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Atmospheric air quality in Poland in the context of pollutant emissions from the municipal and domestic sector in the years 1990–2023 and their impact on the health of children and adolescents

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ABSTRACT

The aim of this study is to assess the contribution of selected air pollutants from the residential sector to the total emissions in Poland from 1990 to 2023 and to evaluate their impact on the incidence of selected diseases among children and adolescents aged 0 to 18 years. The study used data on emissions of selected pollutants (sulfur dioxide, nitrogen oxides, total suspended particulate matter, particulate matter PM2.5 and PM10, polycyclic aromatic hydrocarbons) obtained from the National Centre for Emission Balancing and Management (KOBIZE). The analyses also included data on the incidence of selected diseases among children and adolescents, obtained from the Silesian Voivodeship Office in Katowice, Health Department, and the National Health Fund (asthma, hypertension, allergic contact dermatitis caused by substances introduced into the body, allergic food-induced inflammation of the stomach, small intestine, and colon). The data covered the period from 1990 to 2023. The obtained results clearly indicate that emissions from the municipal and domestic sector have a significant impact on the overall emissions of air pollutants such as nitrogen oxides, sulfur dioxide and total suspended particulate matter. Studies have often shown very strong and statistically significant connections between the concentration of analyzed air pollutants and the occurrence of selected diseases in children and adolescents aged 0–18.

Keywords: municipal and domestic pollution, air pollution, morbidity, children and youth.

INTRODUCTION

The long-term vision of the EU's sustainable development encompasses elements such as economic development, social cohesion, and environmental protection. An important aspect of the eco-development strategy is the issue of public health. The paradigm of sustainable development involves creating a socio-economic model based on progress that ensures a better quality of life while simultaneously taking care of the state of the natural environment. Public health depends on environmental factors (related to climate change, natural resource management, transportation intensity, production, and consumption of goods), economic factors (societal wealth, unemployment), and social factors (demographic issues, social exclusion). For this reason, public health issues receive special attention in the strategic documents of the European Union. The Renewed Sustainable Development Strategy of 2006 identified seven key challenges in the areas of economic, social, and environmental policy. One of these challenges is public health, with the main goal being to promote public health and improve protection against health threats [Review of the EU Sustainable Development Strategy, 2006]. Promoting health was also an important element of the Europe 2020 strategy [Communication COM (2010), 2020]. Research indicates that Norway and Iceland are two leading European countries in terms of sustainable development in the area of public health, whereas Romania, Lithuania, Latvia, and some of the newer EU member states rank the lowest. Environmental aspects such as air pollution or exposure to toxic substances, as well as a persistently low standard of living, naturally lead to adverse health effects [Public Health Agency of Canada, 2006]. An important aspect of public health in the context of sustainable development is the ongoing monitoring of this phenomenon and the socio-economic aspects directly related to it.

Literature review

Currently, there are over 47,000 deaths of Poles each year due to the effects of various air pollutants, including 36.500 from particulate matter PM2.5. Poor air quality is one of the contemporary public health issues both in Poland, Europe, and globally [WHO, 2021; Badyda et al., 2016]. Children, due to their less developed respiratory and immune systems and significantly higher breathing rates per minute, are more exposed than adults to the risk of infections from polluted air. During air exchange, a higher dose of various pollutants enters the child's body. In adulthood, this generally leads to a deterioration in quality of life [Czubaj-Kowal et al., 2022; WHO, 2019].

Approximately 300 million children worldwide live in areas where air pollution levels exceed WHO recommended norms by six times, and nearly 1.8 million of them die as a result of smog, including one in ten below the age of five [Ahn et al., 2024; Zhang and Zhang, 2023]. WHO studies show that in Europe, around 3% of deaths from cardiovascular diseases and 5% of deaths related to lung cancer can be attributed to exposure to particulate matter. Recent research indicates that the burden of disease associated with air pollution, particularly fine particulate matter, may be even higher, placing PM2.5 among the ten most significant public health risk factors worldwide. It is estimated that PM2.5 is responsible for about 3.1% of lost life years globally [WHO, 2021; Kuehn, 2021; Badyda et al., 2016]. PM2.5 suspended dust is atmospheric aerosols whose diameter is not larger than 2.5 μg. It is very fine, and in this form it can get directly into the bloodstream and respiratory system. PM10 suspended dust is a mixture of particles suspended in the air, the diameter of which does not exceed 10 μg. Both PM 2.5 and PM10 suspended dust are harmful due to the content of benzopyrenes, furans, dioxins and other heavy metals. These dusts are responsible for the occurrence of respiratory diseases, including asthma, chronic obstructive pulmonary disease, lung cancer [Czubaj-Kowal et al., 2022], circulatory system diseases (arterial hypertension, cardiac arrhythmias) [Huang et al., 2021], cancer [Zhang et al., 2023], they also contribute to premature miscarriages [Yan et al., 2022]. It should also be mentioned that pollutants from street sweeping can cause particles of various sizes to be resuspended in the air, which in turn causes high human exposure to heavy metals, metalloids and minerals [Generowicz et al., 2023; Gronba-Chyła et al., 2023].

The impact of air pollution on health is primarily manifested through changes in the respiratory and circulatory systems. In the process of breathing, the upper respiratory tract initially experiences irritation of the trachea and vocal disturbances. Air pollution is a leading environmental risk factor for certain respiratory diseases, such as asthma, chronic obstructive pulmonary disease (COPD), and lung cancer. Asthma is a respiratory condition that can develop due to exposure to toxic substances. The impact of pollution on the respiratory system begins even in fetal life, and both short-term and long-term exposures have a significant effect. Short-term exposure to air pollution most often exacerbates symptoms that have already occurred in the past in the respiratory system [Santos et al., 2021; Bălă et al., 2021; Seke et al., 2013].

In addition to the respiratory conditions mentioned above, inhalation of polluted air can lead to other ailments and effects such as: neurological disorders (including central nervous system tumors, attention problems, and memory issues); allergic diseases, including atopic dermatitis, food allergies, and skin allergies; lower birth weight of newborns; cardiovascular diseases (anemia, heart attack, hypertension); cancer; and increased school and work absenteeism [Amato-Lourenço et al., 2020; Pope et al., 2020; Khomenko et al., 2021; Shetty et al., 2023; Ratajczak et al., 2021].

The residential sector is a major source of air pollution emissions (households). Due to the low height of the emitter, emissions from these sources are referred to as residential emissions. This sector is the largest contributor to the total annual national emissions of total suspended particulates (TSP) as well as PM10, PM2.5, heavy metals, and polycyclic aromatic hydrocarbons (PAHs). Local solid fuel-fired and heavy oil-fired boilers, as well as individual household stoves burning fossil fuels, especially coal and biomass, are primarily responsible for low emissions. Low emissions significantly impact air quality, as low-level emission sources often lead to high concentrations of pollutants (mainly PAHs, suspended particulates, dioxins, furans, and heavy metals: mercury, cadmium, lead, as well as sulfur and nitrogen oxides) in the areas where people live, particularly in densely populated regions [Adamiec et al., 2019; Seke et al., 2013].

Air quality is shaped by many factors. The most significant influences on its quality include: the number of emission sources from households (use of low-quality fuels and/or inefficient heating systems), increased transportation, proximity to industrial facilities, reduction in green areas - lack of pollution filtering functions, geographical location - low-lying areas (e.g., being situated in a basin or river valley) hinder air circulation and cause pollution accumulation, weather - low precipitation and calm weather lead to pollution concentration, and dense development - building development obstructs ventilation corridors and air regeneration, hindering air circulation and exchange [Sówka et al., 2019; Dziok et al., 2022]. Other factors may also determine susceptibility to disease. In addition to exposure to environmental factors (including air pollution), they include smoking, alcohol abuse, obesity, physical inactivity, genetic predispositions, various types of mental disorders that are both cause and effect, and chronic stress. However, environmental factors largely determine the occurrence of diseases, which is confirmed by some authors [Wojtal, 2018].

The atmospheric air quality in Poland has significantly improved compared to the previous five years. According to an analysis by the Chief Inspectorate for Environmental Protection (GIOŚ), the analysis of annual average concentrations of air pollutants [sulfur dioxide, nitrogen dioxide, particulate matter PM10 and PM2.5, and polycyclic aromatic hydrocarbons (PAHs)] indicates a very favorable situation in recent years [Chief Inspectorate for Environmental Protection, 2024].

The aim of this study is to assess the contribution of selected air pollutants from the residential sector to the total emissions in Poland from 1990 to 2023 and to evaluate their impact on the incidence of selected diseases among children and adolescents aged 0 to 18 years. The study hypothesized that the municipal and domestic sector has a significant share in the emission of selected air pollutants and contributes to the occurrence of some diseases in children and adolescents.

METHODOLOGY

Emissions of pollutants

The study used data on emissions of selected pollutants in Poland obtained from the National Centre for Emission Balancing and Management (KOBIZE). The data included both total emissions and emissions from the residential sector and covered:

- sulfur dioxide (SO_x/SO_2),
- nitrogen oxides (NO_x/NO_2),
- total suspended particulate matter,
- particulate matter PM2.5,
- particulate matter PM10,
- polycyclic aromatic hydrocarbons (PAHs).

The data covered the period from 1990 to 2023.

Disease incidence

The analyses also included data on the incidence of selected diseases among children and adolescents in Poland, obtained from the Silesian Voivodeship Office in Katowice, Health Department, and the National Health Fund, based on the annual MZ-11 report. The data from the Silesian Voivodeship Office in Katowice covered the period from 1990 to 2023. Data for the years 1990 and 2005 were ultimately excluded from the analyses due to the lack of reporting both by the National Health Fund and the Ministry of Health. The health information pertains to children and adolescents aged 0 to 18 years under the care of a primary care physician (family doctor), diagnosed with the selected conditions (as of December 31 of the given year) according to the ICD-10 disease code (the incidence rate is presented as the number of cases per 10,000 residents). The following ICD-10 disease units were included in the analyses:

- asthma (J45),
- hypertension (I10-I15),
- allergic contact dermatitis caused by substances introduced into the body (L27),
- allergic food-induced inflammation of the stomach, small intestine, and colon (K52.2).

Statistical analyses

The analysis of the relationship between the emissions of selected pollutants and the frequency of specific diseases was conducted using Pearson linear correlation coefficients and Spearman non-parametric correlation coefficients. Normality tests for the distribution of variables were performed using Shapiro-Wilk tests. A p-value of < 0.05 was considered significant. All statistical analyses were conducted using Statistica version 13.1.

RESULTS AND DISCUSSION

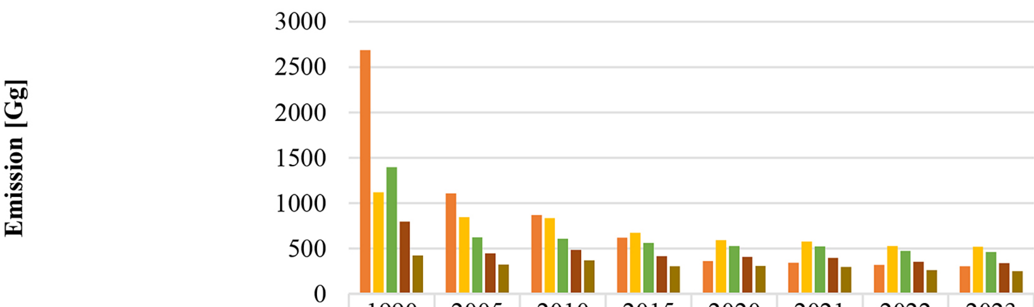
Dynamics of air pollutant emissions

The main source of sulfur dioxide emissions is the energy combustion of fuels (primarily coal) in stationary sources, which collectively account for 95% of the national sulfur dioxide emissions. 40% of SO_2 emissions come from residential sources, and this emission has decreased by 88% from 1990 to 2023. The changes were initiated by the collapse of heavy industry in the late 1980s and early 1990s. The gradual reduction in the use of hard coal and lignite in fuels for heat and electricity production also contributed to the decrease in emissions of this pollutant. The reduction in SO_2 emissions is due to the decreased consumption of fuels, especially solid fuels, in the residential sector. According to the NEC Directive [Directive of the European Parliament and of the Council, 2016], Poland was expected to achieve a reduction level of at least 59% in SO_2 by 2020 compared to 2005. The reduction of this pollutant in relation to 2005 has already exceeded the level required by the NEC Directive, reaching 67.4% in 2020 and 71.1% in 2022. The highest total sulfur dioxide emission was recorded in 1990 (2687 Gg), and the lowest in 2023 (303 Gg). For the residential sector, the emissions were 234 Gg in 2010 and 121 Gg in 2023 (Figures 1 and 2).

Nitrogen oxide emissions decreased by 53% from 1990 to 2023. Since the late 1990s, the largest source of nitrogen oxides has been fuel combustion in road transport, with emissions systematically increasing until 2017. This was mainly due to a 219% increase in the number of vehicles since 1990, which led to higher transport activity and fuel consumption (including gasoline, diesel, LPG, and CNG). However, the decrease in NO_x emissions since 2017 is due to the growing share of vehicles meeting the latest emission standards. Overall nitrogen oxide emissions have been progressively decreasing in recent years, mainly from road transport, households, and energy production.

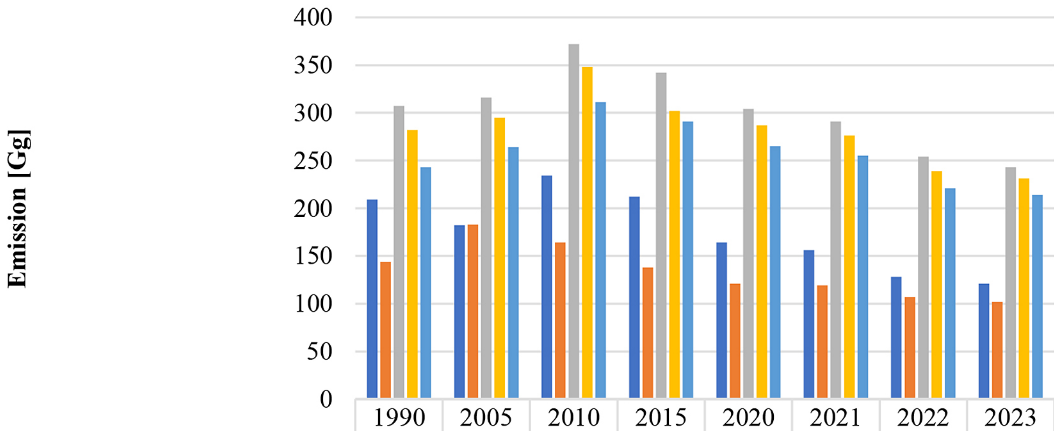
The reduction target for Poland regarding NO_x emissions for the years 2020–2029, as specified in the NEC Directive, is 30% compared to 2005. The national NO_x emissions in 2020 were 33.4% lower than in 2005, and in 2023, they were 40.8% lower. The highest total nitrogen oxide emissions were recorded in 1990 (1117 Gg), and the lowest in 2023 (517 Gg). For the residential sector, emissions were 183 Gg in 2005 and 121 Gg in 2023 (Figures 1 and 2).

The main source of total suspended particulate (TSP) emissions in Poland is stationary combustion processes, from which the majority of national emissions originate. The emissions



	1990	2005	2010	2015	2020	2021	2022	2023
Sulfur dioxide	2687	1106	867	617	360	342	319	303
Nitrogen dioxides	1117	846	833	673	591	578	528	517
Total Suspended Particulates	1394	624	606	561	527	524	473	462
Suspended dust PM10	797	445	486	414	409	397	353	337
Suspended dust PM2.5	422	321	368	302	307	297	262	251

Figure 1. Total emission of individual air pollutants in Poland in 1990–2023



	1990	2005	2010	2015	2020	2021	2022	2023
Sulfur dioxide	209	182	234	212	164	156	128	121
Nitrogen dioxides	144	183	164	138	121	119	107	102
Total Suspended Particulates	307	316	372	342	304	291	254	243
Suspended dust PM10	282	295	348	302	287	276	239	231
Suspended dust PM2.5	243	264	311	291	265	255	221	214

Figure 2. Emission of individual air pollutants from municipal and domestic sources in Poland in the years 1990–2023

from the residential and commercial sector account for nearly 55%. This sector has seen the largest decrease in TSP emissions, which was driven by reduced fuel consumption. TSP emissions in 2023 decreased by 66% compared to 1990. This reduction was caused by changes in activity across various sectors, particularly reduced fuel consumption in the energy sector and road transport, as well as a decline in mineral extraction. The highest total suspended particulate emissions were recorded in 1990 (1394 Gg), while the lowest were in 2023 (462 Gg). Emissions from the residential and commercial sector were observed at 372 Gg in 2005 and 243 Gg in 2023 (Figures 1 and 2).

The main source of PM10 emissions in Poland, similar to total suspended particulate (TSP), is stationary combustion processes, with the majority coming from the residential and commercial sector (68%), mainly from fuel combustion in households. PM10 emissions in 2023 decreased by 55% compared to 1990. The largest drop in PM10 emissions, as with TSP emissions, was linked to reduced fuel consumption in the residential and commercial sector. The highest PM10 emissions were recorded in 1990 (797 Gg) and the lowest in 2023 (337 Gg). From the residential and commercial sector, emissions were 348 Gg in 2010 and 231 Gg in 2023 (Figures 1 and 2).

The main source of fine particulate matter (PM2.5) emissions is the residential and commercial sector. In 2023, 93% of total emissions of this pollutant came from the combustion of hard coal and biomass in households. The residential and commercial sector is a significant source of particulate emissions, including condensable fractions, especially from biomass combustion. PM2.5 emissions in 2023 decreased by 38% compared to 1990, due to reduced fuel consumption in households.

PM2.5 is a pollutant covered by an emissions limit under the NEC directive. According to this directive, by 2020, Poland was supposed to reduce PM2.5 emissions by 16% compared to 2005. In 2020, the reduction compared to 2005 was 4.8%, and in 2023 it was 18.8%. According to national monitoring data, the emission trend in recent years is therefore decreasing. The highest PM2.5 emissions were recorded in 2023 (422 Gg) and the lowest in 2023 (201 Gg). Emissions from the residential and commercial sector were recorded at 311 Gg in 2010 and 214 Gg in 2023 (Figures 1 and 2).

The role of air pollution in causing allergies consists in both an adjuvant effect at the stage of sensitization and an allergen provocation leading to the development of allergic disease. Exposure to natural inhalant allergens, mainly plant pollen, often coincides with high concentrations of suspended dust. When combined with air pollutants, allergens have a greater allergen potential. Pollution particles may be suspended in the air, facilitate the penetration of allergens through mucous membranes and skin, and increase sensitivity to aeroallergens by directly affecting the respiratory mucosa. Air pollution related to car traffic (TRAP - traffic-related air pollutants) reduces the ventilation parameters of the lungs and may also contribute to the development of asthma, allergic rhinitis, eczema, and cause asthma exacerbations. Heavy metals in polluted air play an important role in the development of various types of allergies [Lu et al., 2020; Wang et al., 2022].

A significant portion of PAH (polycyclic aromatic hydrocarbons) emissions comes from fuel combustion in households (88%) and is estimated based on the evaluation of emissions of four compounds from this group: benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, and indeno(1,2,3cd) pyrene. Their emissions in 2023 decreased by 35% compared to 1990. The most significant contribution to the reduction of national PAH emissions in 2023 was due to the decreased use of hard coal and the introduction of modern heating devices for burning wood biomass. The highest total emissions of polycyclic aromatic hydrocarbons were recorded in 2010 (384 Mg) and the lowest in 2023 (201 Gg). From the residential and commercial sector, emissions were recorded at 290 Mg in 2010 and 186 Mg in 2023 (Figures 3 and 4)

During the period under study, the incidence of hypertension and food and skin allergies among children and adolescents in Poland showed a downward trend. In the case of asthma, we are observing an increasing trend (Figure 5).

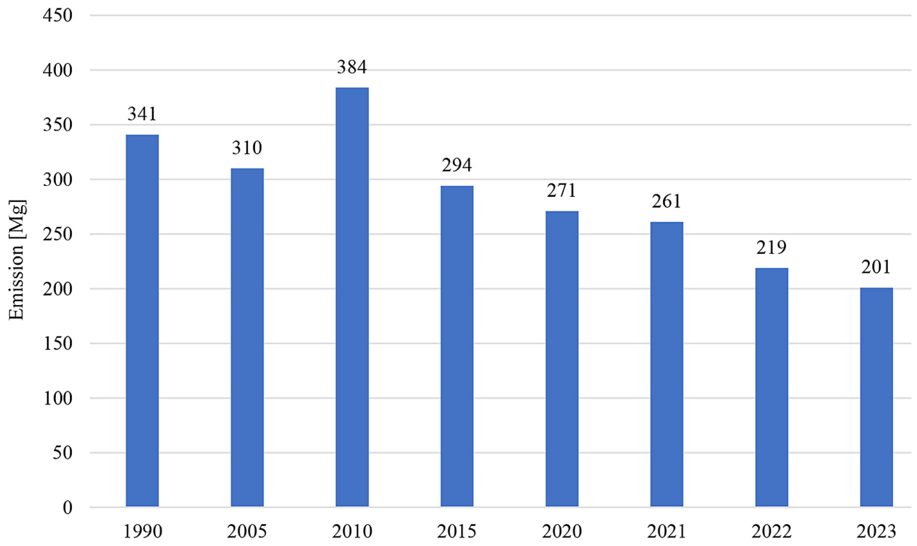


Figure 3. Total emission of polycyclic aromatic hydrocarbons in Poland in 1990–2023

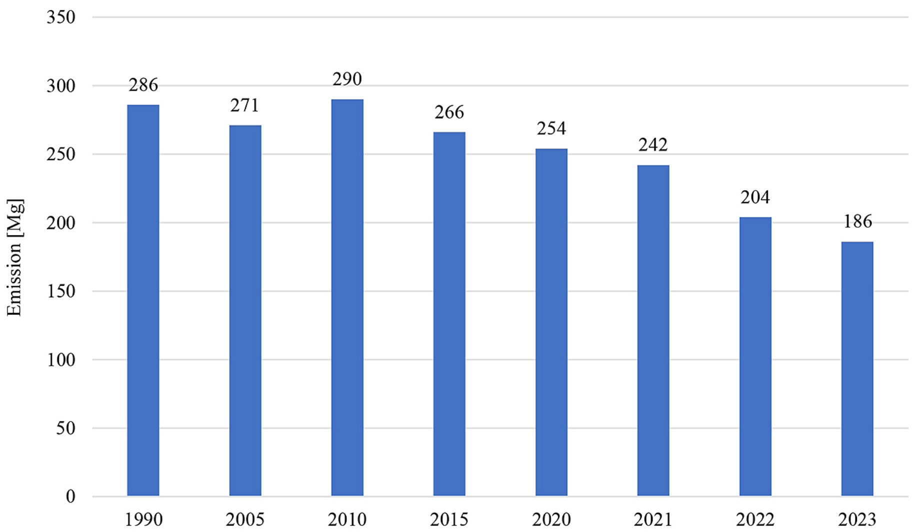
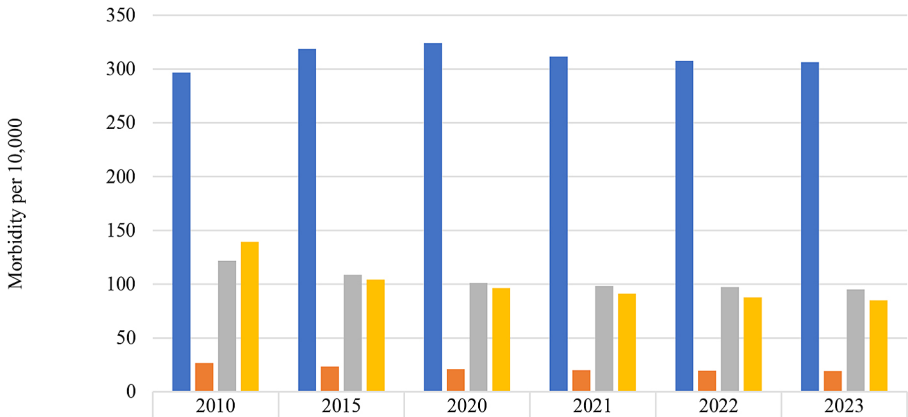


Figure 4. Emission of polycyclic aromatic hydrocarbons from municipal and domestic sources (sector) in Poland in 1990–2022



	2010	2015	2020	2021	2022	2023
Asthma	296,7	318,6	324,1	311,6	307,5	306,4
Hypertension	26,6	23,5	20,9	20,1	19,6	19,3
Food allergies	121,8	108,6	101,1	98,4	97,3	95,2
Skin allergies	139,2	104,3	96,3	91,2	87,6	84,9

Figure 5. Incidence of selected diseases among children and adolescents aged 0–18 in Poland (incidence rate per 10.000)

The relationship between general pollutant emissions and emissions from the municipal and domestic sector

The majority of the variables for total pollution emissions did not meet the assumption of normality (Table 1). Since the sample size was small (n = 8), Spearman's rank correlation was used to examine the relationships between the variables. The results of the correlation tests are presented below. The analysis of the relationship between total pollution emissions and emissions from the residential and commercial sector showed statistically significant correlations for most of the pollutants studied (Table 2). The strongest correlation was found for nitrogen oxide emissions (rS = 0.93, p-value = 0.0009), indicating a very strong positive relationship between total emissions and emissions from the residential and commercial sector. A strong correlation was also observed for sulfur dioxide (rS = 0.81, p-value = 0.0149), suggesting that emissions from the residential and commercial sector significantly affect the total emissions of this pollutant.

Additionally, a strong correlation was found for total suspended particulate (rS = 0.79, p-value = 0.0208), while a moderately strong correlation was observed for PM10 (rS = 0.74, p-value = 0.0366). In both cases, the results indicate a significant impact of emissions from the residential and commercial sector on overall particulate matter emissions. Only for PM2.5 was a moderate but statistically insignificant correlation observed (R = 0.55, p = 0.1600), indicating that for this pollutant, the relationship between total emissions and emissions

Table 1. Normality tests for the relationship between total pollutant emissions and emissions from the municipal and domestic sector

Emission	Variable	W	p
Total emission of pollutants	Sulfur dioxide (Gg)	0.707419	0.002732
	Nitrogen oxides (Gg)	0.869373	0.148614
	Total suspended dust (Gg)	0.595989	0.000143
	Suspended dust PM10 (Gg)	0.724324	0.004231
	Suspended dust PM2.5 (Gg)	0.920559	0.434419
Emissions from the municipal and domestic sector	Sulfur dioxide (Gg)	0.950051	0.711742
	Nitrogen oxides (Gg)	0.942253	0.633373
	Total suspended dust (Gg)	0.987615	0.990507
	Suspended dust PM10 (Gg)	0.943174	0.642555
	Suspended dust PM2.5 (Gg)	0.964880	0.855084

Note: * The marked correlation coefficients (red color) are significant from p < 0.050.

Table 2. Spearman's rank order correlation for total emissions and the municipal and housing sector*

Pair of variables	R Spearman	t(N-2)	p
Sulfur dioxide (Gg) & Sulfur dioxide (Gg)	0.809524	3.377558	0.014903
Nitrogen oxides (Gg) & Nitrogen oxides (Gg)	0.928571	6.128259	0.000863
Total suspended dust (Gg) & Total suspended dust (Gg)	0.785714	3.111270	0.020815
Suspended dust PM10 (Gg) & Suspended dust PM10 (Gg)	0.738095	2.679659	0.036553
Suspended dust PM2.5 (Gg) & Suspended dust PM2.5 (Gg)	0.547619	1.603135	0.160026

Note: * The marked correlation coefficients (red color) are significant from $p < 0.050$.

from the residential and commercial sector is weaker (Table 2). Normality tests were conducted for the total emissions of polycyclic aromatic hydrocarbons (PAHs) and emissions from the residential and commercial sector to check if their distributions are close to a normal distribution. The results of the Shapiro-Wilk test for total hydrocarbon emissions ($W = 0.981$, p-value = 0.969) and emissions in the residential and commercial sector ($W = 0.906$, p-value = 0.325) indicate that in both cases, there is no basis for rejecting the hypothesis of normal distribution (Table 3). Since the distributions of both variables do not differ significantly from a normal distribution, Pearson's correlation coefficient can be applied (Table 4).

The results indicate a very strong positive correlation between total hydrocarbon emissions and emissions from the residential and commercial sector ($r = 0.951$) (Table 4). Additionally, with a p-value = 0.000, the result is statistically significant, meaning that emissions from the residential and commercial sector have a significant and very strong impact on total emissions.

The relationship between overall pollutant emissions and the incidence of specific diseases

The data from 1990 and 2005 regarding morbidity are significantly underestimated compared to 2010. Such discrepancies may indicate incomplete data sets, which could be due to limited monitoring or insufficient reporting of disease cases during those periods. Therefore, these years were excluded from further analysis. To ensure the reliability and consistency of the results, the analysis was limited to the years 2010–2023, for which the available data are more reliable and do not show similar irregularities. Based on the obtained data, normality tests were conducted for the variables. The results of the Shapiro-Wilk tests indicate that the distributions of variables such as sulfur dioxide, hypertension, and skin allergies deviate from a normal distribution (p-value < 0.05) (Table 5). The remaining variables, including nitrogen oxides, total suspended particulates, PM10, PM2.5, hydrocarbon emissions, asthma, and food allergies, have distributions consistent with a normal distribution (p-value > 0.05). However, due to the small sample size ($n = 6$) and the fact that the Spearman test is more resistant to deviations from normality and performs better with small samples, Spearman's rank correlation coefficient was used for further analysis (Table 6).

The results of the Spearman rank-order correlation analysis for the concentration of various air pollutants and asthma show that the correlations between sulfur dioxide, nitrogen oxide, total suspended particulates (PM10 and PM2.5), and hydrocarbons with asthma incidence are very low (Table 6). The correlation coefficients for all these variable pairs ranged from 0.085714 to 0.142857, and the p-values were high (from 0.787172 to 0.871743), indicating no statistically significant associations and no impact of pollutant concentrations on asthma incidence.

The impact of pollutants on the occurrence of hypertension was also examined (Table 7). The Spearman rank correlation analysis for the concentration of various air pollutants and hypertension showed that in most cases, the correlations

Table 3. Normality tests for total emissions of polycyclic aromatic hydrocarbons and emissions of these compounds from the municipal and domestic sector

Variable	W	p
Hydrocarbons summary mission	0.981262	0.968876
Hydrocarbon emissions in the municipal and domestic sector	0.905705	0.324810

Table 4. The relationship between total hydrocarbon emissions and emissions from the municipal and domestic sector – Pearson correlation coefficients

Variable	Hydrocarbon emissions in the municipal and domestic sector
Hydrocarbons summary mission	0.9509
	p = 0.000

Note: The marked correlation coefficients (red color) are significant from $p < 0.050$.

Table 5. Normality tests for emissions of individual pollutants and analyzed diseases

Variable	W	p
Sulfur dioxide (Gg)	0.776387	0.035661
Nitrogen oxides (Gg)	0.859475	0.187371
Total suspended dust (Gg)	0.950855	0.747201
Suspended dust PM10 (Gg)	0.937599	0.639922
Suspended dust PM2.5 (Gg)	0.916995	0.483989
Hydrocarbon emissions (Mg)	0.928033	0.565000
Asthma	0.980104	0.952076
Arterial hypertension	0.750951	0.020352
Food allergies	0.834451	0.117191
Skin allergies	0.791766	0.049493

Note: *The marked correlation coefficients (red color) are significant from $p < 0.050$.

Table 6. Spearman's rank order correlation for the analyzed pollutant emissions and the frequency of asthma occurrence

Pair of variables	R Spearman	t(N-2)	p
Sulfur dioxide (Gg) & Asthma	0.085714	0.172062	0.871743
Nitrogen oxides (Gg) & Asthma	0.085714	0.172062	0.871743
Total suspended dust (Gg) & Asthma	0.085714	0.172062	0.871743
Suspended dust PM10 (Gg) & Asthma	0.085714	0.172062	0.871743
Suspended dust PM2.5 (Gg) & Asthma	0.142857	0.288675	0.787172
Hydrocarbon emissions (Mg) & Asthma	0.085714	0.172062	0.871743

Note: The marked correlation coefficients (red color) are significant from $p < 0.050$.

Table 7. Spearman's rank order correlation for the analyzed pollutant emissions and the frequency of hypertension

Pair of variables	R Spearman	t(N-2)	p
Sulfur dioxide (Gg) & Arterial hypertension	1.000000	~	~
Nitrogen oxides (Gg) & Arterial hypertension	1.000000	~	~
Total suspended dust (Gg) & Arterial hypertension	1.000000	~	~
Suspended dust PM10 (Gg) & Arterial hypertension	1.000000	~	~
Suspended dust PM2.5 (Gg) & Arterial hypertension	0.942857	5.659453	0.004805
Hydrocarbon emissions (Mg) & Arterial hypertension	1.000000	~	~

Note: The marked correlation coefficients (red color) are significant from $p < 0.050$.

were nearly perfect, with values of 1. This indicates an excellent positive monotonic relationship between these variables and hypertension. However, the absence of t-test values and p-values for these results is due to computational limitations associated with the small sample size ($n = 6$), which makes it difficult to assess the statistical significance of these findings.

For PM2.5 dust, the correlation coefficient was 0.942857, which also indicates a strong positive monotonic relationship between PM2.5 concentration and hypertension (Table 7). The p-value = 0.004805 confirms that the observed relationship is statistically significant.

The Spearman rank correlation analysis for the concentration of individual air pollutants and food allergies reveals strong positive relationships. The correlation coefficients for sulfur dioxide, nitrogen oxides, total suspended particulates, and hydrocarbon emissions were approximately rS ≈0.986, indicating a very strong monotonic relationship with food allergies (Table 8). The p-values for these correlations are very low (p-value < 0.001), confirming their statistical significance and indicating that the observed relationships are not random. For PM2.5 concentration, the correlation coefficient was approximately rS ≈0.928, which also indicates a strong positive monotonic relationship with food allergies. The p-value ≈0.0077 is statistically significant, meaning that the relationship between PM2.5 concentration and food allergies is also significant.

The results of the Spearman rank correlation analysis for the concentration of individual air pollutants and skin allergies show very strong positive relationships. The correlation coefficients for sulfur dioxide, nitrogen oxides, total suspended particulates, and hydrocarbon emissions were 1, indicating a perfect positive relationship between these variables and skin allergies (Table 9). The absence of p-values for these correlations is due to computational limitations associated with the very small sample size (n = 6), making it difficult to assess statistical significance, but the high correlation suggests a strong connection.

For PM2.5, the correlation coefficient was 0.942857, which also indicates a strong positive monotonic relationship with skin allergies. The p-value ≈ 0.0048 means that the obtained correlation coefficient is statistically significant.

Despite improvements in air quality across many European countries, levels of air pollution still exceed standards, posing a serious health problem for Europeans. High concentrations of PAHs, PM10, and PM2.5 (typical air pollutants from the residential and commercial sector) in Warsaw may be responsible for 1.400 to 1.800 deaths annually, primarily due to cardiovascular and pulmonary diseases, particularly COPD. Excessive concentrations of these pollutants may also contribute to 600 to 1.000 deaths from ischemic heart disease and 350 deaths from lung cancer [Dąbrowiecki et al., 2022; Nazar and Niedoszytko, 2022).

Communities exposed to the negative impacts of air pollution from the residential and commercial sector are primarily those living in settlements often lacking central heating. These buildings are equipped with inefficient or degraded heating systems. A significant problem is residential areas without emissions-free heating systems, lacking gas networks, and built with outdated technologies and low energy efficiency. This situation is

Table 8. Spearman's rank order correlation for the emissions of analyzed pollutants and the frequency of food allergies

Pair of variables	R Spearman	t(N-2)	p
Sulfur dioxide (Gg) & Food allergies	0.985611	11.66190	0.000309
Nitrogen oxides (Gg) & Food allergies	0.985611	11.66190	0.000309
Total suspended dust (Gg) & Food allergies	0.985611	11.66190	0.000309
Suspended dust PM10 (Gg) & Food allergies	0.985611	11.66190	0.000309
Suspended dust PM2.5 (Gg) & Food allergies	0.927634	4.96736	0.007666
Hydrocarbon emissions (Mg) & Food allergies	0.985611	11.66190	0.000309

Note: The marked correlation coefficients (red color) are significant from p < 0.050.

Table 9. Spearman's rank order correlation for the emission of analyzed pollutants and the frequency of skin allergies

Pair of variables	R Spearman	t(N-2)	p
Sulfur dioxide (Gg) & Skin allergies	1.000000	~	~
Nitrogen oxides (Gg) & Skin allergies	1.000000	~	~
Total suspended dust (Gg) & Skin allergies	1.000000	~	~
Suspended dust PM10 (Gg) & Skin allergies	1.000000	~	~
Suspended dust PM2.5 (Gg) & Skin allergies	0.942857	5.659453	0.004805
Hydrocarbon emissions (Mg) & Skin allergies	1.000000	~	~

Note: The marked correlation coefficients (red color) are significant from p < 0.050.

further exacerbated by poverty and the economic situation of the population, which prevents or severely limits access to adequate energy services. Consequently, these communities, in search of alternative and inexpensive solutions, resort to heating with waste or low-quality solid fuels. Energy poverty intensifies air pollution emissions and further exposes communities to reduced quality of life and chronic diseases caused by air pollution, ultimately leading to a shortened life span [Zathey, 2017; Oleniacz and Gorzelniak, 2021].

On a national scale, in Poland, the residential and commercial sector is responsible for nearly 93% of the national PAH emissions and 68% of dioxins and furans. Pollutants emitted from the residential and commercial sector (especially suspended particulates and PAHs) are toxic and carcinogenic, posing real threats to human health and life. Therefore, awareness-raising public campaigns should be conducted, coordinated by local authorities, for example through leaflets and newsletters. Chimney services could also play a significant role through periodic inspections of heating devices. Media campaigns should be intensified, particularly through local television and radio stations, as well as local newspapers. At the same time, educational and control measures should be directed towards users of residential solid-fuel heating devices to prevent waste burning. However, the most urgent issue is to resolve the problem of providing adequate fuels (including hard coal) for the residential sector at affordable prices for consumers.

CONCLUSIONS

The hypothesis put forward in the study about the influence of the municipal and housing sector on the occurrence of certain diseases in children and adolescents was confirmed. The municipal and domestic sector also has a significant share in the emission of selected air pollutants, as presented in the work and the conclusions below.

The results indicate that emissions from the residential and commercial sector have a significant impact on the overall emission of pollutants, especially for substances such as nitrogen oxides, sulfur dioxide, and total suspended particulates. This highlights the importance of this sector in the context of air quality management.

For the diseases analyzed, except for asthma, a cyclical decrease in incidence was observed over the study period, which may be attributed to the reduction in emissions of all analyzed air pollutants from both general and residential/commercial sources. For asthma, an increase in incidence was recorded, which may suggest other factors contributing to the frequency of this disease.

The analyses revealed that all studied air pollutants (sulfur dioxide, nitrogen oxides, total suspended particulate matter, PM2.5 and PM10, polycyclic aromatic hydrocarbons) affect the occurrence of hypertension. However, the studies were conducted with a small sample size (n = 6), which complicates the assessment of statistical significance of these results.

The results indicate strong and statistically significant correlations between the concentration of various air pollutants and the occurrence of food allergies. Increases in sulfur dioxide, nitrogen oxides, total suspended particulates, PM10, PM2.5, and hydrocarbon emissions are associated with a higher frequency of food allergies.

The analysis showed very strong and statistically significant correlations between the concentration of air pollutants and the occurrence of skin allergies. Increases in sulfur dioxide, nitrogen oxides, PM10, PM2.5, and hydrocarbon emissions are associated with a higher frequency of skin allergies.

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