciences and health sciences. Restricting movement to the necessary minimum has led to a reduction in road traffic and a reduction in the work of both production plants and service units. Households could see increased burning to heat their homes during the heating season – with some workers incurring additional costs as a result, necessitated by remote working. The issue of fuel poverty and energy efficiency is undoubtedly a significant challenge not only for governments/self-governments but also for households themselves. Although many studies have already been conducted on the impact of quarantine phenomena on air quality, their results are not unambiguous. It should be remembered that air quality is a complex issue influenced by many interrelated factors. Studies conducted in selected Polish cities showed statistically significant changes in the amount of pollutants in most cases. Nevertheless, the amount of post-pandemic data currently available is not yet large enough to determine with certainty how much of an impact the spread, or exacerbation, of COVID-19 diseases has on air quality. Global economic activity is expected to

DOI: 10.34659/eis.2024.90.3.784

return in the coming months in most countries (even if slowly), so the conclusion that reducing greenhouse gas concentrations for the short term is not a sustainable way to clean up our environment is undoubtedly valid (Zambrano-Monserrate et al., 2020). Further interdisciplinary research on the problem under analysis is needed (Sun et al., 2023).

The contribution of the authors

Conceptualization, M.P.F. and M.H.S.; literature review, B.F., M.H.S., P.B., E.S. and M.P.F.; methodology, M.P.F., B.F. and M.H.S.; formal analysis, M.P.F., B.F., E.S., P.B. and M.H.S.; writing, M.P.F., P.B., B.F., E.S. and M.H.S.; conclusions and discussion, M.P.F., M.H.S., B.F., E.S. and P.B.

The authors have read and agreed to the published version of the manuscript.

References

Adamkiewicz, Ł., & Matyasiak, N. (2019). *Smog w Polsce i jego konsekwencje.* https://pie.net.pl/wp-content/uploads/2020/03/PIE-WP_5-2019.pdf (in Polish).

Almetwally, A. A., Bin-Jumah, M., & Allam, A. A. (2020). Ambient air pollution and its influence on human health and welfare: an overview. Environmental Science and Pollution Research, 27(20), 24815-24830. https://doi.org/10.1007/s11356-020-09042-2

Augusewicz, A., Breńko, T., Kozłowska, A., Miłaszewski, R., Karolinczak, B., Werner-Juszczuk, A., & Winiarek, P. (2012). Economic aspects of environmental protection. Civil and Environmental Engineering, 3(1), 17-23. https://www.researchgate.net/publication/327573483_Ekonomiczne_aspekty_ochrony_srodowiska (in Polish).

Barcelona Institute for Global Health. (2021). *Is Global Ranking of Cities.* https://isglobalranking.org/

Bonnet, J., Coll-Martínez, E., & Renou-Maissant, P. (2021). Evaluating sustainable development by composite index: Evidence from french departments. Sustainability, 13(2), 1-23. https://doi.org/10.3390/su13020761

Burchard-Dziubińska, M. (2019). Air pollution and health in Poland: anti-smog movement in the most polluted polish cities. Economics and Environment, 69(2), 15. https://doi.org./10.34659/2019/2/22

Chantret, F., Chateau, J., Dellink, R., Durand-Lasserve, O., & Lanzi, E. (2020). Can better technologies avoid all air pollution damages to the global economy? Climatic Change, 163(3), 1463-1480. https://doi.org/10.1007/s10584-019-02631-2

Chen, Y., & Borken-Kleefeld, J. (2016). NOx Emissions from Diesel Passenger Cars Worsen with Age. Environmental Science and Technology, 50(7), 3327-3332. https://doi.org/10.1021/acs.est.5b04704

Czajkowska, A., Pacana, A., & Ingaldi, M. (2018). *Współczesne systemy zarządzania w organizacjach.* Kielce: Oficyna Wydawnicza Stowarzyszenia Menedżerów Jakości i Produkcji. (in Polish).

D'Amato, G., & Akdis, C. (2020). Global warming, climate change, air pollution and allergies. Allergy, 75(9), 2158-2160. https://doi.org/10.1111/all.14527

Dardanoni, V., & Guerriero, C. (2021). Young people' s willingness to pay for environmental protection. Ecological Economics, 179, 106853. https://doi.org/10.1016/j.ecolecon.2020.106853

Decyzja wykonawcza Komisji (UE) 2017/1442 z dnia 31 lipca 2017 r. ustanawiająca konkluzje dotyczące najlepszych dostępnych technik (BAT) w odniesieniu do dużych obiektów energetycznego spalania zgodnie z dyrektywą Parlamentu Europejskiego i Rady 2010/75/UE, Pub. L. No. 32017D1442, 212 OJ L (2017). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2017.212.01.0001.01.POL (in Polish).

Degai, T. S., & Petrov, A. N. (2021). Rethinking Arctic sustainable development agenda through indigenizing UN sustainable development goals. International Journal of Sustainable Development and World Ecology, 28(6), 518-523. https://doi.org/10.1080/13504509.2020.1868608

Deloitte. (2018). *Clean Air Challenge. Transport and Heating Solutions for Better Air Quality.* https://eit.europa.eu/sites/default/files/clean-air-challenge-report-s-new.pdf

Dyrektywa Parlamentu Europejskiego i Rady (UE) 2015/2193 z dnia 25 listopada 2015 r. w sprawie ograniczenia emisji niektórych zanieczyszczeń do powietrza ze średnich obiektów energetycznego spalania, Pub. L. No. 32015L2193, 313 OJ L (2015). https://eur-lex.europa.eu/legal-content/pl/TXT/?uri=CELEX:32015L2193 (in Polish).

EEA. (2020). *Air quality in Europe – 2020 report.* https://www.eea.europa.eu//publications/air-quality-in-europe-2020-report

EPA United Stated Environmental Protection Agency. (2023). *Nitrogen Oxides (NOx) Control Regulations.* https://www3.epa.gov/region1/airquality/nox.html

European Automobile Manufacturers' Association. (2021). *Average age of the EU vehicle fleet, by EU country.* https://www.acea.be/statistics/article/average-vehicle-age

Fan, S. J., Heinrich, J., Bloom, M. S., Zhao, T. Y., Shi, T. X., Feng, W. R., Sun, Y., Shen, J.-Ch., Yang, Z.-C., Yang, B.-Y., & Dong, G.-H. (2020). Ambient air pollution and depression: A systematic review with meta-analysis up to 2019. Science of the Total Environment, 701, 134721. https://doi.org/10.1016/j.scitotenv.2019.134721

DOI: 10.34659/eis.2024.90.3.784

Finonchyk, M., Hurynovich, V., & Yan, H. (2021). Impact of Covid-19 lockdown on air quality in the Poland, Eastern Europe. Environmental Research, 198, 110454. https://doi.org/10.1016/j.envres.2020.110454

Fu, X., Li, L., Lei, Y., Wu, S., Yan, D., Luo, X., & Luo, H. (2020). The economic loss of health effect damages from PM2.5 pollution in the Central Plains Urban Agglomeration. Environmental Science and Pollution Research, 27(20), 25434-25449. https://doi.org/10.1007/s11356-020-08560-3

GIOŚ. (2024). *Bank danych pomiarowych.* http://powietrze.gios.gov.pl/pjp/archives (in Polish).

Górka-Kostrubiec, B., & Dudzisz, K. (2023). Effect of COVID-19 pandemic restrictions on air pollution at a local scale in urban areas affected by high-intensity vehicle traffic in Poland. Acta Geophysica, 71, 1085-1097. https://doi.org/10.1007/s11600-022-01005-0

Grzywa-Celińska, A., Krusiński, A., & Milanowski, J. (2020). 'Smoging kills' – Effects of air pollution on human respiratory system. Annals of Agricultural and Environmental Medicine, 27(1), 1-5. https://doi.org/10.26444/aaem/110477

Han, F., & Li, J. (2021). Environmental protection tax effect on reducing PM2.5 pollution in China and its influencing factors. Polish Journal of Environmental Studies, 30(1), 119-130. https://doi.org/10.15244/pjoes/122228

Hassan, A., Ilyas, S. Z., Agathopoulos, S., Hussain, S. M., Jalil, A., Ahmed, S., & Baqir, Y. (2021). Evaluation of adverse effects of particulate matter on human life. Heliyon, 7(2), e05968. https://doi.org/10.1016/j.heliyon.2021.e05968

Hu, F., & Guo, Y. (2021). Health impacts of air pollution in China. Frontiers of Environmental Science and Engineering, 15(4), 74. https://doi.org/10.1007/s11783-020-1367-1

Ibn-Mohammed, T., Mustapha, K. B., Godsell, J., Adamu, Z., Babatunde, K. A., Akintade, D. D., Acquaye, A., Fujii, H., Ndiaye, M. M., Yamoah, F. A., & Koh, S. C. L. (2021). A critical review of the impacts of COVID-19 on the global economy and ecosystems and opportunities for circular economy strategies. Resources, Conservation and Recycling, 164, 105169. https://doi.org/10.1016/j.resconrec.2020.105169

IMGW-PIB. (2021). *Serwis internetowy FAPPS powstały w ramach projektu rozwojowego własnego NR14-0013-10/2010 „Utworzenie systemu prognozowania rozprzestrzeniania zanieczyszczeń powietrza, opartego o meteorologiczne modele mezoskalowe oraz dyspersyjny model obłoku".* http://smog.imgw.pl/ (in Polish).

India State-Level Disease Burden Initiative Air Pollution Collaborators. (2021). Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. The Lancet Planetary Health, 5(1), e25-e38. https://doi.org/10.1016/S2542-5196(20)30298-9

Ivanova, V. R. (2020). The anthropogenic air pollution and human health. Journal of IMAB - Annual Proceeding (Scientific Papers), 26(2), 3057-3062. https://doi.org/10.5272/jimab.2020262.3057

Jaafar, H., Razi, N. A., Azzeri, A., Isahak, M., & Dahlui, M. (2018). A systematic review of financial implications of air pollution on health in Asia. Environmental Science and Pollution Research, 25(30), 30009-30020. https://doi.org/10.1007/s11356-018-3049-0

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. Environmental Pollution, 151(2), 362-367. https://doi.org/10.1016/j.envpol.2007.06.012

Khokhobaia, M. (2017). Tourism and Sustainable Development in Developing Countries: A Case of Georgia. International Journal of Strategic Management, 17(1), 89-94. https://doi.org/10.18374/IJSM-17-1.7

Kim, M. J. (2021). Air Pollution, Health, and Avoidance Behavior: Evidence from South Korea. Environmental and Resource Economics, 79, 63-91. https://doi.org/10.1007/s10640-021-00553-1

Kim, Y., Manley, J., & Radoias, V. (2020). Air pollution and long term mental health. Atmosphere, 11(12), 1355. https://doi.org/10.3390/atmos11121355

Kleczkowski, P. (2020). What Makes Smog in Poland? Aura, (2), 3-7. (in Polish).

Kumar, R., Barth, M. C., Pfister, G. G., Delle Monache, L., Lamarque, J. F., Archer-Nicholls, S., Tilmes, S., Ghude, S. D., Wiedinmyer, C., Naja, M., & Walters, S. (2018). How Will Air Quality Change in South Asia by 2050? Journal of Geophysical Research: Atmospheres, 123(3), 1840-1864. https://doi.org/10.1002/2017JD027357

Li, H., Xu, X. L., Dai, D. W., Huang, Z. Y., Ma, Z., & Guan, Y. J. (2020). Air pollution and temperature are associated with increased COVID-19 incidence: A time series study. International Journal of Infectious Diseases, 97, 278-282. https://doi.org/10.1016/j.ijid.2020.05.076

Lian, X., Huang, J., Huang, R., Liu, C., Wang, L., & Zhang, T. (2020). Impact of city lockdown on the air quality of COVID-19-hit of Wuhan city. Science of the Total Environment, 742, 140556. https://doi.org/10.1016/j.scitotenv.2020.140556

Liang, J. (2020). Sustainable development of marine ecological economy under the background of coordinated evolution of marine and land industries. Journal of Coastal Research, 112(sp1), 5-7. https://doi.org/10.2112/JCR-SI112-002.1

Linder-Cedrowska, K., Leziak, K., & Bröde, P. (2022). How Covid-19 pandemic influenced air quality in Polish cities – lessons from three lockdowns. Geographia Polonica, 95(3), 255-274. https://rcin.org.pl/igipz/publication/272789

Linnerud, K., Holden, E., & Simonsen, M. (2021). Closing the sustainable development gap: A global study of goal interactions. Sustainable Development, 29(4), 738-753. https://doi.org/10.1002/sd.2171

Lis, A., & Ujma, A. (2016). Redukcja emisji pyłów zawieszonych w wyniku poprawy izolacyjności cieplnej przegród i zmiany nośnika energii. Budownictwo o Zoptymalizowanym Potencjale Energetycznym, 17(1), 47-54. https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-5286b2a2-1382-4386-996a-552554970dd9 (in Polish).

Matuszak-Flejszman, A., Szyszka, B., & Jóhannsdóttir, L. (2019). Effectiveness of EMAS: A case study of Polish organisations registered under EMAS. Environmental Impact Assessment Review, 74, 86-94. https://doi.org/10.1016/j.eiar.2018.09.005

Miao, W., Huang, X., & Song, Y. (2017). An economic assessment of the health effects and crop yield losses caused by air pollution in mainland China. Journal of Environmental Sciences, 56, 102-113. https://doi.org/10.1016/j.jes.2016.08.024

Ministerstwo Klimatu i Środowiska. (2014). *Krajowy Program Ochrony Powietrza.* https://bip.mos.gov.pl/strategie-plany-programy/krajowy-program-ochrony-powietrza/ (in Polish).

Najwyższa Izba Kontroli. (2018). *Ochrona powietrza przed zanieczyszczeniami. Lata 2014-2017 (I półrocze).* https://www.nik.gov.pl/plik/id,18090,vp,20682.pdf (in Polish).

Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 29 maja 2020 r. w sprawie ogłoszenia jednolitego tekstu ustawy – Prawo ochrony środowiska. (Dz. U. z 2020 r., poz. 1219). https://dziennikustaw.gov.pl/DU/rok/2020/pozycja/1219 (in Polish).

OECD. (2001). *OECD Environmental Outlook.* https://doi.org/10.1787/9789264188563-en

Owczarek, T., Rogulski, M., Czechowski, P. O., Badyda, A., & Czermański, E. (2024). Equivalence of low-cost PM10 concentration measuring devices with a reference method using various correction functions. Economics and Environment, 87(4), 627. https://doi.org/10.34659/eis.2023.87.4.627

Poskrobko, B., & Poskrobko, T. (2012). *Zarządzanie środowiskiem w Polsce.* Warszawa: Polskie Wydawnictwo Ekonomiczne. (in Polish).

Raju, S., Siddharthan, T., & McCormack, M. C. (2020). Indoor Air Pollution and Respiratory Health. Clinics in Chest Medicine, 41(4), 825-843. https://doi.org/10.1016/j.ccm.2020.08.014

Rodríguez-Urrego, D., & Rodríguez-Urrego, L. (2020). Air quality during the COVID-19: PM2.5 analysis in the 50 most polluted capital cities in the world. Environmental Pollution, 266, 115042. https://doi.org/10.1016/j.envpol.2020.115042

Rozporządzenie Ministra Środowiska z dnia 24 sierpnia 2012 r. w sprawie poziomów niektórych substancji w powietrzu. (Dz. U. z 2021 r., poz. 1031). https://dziennikustaw.gov.pl/DU/rok/2012/pozycja/1031 (in Polish).

Rozporządzenie Ministra Środowiska z dnia 8 października 2019 r. zmieniające rozporządzenie w sprawie poziomów niektórych substancji w powietrzu. (Dz. U. z 2019 r., poz. 1931). https://dziennikustaw.gov.pl/DU/rok/2019/pozycja/1931 (in Polish).

Rozporządzenie Parlamentu Europejskiego i Rady (UE) 2018/1999 z dnia 11 grudnia 2018 r. w sprawie zarządzania unią energetyczną i działaniami w dziedzinie klimatu, zmiany rozporządzeń Parlamentu Europejskiego i Rady (WE) nr 663/2009 i (WE) nr 715/2009, dyrektyw Parlamentu Europejskiego i Rady 94/22/WE, 98/70/WE, 2009/31/WE, 2009/73/WE, 2010/31/UE, 2012/27/UE i 2013/30/UE, dyrektyw Rady 2009/119/WE i (EU) 2015/652 oraz uchylenia rozporządzenia Parlamentu Europejskiego i Rady (UE) nr 525/2013, Pub. L. No. 32018R1999, 328 OJ L (2018). https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX%3A32018R1999 (in Polish).

Saadat, S., Rawtani, D., & Hussain, C. M. (2020). Environmental perspective of COVID-19. Science of The Total Environment, 728, 138870. https://doi.org/10.1016/j.scitotenv.2020.138870

Sekar, A., Jasna, R. S., Binoy, B. V., Mohan, P., & Kuttiparichel Varghese, G. (2023). Air quality change and public perception during the COVID-19 lockdown in India. Gondwana Research, 114, 15-29. https://doi.org/10.1016/j.gr.2022.04.023

Selvam, S., Jesuraja, K., Venkatramanan, S., Chung, S. Y., Roy, P. D., Muthukumar, P., & Kumar, M. (2020). Imprints of pandemic lockdown on subsurface water quality in the coastal industrial city of Tuticorin, South India: A revival perspective. Science of the Total Environment, 738, 139848. https://doi.org/10.1016/j.scitotenv.2020.139848

Sówka, I. M. (2017). Road transport as a source of air pollution in urban agglomerations. Czysta Energia, 1-2, 24-28. https://www.researchgate.net/publication/312949957_Transport_drogowy_jako_zrodlo_zanieczyszczenia_powietrza_na_terenie_aglomeracji_miejskich_Road_transport_as_a_source_of_air_pollution_in_urban_agglomerations (in Polish).

Statistics Poland. (2011). *Road transport in Poland in the years 2005-2009.* https://stat.gov.pl/cps/rde/xbcr/gus/tc_road_transport_2005-2009.pdf (in Polish).

Statistics Poland. (2013). *Road transport in Poland in the years 2010, 2011.* https://stat.gov.pl/en/topics/transport-and-communications/transport/road-transport-in-poland-in-the-years-2010-2011,5,2.html (in Polish).

Statistics Poland. (2021). *Road transport in Poland in the years 2018 and 2019.* https://stat.gov.pl/en/topics/transport-and-communications/transport/road-transport-in-poland-in-the-years-2018-and-2019,5,6.html (in Polish).

Stec, M., Grzebyk, M., Caputa, W., & Krawczyk-Sokołowska, I. (2024). A comparative analysis of the level of sustainable development in Polish voivodeships in 2012 and 2021. Economics and Environment, 89(2), 766. https://doi.org/10.34659/eis.2024.89.2.766

Sulich, A., Sołoducho-Pelc, L., & Ferasso, M. (2021). Management styles and decision-making: Pro-ecological strategy approach. Sustainability, 13(4), 1604. https://doi.org/10.3390/su13041604

Sun, X., Wandelt, S., & Zhang, A. (2023). A data-driven analysis of the aviation recovery from the COVID-19 pandemic. Journal of Air Transport Management, 109, 102401. https://doi.org/10.1016/j.jairtraman.2023.102401

Tobías, A., Recio, A., Díaz, J., & Linares, C. (2015). Health impact assessment of traffic noise in Madrid (Spain). Environmental Research, 137, 136-140. https://doi.org/10.1016/j.envres.2014.12.011

Tomala, M. (2023). Monitorowanie jakości powietrza w Polsce w świetle koncepcji smart city. Środkowoeuropejskie Studia Polityczne, (1), 45-70. https://doi.org/10.14746/ssp.2023.1.3 (in Polish).

Treder, M. (2017). Smog zagrożeniem bezpieczeństwa zdrowotnego w Polsce. Rocznik Bezpieczeństwa Międzynarodowego, 11(1), 190-204. https://doi.org/10.34862/rbm.2017.1.12 (in Polish).

Trollman, H., Colwill, J., & Brejnholt, A. (2020). Ecologically embedded design in manufacturing: Legitimation within circular economy. Sustainability, 12(10), 4261. https://doi.org/10.3390/su12104261

Turoń, K., Sierpiński, G., & Tóth, J. (2020). Support for pro-ecological solutions in smart cities with the use of travel databases – a case study based on a bike-sharing system in Budapest. In G. Sierpiński (Ed.), *Smart and Green Solutions for Transport Systems. TSTP 2019. Advances in Intelligent Systems and Computing* (pp. 225-237). Cham: Springer. https://doi.org/10.1007/978-3-030-35543-2_18

UN Global Compact. (2022). *UN Global Compact Yearbook Poland 2022.* https://ungc.org.pl/yearbook-2024/

Ustawa z dnia 16 lipca 2020 r. o zmianie ustawy o odnawialnych źródłach energii. (Dz. U. z 2020 r., poz. 1503). https://dziennikustaw.gov.pl/DU/rok/2020/pozycja/1503 (in Polish).

Ustawa z dnia 20 lutego 2015 r. o odnawialnych źródłach energii. (Dz. U. z 2015 r., poz. 478). https://dziennikustaw.gov.pl/DU/rok/2015/pozycja/478 (in Polish).

Viegi, G., Baldacci, S., Maio, S., Fasola, S., Annesi-Maesano, I., Pistelli, F., Carrozzi, L., La Grutta, S., & Forastiere, F. (2020). Health effects of air pollution: A Southern European perspective. Chinese Medical Journal, 133(13), 1568-1574. https://doi.org/10.1097/CM9.0000000000000869

Von Schneidemesser, E., Driscoll, C., Rieder, H. E., & Schiferl, L. D. (2020). How will air quality effects on human health, crops and ecosystems change in the future? Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 378(2183), 20190330. https://doi.org/10.1098/rsta.2019.0330

Wang, C., Zhang, Y., Liu, C., Hu, F., Zhou, S., & Zhu, J. (2021). Emergy-based assessment and suggestions for sustainable development of regional ecological economy: A case study of Anhui Province, China. Sustainability, 13(5), 2988. https://doi.org/10.3390/su13052988

Wang, J., & Lei, P. (2021). The tournament of Chinese environmental protection: Strong or weak competition? Ecological Economics, 181, 106888. https://doi.org/10.1016/j.ecolecon.2020.106888

WHO. (2018a). *WHO Ambient Air quality database.* https://www.who.int/data/gho/data/themes/air-pollution/who-air-quality-database

WHO. (2018b). *Air quality database 2018.* https://www.who.int/data/gho/data/themes/air-pollution/who-air-quality-database/2018

Wiech, J. (2018). *Energetyka 24. Raport. Kompendium smogowe.* https://cdn-legacy.defence24.pl/energetyka24.com/upload/2018-10-25/ph5owp_RaportSmogowyNetSS.pdf (in Polish).

Xie, Y., Dai, H., Zhang, Y., Wu, Y., Hanaoka, T., & Masui, T. (2019). Comparison of health and economic impacts of PM2.5 and ozone pollution in China. Environment International, 130, 104881. https://doi.org/10.1016/j.envint.2019.05.075

Xu, L. (2021). Quantitative evaluation method for coordinated development of ecological economy in mountainous areas based on grey clustering analysis. Arabian Journal of Geosciences, 14(7), 614. https://doi.org/10.1007/s12517-021-06967-x

Yunus, A. P., Masago, Y., & Hijioka, Y. (2020). COVID-19 and surface water quality: Improved lake water quality during the lockdown. Science of the Total Environment, 731, 139012. https://doi.org/10.1016/j.scitotenv.2020.139012

Zambrano-Monserrate, M. A., Ruano, M. A., & Sanchez-Alcalde, L. (2020). Indirect effects of COVID-19 on the environment. The Science of the Total Environment, 728, 138813. https://doi.org/10.1016/j.scitotenv.2020.138813

Zangari, S., Hill, D. T., Charette, A. T., & Mirowsky, J. E. (2020). Air quality changes in New York City during the COVID-19 pandemic. Science of the Total Environment, 742, 140496. https://doi.org/10.1016/j.scitotenv.2020.140496

Zgłobicki, W., & Baran-Zgłobicka, B. (2024). Air pollution in major Polish cities in the period 2005–2021: Intensity, effects and attempts to reduce it. Environmental Research, 240, 117497. https://doi.org/10.1016/j.envres.2023.117497

Zhao, T., Tesch, F., Markevych, I., Baumbach, C., Janßen, Ch., Schmitt J., Romanos, M., Nowak, D., & Heinrich, J. (2020). Depression and anxiety with exposure to ozone and particulate matter: An epidemiological claims data analysis. International Journal of Hygiene and Environmental Health, 228, 113562. https://doi.org/10.1016/j.ijheh.2020.113562

Zhou, L., Chen, X., & Tian, X. (2018). The impact of fine particulate matter (PM2.5) on China's agricultural production from 2001 to 2010. Journal of Cleaner Production, 178, 133-141. https://doi.org/10.1016/j.jclepro.2017.12.204

Zimny, P. (2017). *Uwaga! SMOG.* http://staszow.pl (in Polish).

Marzena HAJDUK-STELMACHOWICZ • Paulina BEŁCH • Elżbieta SZCZYGIEŁ • Michał Piotr FRANKIEWICZ • Barbara FURA

WPŁYW PANDEMII COVID-19 NA JAKOŚĆ POWIETRZA W POLSKICH MIASTACH – WYZWANIA DLA MENADŻERÓW

STRESZCZENIE: Celem niniejszego artykułu było zbadanie wpływu pandemii koronawirusa na jakość powietrza w Polsce. W badaniu wykorzystano dane z lat 2015-2023 ze stacji pomiarowych zlokalizowanych w pięciu dużych polskich miastach o różnym położeniu geograficznym. Dane dotyczyły pyłu zawieszonego (PM2.5, PM10) oraz tlenków azotu (NOx). Na podstawie przeprowadzonych analiz statystycznych stwierdzono spadek ilości wszystkich rodzajów zanieczyszczeń w 2020 r., przy czym redukcja stężenia tlenków azotu była istotna statystycznie tylko dla dwóch z trzech badanych miast (Krakowa i Wrocławia). Stwierdzono, że wprowadzone ograniczenia związane z wirusem SARS-CoV-2 mogły przyczynić się do poprawy jakości powietrza w polskich miastach względem lat wcześniejszych.

SŁOWA KLUCZOWE: COVID-19, jakość życia, zielony ład, zielona gospodarka, zrównoważony rozwój

DOI: 10.34659/eis.2024.90.3.784