Article

The Role of Public Spending in CO₂ Emissions Reduction in Polish Regions: An LMDI Decomposition Approach

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Abstract: Global climate change and air pollution are critical environmental problems in the modern world. Therefore, the reduction of CO₂ emissions has long been a crucial challenge for individual countries. In this area, numerous technological, legal, and economic solutions are used. The purpose of this article is to examine the impact of public spending on the level of CO₂ emissions in Polish regions. The study uses the logarithmic mean Divisia index (LMDI) method, proposing a unique proprietary set of factors that influence the level of CO₂ emissions. The results of the study confirm that public expenditure contributes to reducing CO₂ emissions at the regional level, while environmental expenditure is counterproductive. This tendency is observed mainly in regions with a high level of socioeconomic development, higher energy consumption, and high carbon emissions. The failure of environmental spending to reduce carbon dioxide emissions in Polish regions is explained by the “green paradox” hypothesis.

Keywords: CO₂ emission; public expenditures; decarbonization; LMDI approach

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1. Introduction

The reduction of CO₂ emissions has long been a critical global challenge. This is reflected in the numerous legal regulations and actions aiming to reduce emissions in individual countries. These regulations, often international in nature, contain compromise solutions and take into account the principle of state sovereignty, the shared use of the public good that is the natural environment, as well as socioeconomic development [1] (p. 7).

The first international treaty to address the problem of emissions directly was the Kyoto Protocol [2]. It implemented the United Nations Framework Convention on Climate Change [3], which obliges countries to reduce their economies' greenhouse gas emissions based on individually established goals. This convention only required the adoption of appropriate policies and mechanisms, as well as the submission of periodic reports [4]. Climate and environmental protection issues have been longstanding priorities in the policy implemented by the European Union (EU). According to Art. 3 of the Treaty on the European Union, the member states are obliged to “a high level of protection and improvement of the environmental quality” [5] while they implement the EU's overarching goal of sustainable development. The Paris Agreement [6] ratified by the EU in 2016 noted the important role of cities, lower-level authorities, and the private sector in combating climate change. The interested parties were called upon to, inter alia, step up their efforts and support actions to reduce emissions. Mention should also be made of the European Green Deal [7], a set of policy initiatives with the priority objective of achieving climate neutrality in Europe by 2050. The latest crucial event was the United Nations Climate Change Conference in Glasgow (COP26), during which world leaders were tasked with determining actions aimed at solving the climate crisis.

To achieve the goal of reducing CO₂ emissions, individual countries use various types of instruments. Undoubtedly, fiscal policy (public revenues and expenditures) plays an important role. However, the results of the research conducted so far on the effectiveness

of fiscal policy instruments in this area are not unequivocal. On the one hand, research by Yilanci et al. [8] for G7 countries shows that fiscal policy can contribute to mitigating climate change. Ghazouani et al. [9] have shown that the impact of the carbon tax on mitigating CO₂ emissions varies depending on the country studied but generally fulfills the desired role. On the other hand, numerous researchers, including van der Ploeg [10], Hoel [11], and Grafton et al. [12], highlight the green paradox, which states that intensive use of climate policy instruments (e.g., renewable energy sources or a carbon tax) prompts fossil fuel owners to extract raw materials faster and accelerates global warming.

The purpose of this article is to examine the impact of public spending on the level of CO₂ emissions in Polish regions. The research was carried out to establish how total public expenditure and particularly environmental expenditure determines differences in the level of CO₂ emissions between regions in Poland, taking into account disproportions in their socio-economic potentials. The analyses we have conducted make it possible to evaluate the regional environmental policy implemented via public expenditure to reduce greenhouse gas emissions in the regions.

The study contributes to the existing research achievements. Most research comparing various instruments that support CO₂ emissions reduction focuses on the national level. Meanwhile, few publications have compared the regions of a given country in this respect. The studies conducted so far in this area mainly concern China and the countries of North and South America. Only a few publications individually refer to EU countries. Poland seems to be an interesting case among EU countries that strive for climate neutrality because it still uses high-emission conventional energy sources to a large extent. Previous analyses have used the logarithmic mean Divisia index (LMDI) to investigate the impact of various factors on the level of CO₂ emissions. Fiscal policy (public expenditure) was one of the factors in only a few studies. This study proposes a unique proprietary set of factors that were taken into account in the construction of the LMDI model and affect the level of CO₂ emissions. For a more complete identification of the regularities, a 10-year horizon was adopted for the analysis.

The study is divided into six sections. Section 2 reviews the research conducted so far on the impact of various factors on the level of CO₂ emissions in selected countries. Particular attention is paid to analyses of the relationship between fiscal instruments and CO₂ emissions. Section 3 focuses on the organizational and financial aspects of the air protection system in Poland, under which initiatives are taken to reduce CO₂ emissions. They also provide summaries showing both the level of CO₂ emissions in Poland and the share of general government expenditure on environmental protection in the GDP compared to other EU countries. Section 4 describes materials and methods, whereas Section 5 presents the empirical results of the research. The article ends with a discussion and conclusions (Section 6).

2. The Importance of Fiscal Policy as an Instrument to Support a Low-Carbon Economy

The problem of the emission of pollutants (especially CO₂) and the factors influencing the increase in emissions are still current, which is reflected in numerous scientific publications on the subject. Researchers in numerous and often distant fields thoroughly analyze the influence of various factors, including economic, social, and technical factors, on the level of CO₂ emissions in different countries or regions. For this article, the research conducted so far analyzing the impact of economic factors on greenhouse gas emission levels has been reviewed. In particular, items illustrating the relationship between the level of public expenditure and the reduction of CO₂ emissions were included. It should be noted that over the last few years, scientific research in this area has been dominated by Asian countries, in particular China.

Fan et al. [13] studied the relationship between government spending and CO₂ emissions in 30 provinces of China in 2007–2015. Their empirical results indicated that the regional inequality in emission levels resulted not only from differences in the economic development of the regions, disparities in population density, and energy structure but

also from differences in the level of government spending. Zhou and Zhang [14] analyzed the impact of the decentralization of fiscal revenues and expenditures on the effectiveness of fiscal policy in controlling environmental pollution in Chinese provinces. They found that the decentralization of fiscal expenditures had a negative impact on the effectiveness of fiscal policy in the area of environmental pollution control. Conversely, in the case of the decentralization of fiscal revenues, this impact was insignificant. Guo et al. [15] carried out studies on the impact of fiscal decentralization on environmental pollution. The spatial scope of their analysis also included Chinese provinces. The results indicate that the decentralization of fiscal revenues had a greater impact on the increase in the level of environmental pollution than the decentralization of fiscal expenditure. Research in this area was also carried out at the level of Chinese cities. Cheng et al. [16] studied the causes of differences in CO₂ emissions between cities with different socioeconomic conditions from the perspective of local fiscal spending.

Taking into account other countries, the research by Galinato and Galinato [17] concerning South American and Asian countries should be mentioned. The empirical analysis shows that the increase in total government spending significantly stimulated the cutting down of forest land for agricultural production, which, in turn, boosted CO₂ emissions. However, this relationship was not of a long-term nature. In the context of European countries, attention should be paid to the results of empirical analyses by López and Palacios [18], who concluded that fiscal policy and energy taxes are effective in reducing the concentration of some pollutants through various mechanisms. In another study, the same authors [19] noted that increasing government spending on public goods, which leads to lower spending on private goods, reduces pollution levels.

Yilanci and Pata [8] examined the impact of fiscal policy and economic growth on CO₂ emissions using a bootstrap causality test in the frequency domain. Their results suggest that fiscal policy can contribute to the mitigation of climate change at different points in time. Furthermore, the authors noticed that the relationship between government spending and CO₂ emissions varied over time. Ghazouani et al. [9] used the propensity score matching method in their research and showed a positive and significant impact of the introduction of a carbon tax on the reduction of carbon dioxide emissions. The authors also pointed to the “green paradox.” Hoel [11] noted that a sufficiently fast-growing carbon tax may increase emissions in the short term. However, implementing a carbon tax can reduce total coal extraction in the long term, thus lowering the costs associated with climate change. Grafton et al. [12] also showed that subsidizing renewable energy to encourage the substitution of fossil fuels can accelerate the extraction of fossil fuels, which promotes climate change.

Table 1 presents a synthetic overview of the research conducted so far on the impact of economic factors (especially fiscal instruments) on the level of CO₂ emissions.

Most of the analyses conducted so far focused on the national level. When considering research at the regional level, the analysis of China is advantageous. However, due to its specificities, this country differs significantly from the standards of European countries. Moreover, the results of the existing research are not unequivocal. Some of them emphasize the effectiveness of the fiscal policy instruments employed in reducing CO₂ emissions. Others, meanwhile, deny the effectiveness of this type of instrument, pointing to the emergence of a “green paradox.” It should also be noted that only a few studies have taken into account the impact of fiscal policy as a component of the LMDI decomposition.

This study fills the existing research gap regarding the estimation of the impact of various factors on the emissions scale in Polish regions. Goals and guidelines for reducing CO₂ emissions in Poland can be found, among others, in the National Environmental Policy 2030 “development strategy in the field of environment and water management” [22], which supports the implementation of Poland’s commitments at the international level, especially in the context of the 2030 EU climate and energy policy goals and the sustainable development goals. Another key document is Poland’s Energy Policy until 2040 [23]. One of the main objectives of this policy is to reduce the impact of the energy sector on the

environment while optimizing the use of energy resources. Therefore, the topicality of the research issues discussed is based on the challenges facing the Polish economy, that is, decarbonization and the achievement of emission neutrality by 2050.

Table 1. Review of research on the impact of economic factors (especially fiscal instruments) on the level of CO₂ emissions.

Authors	Title	Findings
Wei Fan, Li Li, Feiran Wang, and Ding Li [13]	Driving factors of CO ₂ emission inequality in China: The role of government expenditure (2020)	The increase in carbon dioxide emissions per capita may result from the irrational structure of local expenditure.
Caihua Zhou and Xinmin Zhang [14]	Measuring the Efficiency of Fiscal Policies for Environmental Pollution Control and the Spatial Effect of Fiscal Decentralization in China (2020)	The decentralization of fiscal spending has a significant direct negative impact on environmental pollution control.
Shufen Guo, Ludi Wen, Yanrui Wu, Xiaohang Yue, and Guilian Fan [15]	Fiscal Decentralization and Local Environmental Pollution in China (2020)	The decentralization of fiscal revenues increases local environmental pollution more than the decentralization of expenditure.
Shulei Cheng, Yongtao Chen, Fanxin Meng, Jiandong Chen, Gengyuan Liu, and Malin Song [16]	Impacts of local public expenditure on CO ₂ emissions in Chinese cities: A spatial cluster decomposition analysis (2021)	The level of CO ₂ emissions in cities is influenced not only by socioeconomic conditions but also by other factors, such as the fiscal expenditure of local governments.
Gregmar Galinato and Suzette Galinato [17]	The Effects of Government Spending on Deforestation and CO ₂ Related Emissions (2015)	The increase in total government spending significantly increases the cutting down of forest land for agricultural production, which, in turn, increases CO ₂ emissions.
Ramón López and Amparo Palacios [18]	Why has Europe Become Environmentally Cleaner? Decomposing the Roles of Fiscal, Trade and Environmental Policies (2014)	Increasing the share of fiscal spending and shifting its focus to public goods and non-social subsidies has a surprising and unintended positive effect on ozone concentrations, perhaps the most difficult kind of pollution to control.
George Halkos and Epameinondas Paizanos [20]	The impact of government expenditure on the environment: An empirical investigation (2013)	The direct impact of government spending was negative for both SO ₂ and CO ₂ emissions per capita, with a lag of one year. The negative direct effect of government size on pollution has been estimated.
Sacchidananda Mukherjee and Debashis Chakraborty [21]	Does Fiscal Policy influence per capita CO ₂ emission? A cross country empirical analysis (2016)	Higher proportional decentralization of budget subsidies leads to higher CO ₂ emissions. Countries with higher CO ₂ emissions are also characterized by a higher GDP per capita, a greater share of the manufacturing sector in their GDP, and a higher level of urbanization.

3. Organizational and Financial Aspects of the Air Protection System in Poland

The effective implementation of measures aimed at increasing air protection depends to a large extent on both the structure of the system within which this process takes place and the instruments used. The Polish system of air protection against pollution (including CO₂ emission) is very complex. It requires interactions between many often-independent actors operating at different administrative levels [24] (p. 72).

The entities included in the air protection system against pollution operate at the levels of the central government and the regional and local administration. At the central level,

the Ministry of Climate and Environment [25] is responsible for national legal regulations in the field of air protection, and the Ministry of State Assets [26] deals, inter alia, with energy policy. The Ministry of Economic Development and Technology [27] recommends a low-carbon economy, and the Chief Inspectorate for Environmental Protection [28] is tasked notably with informing the public about the state of the environment. Additionally, in the government administration but at the regional level, regional environmental protection inspectors [29] monitor air quality in a given region.

Taking into account the level of subcentral governments, the important role of regional governments (voivodeships) and local governments (poviats and gminas) should be emphasized. Regional governments are responsible for developing special air protection programs, while local governments are entrusted with the implementation of the tasks indicated in these programs [30]. In the Polish air protection system, the important role of the Environmental Protection and Water Management Funds must be highlighted both at the central level (National Fund for Environmental Protection and Water Management) and at the regional level (Regional Funds for Environmental Protection and Water Management). The main tasks of these funds include financing the country's environmental policy [24] (p. 73). The system described above is presented in Figure 1.

Figure 1. The Polish system of air protection against pollution. Source: Informacja o wynikach kontroli “Ochrona powietrza przed zanieczyszczeniami”/Information on the results of the inspection “Protection of air against pollution.” Najwyższa Izba Kontroli/Supreme Audit Office: Warszawa, Poland, 2018, p. 73. (In Polish). Available online: <https://www.nik.gov.pl/kontrola/P/17/078/> (accessed on 29 August 2021).

The complexity of this system does not facilitate the implementation of tasks aimed at achieving climate neutrality by 2050. However, this is not the only barrier to achieving this goal. Transforming the national energy system by significantly reducing the role of coal-fired power plants and simultaneously developing renewable energy has become necessary [30]. The result of one such transformation will be, among others, a significant change in the employment structure, which is politically costly as it may lead to a significant increase in social dissatisfaction, especially during the initial phase.

CO₂ emissions in Poland arise mainly from fuel combustion (1.A subcategory in Figure 2). This sector accounted for 92.1% of the country's total CO₂ emissions in 2019. The shares of the main subcategories were as follows: energy industries—46.9%, manufacturing industries and construction—9.7%, transport—20.4%, and other sectors—15.0%. Industrial processes were responsible for 6.1% of the CO₂ emissions in 2019, with the mineral industry as the main source of emissions in this sector. All these areas must be addressed to achieve carbon neutrality by 2050, primarily by increasing energy efficiency and switching from fossil fuels to zero-emission energy sources (including electricity, hydrogen, and ammonia) [31] (p. 6).

Table 2 shows data on CO₂ emissions per capita (expressed in tons) in Poland and EU countries [32].

As can be seen, Poland is characterized by a high level of CO₂ emissions in tones per capita compared to other EU countries. The main source of greenhouse gas emissions in Poland is the energy sector, whose structure is significantly different from that of other countries in the EU. This is due to a much greater reliance on hard coal and lignite, high-emission primary energy resources. Taking into account the outdated technologies and low efficiency of the power plants, the energy sector is considered the primary sector responsible for the national emissions [33] (p. 126).

Taking a closer look at the emissions levels in individual regions in Poland is also worthwhile. Table 3 presents the level of carbon dioxide emissions of particularly burdensome plants in 2010–2019.

Figure 2. Carbon dioxide emission (in %) in Poland by sector (in 2019). Source: Poland's National Inventory Report 2021 Greenhouse Inventory for 1988–2019 Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol, National Centre for Emission Management (KOBiZE) at the Institute of Environmental Protection—National Research Institute, Warsaw 2021, p. 16.

Table 2. Level of CO₂ emissions per capita (in tons) in Poland and other EU countries.

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Luxembourg	24.89	24.05	22.83	21.30	20.10	19.04	18.42	18.59	18.95	18.81
Czech Republic	11.43	11.17	10.77	10.29	10.06	10.11	10.27	10.34	10.19	9.65
Netherlands	11.60	10.77	10.48	10.46	10.04	10.42	10.43	10.25	9.99	9.57
Cyprus	10.91	10.30	9.40	8.50	9.01	9.12	9.73	9.98	9.70	9.56
Estonia	14.32	14.46	13.60	15.06	14.46	12.18	13.45	14.42	13.76	9.50
Belgium	10.95	9.95	9.61	9.56	9.03	9.38	9.22	9.18	9.24	9.16
Germany	10.48	10.38	10.44	10.64	10.12	10.10	10.07	9.88	9.47	8.93
Poland	8.85	8.82	8.62	8.52	8.21	8.30	8.60	8.96	8.95	8.50
Ireland	9.69	8.79	8.71	8.52	8.44	8.81	9.04	8.81	8.79	8.28
Finland	12.30	10.92	9.85	9.90	9.10	8.43	8.98	8.50	8.76	8.19
Austria	8.87	8.60	8.25	8.25	7.77	7.98	7.99	8.19	7.83	8.00
Slovenia	8.06	8.00	7.69	7.37	6.60	6.64	7.02	7.10	7.06	6.77
Greece	8.99	8.74	8.46	7.65	7.46	7.17	6.90	7.27	7.04	6.50
Slovakia	7.16	7.08	6.68	6.59	6.23	6.38	6.46	6.67	6.66	6.24
Bulgaria	6.52	7.28	6.66	5.92	6.31	6.78	6.45	6.80	6.30	6.14
Denmark	9.41	8.47	7.65	7.96	7.21	6.74	7.03	6.60	6.57	5.90
Italy	7.52	7.30	6.94	6.34	5.90	6.10	6.07	6.01	5.97	5.89
Spain	6.38	6.40	6.24	5.70	5.79	6.16	5.96	6.28	6.17	5.76
France	6.22	5.85	5.85	5.84	5.32	5.37	5.41	5.45	5.22	5.13
Lithuania	4.48	4.74	4.84	4.56	4.53	4.64	4.72	4.88	5.01	5.12
Hungary	5.27	5.10	4.76	4.45	4.48	4.79	4.85	5.12	5.14	5.11
Portugal	5.28	5.18	5.02	4.88	4.90	5.36	5.22	5.75	5.42	5.07
Croatia	4.95	4.89	4.54	4.41	4.25	4.30	4.40	4.61	4.45	4.51
Malta	6.96	6.96	7.32	6.53	6.47	4.76	3.95	4.32	4.23	4.42
Sweden	5.91	5.47	5.16	4.97	4.73	4.70	4.65	4.54	4.43	4.26
Latvia	4.21	3.94	3.86	3.83	3.76	3.83	3.86	3.93	4.31	4.24
Romania	3.97	4.41	4.33	3.91	3.96	4.04	3.94	4.12	4.15	3.99

Source: own study based on Eurostat database <http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do> (accessed on 8 July 2021).

Table 3. Level of CO₂ emissions (in millions of tones) of particularly burdensome plants in Polish regions.

Region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Lodz	35,538	39,769	40,681	42,814	41,691	42,108	40,120	43,092	43,710	38,116
Mazovia	29,332	28,419	27,689	28,508	28,290	28,440	28,687	29,044	31,562	32,469
Silesia	42,701	42,717	40,174	40,508	36,532	37,985	37,920	38,943	35,600	31,822
Opole	13,670	13,902	12,533	12,148	13,003	12,323	12,336	12,829	14,827	13,761
Swietokrzyskie	13,252	13,770	12,615	11,454	11,999	12,449	13,947	13,563	15,201	13,589
Greater Poland	16,722	16,616	16,662	17,090	16,245	16,229	15,357	14,386	11,436	10,865
Lower Silesia	16,261	15,866	15,963	15,223	13,431	12,789	12,773	11,997	11,771	10,217
Kujawsko-pomorskie	6942	6980	8399	7887	8055	8329	9276	9730	9866	9689

Table 3. *Cont.*

Region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Lesser Poland	10,345	10,840	10,463	10,893	10,129	10,738	9978	10,841	10,400	8926
Pomerania	6489	6872	6868	6483	6382	6590	6802	6669	6695	6617
West Pomerania	9108	9199	9199	9432	8843	8577	8403	7712	7090	6223
Lublin	5163	5545	5293	4703	4945	4979	5077	5049	5068	4968
Lubusz	2053	2066	2030	1986	1986	1981	2175	2185	2235	3311
Subcarpathian	3747	3682	3342	3225	2511	3034	2790	2799	2763	2869
Podlaskie	1607	1637	1472	1965	2004	1969	2199	2056	2032	2128
Warminsko-mazurskie	1523	1382	1505	1583	1449	1441	1580	1648	1658	1712

Source: Bank Danych Lokalnych Database, <https://bdl.stat.gov.pl/BDL/dane/podgrup/tablica> (accessed on 8 July 2021).

As shown in the table above, the highest emissions levels during the analyzed period occurred in the Silesia, Lodz, and Mazovia regions, which host numerous plants that emit atmospheric pollutants. In particular, it should be mentioned that many hard and brown coal mines operate in the Silesia and Lodz regions. Meanwhile, the regions with the lowest emissions levels are Warminsko-mazurskie, Podlaskie, and Lubusz.

One of the important instruments used to reduce CO₂ emissions is public expenditure on environmental protection. Table 4 shows the ratio of general government expenditure on environmental protection to GDP (in %) in EU countries [34].

As shown in the table above, the ratio of general government expenditure on environmental protection to GDP in Poland is lower than the EU average, which oscillates between 0.7% and 0.9% of GDP over the analyzed period. The highest ratios are found in Belgium, the Netherlands, and Malta, and the lowest in the Scandinavian countries (Finland, Denmark, and Sweden) and Cyprus. Comparing Tables 3 and 4, we find no evident connection between the level of CO₂ emissions in a given country and the share of environmental expenditures in its GDP.

Table 4. General government expenditures on environmental protection to GDP (in %) in EU countries.

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Greece	0.8	0.9	1.1	1.7	1.5	1.5	1.5	1.4	1.4	1.4
Malta	1.9	1.3	1.4	1.4	1.5	1.9	1	0.9	1.2	1.4
Netherlands	1.6	1.6	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4
Belgium	1.2	1.5	1.6	1.5	1.4	1.3	1.2	1.3	1.3	1.3
France	1	1	1	1	1	1	0.9	0.9	1	1
Spain	1.1	1	1	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Italy	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Luxembourg	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.9	0.9
Czech Republic	1	1.3	1.3	1	1.1	1.1	0.7	0.8	0.9	0.8
Slovakia	0.9	0.8	0.9	0.9	0.8	0.9	0.7	0.8	0.8	0.8
Bulgaria	0.7	0.7	0.7	0.9	0.7	0.8	0.7	0.7	0.7	0.7
Estonia	−0.3	−0.2	0.9	0.7	0.7	0.7	0.6	0.7	0.7	0.7
Croatia	0.6	0.6	0.6	0.7	0.6	0.7	0.7	0.6	0.7	0.7
Romania	0.8	0.9	0.8	0.8	0.8	1	0.6	0.5	0.7	0.7

Table 4. Cont.

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Iceland	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Germany	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.6
Latvia	0.3	0.7	0.7	0.7	0.7	0.7	0.5	0.5	0.6	0.6
Portugal	0.7	0.7	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6
Slovenia	0.7	0.8	0.8	0.7	1	1	0.6	0.5	0.5	0.6
Hungary	0.6	0.7	0.7	0.9	1.2	1.2	0.5	0.4	0.4	0.5
Poland	0.7	0.7	0.6	0.6	0.6	0.6	0.4	0.4	0.5	0.5
Sweden	0.4	0.4	0.5	0.5	0.4	0.4	0.4	0.5	0.5	0.5
Denmark	0.4	0.4	0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Lithuania	1.3	0.7	0.8	0.5	0.6	0.5	0.5	0.4	0.3	0.4
Austria	0.6	0.5	0.5	0.4	0.5	0.4	0.4	0.4	0.4	0.4
Cyprus	0.3	0.3	0.3	0.2	0.3	0.4	0.2	0.3	0.3	0.3
Finland	0.3	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2

Source: Eurostat database, https://ec.europa.eu/eurostat/databrowser/view/gov_10a_exp/default/table?lang=en (accessed on 8 July 2021).

In conclusion, the Polish air protection system is very complex and dispersed. It requires interactions between numerous entities at various levels of government. This situation hampers the coordination between the participants in the system, although the implementation of air protection mainly falls to individual citizens and economic entities [24] (p. 77). At the same time, Poland is one of the countries with the highest emissions level in the EU. Bearing in mind the goal of achieving climate neutrality by 2050, research on the impact of various factors on the country's emissions levels is indispensable. The present study focuses on one of the economic factors, namely public expenditure.

4. Materials and Methods

A decomposition analysis was conducted to examine how public expenditure determines the differences in CO₂ emissions between Polish regions with different socioeconomic conditions. A decomposition model can not only identify the main driving forces of the variations in an aggregation but also show quantitative results regarding the extent of the driving forces' influence on the variations. The literature reveals two main methodological approaches to decomposition analysis: structural decomposition analysis (SDA) and index decomposition analysis (IDA). The first is used primarily to study changes in energy consumption or emissions [35,36], and the second is most frequently utilized to better understand differences in energy consumption (or emissions) in specific sectors or in different regions [16,37].

In general, IDA is more widely employed than SDA. The main advantage of IDA is that it has greater applicability and allows for a broader interpretation of the results than other decomposition models [38]. The LMDI proposed by Ang and Choi [39] is the most mature model used in IDA. This method is preferred because of its symmetry, path independence, ability to handle zero, and consistency in aggregation. LMDI enables perfect decomposition because it does not leave any residual term. Ang [40] provides a practical guide to the LMDI method. This method is often applied to quantify change over time within a single country (e. g. China [41], Spain [42], Iran [43]) or between countries (e.g., Austria and Czechoslovakia [44] or the APEC countries [45]). Much less research has been carried out on the differences in CO₂ emissions between regions or municipalities, and most of them have focused on Chinese provinces [46], autonomous regions [47,48], or the largest cities [16]. Importantly, previous surveys mainly adopted the LMDI model to study the determinants of variations of an aggregate based on the data collected at a given time

for a specific group of entities. In contrast, our study uses the LMDI method to conduct a temporal decomposition analysis of the changes in regional CO₂ emissions.

To compare the differences in drivers of CO₂ emissions between Polish regions, we used a modified Kaya identity, a mainstream model that explains the impact of socioeconomic variables on carbon emissions [40,49]. The Kaya identity model takes into consideration three main effects determining changes in emissions: activity, structure, and intensity. In previous studies, economic growth and population were used most frequently as effects of activity, energy, and industrial structures as effects of structural effects, and carbon and energy intensities as effects of intensity [50].

Although public expenditures also influence CO₂ emissions, this relationship is not well represented by the Kaya identity [50]. Public spending is not the main source of carbon dioxide emissions, because most are caused by the energy and manufacturing industries, construction, transportation, and the daily life of households. Environmental public expenditure is used to directly mitigate CO₂ emissions from the commercial and residential sectors. However, the effects of public spending on the environment are much broader and may be classified as direct (results of the impact of government spending on changes in the output of an industry that experiences greater demand), indirect (results of output changes in industries supplying the industries providing goods and services directly to the general government sector), or induced (results of extra income in terms of wages and salaries of households, generated by direct and indirect output changes).

Therefore, in our study, the Kaya identity was modified to evaluate the impacts of public expenditure on CO₂ emissions across regional governments in Poland. In our model, the scale of public expenditures and energy consumption are considered the activity effect. The impact of environmental public expenditures on population and the share of environmental public expenditures in the total public spending is regarded as structural effects. The carbon intensity of public expenditures and energy efficiency are considered the intensity effects.

Based on the internal connection between CO₂ emissions, GDP, public expenditures, population, public environmental expenditures, and energy consumption, we use Equation (1) to express the driving force of CO₂ emissions:

$$\begin{aligned} C &= \sum_i C_i = \sum_i \frac{C_i}{PE_i} \frac{PE_i}{Y_i} \frac{Y_i}{EC_i} \frac{EC_i}{P_i} \frac{P_i}{EPE_i} \frac{EPE_i}{PE_i} \\ &= \sum_i CIPE_i ALG_i EE_i ECP_i PEPE_i EPES_i \end{aligned} \quad (1)$$

where:

i denotes each region in Poland;

C_i denotes CO₂ emissions in region i ;

PE_i denotes total public expenditures in region i ;

Y_i denotes the gross product of region i ;

P_i denotes the population of region i ;

EPE_i denotes public environmental expenditures in region i ;

EC_i denotes the total energy consumption in region i .

And:

$CIPE_i = \frac{C_i}{PE_i}$ denotes the carbon intensity of public expenditures;

$ALG_i = \frac{PE_i}{Y_i}$ denotes the scale of public expenditures;

$EE_i = \frac{Y_i}{EC_i}$ denotes energy efficiency;

$ECP_i = \frac{EC_i}{P_i}$ represents energy consumption;

$PEPE_i = \frac{P_i}{EPE_i/PE_i}$ represents the impact of environmental public expenditures on population and, subsequently, on CO₂ emissions (This indicator was constructed based on Cheng et al. [16]. However, Cheng et al. used public expenditures other than environmental to reflect their impact on the population and, as a result, on CO₂ emissions. PEPE shows how many people in a region benefit from a 1% share of environmental expenditure in the total public spending. The lower the PEPE indicator, the smaller the population of a given

region that uses the 1% share of environmental expenditure; therefore, this percentage meets the population's needs to a greater extent.).

$EPES_i = \frac{EPE_i}{PE_i}$ represents the share of environmental public expenditure in the total public spending.

The additive LMDI decomposition technique can be applied to attribute the changes in CO₂ emissions in each of the 16 Polish regions from 2010 to 2019 to six effects, as shown in Equation (2):

$$\Delta C_i = \Delta CIPE_i + \Delta ALG_i + \Delta EE_i + \Delta ECP_i + \Delta PEPE_i + \Delta EPES_i \quad (2)$$

$\Delta CIPE$ represents the change in CO₂ emissions between 2010 and 2019 due to the change in the intensity of public expenditure in region *i*. ΔALG_i denotes the public expenditure scale effect that reflects the changes in CO₂ emissions caused by the fiscal activity of public authorities in a particular region. The next two effects— ΔEE_i and ΔECP_i —relate to energy indicators and show the change in CO₂ emissions caused by changes in energy consumption or energy efficiency. $\Delta PEPE_i$ is used to measure how the changes in the percentage of public environmental expenditure at the disposal of the population in region *i* contribute to changes in the CO₂ emissions, and $\Delta EPES_i$ represents the change in CO₂ emissions resulting from changes in the share of environmental public expenditure in the total public spending.

The study uses data from 16 regions in Poland from 2010 to 2019. Data on CO₂ emissions, energy consumption, population, and the gross domestic product of each region were derived from the Local Data Bank of the Polish Central Statistical Office, whereas data on public expenditure and environmental public spending come from the annual budget reports.

5. Results

Figure 3 shows the relative cumulative percentage change in CO₂ emissions (ΔC) in Polish regions from 2010 to 2019 (in relation to 2010 levels). On this basis, the regions were classified into three groups, as follows:

- (1) Regions with $\Delta C \leq -10\%$;
- (2) Regions with $-10\% < \Delta C \leq 10\%$;
- (3) Regions with $\Delta C > 10\%$.

To describe the main driving forces of the changes in CO₂ emissions in each region, a temporal LMDI decomposition analysis was conducted. The cumulative contributions of various factors over the 2010–2019 period are provided in Figure 4. Regions within each of the three groups defined above were ranked in ascending order of cumulative absolute change in CO₂ emissions between 2010 and 2019.

The first group includes six regions located in the western and southern parts of the country, with the highest percentage decrease in CO₂ emissions over the 2010–2019 period, exceeding 10% (Silesia, Lower Silesia, Greater Poland, Lesser Poland, West Pomerania, and Subcarpathian). These regions (except for Subcarpathian) also had the highest initial level of CO₂ emissions in 2010. The first four voivodeships in this category shared quite similar demographic and socioeconomic development characteristics (large population, high population density, large economic scale, high level of industrialization, urbanization, and technology). Silesia and Lower Silesia are highly resource-based mining regions; West Pomerania and Subcarpathian are slightly less developed regions, but their socioeconomic development characteristics remain close to the national average. In the first category of regions, industrial development, the high level of urbanization and economic increment induced massive energy consumption, especially in 2015–2019. For example, ΔECP (the energy consumption effect) in Silesia reached 1.85 Mt. over the 2015–2019 period, followed by Greater Poland (1.38 Mt.) and Lower Silesia (1.15 Mt.). Interestingly, in all these regions, the rapid increase in energy consumption was accompanied by an increase in the energy efficiency ratio (measured as the ratio of GDP to total energy consumption).

Figure 3. Relative cumulative percentage change in CO₂ emissions (ΔC) in Polish regions from 2010 to 2019 (in relation to 2010 levels). Source: own elaborations.

Energy efficiency can be improved even with an increase in energy consumption (e.g., when the introduction of new energy-saving technological solutions allows a company to reduce costs and therefore produce more, ultimately leading it to consume more energy in production processes than before the implementation of the technological change). From the point of view of energy efficiency, the production process after technological modernization is less energy-consuming (per unit of product), but total energy consumption increases. As a result, ΔEE , the energy efficiency effect) remains positive in all regions and contributes to the increase in CO₂ emissions.

Moving on to public expenditure, the impact of ΔALG (the effect of the scale of public expenditures) on CO₂ emissions was quite limited. However, it should be noted that in the regions concerned, the ratio of public expenditure to GDP remained relatively stable. In contrast to ΔALG , the three remaining effects related to public expenditure played a major role in CO₂ emissions changes. $\Delta CIPE$, $\Delta PEPE$, and $\Delta EPES$ are the strongest drivers of the regional differences in CO₂ emissions. $\Delta CIPE$ (the carbon intensity of public expenditure) was the key factor in curbing CO₂ emissions in the surveyed regions. Its impact was relatively high, especially in Silesia.

Figure 4. Temporal decomposition of cumulative absolute changes in CO₂ emissions in 16 Polish regions in 2010–2019 (in Mt). Source: own elaborations.

A second important expenditure factor was ΔPEPE (the impact of environmental expenditures on the population and, subsequently, on CO₂ emissions). The average PEPE indicator decreased in 2010–2019 in all regions in the first group. However, this was mainly due to a reduction in the size of those regions' population (population is the numerator of a fraction in the PEPE indicator), as well as, to a lesser extent, a slight increase in the share of environmental expenditure in the total public spending (denominator of the fraction). The decrease in PEPE means that 1% of the share of environmental expenditure benefited a smaller part of the population of the regions, thus better satisfying their needs. Consequently, the accumulation of ΔPEPE remained negative, contributing to the reduction in CO₂ emissions.

The situation was entirely different in Silesia, where ΔPEPE contributed to CO₂ emissions growth. ΔPEPE reflects the impact of environmental spending primarily on those sources of CO₂ emissions that are strongly correlated with the size of the population (mainly of a non-commercial nature, e.g., CO₂ emissions from the residential sector); however, in Silesia, the most industrialized region in Poland, the industry and energy sectors remained the main sources of emissions.

The last expenditure effect, Δ EPES was a positive factor in promoting CO₂ emissions in all the regions, except for Silesia, where it had a negative effect. This is surprising as the average share of public environmental spending increased between 2010 and 2019 in all regions of the first group. In contrast to Δ PEPE, Δ EPES showed that environmental expenditure contributes to CO₂ emissions arising from any (and not only directly population-related) sources, including the power generation, industrial, and transport sectors. Δ EPES was positive in all surveyed regions except for Silesia.

The combined analysis of Δ PEPE and Δ EPES showed that environmental expenditure was not effective in reducing CO₂ emissions. Indeed, Δ PEPE contributed to the mitigation of carbon emissions, but a favorable decrease (in terms of CO₂ emissions curbing) in the PEPE indicator was mainly due to a significant reduction in the population size of the regions.

Generally, the absolute cumulative changes in the CO₂ emissions caused by Δ PEPE and Δ EPES were very similar, and both factors offset each other. Therefore, in the first group of regions, the effectiveness of environmental policy in restraining emissions resulted primarily from the decline in the carbon intensity of public expenditures (Δ CIPE).

The second group of regions consisted of five regions (Lublin, Opole, Pomerania, Swietokrzyskie, and Lodz) that experienced much smaller changes in CO₂ emissions than the first group. In these regions, environmental policy turned out to be less effective because most experienced a slight increase in the level of CO₂ emissions (except for Lublin, where CO₂ emissions decreased in 2019 by about 4% compared to 2010).

In this category of regions, the initial level of CO₂ emissions in 2010 was generally lower than in the first group. The only exception was Lodz, the second region (after Silesia) with the highest emission levels in 2010. In terms of socioeconomic conditions, this group of regions is quite diverse. It includes urbanized, industrial, and highly populated areas (i.e., Lodz and Pomerania), as well as less developed ones (Lublin, Swietokrzyskie, and Opole). At the same time, Lodz and, to a lesser extent, Lublin, are resource-based regions with brown coal and hard coal mining, respectively.

In this category of regions, the energy consumption effect (Δ ECP) played an even greater role in the increase in CO₂ emissions than in the other regions. This could be due to higher average energy consumption per capita than in the first group. Δ ECP during 2010–2019 reached 7.95 Mt. in Lodz, 2.12 Mt. in Opole, and 1.75 Mt in Swietokrzyskie. The increase in energy consumption was accompanied by an improvement in energy efficiency, as a result of which the influence of Δ EE (energy efficiency) was positive. In addition, the greatest effect for Δ EE was recorded in regions where the impact of Δ ECP was also high.

The effect of the scale of public expenditures (Δ ALG) on changes in CO₂ emissions was also positive but rather limited. However, in some regions, such as Lodz and Opole, its contribution was considerable. The impact of the carbon intensity of public expenditures (Δ CIPE) was negative in all regions in the second group, but this effect played a smaller role than in the first group.

Δ PEPE was the main public expenditure factor leading to a reduction in CO₂ emissions in the second group of regions. The only exception was Pomerania, where PEPE contributed to a growth in emissions levels.

The negative impact of Δ PEPE on carbon emissions was on average stronger in the second group of regions than in the first. However, the reduction of the population size was also greater in the second group than in the first, which caused an even larger decline in the PEPE indicator for this group. Nevertheless, Pomerania was the only area where Δ PEPE caused an increase in CO₂ emissions and PEPE remained the highest. Moreover, in Pomerania, PEPE fluctuated over time, in contrast to the remaining regions where it showed a fairly steady downward trend. Thus, Δ PEPE played the greatest role in the regions with the lowest and/or a decreasing PEPE indicator (i.e., Lodz, Swietokrzyskie, and Opole). This means that the increasing percentage of environmental expenditure available to the population of these regions was responsible for the reduction in CO₂ emissions.

However, as with the previous group of regions, Δ PEPE should be analyzed together with Δ EPES. Contrary to Δ PEPE, Δ EPES contributed to the increase in CO₂ emissions. This was the case in all regions except for Pomerania, where Δ EPES caused a slight decrease in CO₂ emissions. Nonetheless, the share of environmental expenditure in the total public spending in Pomerania remained the lowest and stayed very stable over time. The largest increase in CO₂ emissions as a result of Δ EPES occurred in Lodz, Swietokrzyskie, and Opole, regions where the percentage of environmental expenditure was also the highest.

As in the first category of regions, the aggregate impact of Δ PEPE and Δ EPES revealed that environmental expenditures reduced CO₂ emissions mainly from population-related sources but failed to mitigate the total carbon emissions. However, the success of Δ PEPE in reducing CO₂ emissions was mainly due to the reduction in population size. As a result, at a given level of environmental expenditure, it was possible to satisfy the environmental needs of a greater number of inhabitants of a given area.

Additionally, while in the first group of regions, the inefficacy of environmental spending in reducing CO₂ emissions was offset by the combined Δ CIPE and Δ PEPE, in the second category of regions, Δ CIPE was lower and did not fully compensate for the impact of Δ EPES.

The last group of regions comprises Mazovia, Kujawsko-pomorskie, Warminsko-mazurskie, and Podlaskie (located in the central and northeastern parts of the country), as well as Lubusz (situated on the western border). The last four are densely populated and low-urbanized regions with relatively low GDP per capita and poor industrialization, as well as high afforestation. The only exception is Mazovia, the capital region, which has the highest socioeconomic development.

In these regions, the CO₂ mitigation policy turned out to be completely ineffective as those regions experienced the highest increase in CO₂ emissions in 2010–2019, which reached 61% in Lubusz, nearly 40% in Kujawsko-pomorskie, and more than 30% in Podlaskie (Figure 3). Mazovia and Warminsko-mazurskie faced a slightly smaller increase (exceeded 10%). In absolute values, the highest cumulative increases in CO₂ emissions occurred in Mazovia (3.14 Mt.), Kujawsko-pomorskie (2.77 Mt.), and Lubusz (1.26 Mt.).

However, the need to reduce CO₂ emissions in this category of regions was weaker because the initial average emissions level in 2010 was the lowest among all groups of regions (the only exception was Mazovia, which was third in terms of CO₂ emissions in the country in 2010). In the third category of regions, low CO₂ emissions were due to relatively low energy consumption per capita (ECP) compared to other groups. For this reason, the energy consumption effect (Δ ECP) on CO₂ emissions remained positive and relatively small in all regions except for Mazovia. This was similar to the energy efficiency effect (Δ EE), which remained strongly correlated with Δ ECP.

In terms of public expenditure-related forces of change in CO₂ emissions, the public expenditure scale effect (Δ ALG) had a modest but positive impact. In general, as in the other groups of regions, the average share of public expenditure in the GDP remained rather low and stable.

Other expenditure factors had a similar impact as with previous groups, although their strength was weaker. The carbon intensity of public expenditure (Δ CIPE) contributed to reductions in CO₂ emissions in all regions except for Lubusz. Some differences were observed in the case of environmental expenditures. Unlike most other regions, in Lubusz and Kujawsko-pomorskie, the effect of environmental expenditure on population-related CO₂ emissions (Δ PEPE) contributed to an increase in carbon emissions, while the share of environmental expenditure in the total expenditure (Δ EPES) contributed to a decrease in total CO₂ emissions. In general, in 2010–2019, the average PEPE indicator in Kujawsko-pomorskie and Lubusz showed a downward and very fluctuating trend. In turn, a fluctuating upward trend was found for the EPES index.

Importantly, Δ PEPE and Δ EPES compensated each other in most cases; the only exception was Mazovia, where the positive influence of Δ EPES outweighed the negative impact of Δ PEPE. Furthermore, the carbon intensity of public expenditures reduced CO₂

emissions. Therefore, in the third group of regions, the increase in CO₂ emissions was mainly determined by factors unrelated to public expenditures: increase in energy consumption and energy efficiency. This last factor played a particularly important role in the increase in CO₂ emissions as the dynamics of energy efficiency improvement in those regions remained the highest in the country.

6. Discussion and Conclusions

In general, the results of the study confirm that public expenditure effects played a role in shaping CO₂ emissions at the regional level.

However, the impact of particular expenditure forces varies in terms of degree and direction and from one group of regions to another. In this sense, our findings are supported by earlier research indicating that public expenditure policy affects carbon emissions. Studies by Cheng et al. [50] showed that optimizing spending responsibilities between different levels of government and reducing the energy intensity of public expenditure are important drivers of CO₂ emissions mitigation in Chinese regions. For their part, Wang and Li [51], studying the relationship between local expenditure and the reduction in CO₂ emissions in China, found that the growth of total public expenditure does not curb carbon emissions. However, when the increase is focused on spending on public goods (i.e., culture, education, science, or public safety), it tends to mitigate the emissions. Nevertheless, Huimin et al. [52] revealed a significantly negative relationship between local government spending and CO₂ emissions. The general conclusion of our study is that in regions with a higher level of socioeconomic development (mainly Group I) and, consequently, higher energy consumption, public expenditure is generally more effective in reducing CO₂ emissions than in less developed regions (Group III). Therefore, the state's environmental policy is more effective in the regions that experienced the highest levels of carbon emissions. This is due to the fact that most public environmental programs introduced in recent years were aimed primarily at the most polluted regions of the country. Documents such as the Lower Silesia Voivodship Environmental Protection Program for 2014–2017 with a perspective until 2021 [53] or the Air Protection Program for the Wielkopolska zone [54] can be mentioned. As part of the programs presented, various corrective actions were implemented to improve air quality. They include the reduction of emissions from individual heating systems by eliminating low-efficiency solid-fuel devices, reducing emissions by lowering the demand for heat energy through thermo-modernization measures limiting heat losses, or improving atmospheric air quality. The programs mentioned above were individualized and concerned regions with alarmingly high levels of CO₂ emissions.

These results are in line with the conclusions of Cheng et al. [16], who showed that socioeconomic conditions are one of the factors that explain the differences in CO₂ emissions between regions. They emphasize that an effective reduction in CO₂ emissions requires the adoption of different environmental policies based on the level of carbon emissions of each region. Entities with CO₂ emissions above the national average should be placed on a key list to address the difficulties that they face in achieving CO₂ emissions reductions. Hao et al. [55] came to similar conclusions, that is, that provinces with different levels of economic and social development should choose different levels of fiscal decentralization to maximize the positive impact on environmental quality.

Moving on to more detailed findings, our study takes into account four public expenditure-related factors of carbon emissions: the carbon intensity of total public expenditures, the public expenditure scale, the percentage of public environmental expenditure at the disposal of the population, and the share of environmental expenditure in the total public spending.

The detailed conclusions of this study are as follows:

1. Our findings confirm that total public spending mitigated carbon emissions in all Polish regions except Lubusz, where the influence of the carbon intensity of public expenditure was negative. Therefore, the findings of our study support those of

some other studies (see, e.g., Fan et al. [13], Huang [56], Gupta et al. [57]) showing that increased public expenditure benefits the environment and thus steers the economy towards sustainable development. The negative correlation between total fiscal expenditures and CO₂ emissions may arise from the fact that public spending is a tool to reduce market failure (excessive CO₂ emissions from production and consumption), encouraging producers to adopt advanced low-carbon technologies and consumers to opt for low-carbon vehicles and appliances in the long term. An increase in public expenditure can change the structure of the input factor per unit of output. Furthermore, investments in research and development aimed at discovering new technological opportunities to achieve emissions reduction targets and supporting the energy transition play an important role.

2. Our study also found that the scale of public expenditure does not play a significant part in the evolution of CO₂ emissions in Polish regions. It should be noted, however, that the ratio of public expenditure to GDP remained relatively stable in all the regions over the analyzed period. Therefore, it was not possible to confirm previous findings regarding the negative impact of expenditure decentralization on the environment [15,58].
3. All the conclusions presented above concern the impact of total public spending on CO₂ emissions, but our research also investigated the effects of environmental expenditures specifically.
4. Our results show a positive direct effect on CO₂ emissions in all regions (except for Silesia, Kujawsko-pomorskie and Lubusz). Surprisingly, this positive relationship was most evident in regions with a successful carbon dioxide mitigation policy (regions from Groups I and II).
5. In contrast, the impact of environmental expenditures on population and, subsequently, on CO₂ emissions was negative in most of the Polish regions. However, this resulted not so much from the effectiveness of this category of spending in reducing carbon emissions as from the decline in population observed over the analyzed period in all the regions.

This finding may be explained by the “green paradox” effect mentioned at the beginning of this study, which has been demonstrated by many researchers. Among others, Zhang et al. [59] conducted an empirical analysis of China’s green paradox in the context of fiscal decentralization and proved that imperfect environmental policy may lead to an unintended increase in emissions. Similarly, Grafton et al. [12] indicated that public environmental subsidies can accentuate the damage associated with climate change in the short term by accelerating the extraction of fossil fuels that contribute to an increase in CO₂ emissions.

Our study is part of research on the impact of fiscal policy on the quality of the natural environment. It shows that total public expenditure contributes essentially to reducing CO₂ emissions at a regional level, while environmental expenditure itself is counterproductive. This tendency is observed mainly in regions with a high level of socio-economic development, higher energy consumption, and high carbon emissions.

When examining the reasons for the failure of environmental spending to reduce CO₂ emissions in Polish regions, several issues should be noted.

First, despite a slight increase in 2010–2019, public environmental expenditure in Poland remains very low (not exceeding 0.6% of total public spending, on average). This makes it impossible to effectively finance the pursuit of even a portion of the environmental policy targets required to achieve CO₂ mitigation.

Second, we cannot ignore the very high dependence of the Polish economy on fossil fuels. From a political standpoint, it is very difficult to reduce CO₂ emissions in highly resource-based regions with coal mining industries, which contributes to certain “appearances” of public environmental actions. To meet the emissions targets set at the EU level, some Polish politicians adopt extreme and short-sighted measures. Such actions, although

effective in the short term, do not ensure the persistence of the upward trend in CO₂ emissions in the long run.

Third, the success of environmental spending in reducing carbon emissions is largely dependent on the proper organization and functioning of the public air protection system. Unfortunately, the organization and financing of environmental policy in Poland are very complex, unclear, and highly dispersed at different levels of government—central, regional, and local, with an important role played by the Environmental Protection and Water Management Funds at both the central and regional levels. The central government is the main environmental policymaker, whereas subcentral governments are those who implement the policy. The central emissions reduction targets may conflict with the objective of regional or local officials to pursue economic development and save jobs (especially in regions heavily dependent on coal). To attract investments and promote economic growth, sub-national authorities can make exceptions for high energy-dissipation and high-emissions enterprises by weakening the environmental policy. All of this creates inevitable lags in implementation or incomplete enforcement of environmental policies.

Fourth, another issue described in the literature in the context of the green paradox is the time lag between the announcement of an environmental policy and its implementation. Agents like exhaustible resource owners or households can change their behavior during the interim period if they know the planned deadlines for achieving the CO₂ emissions reduction targets, leading to an increase in near-term emissions.

Finally, it is also worth mentioning public policies to support alternative energy, which are one of the most important kinds of environmental spending in Poland. The implementation of environmental policies to support clean energy will make low carbon energy more widely available and will lead the owners of non-renewable resource owners to front-load extraction.

In terms of practical implications based on the above findings, this study suggests that all planned and implemented activities aimed at mitigating CO₂ emissions should be coordinated under the leadership of the Ministry of Climate and Environment in cooperation with other actors operating at different administrative levels. The central government should play a much greater role and set reasonable carbon emission targets considering the different characteristics among regions, such as the economy and population. Regional and local governments should formulate specific emission reduction measures and implementation paths under the constraints established by the central government, taking into account energy consumption, the level of carbon emission, and the socio-economic development of each region. Moreover, it is necessary to implement a uniform and complete system of collecting information (currently dispersed, held by various ministries and public entities) on public environmental expenditure spent by the central budget, earmarked public funds, and subcentral governments). Another challenge is the development of proper indicators enabling the assessment of the effectiveness of public expenditure in terms of the assumed level of CO₂ emissions reduction. This would allow one to establish effective mechanisms of monitoring environmental policies and prompt regional and local authorities to achieve the objectives of this policy. Moreover, public expenditure on technology, education, culture, health, and other services should play a special role, helping to increase the efficiency of human capital, promote technological innovation or energy-saving awareness, and indirectly contribute to the reduction of carbon dioxide emissions.

Our study provides evidence that public expenditure plays an important role in changes in CO₂ emissions at the regional level in Poland; however, there are still three limitations.

First, we relied on available public statistics and budget reports, which are assumed to be fairly general and do not provide sufficiently detailed information. Therefore, in future research, it would be good to supplement them with data from direct research, including interviews and surveys. This would allow more specific categories of public expenditure to be taken into account in the context of the impact on CO₂ emissions mitigation.

Second, we are using a modified Kay identity to represent the relationship between public expenditure and CO₂ emissions. The impact of public spending on carbon emissions

is multidimensional and complex, whereas Kay's identity is mainly used to reveal the only direct influence of specific factors (such as, for example, GDP or energy consumption) on the level of CO₂ emissions. The identity does not take into account indirect or induced effects. Therefore, in future research, the role of public expenditure in reducing CO₂ emissions should also be examined from that point of view.

Third, we explained some of our findings in the context of a "green paradox", but this hypothesis initially referred to detrimental outcomes that resulted from the implementation of carbon taxes. However, we used a generalized concept of the "green paradox" to provide some common conclusions with respect to the implementation of the environmental policy through public expenditure instruments.

Nevertheless, research into the impact of non-expenditure fiscal measures such as carbon taxes on CO₂ emissions would be very important theoretically and practically. Therefore, further research is required on the "green paradox" effect in Poland.

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