ECONOMICS
& Sociology

Ginevičius, R. (2022). Assessment of the impact of air pollution on population mortality in EU countries. *Economics and Sociology*, *15*(2), 219-230. doi:10.14254/2071-789X.2022/15-4/11

ASSESSMENT OF THE IMPACT OF AIR POLLUTION ON POPULATION MORTALITY IN EU COUNTRIES

Romualdas Ginevičius
Mykolas Romeris University,
Vilnius, Lithuania
E-mail:
romualdas.ginevicius@mruni.eu
ORCID 0000-0003-2067-4398

Received: December, 2021
1st Revision: June, 2022
Accepted: October, 2022

DOI: 10.14254/2071-789X.2022/15-4/11

ABSTRACT. Particulate matter (PM 2.5), ozone, lead and radon are among the main sources of air pollution. The differences in mortality rates across the European Union due to their impact are very high, ranging from 4 to 16 times. Mortality from PM 2.5 particles is excreted 12.3 – fold compared to ozone, 4.6 – fold for lead and 10.6 – fold for radon. The state of economic development of countries and health expenditures have a significant impact on the rate of human mortality caused by air pollution. Their impact is uneven. Most of these depend on mortality from PM 2.5 particles, to a large extent from lead and ozone, and to a smaller extent to radon. All the countries of the European Union concerned pay considerable attention to health protection, since the level of the costs involved is closely linked to the per capita Gross Domestic Product (GDP). On the other hand, the real situation is illustrated by the trend in population mortality from the sources of air pollution in question. Absolute positive changes in population mortality from particulate matter (PM 2.5) have been observed over the period 2009–2018 (the situation has improved in all countries); significant positive changes in mortality due to lead air pollution (the situation has improved in 13 countries); moderate and negative changes due to ozone contamination (the situation improved in 11 countries) and very strong negative changes in mortality due to air pollution by ozone (the situation improved in only 8 countries).

JEL Classification: Q51, Q53

Keywords: air pollution by particulate matter PM 2.5, ozone, lead, radon; population mortality, condition, trends

Introduction

Air pollution (AP) means the release into the atmosphere of substances harmful to humans and other organisms or harmful to the environment. Sources of pollution are the location, action or factor causing emissions to the atmosphere. They can be primary and secondary. Primary emissions directly (sulphur and nitrogen oxides, carbon monoxide and dioxide, etc.); secondary is produced by primary reacting with each other or with substances present in the environment (Roman & Rusu, 2021; Budică et al., 2015). A typical secondary pollutant is ozone produced in the soil. In addition to it, other sources, both natural (natural) and anthropogenic (related to human activity), pollute the environment. These are in particular matter, lead and radon (Implementation of the European Green Deal, 2020).

In particular, the expansion of industry, energy, transport and increased consumption leads to increasing emissions of various substances and other pollutants, leading to an increase in air pollution worldwide over the last few decades. The short-term improvements in air quality during the lockdown caused by COVID-19 return to previous levels and continue to deteriorate. Overall, this situation is determined not only by the above-mentioned, subjective, but also objective reasons (volcanic eruption, sandstorms, etc.). However, unambiguously predominant are subjective, i.e. causes related to human activity (Linhartova, 2021; Haque et al., 2019). Negative environmental changes attract constant attention nowadays due to the high awareness regarding the impact on overall well-being (Mishchuk & Grishnova, 2015) as well as the growing responsibility of the communities at different levels (Pakurár et al., 2020; Piwowar, 2020).

The negative effects of AP are manifested in three essential aspects: the impact on human health, the economy and the ecosystem. The extent of the impact of air pollution on human health is illustrated by the following facts:

– 91% of the world's population breathes air that does not match World Health Organisation (WHO) air quality requirements (WHO data);

– particulate concentration reduces human life by year (WHO data);

– In 2015, PM 2.5 was the cause of 422 000 premature deaths in 41 European countries (European Environment Agency (EEA) study);

– In 2015, exposure to ozone caused 17,700 premature deaths in 41 European countries (EAA data);

– 6% in 2016. Residents of cities in the 28 EU countries were exposed to PM 2.5 and smaller particulate matter. An average of 74%. EU urban populations were exposed to PM 2.5 concentrations that exceeded WHO guidelines (EEA study data);

– Approximately 12% in 2016. Residents of cities in the EU-28 have been exposed to ozone concentrations that have exceeded the EU's norms. Almost 98% of the population is exposed to O_3 concentrations above the stricter WHO guideline values (EEA study data);

– in economically developing countries, an average of 25–40% of deaths were caused by high levels of air pollution (EEA study).

The disastrous effects of AP on human health are associated with oxidative stress and cell inflammation. This leads to chronic diseases and cancer. Particulate matter affects the airways, enters the bronchi. Small particles enter the blood and lungs, impairing the functions of internal organs. During the period of increased concentrations of particulate matter, human mortality has been observed to increase.

The damage of air pollution to the economic development of the countries is manifested in the following aspects: worsening people's health reduces life expectancy (3–5 years), increases medical costs and reduces overall economic productivity.

Damage to the ecosystem: contaminated soil, forests, lakes and rivers, reducing agricultural yields.

The Rest result of the harmful effects of air pollution on human health is an increase in premature deaths. According to the European Environment Agency, mortality can be a quantification of the impact of air pollution on human health.

The aim of the article is to assess the impact of air pollution on the health of the population of EU countries. It will address the following challenges: first, an analysis of the state of mortality from the sources of air pollution in question; secondly, it determines what its scale depends on; thirdly, it is determined to what extent countries exploit their potential to reduce mortality from APs.

1. Review of literature

The Green Growth Strategy has identified the following sources of human mortality from air pollution: particulate matter, ozone, lead and radon (Gundacker et al., 2021; Case..., 2017; Huang et al., 2021; Nuvolone et al., 2018; Saari et al., 2017; Holm and Balmes, 2013; Feng et al., 2019; Kang et al., 2019; Guadie Degu Belete and Yetsedaw Alemu Anteneh, 2021; DAS, 2021; Vogiannis and Nikolopoulos, 2015).

Particulate matter is dominated by PM 2.5 particles, i.e. those with an aerodynamic diameter of less than 2.5 µm (micron). They come from two sources: natural and human activities The former include volcanoes, deserts, forest and grass fires, splashes of seas and oceans, etc., the second include burning fossil fuels in internal combustion engines, power plants, various industrial processes ((Kumar et al., 2021). Most of the *particulate matter* is emitted by the oceans in the form of salt particles. Human activity accounts for about 10% of all particulate matter.

PM 2.5 is considered to be the most dangerous of all air pollutants. Due to their fineness, they can penetrate the airways and at the same time increase the risk of lung cancer and cause skin and eye diseases. They can also enter the bloodstream, causing mutations of DND, myocardial infarction and premature death. The *International Agency for Research on Cancer* (IARC) and the World Health Organisation (WHO) classified them as carcinogenic particles in the first group. A study conducted in 9 countries found that an increase in PM 2.5 by 10 $\mu m/m^3$ increased the chances of developing cancer by 36% (Raaschou-Nielsen et al., 2013).

Ozone is produced by exposure to ultraviolet rays under the influence of oxygen molecules. Its impact on land and human health is twofold. On the one hand, it absorbs about 14% of the sun’s radiation and thus protects against skin cancer. On the other hand, ground ozone O_3 directly affects both humans and all living nature and is therefore one of the most toxic gases. It increases by 1–2% every year in Europe. Studies conducted in recent years have shown a clear short-term harmful effect on respiratory, cardiovascular systems (Holm and Balmes, 2022). Its long-term effects can be asthma in both children and adults and increased respiratory effects (Nuvolone et al., 2018).

Ozone affects not only human health, but also their economic well-being. Depending on household income, the quality of housing may increase or decrease in concentration (Saari et al., 2017).

In addition to the adverse effects of ozone on human health, literature examines its effects on vegetation. It is characterised by a decrease in yield and biomass. In the future, O_3 pollution is expected to cause greater damage to global food production than climate change (Feng et al., 2019).

Lead, as a heavy metal, is also classified as carcinogenic. It is a potent toxic compound, especially dangerous for new-borns and children (Huang et al., 2021). It disrupts cell development, which affects growth (Balali-Mood et al., 2021). Its sources are lead production, metal processing, lead coating companies; soldering workshops; printing houses; paint, rubber, chemical plants; batteries and glazed dishes are used in the household. It enters the human body by breathing, less often by eating through the mouth. It accumulates in human bones (about 70% of total intake) and less in other organs. Its negative effects are manifested by violations of the circulation of proteins, carbohydrates and phosphorus. This allows for the development of ferodeficial anemia (Gundacker et al., 2021).

Harmful conditions of production provoke chronic human lead poisoning. Consequences – damage to the nervous, circulatory, digestive, etc. systems, liver.

Radon is a source of ionising radiation or radiation and is therefore the cause of human death (Torres-Durán et al., 2014). It is a radioactive, colorless and odorless gas that results from the decomposition of radium. Radon is present in soil, water, rocks, food, even in the human body (Das, 2021). Its unique feature is that it can accumulate in building structures (Table 1).

Table 1. Sources of radon

Sources of radon	Content, %
Construction materials, constructions	18.0
Weather outside	18.0
Primer	61.0
Tap water	2.0
Natural gas	0.005
Other	0.995

Source: *Morkunas et al., 2002*

Radon concentrations increase indoors if they are not ventilated (Vogiannis and Nikolopoulos, 2015). Its effects on human health manifest in particular negative effects on the lungs (Kang et al., 2019) by destroying sensitive lung cells, causing mutations that subsequently turn into cancer (Kang et al., 2019; Guadie Degu Belete and Yetsedaw Alemu Anteneh, 2021. Radon concentrations are highest in autumn and early winter, the lowest in spring. During the day it is distributed as follows: the biggest – early in the morning, when the sun rises – high, in the afternoon – decreases. As the sunset approaches, it grows again as the earth cools and increases atmospheric stability (Vogiannis and Nikolopoulos, 2015).

2. Research methodology

The literature review shows that the analysis of the impact of population mortality due to air pollution is appropriate in three stages. The first phase examines the state of mortality due to air pollution; second, the factors that influence this condition; the third is the result, i.e. trends in mortality due to air pollution (Figure 1).

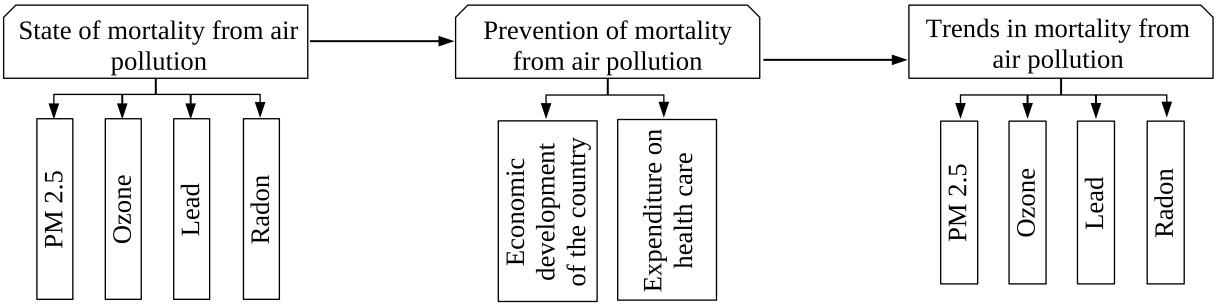

Figure 1 Scheme for analysis of population mortality due to air pollution
Source: *own data*

The first stage of analysis. The state of population mortality due to air pollution at EU level is reflected in two aspects: the level of mortality and its fluctuations between countries and between individual sources of air pollution. Sources of data on population mortality due to air pollution are provided by the OECD's Green Growth Strategy. Fluctuations are reflected in the following relationships:

$$\Delta P_k = \frac{P_k^{\max}}{P_k^{\min}} \tag{1}$$

$$\Delta P_e^{\max} = \frac{P_k^{\max}}{P_{k+1}^{\max}} \tag{2}$$

$$\Delta P_e^{\min} = \frac{P_k^{\min}}{P_{k+1}^{\min}} \quad (3)$$

here ΔP_k is the indicator of the extent of fluctuations in population mortality due to air pollution source k; $\Delta P_k^{\max}$– population mortality due to the 'k' emission indicator in the country where it was the highest fluctuation rate; $\Delta P_k^{\min}$the same, the smallest; $P_k^{\max} -$ population mortality due to the 'k' source of air pollution in the country where it was highest; $P_k^{\min}$ the same, the smallest.

The second stage of analysis. In order to carry out the structural analysis of population mortality from air pollution, potential influence factors need to be identified. The obvious fact that the more economically developed countries can pay greater attention to ecology can be used. In this way, two key factors in the prevention of population mortality are highlighted: the state of economic development of the country and the resulting health expenditure.

Today, there is no unanimous opinion on the country's economic development indicator. Also because it is difficult to adequately reflect the state of economic development of the country due to its complexity as a phenomenon (Liu et al., 2009; Jia et al., 2017) This fact dictated two approaches to solving the problem. In the first case, it is based on an index which, in its complexity, comes closest to the complexity of the phenomenon under assessment. This is gross domestic product per capita (Lisiński et al., 2020; Jędrzejczak-Gas and Barska, 2019; Kozyreva et al., 2017; Brizga et al., 2014; Moldan et al., 2012).

Greater adequacy of the country's economic development situation can be achieved by taking a different path – by combining a potentially larger number of indicators reflecting this development in different aspects into one aggregated size (Oželienė, 2019; Gedvilaitė, 2019; Molly, 2018; Strezov et al., 2017; Radovanović and Lior, 2017; Jia et al., 2017).

Studies in recent years show that such a method is used only to determine the state of economic development of an individual country. This is because it is based on a different number of indicators and a set of indicators. This makes international comparison impossible (Bolcarova and Kološta, 2015; Babu and Datta, 2015; Chursan, 2013). Meanwhile, the Gross Domestic Product per capita (GDP) is calculated by countries using a single methodology and easily accessible. For these and other reasons, it is used today as a generally accepted indicator of the state of economic development of the country.

The impact of the country's economic development and health expenditure on air pollution mortality can be determined on the basis of a correlation-regressive analysis. For that purpose, it is necessary, in particular, to assign the appropriate symbols to all the sizes in question (Table 2).

Table 2. Conditional certificates of the sizes under consideration

Verse No.	The amount at issue	Nature	Conditional Certificate
1.	Gross domestic product per capita (GDP) in 2018	The argument	X_1
2.	Countries' spending on health care 2018	The argument	X_2
3.	Average exposure of the country's population to PM 2.5 particles	Function	Y_1
4.	Total deaths of the country's population in 2017, live/1 million lives.	Function	Y_2
5.	National population mortality due to exposure to PM 2.5 particles in 2018	Function	Y_3 (ΔP^k)
6.	Population mortality due to exposure to ozone in 2018	Function	Y_4 (ΔP^o)
7.	Population mortality due to exposure to lead in 2018	Function	Y_5 $(\Delta P^{š})$
8.	Mortality due to radon exposure of the country's population in 2018	Function	Y_6 (ΔP^r)

Source: *own data*

Correlation-regressive analysis can be performed on the basis of the following models:

$$Y_1 = f(X_1) \tag{4}$$
$$Y_2 = f(X_2) \tag{5}$$
$$Y_3 = f(X_3) \tag{6}$$
$$Y_4 = f(X_3) \tag{7}$$
$$Y_5 = f(X_3) \tag{8}$$
$$Y_6 = f(X_3). \tag{9}$$

This analysis shows how countries have exploited the potential of preventing population mortality from air pollution. This is reflected in the changes that took place during the period considered. They can be determined as follows:

$$\Delta P_j^k = \frac{M_{Fj}^k - M_{Bj}^k}{M_{Bj}^k}. \tag{10}$$

here, changes in the mortality rate ΔP_j^k of the country's population during the period considered due to air pollution at source k; M_{Fj}^k – mortality of the population of country J at the end of the reference period due to source k of air pollution; M_{Bj}^k the same is true at the beginning of the period in question.

The magnitude ΔP_j^k shall reflect the nature and extent of the mortality rate of the population from the k-th source of air pollution in a country j. If $\Delta P_j^k < 0$, means the situation improved ΔP_j^k by percentage, if $\Delta P_j^k > 0$ – the situation deteriorated accordingly, i.e. the mortality rate increased.

The formula (10) does not reflect a general trend across EU countries. They may have been positive in some countries and negative in others. The overall picture can be determined as follows:

$$\Delta P^k = \frac{\sum_{i=1}^{e} P_{+}^{k}\eta_{+}^{k} - \sum_{i=1}^{r} P_{-}^{k}\eta_{-}^{k}}{\sum_{i=1}^{e} P_{+}^{k}\eta_{+}^{k}} \tag{11}$$

here, P^k a factor reflecting the improvement or deterioration of the situation at the level of all the countries concerned; P_{+}^{k} – cumulative improvement in population mortality due to exposure to air pollution source k; P_{-}^{k} – the same, deterioration; η_{+}^{k} – number of countries whose situation has improved; η_{-}^{k} the same thing, it got worse.

It's easy to see that $\eta_{+}^{k} + \eta_{-}^{k} = N$. If $Q_{+}^{k} > Q_{-}^{k}$, then the size P^k will reflect the overall improving trend and vice versa.

3. Empirical research

According to Figure 1, the analysis of the population mortality due to air pollution begins with the determination of the current state. Input data are given in Table 3. It shows that it fluctuates within a very wide range, both among countries and among individual sources of air pollution. Between countries 4.4 to 16.6 times, between sources of air pollution – 0.2 to 10.6 times (Table 3).

Table 3. Differences in mortality rates between European Union countries

Nature	Mortality of the population				
	Max		min		relationship
	country	pcs.	country	pcs.	
Pm 2.5 particles	Hungary	732.9	Finland	60.3	12.2
Ozone	Spain	59.6	Ireland	3.6	16.6
Lead	Portugal	160.1	Finland	15.1	10.6
Radon	Hungary	69.2	The Netherlands	15.6	4.4

Source: *own data on the basis of OECD Publishing*

Table 4. Mortality ratios for the causes of the population in the European Union

Nature of population mortality	Total mortality of the population		Sources of population mortality							
			Pm 2.5 particles		Ozone		Lead		Radon	
	Max	min	Max	min	Max	min	Max	min	Max	min
Pm 2.5 particles	–	–			12.3	16.7	4.6	4.0	10.6	3.9
Ozone	–	–	–	–			0.4	0.2	0.9	0.2
Lead	–	–	–	–	–	–			2.3	1.0
Radon	–	–	–	–	–	–	–	–		

Source: *own data, based on OECD Publishing*

Table 4 illustrates the possible causes of fluctuations in such high mortality rates among separate countries. In particular, it appears that the highest mortality rate is in the EU's Southern countries. This is primarily due to their climatic characteristics. They are much more exposed to forest fires due to high temperatures and are closer to deserts such as Sahara, i.e. more exposed to major sources of air pollution. Another possible reason is the level of economic development. Table 5 shows that the lowest mortality rates for all sources of air pollution are found in economically developed EU countries, i.e. those with greater financial access to health.

Table 5. Morality statistics for the population of the EU countries

		2018				2009		ΔP_j				ΔP_j^m			
		Y_1	Y_2	Y_3	Y_4	X_1	X_2	Y_1	Y_2	Y_3	Y_4	$\Delta P_j^{PM\ 2}$	ΔP_j^o	$\Delta P_j^{š}$	ΔP_j^r
1	Austria	369.98	30.71	55.31	44.54	43.6	10.3	386.19	25.86	57.92	45.30	6.8	18.8	− 4.5	–1.7
2	Belgium	300.56	26.64	124.77	38.03	40.3	10.8	437.84	23.50	136.79	36.62	–31.4	13.4	8.8	3.9
3	Czechia	585.81	28.96	74.52	58.02	19.9	7.5	709.22	18.65	75.60	39.76	–17.4	55.3	–1.5	− 3.0
4	Denmark	233.67	30.70	31.57	44.02	52.2	10.1	361.55	30.62	37.05	45.40	− 35.4	0.3	–14.8	− 3.1
5	Estonia	113.57	5.66	40.93	38.55	19.7	6.7	273.75	5.91	40.06	40.46	− 58.6	− 4.3	2.2	–4.8
6	Finland	60.25	5.74	15.09	35.80	42.3	9.0	131.29	8.72	15.07	32.86	–54.1	34.2	0.2	9.0
7	France	200.00	17.01	70.06	30.99	35.1	11.2	278.78	14.97	72.63	30.08	–28.3	13.7	− 3.6	3.1
8	Germany	320.44	27.99	54.38	33.95	40.5	11.5	445.24	22.94	51.47	35.47	–28.1	22.1	5.7	− 4.3
9	Greece	533.20	47.98	126.14	63.05	16.8	8.0	641.40	51.45	114.32	57.78	–16.9	7.7	10.4	9.2
10	Hungary	732.87	41.74	96.27	69.17	13.9	6.5	870.58	43.09	94.58	70.08	–15.9	–3.2	1.8	–1.3
11	Ireland	103.81	3.63	46.24	32.38	67.1	6.9	168.57	10.00	51.23	32.45	–38.5	− 63.7	–9.8	–0.3
12	Italy	399.27	54.71	100.15	40.28	29.6	8.7	505.91	35.88	101.85	41.18	–21.1	52.5	–1.7	–2.2
13	Latvia	566.87	6.28	58.56	40.49	15.1	6.2	928.00	5.82	60.25	42.74	− 39.0	7.9	2.8	–5.3
14	Lithuania	445.84	6.22	47.57	21.34	16.2	6.5	677.28	8.61	45.18	20.49	–32.7	–27.8	5.3	4.2
15	Luxembourg	142.34	19.34	31.31	40.81	98.6	5.3	255.98	18.97	40.70	46.70	–44.4	2.0	–23.1	–12.7
16	The Netherlands	267.69	23.89	38.59	15.62	44,9	10.0	347.44	16.26	39.49	14.44	–23.0	47.0	–2.3	8.2
17	Poland	725.21	17.26	99.48	30.85	13.0	6.3	820.77	15.76	103.29	27.72	–13.2	9.6	3.7	11.3
18	Portugal	203.10	29.70	160.12	28.64	20.0	9.4	262.71	33.78	159.03	26.17	–22.7	–12.1	0.7	9.5
19	Slovakia	622.47	14.37	75.81	38.06	16.4	6.7	786.32	16.37	85.29	35.35	− 20.9	–12.3	–11.2	7.7
20	Slovenia	383.49	28.95	51.13	44.55	22.1	8.3	430.87	20.08	48.23	42.43	− 11.0	44.2	6.1	5.0
21	Spain	187.30	59.63	88.47	36.10	25.8	9.0	236.28	44.77	87.01	34.15	–20.8	33.2	1.7	5.8
22	Sweden	65.77	11.47	28.99	27.43	46.3	10.9	138.05	14.39	33.19	26.19	− 52.4	− 20.3	–12.7	4.8
23	Croatia	725.36	40.58	84.52	37.07	12.7	6.8	858.87	31.64	83.90	40.11	–15.6	28.3	0.8	7.6

Source: *own data based on OECD Publishing*

In the second phase of the analysis of population mortality from air pollution, options for its prevention are explored. Two key areas are identified: the state of economic development of the country (as confirmed Table 5 and national health expenditure (Figure 1).

The sources of air pollution in question can be divided into two groups: first, particulate pollution (PM 2.5) and air pollution by gas (ozone, lead, radon). Correlation-regressive analyses of their effect on population mortality based in the (4–9) formulas, the results are given in Table 6.

Table 6. Results of the correlation-reflective analysis of the impact of economic development and health expenditure in the European Union on population mortality by different sources of air pollution in 2018

Verse No.	Correlative-regressive model	Equation	Value of correlation coefficient *r*	Significance of the Student Criteria	
				actual	critical
1	$Y_1 = f(X_1)$	$Y_1 = -7.1778X_1 + 648.09$	–0.78	5.1185	2.093
2	$Y_2 = f(X_1)$	$Y_2 = 0.101X^2 - 3.331X + 45.368$	–0.46	2.2589	2.080
3	$Y_3 = f(X_1)$	$Y_3 = 0.0057X_1^2 - 1.4136X_1 + 111.28$	–0.53	2.6852	2.086
4	$Y_4 = f(X_1)$	$Y_4 = 0.0047X_1^2 - 0.5848X_1 + 52.709$	–0.36	1.6509	2.086
5	$Y_1 = f(X_2)$	$Y_1 = 15.812X_2^2 - 368.62X_2 + 2369.7$	0.87	7.1224	2.093
6	$Y_2 = f(X_2)$	$Y_2 = -2.1544X_2^2 + 38.291X_2 - 137.09$	–0.42	2.2470	2.069
7	$Y_3 = f(X_2)$	$Y_3 = -3.2853X_2^2 + 52.219X_2 - 159.7$	–0.26	1.2770	2.069
8	$Y_4 = f(X_2)$	$Y_4 = -0.9643X_2^2 + 14.834X_2 - 12.784$	–0.39	1.7816	2.086
9	$X_2 = f(X_1)$	$X_2 = -0.0045X_1^2 + 0.3936X_1 + 1.8527$	0.91	9.4938	2.080

Source: *own data*

Table 6 shows that the population’s mortality from air pollution by particulate matter depends to a large extent both on the state of economic development of the country and on health expenditure, which is decreasing as the situation improves. This testifies to the fact that effective prevention measures can be envisaged, despite the fact that today’s deaths are the highest in comparison with other sources of air pollution. Such measures can include greater opportunities for the development of advanced, environmentally friendly technologies and vehicles, efficient monitoring systems, etc.

The number of deaths of harmful gases (ozone, lead, radon) is significantly reduced compared to air pollution by particulate matter (Table 4). On the other hand, because of their nature, their effects are much more difficult to localise. This is evidenced by the results of the correlation-regression analysis (Table 6). In part, it is objective, since much of this gas is produced in a medium that today is still difficult to influence – ozone in the ground, lead in production processes, radon – in the ground, water, rocks, construction structures, and thus in the walls of residential houses (Table 4).

The mortality rate of the population depends to a large extent on spending on health, and it is therefore important to determine how the state of economic development of the country is affected. From the Table 6 shows that it is very strong (*r* = 0.91). This means that EU countries pay sufficient attention to protecting the health of their population. On the other hand, the true picture is not revealed by one or several years, but by changes that have taken place over a sufficiently long period of time, e.g. 10 years, both in individual countries and in the EU as a whole. This can be determined on the basis of and formulae. The results of the calculations are given in Table 7.

Table 7. Results of the calculation of population mortality from air pollution trends in European Union countries

Indicators	Sources of air pollution			
	Pm 2.5 particles	Ozone	Lead	Radon
ΔP^k	–1.0	+ 0.98	–0.73	+ 0.48
Trend of change	An absolutely positive trend	Very strong negative trend	A strong positive trend	Moderately negative trend

Source: *own data*

Table 7 shows that significant positive changes in population mortality were due to the localisation of PM 2.5 particles and lead exposure. Very bad situation with ozone mortality due to air pollution and unsatisfactory situation – radon.

Conclusions

As a result of industry, energy, transport, construction, expansion, increased consumption, increased forest fires due to global warming, and other cataclysms, air pollution is increasing with both particulate matter and harmful gases such as ozone, lead and radon. The last result of their harmful effects on human health is premature deaths. In this situation, both scientific and practical issues are gaining importance: identification of the current state of population mortality from air pollution sources; identification of the essential factors which its scale depends on as well as the identification of trends in population mortality. The results of such research are an important basis for improving the situation.

The analysis of the state of population mortality has revealed significant fluctuations between individual European Union countries according to all sources of air pollution analysed. The situation varies from 4 to 16 times. In comparison, there was a high mortality rate among the population due to air pollution by particulate matter.

Population mortality due to air pollution depends to a large extent on the state of economic development of the country. There is a contradictory situation: on the one hand, air pollution caused by particulate matter causes the highest mortality rate in the population, and on the other it depends on the state of economic development of the country. Therefore, everything here is determined by the country's health policy, i.e. how much attention and resources are devoted to it. This is also confirmed by the dependence of population mortality on particulate matter on health resources ($r = 0.87$).

The effectiveness of a country's health policy can be inferred from trends in population mortality. The calculations showed that during the period 2009–2018 all EU countries have made significant progress in reducing air pollution by particulate matter, with improvements in all countries concerned. The same is true of air pollution with lead. Its sources are exclusively production processes, transport, etc. This indicates that the technologies used are improving and making them cleaner.

The worst situation is with ozone air pollution, with only 8 countries improving over a period of 10 years out of the 23 EU countries examined. A better but still negative trend is with radon air pollution, where the situation has improved in 12 countries. This situation was partly due to objective reasons – due to the peculiarities of the formation, accumulation, etc. of these gases (ozone accumulates in the ground, radon – in the ground, construction materials and structures) it is still difficult to apply effective localisation technologies today.

The nature of sources of air pollution indicates the potential for localisation of their effects from a forward-looking perspective. In particular, they are tied to human activities aimed at improving advanced, environmentally friendly production methods.

References

Babu, S., & Datta, S. (2015). Revisiting the link between socio-economic development and environmental status indicators focus on panel data. *Environment Development and Sustainability, 17*(3), 567–586. doi:10.1007/s10668-014-9561-6

Balali-Mood, M.; Naseri, K.; Tahergorabi, Z.; Khazdair, M.R.; Sadeghi, M. (2021). Toxic Machanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic. *Frontiers in Pharmacological, 12*, 643972. doi:10.3389/fphar.2021.643972

Budică, I., Busu, O. V., Dumitru, A., & Purcaru, M. (2015). Waste management as commitment and duty of citizens. *Polish Journal of Management Studies*, 11(1), 7-16

Guadie Degu Belete, Yetsedaw Alemu Anteneh. (2021). General Overview of Radon Studies in Health Hazard Perspectives. *Journal of Oncology, Article ID 6659795*, 1-7. doi:https://doi.org/10.1155/2021/6659795

Bolcarova, P., & Kološta, S. (2015). Assessment of sustainable development in the EU27 using aggregated SD index. *Ecological Indicators, 48,* 699–705. From http://dx.doi.org/10.1016/j.ecolind.2014.09.001

Brizga, J.; Mishchuk, Z.; Golubovska-Onisimova, A. (2014). Sustainable consumption and production governance in countries in transition. *Journal of Cleaner Production, 63,* 45–53. From https://doi.org/10.1016/j.jclepro.2013.06.011

Case Studies in Environmental Medicine, Lead Toxicity. (2017, June 12). From ATSDR Agency for toxic substances and disease registry: https://www.atsdr.cdc.gov/csem/lead/docs/CSEM-Lead_toxicity_508.pdf

Chursan, S. (2013). Assessing the Sustainable Development in Thailand. *Procedia. Environmental Sciences, 17,* 611–619. From https://doi.org/10.1016/j.proenv.2013.02.077

Das, B. (2021). Radon induced health effects: A survey report. *Indian Journal of Science and Technology, 14*(5), 481-507. doi:https://doi.org/10.17485/IJST/v14i5.1049

Europos žaliojo kurso įgyvendinimas. (2020, 09 17). From www.europa.eu

Feng, Z.; De Marco, A.; Anav, A.; Gualtieri, M.; Sicard, P.; Tian, H.; Fornasier, F.; Tao, F.; Guo, A.; Paoletti, E. (2019). Economic losses due to ozone impacts on human health, forest productivity and crop yield acros China. *Environment International, 131*, 104966. doi:10.1016/j.envint.2019.104966

Gedvilaitė, D. (2019). *The assessment of sustainable development of a country's regions. Doctoral dissertation.* Vilnius: Technika. From http://dspace.vgtu.lt/bitstream/1/3797/1/Gedvilaite%20 disertacija%2005%2016nn.pdf

Guadie Dgu Belete; Yetsedaw Alemu Anteneh. (2021). General Overview of Radon Studies in Health Hazard Perspectives. *Journal of Oncology*, 6659795. doi:https://doi.org/10.1155/2021/6659795

Gundacker, C.; Foesthuber, M.; Szigeti, T.; Kakucs, R.; Mustieles, V.; Fenandez, M.F.; Bengtsen, E.; Vogel, U.; Hougaard, K.S.; Saber, A.T. (2021). Lead (Pb) and neurodevelopment: A review on exposure and biomarkers of effect (BDNF, HDL) and susceptibility. *International Journal of Hygiene and Environmental Health, 238*, 113855. doi:https://doi.org/10.1016/j.ijheh.2021.113855

Haque, A.U., Kot, S., & Imran, M. (2019). The moderating role of environmental disaster in relation to microfinance's non-financial services and women's micro-enterprise sustainability. *Journal of Security and Sustainability Issues,* 8(3), 355-373. doi:10.9770/jssi.2019.8.3(6)

Holm, S.M.; Balmes, J.R. (2022). Systematic Review of Ozone Effects on Human Lung Function. *Education and clinic practice, 161*(1), 190-201. doi:https://doi.org/10.1016/j.chest.2021.07.2170

Huang, W.; Shi, X.; Wu, K. (2021). Human Body Burden of Heavy Metals and Health

Consequences of Pb Exposure in Guiyu, an E-Waste Rcycling Town in China. *International Journal of Environmental Research and Public Health, 18*(23), 12428. doi:https://doi.org/10.3390/ijerph182312428

Jędrzejczak-Gas, J.; Barska, A. (2019). Assessment of the Economic Development of Polish Regions in the Context of the Implementation of the Concept of Sustainable Development - Taxonomic Analysis. *European Journal of Sustainable Development, 8*(5), 222–233. From https://doi.org/10.14207/ejsd.2019.v8n5p222

Jia, X., Foo, D. C. Y., Tan, R. R. and Li, Z. (2017). Sustainable development paths for resource-constrained process industries. *Resources, Conservation and Recycling, 119,* 1–13. doi:10.1016/j.resconrec.2016.11.004

Kang, J.K.; Seo, S.; Jin, Y.W. (2019). Health Effects of Radon Exposure. *Yonsei Medical Journal, 60*(7), 597-603. doi:10.3349/ymj.2019.60.7.597

Kozyreva, O.; Sagaidak-Nikituk, R.; Demchenko, N. (2017). Analysis of the Socio-Economic Development of Ukrainian Regions. *Baltic Journal of Economic Studies, 3*(2), 51–58. From http://dx.doi.org/10.30525/2256-0742/2017-3-2-51-58

Kumar, P., Hama, S., Nogueira, T., Abbass, R. A., Brand, V. S., de Fatima Andrade, M., ... & Salam, A. (2021). In-car particulate matter exposure across ten global cities. *Science of the total environment*, 750, 141395.

Linhartova, V. (2021). Analyzing the Role of Public Expenditures in Human Development: Panel Data Analysis of EU-28 Countries. *Montenegrin Journal of Economics, 17*(1), 85-96.

Lisiński, M.; Augustinaitis, A.; Nazarko, L.; Ratajczak, S. (2020). Evaluation of dynamics of economic development in Polish and Lithuanian regions. *Journal of Business Economics and Management, 21*(4), 1093-1110. doi:https://doi.org/10.3846/jbem.2020.12671

Liu, H.; Wu, J.; Chu, J. (2009). Environmental efficiency and technological progress of transportation industry-based on large scale data. *Technological Forecasting and Social Change, 144,* 475-482. doi:https://doi.org/10.1016/j.techfore.2018.02.005

Mishchuk, H., & Grishnova, O. (2015). Empirical study of the comfort of living and working environment–Ukraine and Europe: comparative assessment. *Journal of International Studies,* 8 (1), 67 – 80. DOI: 10.14254/2071-8330.2015/8-1/6

Moldan, B.; Janoušková, S.; Hák, T. (2012). How to understand and measure environmental sustainability: Indicators and targets. *Ecological Indicators, 17,* 4–13. doi:10.1016/j.ecolind.2011.04.033

Molly, K. M. (2018). Regional differences in Slovenia from the viewpoint of achieving Europe's sustainable development. *Acta Geographica Slovenia, 58*(2), 2–46.

Morkunas, I.; Kozlowska, M.; Ratajczak, W. (2002). Role of carbohydrates in early metabolic reactions of germinating lupin seeds infected with Fusarium oxysporum f.sp. lupini. *Journal of the Polish Botanical Society, 55*(1), 247-254.

Nuvolone, D.; Petri, D.; Voller, F. (2018). The effects of ozone on human health. *Environmental Science and Pollution Research, 25,* 8074-8088. doi:10.1007/s11356-017-9239-3

Oželienė, D. (2019). *Modelling the factors of a company's sustainable development. Doctoral dissertation.* Vilnius: Technika.

Pakurár, M., Khan, M. A., Benedek, A., & Oláh, J. (2020). The impact of green practices, cooperation and innovation on the performance of supply chains using statistical method of meta-analysis. *Journal of International Studies, 13*(3), 111-128. doi:10.14254/2071-8330.2020/13-3/8

Piwowar, A. (2020). Challenges associated with environmental protection in rural areas of Poland: Empirical studies' results. *Economics and Sociology, 13*(1), 217-229. doi:10.14254/2071-789X.2020/13-1/14

Raaschou-Nielsen, O., Andersen, Z.J., Beelen, R. et al. (2013). Air pollution and lung cancer incidence in 17 European cohorts: Prospective analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE). *The Lancet Oncology, 14*(9), 813-822. doi:https://doi.org/10.1016/S1470-2045(13)70279-1

Radovanović, M., & Lior, N. (2017). Sustainable economic–environmental planning in Southeast Europe – beyond-GDP and climate change emphases. *Sustainable Development, 25*(6), 580–594. From https://doi.org/10.1002/sd.1679

Roman, A., & Rusu, V.D. (2021). Entrepreneurship and Business Environment: Effects of Regulations in European Countries. *Montenegrin Journal of Economics*, 17(4), 133-144.

Saari, R.K., Thompson, T.M., & Selin, N.E. (2017). Human Health and Economic Impacts of Ozone Reductions by Income group. *Environmental Sciences & Technology, 51*(4), 1953-1961. From https://pubs.acs.org/doi/10.1021/acs.est.6b04708

Strezov, V., Evens, A., & Evans, T. J. (2017). Assessment of the economic, social and environmental dimensions of the indicators for sustainable development. *Sustainable Development, 25*(3), 242–253. https://doi.org/10.1002/sd.1649

Torres-Durán, M., Ruano-Ravina, A., Parente-Lamelas, I. et al. (2014). Lung cancer in never-smokers: a case-control study in a radon-prone area (Galicia, Spain). *European Respiratory Journal, 44*, 994-1001. doi:101183/09031936.00017114

Vogiannis, E.G., & Nikolopoulos, D. (2015). Radon sources and associated risk in terms of exposure and dose. *Frontiers in Public Health, 2*, 207. doi:https://doi.org/10.3389/fpubh.2014.00207