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The Climate-Neutral Economy and the Air Pollution in Poland after 2000: A Descriptive and Model Approach Based on the Energy Market and the Industry Sector

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Introduction

The article is the second one from larger Author's series of articles, in which – broadly understood in the context of operationalization with moderation – the circular economy was described (as the area in connection with the optimization of choices). The first own text in this series was published in the second part of 2023 and had a diagnostic nature. It presented the circular economy, as a new global economic model, in which economically and ecologically effective solutions were sought[1]. From the definitional point of view, the circular economy can be treated as a renewable and self-regenerating system. The task of it is to reduce and/or eliminate the amount of useless wastes and negative externalities in the economy (moreover, to effectively re-engage resources), thus contributing to the creation of new, social, economic and natural capital. On the basis of a preliminary, non-model-based analysis of the available indicators and their interpretation, the author has identified several detailed research areas (one of them is analyzed in this text).

Assuming that the changes are not possible without an increase in consumer environmental awareness, issues such as recycling, recovery or reduction of food waste

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[1] J. Kulczycka (ed.), *Gospodarka o obiegu zamkniętym w polityce i badaniach naukowych*, Kraków: Wydawnictwo IGSMiE PAN, 2019, p. 17.

will be the next pieces of the puzzle. The author plans to describe them in the next article, which will be published before the end of the current year. On the other hand, as the author said *unlimited access to information and knowledge should intensify technological changes and support the development of the green economy*. Let us assume that information about air pollutions in Poland in 21st century is the most important to achieving climate neutrality in our country. Due to the fact that significant changes cannot be made in the short term, the author will take a closer look at the data on emissions of selected air pollutants since 2000[2].

The theoretical range referred by the model

According to *The Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Securing Our Future Europe's 2040 Climate Target and Path to Climate Neutrality by 2050 Building a Sustainable, Just and Prosperous Society*, climate changes are intensifying and their real costs are increasing. It is worth answering, what is the vision for Europe (and thus also for Poland), for the end of the next decade? As we expected, Europe is intended to remain a major destination for investment opportunities (which bring stable, non-obsolete high-quality jobs), ensuring a strong industrial ecosystem. Moreover – by becoming a continent that provides clean, low-carbon and affordable energy, sustainable food and raw materials – Europe aims to be heat resistant to future crises. The implementation of these provisions is intended to strengthen in particular the EU's energy independence from fossil fuels and sustainable development, as this based on fossil fuels and waste of resources is not sustainable[3].

According to preliminary data, total net greenhouse gas emissions in 2022 were 32.5% lower than in 1990. The deployment of renewable and low-carbon technologies is at a record level, according to *the Document 52019DC0640*. In 2023, 17 GW of new wind power and 56 GW of solar (direct current – DC) were installed in the EU. Approximately 3 million heat pump units were sold in 2022[4].

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2 K.J. Chojnacka, *Circular Economy Resources – Operationalization of restraints and optimization of choices*, „Humanities & Social Sciences Reviews" 2023, 11(6), p. 15, https://doi.org/10.18510/hssr.2023.1162 (accessed on: 20.02.2024).

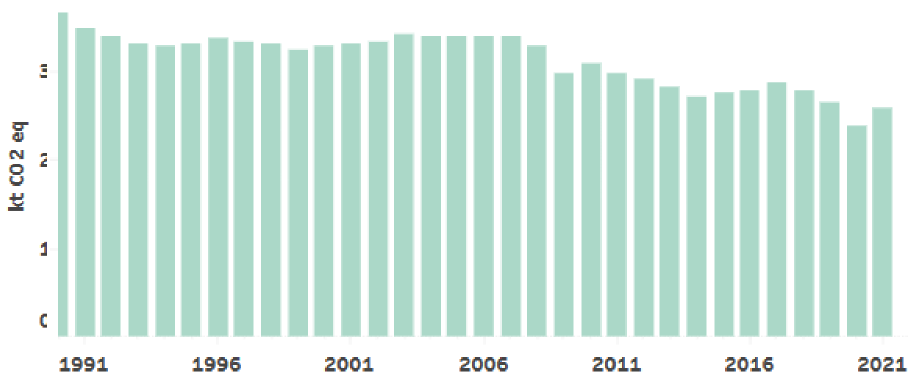
3 Komunikat Komisji do Parlamentu Europejskiego, Rady Europejskiej, Rady, Komitetu Ekonomiczno-Społecznego i Komitetu Regionów Europejski Zielony Ład. Document 52019DC0640, https://eur-lex.europa.eu/legalcontent/PL/TXT/?uri=CELEX :52019DC0640 (accessed on: 10.02.2024)

4 *Air Quality e-Reporting*, https://www.eea.europa.eu/en/datahub/datahubitem-view/3b390c9c-f321-490a-b25a-ae93b2ed80c1 (accessed on: 10.02.2024)

Therefore, as the European Scientific Advisory Committee on Climate Change states and after using detailed impact assessment, this Communication sets out a recommended target for a net reduction of 90% greenhouse gas emissions compared to 1990 levels ("the 2040 target")[5]. The implementation of the legislative framework to achieve the 2030 climate and energy targets is a prerequisite for the EU to achieve the 2040 target and achieve climate neutrality in 2050 (with realize the full potential of the transition). The analysis of the condition of air pollution in Poland, presented in a model, with a selection of potential causes (for data from the beginning of the 21st century), will highlight the main factors that are not conducive to the decarbonization of industry (like the European Green Deal referred), as well as to indicate potential barriers on the way to climate neutrality.

The Participants of COP28 (the 28th annual United Nations (UN) climate meeting, where governments discuss how to limit and prepare for future climate change) agreed that limiting global warming to 1.5°C requires deep, rapid and sustained reductions in global greenhouse gas emissions of 43% by 2030 and 60% by 2035, compared to 2019 levels, and achieving net-zero CO_2 emissions globally by 2050[6].

Figure 1.
CO_2 Emissions in EU-27



Source: *EEA greenhouse gases — data viewer*, https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer (accessed on: 15.02.2024).

Using this information, the author analyzed the data on CO_2 emissions for Poland over 20 years. At the same time, she remembered that CO_2 emissions states how about 2/3 of all greenhouse gas emissions. Sometimes, the detailed data for particular periods

[5] Komunikat Komisji do Parlamentu Europejskiego…, *op. cit.*

[6] *Ibidem.*

were less optimistic. For example, the share of CO_2 emissions was equal 77% of all greenhouse gases in 2006, across the EU (growing slightly year on year). In Poland, more than half of CO_2 emissions in 2019 and 2020 were related to the energy sector (37.01% and 38.25% respectively in the given years) and the industry sector (14.38% and 14.09%, respectively). Poland is a country where most electrical and heat energy is produced from fossil fuels, hard coal and brown coal. Therefore, from the point of view of the objective mentioned, it makes sense for economies to focus on eliminating these CO_2 emissions in the next years. However, it cannot be overlooked that the remaining 1/3 of gas emissions is also a significant problem in Europe and for Poland (Figure 1). Therefore, there are indirect research questions: Is the rate of reduction of CO_2 emissions sufficient in Poland, in the current decade? What about other gaseous and particulate pollutants? What is their impact on air quality?

According to the EU's assumptions, in 2040 the level of fossil fuels for energy production should be reduced how about 80% (compared to 2021). In the context of the widely discussed decarbonization, coal should be reduced, while oil in transport (road, sea and air) is to account for approximately 60% of the remaining fossil fuel energy consumption[7].

The share of other sectors in greenhouse gas emissions in Poland should be considered as well, taking into account: industry, buildings and the power system. Using the international commitment to move away from fossil fuels, the policy would ensure that any remaining burning of fossil fuels is combined with carbon capture (utilization) and storage as soon as possible. The CO_2 pollution is not the only problem. Other types of pollutants should be found a place in the article. Moreover, discussion about CO_2 emissions based only on the industry changes, may not be enough to show the problem as a whole. However, it is necessary due to the economic situation. The question is, which is more responsible for CO_2 emissions: industry or households? Further modelling will focus on industrial data to fill the information gap. There are many more studies on the energy sector or households, than those based on the industry.

Econometric forecasting – model assumptions with statistical data for Poland

The forecasting is one of the most important scientific methods of learning about reality and controlling it, preceded by the construction and use of descriptive econometric models. The final result of the forecasting process is to provide the most objective and

[7] Komunikat Komisji do Parlamentu Europejskiego…, *op. cit.*

scientifically grounded information about selected phenomena and to create the basis for intended actions aimed at illustrating the development of these phenomena[8].

Forecasting methods can be divided into two basic groups: quantitative and qualitative methods. Econometric analyses have particular practical importance. Their primary tool is, as mentioned, the descriptive econometric model. It is an equation (or system of equations) that approximates the key quantitative relationships between the phenomena or values studied. A single phenomenon is usually influenced by many different factors (i.e. economic, social, demographic, environmental, technological, etc.). The strength of these factors, in modelling is usually varied. Some factors affect them significantly, others slightly, and some only randomly. An econometric model is thus a formalized description of the phenomenon under study, which takes into account only the essential elements and omits the less important ones[9].

The main tool of econometric analysis, which will be used by the author in further analysis, is therefore a model in the form of five equations, which approximate the quantitative relationships within the phenomenon (in this case, specifically, the increasing air pollution with gases and dust). Since, as mentioned, the strength of the influence of different variables is different, only the most important elements of economic reality, observed in the long term, will be visible in the model.

The economic phenomena of the descriptive econometric model are therefore divided into the economic phenomenon that is explained by the model, the so-called explained variable (y) and those affecting the explanatory variable, i.e. the so-called predictor variables ($x_1, x_2 \dots x_k$). However, we must emphasize that the set of explanatory variables does not specify in detail how the explanatory variable is shaped. The recorded values of the explanatory variable do not accurately reflect its values determined from the model equation but fluctuate around them (trend analysis). The study of the relationship between these economic phenomena by means of an econometric model is a multi-stage process. This is what will be used in this paper.

The descriptive econometric model that represents the dependence of variable y on variables $x_1, x_2, \dots, x_k$ can be expressed in the general form[10]:

$$y = f(x_1, x_2, \dots, x_k, \varepsilon) \quad (1)$$

where: y – explained variable, xk – k-th predictor variable, ϵ – random deviation.

8 E. Nowak, *Zarys metod ekonometrii*, Warszawa: Wydawnictwo Naukowe PWN, 2002, pp. 7-8.

9 N.R. Farnum, W. Stanton, *Quantitative Forecasting Methods*. Boston: PWS-Kent Publishing Company, 1989, p. 31.

10 Z. Czerwiński, *Matematyka na usługach ekonomii*. Warszawa: Wydawnictwo Naukowe PWN, 1969, pp. 322-323.

Symbol *f* above means the analytic notation of predictor variable function, which is determined when constructing the model. The inclusion of random deviations ϵ in the econometric model is related to its stochastic nature[11].

If relationship (1) is linear, it takes the following form:

$$y = a_0 + a_1 \cdot x_1 + a_2 \cdot x_2 + \cdots + a_k \cdot x_k + \varepsilon \quad (2)$$

where: $a_0, a_1, a_2, \ldots, a_k$ – structural parameters of the model.

The study involved econometric linear models and thus the author demonstrates the methods for constructing them further in the paper. The easiest way to determine individual parameters of a linear model is to apply the classic method of least squares. Using matrix notation[12]:

- matrix (vector) of observations of the explained variable:

$$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} \quad (3)$$

- matrix of observations of predictor variables:

$$X = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdots & x_{1k} \\ 1 & x_{21} & x_{22} & \cdots & x_{2k} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n1} & x_{n2} & \cdots & x_{nk} \end{bmatrix} \quad (4)$$

- matrix (vector) of estimates of structural parameters:

$$a = \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_k \end{bmatrix} \quad (5)$$

11 E. Nowak, *op. cit.*, p. 7.

12 Z. Czerwiński, *op. cit.*, pp. 362-363.

- matrix (vector) of model reminders:

$$e = \begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ e_n \end{bmatrix} \quad (6)$$

then the least squares criterion is:

$$S = e^T \cdot e \rightarrow \min \quad (7)$$

where:

$$e = y - X \cdot a \quad (8)$$

The dependence with which the vector a of estimates of structural parameters can be determined is[13]:

$$a = (X^T \cdot X)^{-1} \cdot X^T \cdot y \quad (9)$$

Random deviation variance is estimated with the following formula [10]:

$$S_e^2 = \frac{e^T \cdot e}{n - k - 1} \quad (10)$$

and the matrix of variance and covariance of estimates of structural parameters with formula:

$$D^2(a) = S_e^2 \cdot (X^T \cdot X)^{-1} \quad (11)$$

In matrix above, elements on the main diagonal are variances $V(a_i)$ ($i = 0,1,2,\ldots k$) of estimates of structural parameters. Values:

$$S(a_i) = \sqrt{V(a_i)} \quad (12)$$

are standard errors of estimates of structural parameters[14].

With model parameters estimated, it has to be verified whether it describes the investigated phenomena well (knowing that it is not easy to construct a correct function, i.e. *a quantitative regularity* for which the independent variables is unambiguously assigned the value of the dependent variable)[15]. The verification involves testing three properties:

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13 E. Nowak, *op. cit.*, p. 38.

14 *Ibidem,* p. 46.

15 Z. Czerwiński, *op. cit.*, pp. 330-334.

- the degree to which the model conforms to empirical data,
- the quality of estimates of structural parameters,
- the distribution of random deviations.

In order to consider the estimators effective, linear regression model assumptions (so-called Gauss – Markov assumptions) must be met:

1. The regression function is linear and constant (its parameters do not change within the set of observations), i.e. the relationship between variables is stable,
2. Predictor variables are non-random; their values are defined real numbers,
3. Observation matrix X, $n(k+1)$ is of full rank: $rz(X)=k+1<n$, i.e.:

- predictor variables are not collinear, i.e. there is no exact linear dependence between them

and

- the number of observations exceeds the number of estimated model parameters,

4. The random component has normal distribution, mean value of 0, and constant standard deviation, and

- the random component is not autocorrelated,
- the random component is not correlated with predictor variables,

5. The information in the sample is the only information used to estimate model parameters.

If the econometric model is verified to be correct, it may be used in research related to forecasting and drawing conclusions on the behavior of the investigated value. There are three basic types of forecasts[16]:

- the point forecast,
- the interval forecast of explained variable values,
- the interval forecast of explained variable expected values.

Econometric modelling for environmental pollution in Poland – own results

Based on comprehensive statistical research and having analyzed in-depth the factors influencing the condition of natural environment in Poland, especially in air area, the author selected over hundred and fifty variables that may potentially affect on it.

16 *Ibidem,* pp. 419-424.

They mainly included the determinants that may have an impact on environmental pollution in the country taking as a whole. In the next step, the Author rejected those for which a connection with air pollution was invisible (taking into account the nuisance aspect). Finally, she determined that the further analysis would be based on emissions from individual types of pollutants and selected them, only for the industrial sector.

The data used in the model analysis were obtained by the author from statistical yearbooks published by the Central Statistical Office, including primarily the Statistical Yearbooks of the Industry for Individual Years and the Statistics of the Polish Power Industry, published by ARE S.A. on an annual basis. The term "industrial", used there includes: sewage, air pollutant emissions and waste, as pollutants reported by entities meeting certain criteria of environmental nuisance (in sections 3, 6 and 7), which according to the Polish Classification of Activities (PKD 2007) have been included in several sections, i.e.: "Mining and quarrying", "Industrial processing", "Generation and supply of electricity, gas, steam, hot water and air for air conditioning systems" and "Water supply; sewage and waste management".

In this article, gas emissions data relate to several main types of pollutants, treated as explanatory variables [Table 1]. They were supplemented with data about total dust emissions and nitrogen dioxide emissions. Total particulate pollution includes dust from the combustion of fuels, cement-lime and refractory materials, silicon, artificial fertilizers, carbon-graphite, soot and other types of particulate pollution. The emission data in question were determined by means of measurements or on the basis of calculations from the raw material and fuel balance based on pollutant emission factors for characteristic technological processes, which appear in this form in national statistics.

After careful investigation, the following variables were selected as the predictor ones in the models: x_1 – expenditures on fixed assets for the protection of ambient air and climate in general [thousand PLN], x_2 – expenditures on fixed assets for environmental protection in industry: total air and climate protection [thousand PLN], x_3 – expenditures on fixed assets for environmental protection in industry: air and climate protection, including new techniques and technologies for fuel combustion [thousand PLN], x_4 – domestic consumption of hard coal [thousand tonnes], x_5 – domestic consumption of lignite [thousand tonnes], x_6 – domestic consumption of crude oil [thousand tonnes], x_7 – domestic consumption of high-methane natural gas [hm^3], x_8 – domestic consumption of nitrified natural gas [hm^3], x_9 – domestic consumption of motor gasoline, including aviation gasoline [thousand tonnes], x_{10} – domestic consumption of diesel fuels [thousand tonnes], x_{11} – domestic consumption of electricity in industry [GWh], x_{12} – domestic consumption of plastics in primary forms (Ethylene polymers in 2000, 2005 and 2010 – polyethylene, polyvinyl chloride with copolymers not mixed with other substances in 2000 including polyvinyl chloride mixed with other substances, polypropylene with copolymers, styrene polymers; in

Table 1.
Data regarding gas and particulate emission from 2000 to 2021: carbon oxide, carbon monoxide, sulphur dioxide, nitrogen oxides, other types of particulate pollutants

Years	*Gas pollutants:* ***CO_2*** *(Total carbon dioxide emissions in thousand t/year)*	*Gas pollutants:* ***CO*** *(Carbon monoxide emissions in thousand tons)*	*Gas pollutants:* ***SO_2*** *(Sulphur dioxide in thousand tons)*	*Nitrogen dioxide* ***NO_2*** *(thousand tons)*	*Particulate pollutants:* ***dusts'*** *total amount (thousand tons)*
2000	316114	3463	1511	838	464
2001	317844	3528	1564	805	491
2002	308277	3410	1456	796	473
2003	319082	3318	1375	808	476
2004	325 382	3426	1241	804	443
2005	321 671	3051	1164	848	430
2006	329 599	2804	1222	921	458
2007	328 511	2553	1216	860	430
2008	325 058	2717	995	832	402
2009	312 248	2778	862	822	404
2010	334 917	3377	860	838	596
2011	327 723	2801	898	846	423
2012	326 970	2791	859	819	406
2013	322 440	2868	853	774	403
2014	307 602	2407	715	720	324
2015	313 262	2844	639	721	515
2016	323 022	2456	591	742	335
2017	337 340	2390	526	780	377
2018	336 992	2318	495	725	364
2019	318 167	2717	396	641	552
2020	303 020	2582	385	605	510
2021	331 576	2521	392	591	510

Source: own elaboration based on GUS, ARE S.A.

the years 2015 – 2021 including polystyrene for foaming [thousand tonnes], x_{13} – number of industrial power plants [pcs], x_{14} – number of thermal power plants [pcs], x_{15} – total electricity consumption in Poland [GWh], x_{16} – number of hydroelectric power plants [pcs], x_{17} – total capacity installed at the end of the year [MW], x_{18} – total electricity production [GWh], x_{19} – electricity production – wind farms in the OECD system [GWh], x_{20} – electricity production – hydroelectric power plants [GWh], x_{21} – electricity production – independent renewable power plants [GWh].

Econometric models were prepared on the basis of the given statistical data set (a set of explanatory and explanatory variables, after eliminating those with too low level of variability). In the next part, the parameters adopted for them were estimated using the least squares method. Then, verification was carried out to indicate whether these models describe the studied relationships well. The Fisher-Snedecor test was used to ensure that the fit between the model and the data was high enough to draw scientific conclusions. The values of individual coefficients are presented in Table 2.

The analysis led to the identification of the following models:

Model I: The amount of gas pollutants: **CO2** [thousand tonnes]

$$y = 0.59x_{18} + 228020.29$$

(0.204) (32605.54)

Model II: The amount of gas pollutants: **CO** [thousand tonnes]

$$y = -0.043x_{19} + 3113.1$$

(0.01) (83.28)

Model III: The amount of gas pollutants: **SO_2** [thousand tonnes]

$$y = (-2.67 \times 10^{-5})x_1 - 0.058x_{21} + 1303.03$$

($5.094 * 10^{-5}$) (0.0095) (103.522)

Model IV: The amount of gas pollutants: **NO_2** [thousand tonnes]

$$y = (-1.81 \times 10^{-5})x_2 - 0.0097x_{19} + 875.596$$

($1.499 * 10^{-5}$) (0.002) (29.28)

Model V: The number of particulate pollutants: **dusts'** total amount [thousand tonnes]

$$y = 0.784x_{13} + 0.003x_{17} + 229.26$$

(0.41) (0.002) (118.92)

Table 2.
Coefficients of determination and standard errors of estimate for the econometric model

Coefficient	*CO_2 emission*	*CO emission*	*SO_2 emission*	*NO_2 emission*	*Total particulate pollutants (dusts)*
R² [-]	0,29	0,49	0,83	0,75	0,279
Se [thousand tonnes/year]	8186,84	286,684	159,216	43,116	63,335
We [%]	2,54	9,992	17,33	5,54	14,238
F	8,35	18,61	47,19	28,17	3,676

Source: own elaboration.

For model, adjusted coefficient of determination R_2 and standard error of estimate S_e, were determined as measures of model quality. The coefficient of determination specifies what part of the variability of the investigated explained variable is the part determined by the predictor variables used in the model. The standard error of estimate indicates how much the actual value of the explained variable differs on average from the value determined by the model. Values R_2 and S_e for the models are shown in Table 2.

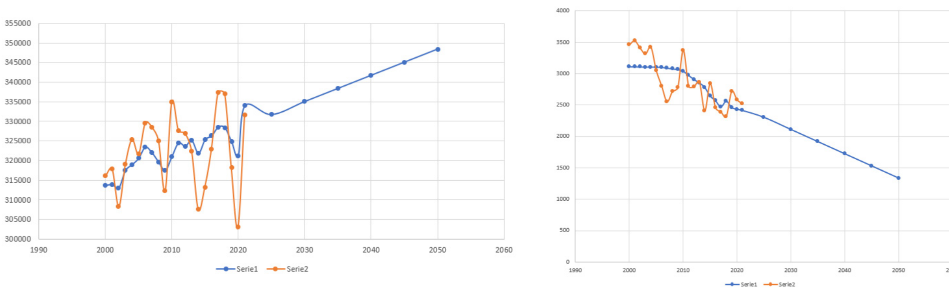
In the analyzed cases, the critical value for the Fisher-Snedecor Test (F*) is equal 4.35 (for models I and II) and 3.52 (for models III, IV and V). Analyzing the values of the F statistic presented in Table 2, we notice that they are greater than the critical value (F*< F). Therefore, we can conclude that the multiple correlation coefficient is important and the degree of fit of all models to the data is sufficiently high.

A set of data accepted for model analysis is considered homogeneous if the coefficient of variation is less than or equal to 30%, while if the coefficient of variation is greater than this value, the data set is considered heterogeneous. Thus, in all models, the data set was considered to be homogeneous.

Forecast of air pollution in Poland until 2050

The forecast of the number of pollutants from particular types of analyzed gases and total dust pollution was made (On the basis of the analysis of the models). For this purpose, a trend line was determined (with Pearson's coefficient of determination R^2) in order to check whether the established trend model matches the data. Figures 2-4 show the graphical depiction of forecasting. The results of the point forecast of explanatory variables are presented in Table 3. It is obvious that the forecast was made on the basis of existing dependencies, without taking into account the new legal and financial standards that are currently being discussed (and the change of which may affect the change in the amount of pollution in the coming years).

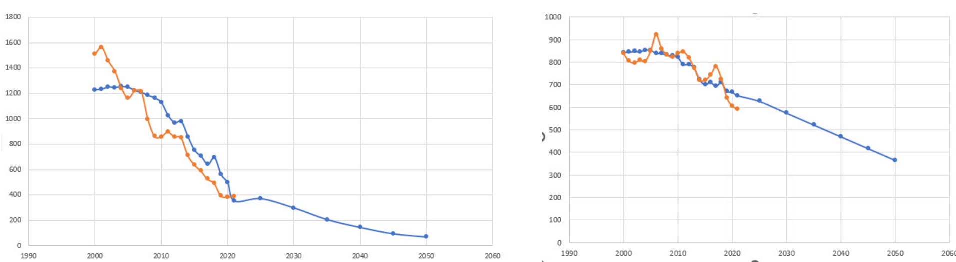
Figure 2.
Empirical values and emission forecast: CO_2 and CO (I – II model)



Source: own elaboration.

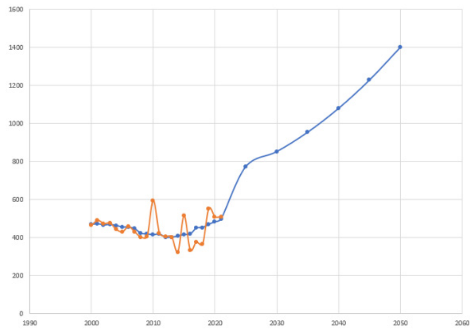
The last step of the analysis was to determine the forecast interval limits, mean forecast error and confidence interval of the forecasts for the forecasted emissions of carbon dioxide, carbon monoxide, sulphur dioxide, nitrogen oxides, other types of particulate pollution.

Figure 3.
Empirical values and emission forecast: SO_2 and NO_2 (III – IV model)



Source: own elaboration.

Figure 4.
Empirical values and emission forecast: total particulate pollutants (dusts) (V model)



Source: own elaboration.

Table 3.
Forecast for number of pollutants based on data regarding gas and particulate emission in Poland for 2025–2050, in thousand tonnes

Years	*CO_2 emission*	*CO emission*	*SO_2 emission*	*NO_2 emission*	*total particulate pollutants*
2025	331733	2306	372	627	774
2030	335068	2112	299	574	852
2035	338403	1919	207	521	955
2040	341739	1725	145	469	1080
2045	345074	1531	95	416	1229
2050	348410	1337	70	364	1401

Source: own elaboration.

The mean forecast error S_{pT} and forecast interval limits are important elements of the forecasting process. The mean forecast error specifies the value by which forecasts will differ on average from the actual values of the forecast variable. Forecast interval limits determine, with an a priori known probability called the forecast reliability, the interval that contains the unknown value of the forecast variable in the forecast period. The interval is defined as follows:

$[P\{d^*_{y_T} < y_T < g^*_{y_T}\} = \beta]$ Mean forecast error and forecast intervals for the assumed forecast reliability b = *0.95* are shown in Table 4. Due to text length limitations, the forecast intervals were limited to the last year of the forecast, i.e. 2050.

Table 4.
Mean error and forecast interval limits for the forecast of carbon oxide, carbon monoxide, sulphur dioxide, nitrogen oxides, other types of particulate pollutants

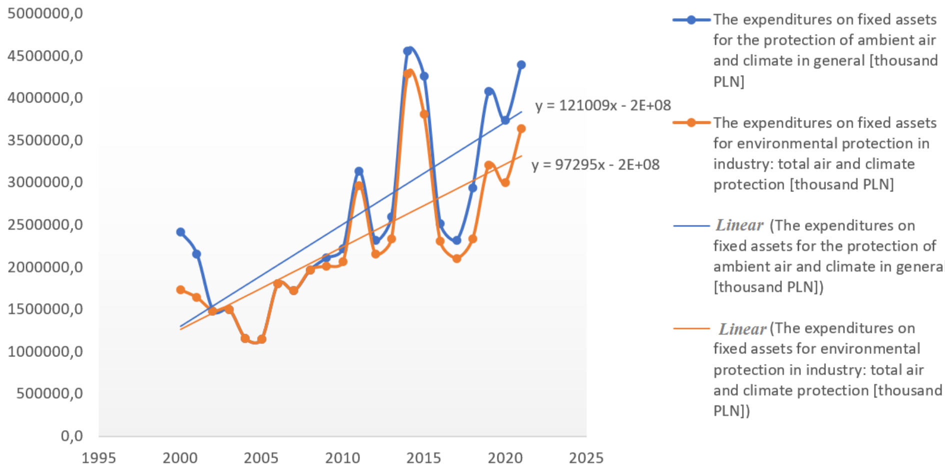
Coefficient	*CO_2 emission*	*CO emission*	*SO_2 emission*	*NO_2 emission*	*total particulate pollutants*
S_{pT}	12382	460	212	70	478
dy_{2050}	324141	434	0	227	465
gy_{2050}	372678	2239	486	500	2337

Source: own elaboration.

Conclusions and recommendations

The model shown above informs that for every GWh of energy produced during the year, there are 0.59 thousand tonnes of CO_2 emissions. There is no comparison with the area of consumption and CO_2 emissions by households (which requires another, extensive model analysis).

Figure 5.
Expenditures on fixed assets for the protection of ambient air and climate in general and for environmental protection in industry: total air and climate protection



Source: own elaboration.

It should also be concluded that increasing the production of electricity in wind farms during a year by 1 GWh results in a decrease in CO emissions by 0.043 thousand tonnes per year. Therefore, this confirms the legitimacy of introducing alternative solutions (here in the sense of ecological) for energy production. Further analysis also showed that increasing expenditures on fixed assets for air and climate protection during the year by every thousand zlotys result in a reduction of SO_2 emissions by 0.0267 tonnes per year. On the other hand, increasing the production of electricity by independent renewable power plants by 1 GWh per year reduces SO_2 emissions by 58 tonnes per year. According to the trend line analysis (Figure 5), the fixed capital formation has been gradually increasing since 2000 (upward trend).

An increase in expenditures on fixed assets for environmental protection in the industry, including air and climate protection in total, by PLN 1,000, reduce NO_2 emissions by 0.0181 tonnes per year. Increasing the production of electricity by wind farms by 1 GWh reduces NO_2 emissions by 9.7 thousand tonnes per year. Moreover, an increase in the number of industrial power plants by 1 pcs per year, causes an increase in total emissions of particulate pollutants by 0.784 thousand tonnes per year. It should be noted that the variable for total particulate pollution does not include only the pollution generated by the industry alone. This parameter also takes into account pollution generated by all modes of transport (road, air, water) as well as housing, agritourism, forestry, fishing and other branches. On the other hand, increasing the installed capacity of power plants at the end of the year by a total of 1 MW per year, results in an increase in the emission of particulate pollutants by 3 tonnes per year. The "power" used here should be understood as *the sum of the nominal power of all generators in power plants*.

The data shown for the Polish industry are not optimistic. It is obvious that air pollution from CO_2 emissions increases over the years. Similarly, we noted an increase in the air pollution from particulate matter. Of course, breaking out of the current trend is possible, but it depends on the fulfilment of many additional conditions, including a change in the mindset of people involved in production with existing methods (which can be treated here as a barrier to making changes). Mental changes, however, are the most difficult and often require demographic changes. According to the author's thinking, the main factors unfavorable to climate neutrality in Poland also include insufficient financial resources allocated to air and climate protection so far. Moreover, the construction of new wind turbines would compensate for the dust pollution generated by industrial power plants (model V). The dependencies shown in the model analysis clearly indicate "the flashpoints" of the entire process. The issue of air pollution is a matter of electrical production (model I) and the technological change necessary in this regard (model II and IV). What is more, an increase in financial outlays (model III) is required, go side by side with new production technologies (models II and IV).

To sum up: the model analysis confirmed the author's assumptions about the need to undertake further pro-ecological activities. Although statistics show that air pollution CO, SO_2 and NO_2 has decreased over the years, new steps should still be taken to maintain this downward trend. The effectiveness of the actions in question will depend on the financial outlays allocated for this purpose, as Figure 2 shown. The analysis presented in the article also highlighted the need for further research in the indicated area. It also seems to be important (in further research) to check how the determined level of emissions correlates with the health of the society and the incidence of diseases resulting from environmental pollution (which seems to be important from the social point of view). This thinking has produced the possibility of further model analyses.

The rapid development of renewable energy in Poland observed in recent years (including the use of wind and solar), when an additional 16.4 GW of installed capacity from RES was connected between 2015 and 2023, does not mean that the power grids and the economy (as a whole) were prepared for it. Here comes another area that should be subjected to model analysis. Recently, there have been problems with obtaining consent for the connection of new capacities from renewable sources. Unfortunately, this may result in the inhibition of the development of new energy sources in the coming years [*Cable pooling*]. And this is not the main goal presented in *The Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Securing Our Future Europe's*

2040 Climate Target and Path to Climate Neutrality by 2050 Building a Sustainable, Just and Prosperous Society. It shows that before 2040, the circular economy will be increasingly important to achieve both: ambitious climate targets and a new prosperity model for Europe. However, the current pace of reduction pollutions and the funds allocated for this purpose in Poland seem to be insufficient in this area (as evidenced by the presented forecast and the observed trend). Therefore, without new structural solutions in our country, it will be necessary to change the time horizon for achieving the climate-neutrality goal.

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The Climate-Neutral Economy and the Air Pollution in Poland after 2000: A Descriptive and Model Approach Based on the Energy Market and the Industry Sector

Abstract

RESEARCH OBJECTIVE: In the context of the analysis based on two economic categories, i.e. "moderation" and "choice", the author will focus on the analysis of the broadly understood market including energy market (seen through the prism of the possibility of achieving climate neutrality by Poland in the time perspective by the EU delivered) in a current text. To this task, it will analyze the air pollutions in the years 2000-2021 (taking into account in particular the issue of emissions of selected gases and other types of particulate pollutants: dusts). The author will also make a forecast, taking into account the current rate of quantitative changes. For this purpose, selected forms of air pollution will observed (explanatory variables). For them models based on selected predictor variables will build (listed in the analytical part).
THE RESEARCH PROBLEM AND METHODS: In addition to descriptive analysis, econometric analysis which is also used in the article, has particular practical importance. The aim was to determine, by means of statistical methods, specific quantitative regularities occurring in the broadly understood economic life, in the analysis of which the key was the condition of the air and the causes of the observed condition of affairs in Poland.
RESEARCH RESULTS: The model, built from five equations, was constructed during the analysis. Each of them concerned the effect of statistically selected explained variables on the predictor variable and allowed to identify the main and significant relationships between them. The choice of equations was not accidental. The explanatory variables are selected types of air pollutants, including examples of gaseous pollutants and the total amount of particulate pollutants. It has been shown that the emission of pollutants decreases when the production of electricity in wind farms and in

independent renewable power plants increases. In addition, the increase in expenditure on fixed assets for the protection of ambient air and climate in general contributes to the reduction of air pollution (especially SO_2 and NO_2 gases), as well as an increase in expenditures on fixed assets for environmental protection in the industry itself. CO_2 emission, on the other hand, is a much more complex issue. The article shown only the relationship between these emissions and electricity production (both variables are positively correlated). However, the author is sure that the total CO_2 emission in the country is not only the responsibility of industry condition, but also other sectors of the economy, what is mentioned in the summary.
CONCLUSIONS, INNOVATIONS, AND RECOMMENDATIONS: The article contributes indirectly to further research on the barriers to entry of the Polish economy into the group of climate-neutral countries. On the other hand, it directly concerns the analysis of selected types of gases and dusts as air pollutants. The article is not a comprehensive report, but it's only a voice in a broader debate. Detailed conclusions from the analysis are presented in the last part of the text.

Keywords: climate neutrality, air, industry, energy market, model analysis

Gospodarka neutralna klimatycznie i zanieczyszczenie powietrza w Polsce po 2000 roku – ujęcie opisowe i modelowe oparte na rynku energii i sektorze przemysłu

CEL NAUKOWY: W kontekście analizy dwóch kategorii ekonomicznych, jakimi są „umiar" i „wybór", w niniejszym tekście autorka skoncentruje się na analizie szeroko pojmowanego rynku (z rynkiem energii włącznie), widzianego przez pryzmat możliwości osiągnięcia przez Polskę neutralności klimatycznej w zakładanej przez UE perspektywie czasowej. W tym celu dokona analizy stanu powietrza na przestrzeni lat 2000-2021 (uwzględniając tu szczególnie kwestię emisyjności wybranych gazów i pyłów). Następnie Autorka dokona prognozy, przyjmując dotychczasowe tempo zmian ilościowych. Uwzględni w tym celu wyselekcjonowane formy zanieczyszczeń powietrza (zmienne objaśniane), dla których skonstruuje modele z uwzględnieniem wybranych zmiennych objaśniających (wymienionych w części analitycznej), wskazując na te najbardziej istotne.
PROBLEM i METODY BADAWCZE: w artykule wykorzystano, obok analizy opisowej, również analizę ekonometryczną, mającą szczególne znaczenie praktyczne. Chodziło bowiem o ustalenie za pomocą metod statystycznych konkretnych ilościowych prawidłowości zachodzących w szeroko pojmowanym życiu gospodarczym, w analizie którego kluczem stała się kondycja powietrza i przyczyny obserwowanego stanu rzeczy w Polsce.

WYNIKI ANALIZY NAUKOWEJ: W trakcie analizy, autorka skonstruowała model, zbudowany z pięciu równań. Każde z nich dotyczyło wpływu wybranych statystycznie zmiennych objaśniających na zmienną objaśnianą i pozwalało na zidentyfikowane głównych i istotnych zależności między nimi. Wybór równań nie był przypadkowy. Zmienne objaśniane to wybrane rodzaje zanieczyszczeń powietrza, wśród których znalazły się przykłady zanieczyszczeń gazowych oraz łączna ilość zanieczyszczeń pyłowych. Wykazano w ten sposób, iż emisja zanieczyszczeń maleje, gdy wzrasta produkcji energii elektrycznej w elektrowniach wiatrowych oraz w elektrowniach niezależnych odnawialnych. Ponadto zwiększenie nakładów na środki trwałe służące ochronie powietrza atmosferycznego i klimatu ogółem, przyczyniają się do obniżenia ilości zanieczyszczeń powietrza (w tym szczególnie gazów SO_2 i NO_2), podobnie jak zwiększenie nakładów na środki trwałe służące ochronie środowiska w samym przemyśle. Emisja CO_2, natomiast to zagadnienie dużo bardziej złożone. W artykule przyjrzano się jedynie związkowi tejże emisji z produkcją energii elektrycznej (obie zmienne okazały się być dodatnio skorelowane). Jednak autorka ma świadomość, że za emisję całkowitą CO_2 w kraju nie odpowiada jedynie przemysł ale również inne sektory gospodarki, o czym wspomniała w podsumowaniu.
WNIOSKI, INNOWACJE, REKOMENDACJE: Artykuł pośrednio stanowi przyczynek do kolejnych badań nad barierami wejścia polskiej gospodarki do grupy państw neutralnych klimatycznie. Bezpośrednio dotyczy natomiast analizy wybranych rodzajów gazów i pyłów, jako zanieczyszczeń powietrza. Ponieważ artykuł nie stanowi kompleksowego raportu a jedynie jest głosem w szerszej debacie, autorka zagadnienie potraktowała modelowo. Szczegółowe wnioski z analizy zawarła w ostatniej części tekstu.

Słowa kluczowe: neutralność klimatyczna, powietrze, przemysł, rynek energii, analiza modelowa

Cytuj jako:

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