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New directions for the realisation of SDGs given the economic and welfare costs incurred by air pollution

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Air pollution is a multidisciplinary research field, which affects sustainable development (SD) and Sustainable Development Goals (SDGs). Its multi-level cause and effect shows the direct influence of air pollution on human health, standards and costs of living, health treatment, and the economies of states. Poor air quality, as an SDG factor, may affect both lower wellbeing and economic growth. As developed economies have faced problems due to poor air quality, they have worked out solutions based on their technological engagement. However, emerging economies are still facing poor air quality as a main problem affecting their economic growth. The particulate matter factor, according to the air quality study, was used as the basis for comparative and statistical research. The findings of the study indicate that air pollution causes a serious impact relating to workforce productivity, absence from work, mortality, and even lower crop yields. There is an obvious research gap in the investigated field of comparative studies considering air pollution as an SD factor, understood as an economic concept. Therefore, the current study is proposed to fulfil this gap, contribute to the knowledge base of the factors affecting human development, and expand the statistical data based on the findings from a comparison between Poland and Germany on their performance in air quality tests. This is a novel approach pointing to air pollution as the proposed focus of research for the realisation of SDGs.

KEYWORDS

sustainable development goals, air pollution, sustainable development, socio-economy, welfare, economic costs

1 Introduction

The relationship between economic development and environmental pollution has been the subject of intense research (Fodha and Zaghoud, 2010; Landrigan, 2016; Tan et al., 2021; Torkayesh et al., 2022). In addition, policymakers have long attempted to promote and sustain economic growth (Sultana et al., 2022) as the basis for the stable and prosperous development of societies. Furthermore, for the development to be sustainable, it must consider social, ecological, and economic issues; the basis of living and non-living resources; and the long- and short-term benefits and drawbacks of alternative actions (Sustainable Development: Evaluation of the Concept and its Economic, Ethical, Political and Cultural Dimension, n.d.). This is typically thought to operate at the crossroads of environmental, economic, and social concerns.

Economic growth, based on the concept of sustainable development, enables emerging economies to gradually close the gap with more developed economies. Activities that develop an

economy in transition may include increasing the standards of living, developing a competitive industrial and commercial base, and improving the infrastructure. Economic growth may also consider access to resources, such as solar energy, clean soil, and air. Moreover, developed economies are not free from the challenges of Sustainable Development Goals (SDGs)—they still reduce the influence of their economics on the natural environment.

Agenda 2030 of the SDGs of the United Nations ([Sustainable Development Goals, 2022a](#)) points to goals such as Goal 3, which aims at improving healthcare and wellbeing; Goal 6, which aims at improving access to clean water and sanitation; Goal 8, which is concerned with decent work and economic growth; Goal 10, which aims at reducing inequalities; Goal 12, which is regarding responsible consumption and production; and Goal 13, which emphasises climate action for achieving sustained economic growth. Creativity, know-how, technology, and financial resources from all societies are needed to achieve SDGs in every context ([Sustainable Development Goals. The SDGs in action. Sustainable Development Goals, 2023](#)). Economic development is not promoted by human or technological capital; instead, it is fuelled by natural resources ([Rahim et al., 2021](#)). Furthermore, by 2030, SDG 3.9 aims at substantially reducing the morbidity, mortality, and illnesses caused by hazardous substances and pollution and contamination of air, water, and soil ([UNDP, 2022b](#)).

In the European Union, air pollution is considered to be the greatest hazard to the health of the EU residents ([Widera et al., 2022](#)). According to Dr Maria Neira, WHO Director, Department of Environment, Climate Change and Health, air pollution is one of the world's biggest public health issues ([WHO, 2022](#)). Poisonous air may affect the proper functionality of the immune system and increase the risk of chronic illnesses. Furthermore, it causes vast comprehensive socio-economic disruption, direct and indirectly, positive and negative effects on the environment, like reduction in the water and air quality, ecological restoration, and noise reduction ([Chakraborty and Maiti, 2020](#)). [Table 1](#) presents the air pollution levels in the two countries examined.

This study aims to formulate a new direction for the realisation of SDGs through an investigation of the role of air pollution as a socio-economic factor in the environmental dimension of sustainable development economic theory. It contemplates air pollution as a factor that influences welfare and has economic costs. However, this exploratory attempt is limited to two countries (Germany and Poland) and is only concerned with data for the year 2020. The results add to the economic knowledge of the development of sustainable development as a concept, especially its environmental dimensions and best practices. Furthermore, this study aims to provide knowledge of current trends in both emerging and developed economies; however, it may be limited by the specificity of the economies on which it focused during the research. The conclusions show that there is a need to conduct research in other economies to fully recognise this problem.

2 Literature review

Sustainable development means different things to different people, such as ecologists, environmental planners, economists, and activists. The discussion on sustainable development is partly interesting because the concept has been borrowed from both

TABLE 1 Air and GHG emissions.

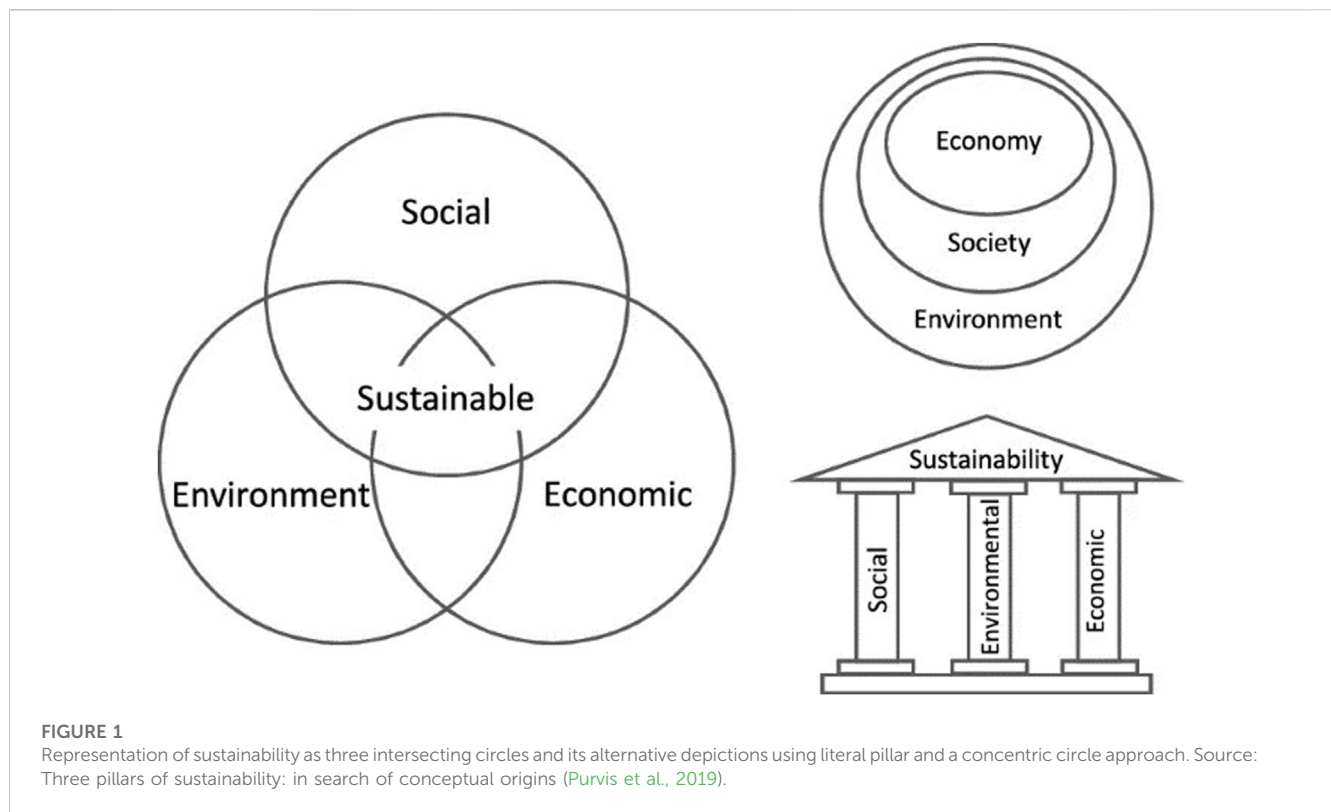
Year	Germany	Poland
2000	9.970	7.570
2001	10.200	7.550
2002	10.030	7.390
2003	10.060	7.680
2004	9.880	7.770
2005	9.680	7.760
2006	9.840	8.080
2007	9.470	8.040
2008	9.580	7.910
2009	8.950	7.570
2010	9.450	7.980
2011	9.110	7.870
2012	9.270	7.710
2013	9.470	7.600
2014	8.930	7.260
2015	8.930	7.350
2016	8.920	7.630
2017	8.700	7.960
2018	8.380	7.920
2019	7.750	7.490
2020	7.040	6.980

Source: Authors' elaboration based on OECD data indicators for CO₂ emissions ([OECD, Environmental Performance Reviews: Finland, 2021](#)). Carbon dioxide (CO₂) in tonnes per capita for the year 2000–2020 (inclusive).

natural and social sciences ([Redclift, 1991](#)). The literature indicates that different economies have different policies and standards, particularly related to the environment. Developed economies typically adopt stricter environmental control policies and advanced technologies to reduce environmental pollution ([Abdouli and Hammami, 2017](#)). The extant body of literature concerning air pollution can be divided into the following areas: sustainable development as a socio-economic concept and air pollution along an environmental dimension.

Sustainable development is a resource-use pattern that attempts to meet human needs while maintaining the environment; therefore, these needs can be addressed not just now but also in the future. The literature highlights a crucial matter concerning the future of humans ([Zhao et al., 2020](#)). As an economic concept, sustainable development is characterised by three dimensions: economic, social, and environmental. Integrating these into public policies presents specific challenges at every stage of the policy cycle ([ESCAP and Scientific, 2015](#)). [Figure 1](#) presents sustainable development using the intersecting circle and concentric circle approaches.

Thus, air pollution can be classified as an environmental factor. According to the literature, air quality is a major environmental concern because of rapid changes in pollutant emissions driven by



complex and intensive human activities (Tan et al., 2021). In addition to climate change, air pollution and quality are key challenges for cities globally and have significant impact on human health and economic development (Liu et al., 2019). The phenomenon has also been linked to environmental and population health (Watt et al., 2015; Shindell et al., 2017). The description of air pollution has gradually developed to be based on the physical and chemical characteristics of specific pollutants, and the focal point has gradually shifted from single to multiple contaminants (Dominici et al., 2010; Carvalho et al., 2019). Many developed countries with superior air quality have implemented pollution control measures, while developing countries with large populations are entering or about to enter the stage of severe air pollution (Han et al., 2018). Table 2 presents the Global Burden of Diseases (GBD) 2017 risk factor hierarchy based on air pollution.

Reducing air pollution, including greenhouse gas (GHG) emissions originating from the extensive use of fossil fuels, is critical for European countries to improve their environment and achieve carbon neutrality by the middle of this century. To optimally reduce air pollutants and mitigate climate change, national and European Union level regulations and international agreements, such as the SDGs, Kyoto Protocol, and Paris Climate Agreement, must be included in these strategies (Torkayesh et al., 2022). Understanding the extent to which air pollution influences the process of achieving the SDGs may help estimate the benefit of reducing air pollution, so as to improve the attempts at sustainable development and for evaluating the necessity and urgency required to reduce air pollutants and, thus, improve air quality (Zhao et al., 2020). As a large number of people are adversely affected by pollution, the following question arose: “Should environmental concerns not encompass social concerns?” Consequently, not only have the studies in environmental and social

fields begun to dovetail, but the study of environmental economics itself has emerged (Rogers et al., 2012).

3 Hypotheses

First, a desk research was conducted. The data used as the base of the research were secondary and included the environmental indicators generated from the 2020 Organisation for Economic Cooperation and Development (OECD). As the comparative method was chosen to verify the hypotheses and the practical aim of the study was to compare emerging and developed economies, Poland and Germany were chosen for analysis. The statistical method, such as the multiple correlation test, was used.

From the aggregate Air Quality Index (AQI), based on the combined effects of five criteria pollutants (CO, SO₂, NO₂, O₃, and PM₁₀) and considering European standards, the particulate matter pollutant, as the most common and measured pollutant in most countries, was chosen for analysis. The usefulness of this factor has been confirmed in previous studies (Zeger et al., 2000; Beloconi et al., 2016; Stafoggia et al., 2017).

The literature indicates that Sweden, Latvia, France, Lithuania, Hungary, and Italy were ranked as the top six countries with the lowest emissions. However, Finland, Poland, the Czech Republic, Luxembourg, and Estonia had the lowest overall rankings and highest *per capita* emissions (Torkayesh et al., 2022). The rankings influenced the choice of countries (economies) to be compared: Poland is an emerging economy with one of the highest emissions, and Germany is a developed economy focussing on green economy development. In addition, strong economic bonds exist between these two economies.

TABLE 2 GBD 2017 risk factor hierarchy and its accompanying exposure definitions, theoretical minimum risk exposure levels, and data representativeness index for each risk factor, pre-2007, 2007–17, and the total (across all years)—air pollution.

1	Risk factor	Exposure definition	Theoretical minimum risk exposure level	Data representativeness index	Risk factor		
2					Before 2007	2007–17	Total
3	Air pollution				100.0%	100.0%	100.0%
4	Particulate matter pollution				82.9%	88.6%	96.4%
5		Ambient particulate matter pollution	Annual average daily exposure to outdoor air concentrations of particulate matter with an aerodynamic diameter of $\leq 2.5 \mu\text{m}$ ($\text{PM}_{2.5}$), measured in $\mu\text{g}/\text{m}^3$	Joint theoretical minimum risk exposure level, for both household and ambient particulate matter pollution, is a uniform distribution between 2.4 and 5.9 $\mu\text{g}/\text{m}^3$, with the burden being attributed proportionally between household and particulate matter pollution on the basis of the source of $\text{PM}_{2.5}$ exposure in the excess of the theoretical minimum risk exposure level	17.1%	57.0%	58.0%
6		Household air pollution from solid fuels	Individual exposure to $\text{PM}_{2.5}$ due to the use of solid cooking fuel	Ambient particulate matter pollution	82.9%	63.4%	85.5%
7	Ambient ozone pollution		Seasonal (6-month period with the highest ozone level) 8-h daily maximum ozone concentrations, measured in ppb	Uniform distribution between 29.1 and 35.7 ppb	100.0%	100.0%	100.0%

The data representativeness index was calculated as the percentage of locations for which we had data for a given time period. $\text{PM}_{2.5}$, particulate matter with an aerodynamic diameter smaller than 2.5 μm , measured in $\mu\text{g}/\text{m}^3$. ppb, parts per billion. Source: GBD, 2017 Risk Factor Collaborators, 2018.

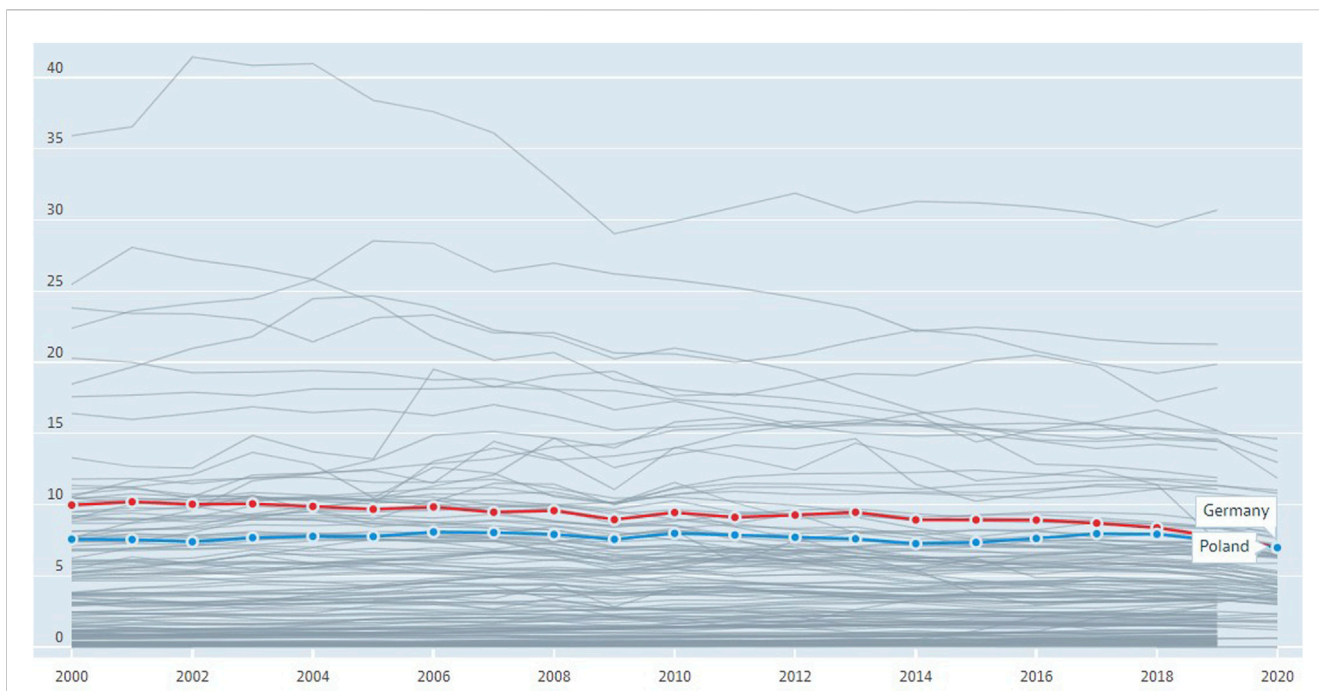


FIGURE 2
Indicators of CO₂ emissions in Germany and Poland during 2000–2020. Source: OECD data indicators for CO₂ emissions.

The proposed methodology consists of the following steps: desk research and data analysis using comparative and statistical methods, in which the use of public statistics data is justified.

To investigate air pollution as a socio-economic factor and to examine its role in the environmental dimension of the sustainable development economic theory concept, based on the aforementioned discussion, the following hypothesis (H) was formulated:

H: Air pollution plays a crucial role in realising SDGs and allows developing sustainable development as an economic concept.

In addition, the following supporting hypotheses were established:

H1: Air pollution is a crucial environmental factor, which helps formulate new directions for SDGs’ realisation.

H2: The environmental dimension of sustainable development is becoming increasingly important and is strongly related to healthcare costs.

H3: Air pollution has serious economic implications, particularly at the national level.

4 Results and findings

Here, we consider the impact of generated waste and its collection on the economic, social, and environmental dimensions and the waste collected and treated by or for municipalities. It covers wastes from trade and commerce, hospitals, office buildings, and households, including bulky waste, garden waste, street sweepings, market cleansing waste, and contents

of litter containers. These exclude wastes from municipal sewage networks and treatment, as well as waste from construction and demolition activities. This indicator is measured in thousands of tonnes and kilogrammes *per capita* (OECD, *Environmental Performance Reviews: Finland, 2021*) examined.

At the same time, the purpose of the air, GHG emissions, and CO₂ data was to determine the gross direct emissions from human activities in both Poland and Germany. Figure 2 shows the indicators of CO₂ emissions for both countries during the same period.

Figure 2 shows the position of examined countries at the background of other OECD countries (grey lines).

The data expressed in CO₂ equivalents refer to gross direct emissions from human activities. CO₂ refers to the gross direct emissions from fuel combustion only, and these data are provided by the International Energy Agency (IEA); air and GHG emissions are measured in thousand tonnes, tonnes *per capita*, or kilogrammes *per capita*, except for CO₂, which is measured in million tonnes and tonnes *per capita* (Air and emissions, 2022). For a comparative study, we also compared the data on population exposure to fine particulates in these two countries. This comparison is presented as a percentage in Table 3.

These data are used to find out the percentage of the population that is being exposed to fine particulate (PM_{2.5}) concentrations exceeding WHO guidelines (10 µg per cubic metre) and its effect on the population in Poland and Germany. It represents the percentage of the population exposed to fine particulate (PM_{2.5}) in the air, which increases the risk of respiratory and cardiovascular diseases in particular. These data indicate the exposure of the population to fine particulate concentrations more than 10 µg/m³ and are expressed as annual averages.

TABLE 3 Air pollution exposure of the population of Poland and Germany, at the OECD background, exposed to fine particulates (PM_{2.5}), with concentrations exceeding the WHO guidelines (10 µg per cubic metre) in the percentage of the population in years 2000, 2005, and 2010–2019.

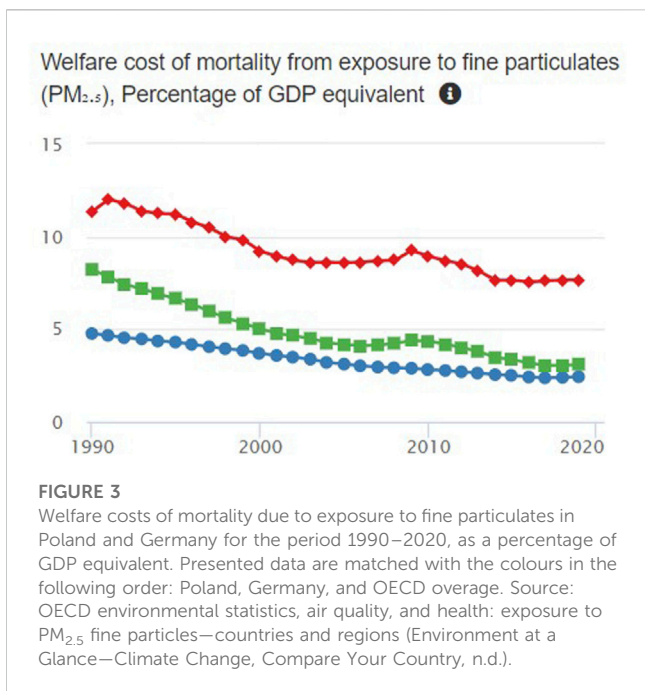
Year	Germany	Poland	OECD
2000	99.8	100	87.5
2005	99.3	100	84.2
2010	99.6	100	74.5
2011	99.6	100	76
2012	98.3	100	71.5
2013	98.6	100	69.9
2014	91.9	100	66.6
2015	95.5	100	66.2
2016	88.3	100	61.6
2017	87	100	62.2
2018	88.7	100	62.5
2019	86.8	100	61.7

Source: OECD environmental statistics, air quality, and Health: exposure to PM_{2.5} fine particles—countries and regions (OECD, *Environmental Performance Reviews: Finland, 2021*) (Environment at a Glance—Climate Change, Compare Your Country, n.d.).

TABLE 4 Mortality attributed to exposure to fine particulates (PM_{2.5}), with the annual deaths per million inhabitants during 2000–2019.

Year	Germany	Poland	OECD
2000	505	836	380
2001	482	813	369
2002	468	793	361
2003	454	787	352
2004	431	790	336
2005	422	791	329
2006	419	799	321
2007	424	812	316
2008	434	817	313
2009	445	821	310
2010	447	800	305
2011	432	786	300
2012	412	772	295
2013	391	739	289
2014	360	698	282
2015	349	705	280
2016	331	701	271
2017	320	712	267
2018	320	725	271
2019	324	733	275

Source: OECD environmental statistics, air quality, and health: exposure to PM_{2.5} fine particles—countries and regions (Environment at a Glance—Climate Change, Compare Your Country, n.d.).



The data reveal interesting observations. For example, the emerging economy (Poland) made no progress during the 20-year period, while OECD countries and the developed economy (Germany) made progress on this count during the same period. This is because the developed economy, Germany, made investments in research and development and new technologies, as well as green energy. The economic and social costs incurred by air pollution are mainly related to a shorter life expectancy (real and expected) and health disorders (also understood as healthcare social costs) in the emerging economy (Poland). The social cost of air pollution is also related to mortality, as shown in Table 4.

Figure 3 shows the welfare costs of mortality due to exposure to fine particulates.

The air pollution effect is reflected in the mortality rate per 1,000,000 inhabitants. In 2019, the cost estimate of inhaled fine particulate matter that causes serious health issues, like respiratory and cardiovascular diseases, exerts a significant effect on children and elderly people, increasing their risk of heart diseases and stroke in particular, eventually leading to death. The cost estimate only represents premature mortalities and is calculated using the estimates of the value of a statistical life (VSL) and the number of premature deaths attributable to ambient particulate matter.

Here, the correlations between mortality and air pollution in Poland and Germany were examined. Table 5 shows welfare costs, mortality, and municipal waste.

The data were used to run multiple correlation tests of the following variables: welfare cost of mortality from exposure to fine particulates (PM_{2.5}), mortality attributed to the exposure to fine particulates (PM_{2.5}), and municipal wastes generated in Germany. Table 6 shows the correlation results.

The results of the correlation test showed that there was a significant positive correlation between the mortality attributed

TABLE 5 Mortality, welfare costs, and municipal wastes of Germany (the developed economy) for the period 2000–2019.

Variable			
Year	Welfare costs: mortality	Mortality attributed to PM _{2.5}	Municipal waste
2000	5	505	648.8
2001	4.8	482	639.3
2002	4.6	468	647.2
2003	4.5	454	608
2004	4.3	431	593.2
2005	4.2	422	570.5
2006	4.1	419	569.8
2007	4.1	424	569.2
2008	4.2	434	596.6
2009	4.4	445	599.1
2010	4.2	447	609.2
2011	4.2	432	621.3
2012	4	412	614.5
2013	3.8	391	610.7
2014	3.5	360	627.4
2015	3.4	349	631.2
2016	3.2	331	634.2
2017	3.1	320	626.6
2018	3.1	320	604.6
2019	3.1	324	606

Source: Authors' own elaboration based on OECD data.

to exposure to fine particulates (PM_{2.5}) and the welfare cost of mortality from exposure to fine particulates (PM_{2.5}). Compared to that, municipal waste had a less significant positive correlation with both the welfare cost of mortality from exposure to fine particulates (PM_{2.5}) and the mortality attributed to exposure to fine particulates (PM_{2.5}). The same tests were conducted for Poland, an emerging economy, and the results are shown in Table 7.

The data were used to run multiple correlation tests of the following variables: welfare cost of mortality from exposure to fine particulates (PM_{2.5}), mortality attributed to the exposure to fine particulates (PM_{2.5}), and municipal wastes generated in Poland. Table 8 shows the correlation results.

The correlation tests showed a strong positive association between mortality attributed to fine particulate exposure (PM_{2.5}) and the welfare cost of mortality from fine particulate exposure (PM_{2.5}), whereas municipal wastes showed a less significant positive correlation. In addition, there was a slight negative correlation between the amount of municipal wastes generated and the cost of mortality due to fine particulate exposure.

TABLE 6 Germany: correlation test.

	Year	Welfare costs: mortality	Mortality attributed to PM _{2.5}	Municipal waste
Year	1			
Welfare costs: mortality	-0.935504954	1		
Mortality attributed to PM _{2.5}	-0.925554468	0.998156632	1	
Municipal waste	0.028839823	0.037511786	0.03574846	1

Source: Authors' own elaboration.

TABLE 7 Correlation test data of mortality, welfare costs, and municipal wastes in Poland (emerging economy) for the period 2000–2019.

Year	Variable		
	Welfare costs: mortality	Mortality attributed to PM _{2.5}	Municipal waste
2000	836	9.2	317.1
2001	813	8.9	288.3
2002	793	8.7	273
2003	787	8.6	258.2
2004	790	8.6	254.1
2005	791	8.6	317.2
2006	799	8.6	319
2007	812	8.7	319.8
2008	817	8.7	317.9
2009	821	9.2	314.3
2010	800	8.9	313.9
2011	786	8.7	316.8
2012	772	8.5	316.1
2013	739	8.1	296
2014	698	7.6	271.2
2015	705	7.6	285.6
2016	701	7.6	306.8
2017	712	7.6	315.4
2018	725	7.7	329.2
2019	733	7.7	336.6

Source: Authors' own elaboration based on OECD data.

5 Discussion

In 2017, air pollution caused 4.9 million deaths worldwide according to the global burden of death (GBod) (Stanaway et al., 2018). Owing to the diversity of its diameter and composition type, particulate matter may have multiple effects on the whole body of a person, especially on the cardiovascular and respiratory systems, such as systemic inflammation and oxidative stress, increase in blood pressure, and changes in serum metabolites (Wang et al., 2015; Goudarzi et al., 2018; Mirabelli et al., 2020).

The environmental, behavioural, and metabolic risks that drive injury and disease are the mechanisms through which public health efforts can most efficiently and effectively prevent health loss. Therefore, effective population health improvements require the understanding of not only the injuries and diseases that drive health burdens but also the risks that drive injury and diseases (Landrigan, 2016). Against the backdrop of increasingly diverse multi-contaminant air conditions, human welfare will be seriously threatened if air pollution cannot be scientifically and effectively quantified and properly controlled (Tan et al., 2021). The health effects of particulate matter in Italy have been widely investigated in multicentre projects, evaluating short-term associations between daily particulate matter concentrations and mortality/hospitalisations across several Italian cities (Biggeri et al., 2005). The research on France and Iran (Sicard et al., 2019) showed that long-term exposure to ambient PM_{2.5} and PM₁₀ has substantially contributed to mortality and hospital admissions in the selected cities: non-accidental causes, cardiovascular diseases, respiratory diseases, and chronic obstructive pulmonary diseases caused approximately 8,200, 2,400, 540, and 220 deaths, respectively, in 2015; in addition, cardiovascular diseases and respiratory diseases caused 18,800 and 3,400 hospital admissions, respectively. A research, in a national cohort of approximately 2.5 million Canadians, covered pollution exposure and its associations with citizen mortality, which showed that exposure to PM_{2.5}, alone, was not sufficient to fully characterise the toxicity of the atmospheric mix or to fully explain the risk of mortality associated with exposure to ambient pollution (Crouse et al., 2015). Increasing evidence suggests that long-term exposure to ambient air pollution is associated with death from cardiopulmonary diseases. A 2002 pilot study reported clear indications that traffic-related air pollution was related to cardiopulmonary mortality in a randomly selected sub-cohort of 5,000 older adults participating in an ongoing Netherlands Cohort Study (Brunekreef et al., 2009). Another study, which was part of the ESCAPE project, measured the concentrations of PM_(2.5), PM_(2.5) absorbance, PM₍₁₀₎, and PM (coarse) in 20 European study areas at 20 sites per area. Predictor variables (e.g., traffic intensity, population, and land-use) were evaluated to model the spatial variation in the annual average concentrations for each study area. Examination of influential factors and skewed variable distributions was essential for developing stable LUR models, which can be used to estimate air pollution concentrations at the home addresses of participants in the health studies involved in the ESCAPE project (Eeftens et al., 2023). The range and number of studies covered by these topics confirmed and underlined their importance.

TABLE 8 Poland: correlation test.

	Year	Welfare costs: mortality	Mortality attributed to PM _{2.5}	Municipal waste
Year	1			
Welfare costs: mortality	-0.8217	1		
Mortality attributed to PM _{2.5}	-0.82114	0.973813	1	
Municipal waste	0.391742	0.069979	-0.00643	1

Source: Authors' own elaboration.

For developing risk attribution for particulate matter pollution, the integrated exposure–response curves combine epidemiological data from ambient, household, secondhand, and active smoking sources to construct a risk curve for the full exposure range (Landrigan, 2016). Evidence suggests that exposure to PM_{2.5} might be mechanistically linked to type 2 diabetes through altered lung function, vascular inflammation, and insulin sensitivity (Rajagopalan and Brook, 2012).

Air pollution can affect businesses through reduced workforce productivity, absence from work, premature deaths, and lower crop yields. Air pollution negatively impacts the U.S. economy, costing the U.S. roughly 5% of its yearly gross domestic product (GDP) in damages (\$790 billion in 2014) (Mirabelli et al., 2020). The highest costs were on account of early deaths, attributable to the exposure to fine particulate matter (PM_{2.5}). While some PM_{2.5} in the atmosphere is due to the result of natural processes, such as forest fires or windblown dust, most damage from PM_{2.5} is related to human activities, most of which can be attributed to different sectors of the economy, such as manufacturing and agriculture. Combining damage with more traditional measures of economic production, such as GDP or gross value added, provides a more accurate picture of a sector's full economic impact (Tschofen et al., 2019). In 2015, the WHO and OECD estimated that the economic cost of premature deaths and disabilities due to air pollution in Europe was close to 1.6 trillion USD. Air pollution takes its toll on the economy in several ways: it costs human lives, reduces people's ability to work, affects vital products, such as food, damages cultural and historical monuments, reduces the ability of ecosystems to perform functions that societies need, and costs money in remediation or restoration (UNECE, 2023). With sustained economic growth, environmental pollution in China has become increasingly serious and displays certain regional differences. Economic growth, energy structure, and industrial pollution in China are spatially correlated, with different agglomeration areas in the spatial distribution. In terms of the temporal dimension, energy consumption and technological pollution effects in China have led to increased environmental pollution, while changes in the structural effect have indirectly improved the environmental situation (Zhang et al., 2020; Zhang et al., 2023). Research indicates that there is a gap between citizens and technologies, which requires the development of more interactive systems and improved citizen education based on the SDGs and air pollution levels (Jasińska-Biliczak, 2022). However, air quality is subjected to many observed and unobserved factors, with evident seasonal changes that may confound the potential impact of enacted policies. Simple

before–after comparisons would fail to differentiate the policy impact from such confounding changes and may thus lead to biased and inconsistent results (Qin et al., 2023).

This study summarises a commonly used air pollution measure, which is particulate matter, and the economic consequences of air pollution in countries representing both emerging and developed economies. The sustainability of the integrated approach in the environment and society remains debatable (Fang et al., 2023). It contributes to the discussion on sustainable development as an economic concept for the practical realisation of SDGs. It also contributes to the discussion on the necessity of immediate action toward lowering the welfare cost of mortality due to exposure to polluted air. At the same time, it addresses the research gap regarding the impact of air pollution on economic costs in EU economies. However, the study has a limitation: it considers only two countries (Germany and Poland) and data for the year 2020.

6 Conclusion

This study assesses the environmental risk caused by air pollution across two representative countries. Poland and Germany had similar air quality and GHG emissions *per capita* in 2020. Germany had a score of 7.040, while Poland had a score of 6.980 (approximately 7.000 tonnes *per capita*). This was due to the lockdown measures to prevent COVID-19 from spreading, resulting in a positive effect of COVID-19 in the form of clean air, but only for a short time. Similarly, between 1990 and 2000, the percentage of population of Germany and Poland exposed to fine particles (PM_{2.5}) was roughly the same, with Germany having 100%, 99.7%, and 99.8% of its population exposed and Poland having 100%, 100%, and 100% of its population exposed in 1990, 1995, and 2000, respectively. The findings show that pollution poses a high risk of causing negative health effects in both countries' populations; however, there are differences between the emerging and developed economies, with developed economies having an advantage.

In contrast, both countries increased their municipal waste (in kilogrammes *per capita*) from 2019 to 2020. Germany produced twice as much waste as Poland at the same time. It follows that in Germany, the COVID-19 pandemic had a greater impact on waste management than that in Poland. In contrast, from 2000 to 2019, Germany's air and GHG emissions of carbon dioxide (CO₂) in tonnes *per capita* increased, whereas those of Poland decreased. Furthermore, from 2000 to 2019, Germany's average population

exposure to fine particulates (PM_{2.5}) in micrograms per cubic metre decreased, while that of Poland increased. This means that people in Poland experienced more negative health effects than those in Germany.

Similarly, mortality due to fine particulate matter (PM_{2.5}) was lower in Germany than that in Poland, with annual deaths per million inhabitants being lower in Germany than that in Poland. As a result, Poland had a higher rate of attributed mortality per million inhabitants than Germany. The most recent data of 2020 are not available yet; however, the study indicates that the mortality attributable to COVID-19 and environmental effects will increase. In 2019, Germany had an almost three times higher mortality rate due to exposure than Poland. In contrast, Germany's welfare cost of mortality from fine particulate exposure (PM_{2.5}), expressed as a percentage of GDP, was lower than that of Poland.

Moreover, mortality is a socio-economic factor associated with the concept of sustainable development. In addition, it is strictly connected to the environmental dimension of sustainable development because the state of the environment has a direct influence on the number of sick and dying people. It also generates an additional cost for the society, which has to bear these costs for the treatment of people.

Air quality and its influence on health, economically understood as both private and public goods, is the subject of the present study and discussions at different levels. The governments of Poland and Germany should take major steps toward a European green deal accord and zero-pollution policy.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

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Author contributions

Conceptualisation and methodology: AJ-B; analysis: AJ-B and EI; data curation: EI; writing—original draft preparation, review, and editing: AJ-B; visualisation and supervision: AJ-B. All authors contributed to the article and approved the submitted version.

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Conflict of interest

Author EI was employed by Cognizant Technology Solutions. The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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