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Are climate taxes used as tools to tackle environmental challenges in food industry?

Lenka Maličká

ABSTRACT

This paper examines the nexus between climate taxes and environmental expenditures, which affect industries that significantly contribute to pollution and greenhouse gas emissions, including the food and agriculture industry. The expectation of a statistically significant positive relationship between climate tax revenues and environmental protection expenditure assumes that when countries aim to mitigate the negative impacts of climate change on the environment by introducing climate taxes, they should spend the revenue generated on environmental protection. The regression analysis is conducted on a sample that comprises 30 European countries from 2000 to 2023, including 27 current European Union members and Norway, Iceland, and Switzerland. To address potential differences across countries, the sample is divided into subsamples using cluster analysis, and the time period is divided into subperiods to capture potential turbulence caused by economic and non-economic shocks. The regression analysis results are ambiguous and presented in a descriptive rather than causal manner. By testing the expectation about the positive relationship between climate tax revenues and environmental protection expenditures several turnovers in the relationship are revealed, which corresponds to the periods of crises hampering the economies and causing the a shift away from policies improving the environment in favor of countercyclical government interventions, and other external factors, such as changes in environemtal policy, mainly adopted in the EU countries.

Keywords: climate tax, public expenditure, fiscal policy, environmental policy, environmental protection, food industry

INTRODUCTION

Climate change is frequently discussed, and countries worldwide, including European countries, are adopting policies to mitigate it and enhance environmental protection. Tax (fiscal) and spending policies also fall within these categories, and climate taxes and environmental protection expenditures are considered government policy instruments **[1]**. Through climate taxes (also known as green or environmental taxes), governments influence the behaviour of economic agents whose activities harm the environment. Climate taxes are an important tool for implementing climate policy **[2]**. On the other hand, through public spending, the government might undertake direct environmental protection activities **[3]**, **[4]**.

Industries that generate substantial greenhouse gas emissions, such as the food and agriculture industry, are significantly affected by climate tax policies. Climate taxes increase the costs of food and agricultural production (e.g., beef and dairy production, energy-intensive food processing operations, and agricultural practices, the use of fertilizers, energy, and fuels for the production and transport of goods). Climate taxes thus exert pressure to internalize the true environmental cost of emission-intensive production by promoting more environmentally responsible practices, such as adopting cleaner, more sustainable technologies and transitioning to renewable energy sources. The effects of environmental tax (fiscal) and spending policies increase short-term costs and thus prices, but in the long run, they should contribute to cost/price stabilization through support programs. Therefore, revenues generated by climate taxes should be used to promote environmentally sustainable production practices (e.g., organic farming, innovations in food processing, reducing food waste, and energy-efficient equipment).

However, the relationship between climate-related taxation and public expenditures on environmental protection can be viewed from two distinct perspectives. A positive relationship between climate tax revenues and environmental protection expenditures is anticipated if governments allocate these revenues directly toward environmental objectives **[3]**, **[4]**, **[5]**. As noted by Oates **[3]**, using revenues from climate taxes for environmentally related projects might increase public spending. Conversely, a negative relationship may indicate that climate tax instruments primarily deter environmentally harmful economic activities, thereby reducing tax revenues as such activities decline or shift toward less polluting alternatives. Simultaneously, governments may increase public spending on environmental protection, reflecting a proactive investment approach. Alternatively, the negative association may indicate inefficiencies in the use of environmental tax instruments, which may be implemented primarily to augment public budgets rather than to achieve genuine environmental improvements, as noted by Oates **[3]** and Zhan et al. **[6]**. Studies such as Zhan et al. **[6]** and Esen et al. **[7]** argue that environmental taxes should reduce environmentally harmful behaviour among businesses and households. On the other hand, according to Zhan et al. **[6]**, taxes may serve as instruments to raise government revenues without further exacerbating environmental issues. Taxes are usually defined as compulsory and unrequited payments collected without being spent on a predefined purpose. This assumption disturbs the direct channel between climate tax revenues and government spending on environmental protection.

There is a research gap in the relationship between climate tax revenues and environmental protection expenditures, as noted in works Knežević et al. **[5]**, Zhan et al. **[6]** and Famulska et al. **[2]** mention that tax and spending policies are tied together. However, in work Zhan et al. **[6]**, which examines climate taxes, the authors do not directly assess their impact on public expenditures for environmental protection. Conversely, the research by Chen et al. **[8]** identifies the channel through which climate taxes affect expenditure on environmental protection. Still, they acknowledge mixed effects due to the multiplicative effect, concluding that welfare is reduced. Some authors **[9]** examined the relationship between public expenditure on environmental protection and the amount of greenhouse gases that are subject to taxation. Esen et al. **[7]** consider environmentally related taxation an instrument of environmental policy. On the contrary, in the work of Famulska et al. **[2]**, the authors admit that the revenue generated by climate taxes might serve to cover, e.g., public deficits. They also note that such revenues should be allocated to environmental issues.

However, climate-related fiscal and expenditure policies are determined by countries' overall economic conditions. Taking this into account, a branch of literature examines the relationship among energy use, gross domestic product (GDP) growth, and environmental pollution, known as the Environmental Kuznets Curve; see, e.g., **[10]**, **[11]**, and **[12]**. It suggests that higher GDP growth is associated with greater pollution and environmental degradation, driven by increased energy use in the early stages of economic development. High GDP levels reverse the trend, and GDP growth supports environmental improvement **[10]**.

Nevertheless, climate tax revenue, as well as public expenditure on environmental protection, accounts for only a small share of GDP and total revenue/expenditure in European countries **[6]**, **[7]**, **[13]**.

Scientific Hypothesis

This paper examines the nexus of climate taxes and environmental expenditures in a sample of European countries. There is a two-fold perspective on the relationship between the climate taxes and public expenditures on environmental protection. The relationship between climate tax revenues and public expenditures on environmental protection is expected to be positive, as the government spends climate tax revenues on environmental protection, consistent with Famulska et al. **[2]**. The negative relationship between them might indicate that the government discourages the economic agents from environmentally harmful economic activities through climate tax instruments (decrease in climate tax revenues due to decline of economic activity or focus on activities that produce fewer pollutants) and/or simultaneously improves the environment by investing public resources (increase in public expenditure on environmental protection), or environment-related tax instruments are not used in an effective way in the field of environmental protection. They are just designed to generate additional resources for public budgets, as Zhan et al. **[6]** mentioned. That might be more evident during periods when crises hamper economies.

Scientific hypothesis: We expect a positive relationship between climate taxes and expenditures on environmental protection, but this relationship differs across fiscal regimes or expenditure structures.

In this paper, we test the above-mentioned scientific hypothesis using regression analysis. The expectation about the statistically significant positive relationship between climate tax revenues and environmental protection expenditure assumes that when countries aim to mitigate the negative impacts of climate change on the environment by introducing climate taxes, they should spend the generated revenue on environmental protection, too.

Objectives

The paper´s objective is to examine the relationship between climate tax revenues and environmental protection expenditures. As noted by Akdag et al. **[1]**, both are government policy instruments, whereas climate taxes are considered more stringent. Authors Kinyar et al. **[14]** consider climate taxes to be more effective than environmental protection expenditures. According to Famulska et al. **[2]**, climate taxes generate government revenues, which should be spent on environmental improvements. However, according to Oates **[3]**, using revenues from climate taxes to fund environmentally related projects might increase public spending. The paper contributes to filling the gap by bridging the climate tax revenues and environmental protection expenditure gap.

MATERIAL AND METHODS

Samples

The sample comprises 30 European countries from 2000 to 2023, including 27 current members of the European Union (EU), as well as Norway, Iceland, and Switzerland. Data is collected from the Eurostat database **[15]**, which also provides data for other European countries, except for EU countries. In the early stages of analysis, we divide the period into four sub-periods, maintaining the proportionality of the sub-samples to capture possible changes in climate tax revenues. The monitored period includes two important external shocks that influenced the economic conditions in Europe, the first is related to the year 2008 - the Global financial crisis that harmed the economies around the world, the second is related to the year 2020 and later - the multicrisis starting with the COVID-19 pandemic, followed by the energy crisis and war conflict in Ukraine. The impact of these shocks is partially smoothed by computing the subperiod averages, but is not entirely omitted. Another reason for using sub-period averaging is the choice of research methods described below, e.g., cluster analysis, which operates on averages. Thus, instead of averaging the values over the entire monitored period 2000-2023, we can partially capture the dynamics by dividing the period into sub-periods.

The variables included in the research consist mainly of climate taxes and public expenditures on environmental protection. Table 1 displays the descriptive statistics of the variables in question.

Table 1 Descriptive statistics.

Variable	Unit	Mean	Median	Min	Max	Std. Dev.	C.V.	Missing. Obs.
Population	mil.persons	15.102	7.5453	0.2791	83.237	20.680	1.3694	0
Climate taxes	mil.EUR	10315.	4292.3	104.39	85723.	16571.	1.6065	8
Climate taxes	mil.EURpc	722.13	654.76	47.209	2036.4	472.76	0.6547	8
Climate taxes	%GDP	2.6347	2.5300	0.8500	5.6000	0.7214	0.2738	8
Energy taxes	%GDP	1.9154	1.8600	0.5100	4.8100	0.5832	0.3045	8
Transport taxes	%GDP	0.5815	0.4500	0.0200	2.2100	0.4322	0.7432	8
Taxes on pollution/resources	%GDP	0.1378	0.0800	0.0000	0.9400	0.1663	1.2065	8
COFOG Total (Total expenditure)	mil.EUR	1.9e+005	81290.	1767.2	2.0e+006	3.4e+005	1.6867	0
COFOG Total (Total expenditure)	%GDP	44.874	45.100	20.600	64.900	6.8586	0.1528	0
COFOG 05 Environmental protection	mil.EUR	3273.8	1110.9	-38.100	28831	5303.1	1.6199	0
COFOG 05 Environmental protection	mil.EURpc	217.75	172.28	-28.576	1359.1	182.54	0.8383	0
COFOG 05 Environmental protection	%GDP	0.7594	0.7000	-0.3000	1.9000	0.3105	0.4089	0
COFOG 05 Environmental protection	%COFOG Total	1.7157	1.6723	0.0000	4.7723	0.7054	0.4112	0
COFOG 05.3 Pollution abatement	mil.EUR	476.34	93.050	-172.30	7107.0	898.22	1.8857	36
COFOG 05.3 Pollution abatement	mil.EURpc	30.639	15.805	-129.58	382.26	48.860	1.5947	36
COFOG 05.3 Pollution abatement	%GDP	0.0887	0.1000	0.0000	0.9000	0.1491	1.6801	36
COFOG 05.3 Pollution abatement	%COFOG Total	0.0021	0.0013	0.0000	0.0154	0.0030	1.5133	36

Note: Negative values for COGOF 05 and COFOG 05.3 are reported by Estonia in 2010 and 2011 **[13]**.

The total revenues from climate taxes are the main research variable. According to the Eurostat methodology, they consist of Energy taxes, Transport taxes, and Taxes on pollution/resources.

Public expenditure on environmental protection is the 05 division of the Classification of the functions of governments (hereinafter, COFOG classification). It consists of expenditure on Waste management (05.1), Wastewater management (05.2), Pollution abatement (05.3), Protection of biodiversity and landscape (05.4), R&D Environmental protection (05.5), and Environmental protection n.e.c. (05.6). In our research, we focus on government total expenditure, government expenditure on environmental protection (COFOG 05), and on expenditures listed in COFOG 05.3 Pollution abatement, in line with the statement of Zhan et al. **[6]**. COFOG classification is employed in line with the proposition of Zhan et al. **[6]** and Georgieva **[9]**. They consider this classification the most useful, even though it has pitfalls. Furthermore, they discuss sub-division COFOG 05.3

Pollution abatement as the most affected expenditure category by climate tax policies. It is directly tied to expenditure to mitigate the negative effects of climate change. Besides, the authors mention that several other measures of the government´s environmental protection are currently being developed (e.g., Green Budget Tagging in France; see **[6]** for more).

Variables capturing climate tax revenues are expressed in EUR per capita, as a percentage of GDP, and as a percentage of the government's total tax revenue. COFOG categories are expressed in the same manner: as EUR per capita, as a percentage of GDP, and as a percentage of government total expenditure.

Statistical Analysis

In this paper, we use R Studio to conduct the analysis. We employ several research methods to project the data and test the hypotheses. We provide data visualization using maps. The maps are created using several packages, such as "rnaturalearthdata" **[16]**, "sf" **[17]**, "ggplot2" **[18]**, and "dplyr" **[19]**.

Cluster analysis is conducted using packages "cluster" **[20]**, "ggplot2" **[18]**, and "dplyr" **[19]**. The k-means method is employed to classify European countries into clusters with the highest possible similarities within each cluster and the highest possible dissimilarities between clusters. Countries are classified according to four variables. The total tax revenue from climate taxes as % of the GDP, energy taxes as % GDP, transport taxes as % GDP, and taxes on pollution/resources as % GDP. We conduct cluster analysis across four sub-periods to capture changes in climate tax dynamics. The Elbow and Silhouette tests are performed to determine the optimal number of clusters for each sub-period. To visualize the two-dimensional cluster plot, the principal component analysis reduced the multidimensionality of four climate tax-related variables. The final cluster plot contains only two principal components (factors) with the highest explanatory power.

The regression analysis is performed using the "plm" package **[21]**. The regression analysis tests the statistical hypothesis of a positive relationship between climate taxes and expenditures on environmental protection. The fixed-effect model is the main research approach, typically used when individual-specific characteristics that remain constant over time may influence the dependent variable **[22]**. We test the scientific hypothesis using a baseline model without control variables and a model with control variables. The regression analysis is preferred over correlation analysis, which might yield biased correlation coefficients and p-values when the panel structure of the data is not accounted for, e.g., using the "correlation" package **[23]**, and **[21]**.

RESULTS AND DISCUSSION

Figure 1 projects the dynamics of climate taxes and environmental protection expenditures from 2000 to 2023, expressed in mil. EUR per capita. It is clear that during the monitored period, both fiscal categories increased. Another evident observation is a decline in climate tax revenues in both recognized crises – the global financial crisis in 2008 and the multicrises stemming from the Covid-19 pandemic starting in 2020, the following energy crisis, and the war conflict. On the contrary, environmental protection expenditures are not sensitive to the crises mentioned above. A decline is observable in 2016, when many EU countries had completed large EU-funded projects in the preceding years (especially 2013-2015), such as wastewater treatment plants, sewage systems, or industrial technology upgrades, in line with the transitional period between EU funding cycles (the start of the 2014-2020 programming period). The delay was due to the funds being approved but not yet fully drawn.

A significant increase in environmental protection expenditure by EU countries observed after 2021 is linked to changes in EU funding and environmental policies following the COVID-19 pandemic. Environmental protection expenditures in the EU increased mainly because it was a year of renewed investment after the pandemic, a period marked by the launch of major EU green funding programs and the ongoing implementation of the European Green Deal **[24]**.

Figure 2 projects changes in the volume of climate taxes from 2000 to 2023, focusing on subperiods that include external shocks influencing government revenue, government spending, and GDP. The sub-periods partially absorb fluctuations, as values are expressed using six-year averages. Climate taxes are expressed as a percentage of GDP and in millions of EUR per capita. This approach helps us to understand the main patterns in climate tax revenues across Europe. While in the 2000-2005 and 2006-2011 periods, Northern European countries exhibit higher values for climate tax revenues as % of GDP, there is an evident decline in the subsequent subperiods.

The observed results are consistent with Zhan et al. [6], who noted that the share of climate taxes to GDP (as well as total tax revenues) is small in OECD and EU countries. Another observation, in line with Esen et al. **[7]**, is also evident in our results. It is that Scandinavian countries are interested in effective environmental policy. They started their activities in 1990 Knežević and Pavlović **[5]**, Esen et al. **[7]**, and they generally exhibit higher portions of climate tax revenues (see Figure 2).

The findings of Knežević and Pavlović **[5]** refer to the decline in climate tax revenues across all EU countries, except Estonia and Slovenia, during the global financial crisis in 2008. In the period 2018-2023, there is an apparent downward trend in the climate tax revenue, in line with the findings of Famulska et al. **[2]**.

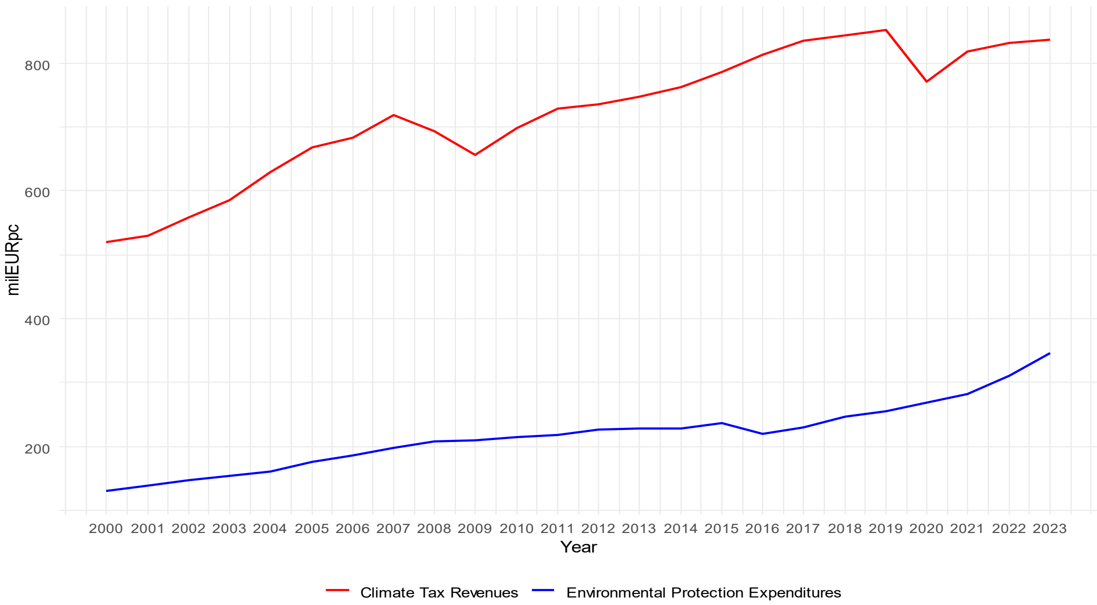

Figure 1 Dynamics of climate taxes and environmental protection expenditure in European countries.

Nevertheless, climate tax revenue, as well as public expenditure on environmental protection, exhibit only small portions of GDP and total revenue/expenditure in EU countries (see Figures 2 and 3), in line with findings of Zhan et al. **[6]**, Esen et al. **[7]**, Eurostat **[15]**, and diminish towards Eastern Europe in line with the findings of Cleveland **[25]**. Based on the paper by Fulai **[26]**, it seems that the situation has not changed dramatically in the last few decades. However, Georgieva **[9]** notes that public expenditure on environmental protection, expressed as a percentage of GDP, is stable during the monitored period. The same is observed also in Bobáková and Mihaliková **[27]**.

Figure 3 projects the changes in the volume of environmental protection expenditures from 2000 to 2023, focusing on subperiods, as it was in the case of climate tax revenues (two contain external shocks influencing government revenue, government spending, and the GDP, and the sub-periods partially absorb the fluctuations as values are expressed using the six-year averages). Environmental protection expenditures are expressed as a percentage of GDP and in millions of EUR per capita. This approach helps us to understand the main patterns in climate tax revenues across Europe. The highest values in all sub-periods are observed in Norway, Finland, Ireland, Iceland, Belgium, and the Netherlands. Differences among European countries are more visible when considering the millions of EUR per capita for the variables in question. The largest increase in both variables is visible in the last sub-period, 2018-2023, when the new EU programming period began and several arrangements were adopted at the EU level, as mentioned hereinbefore. It was a result of a combination of economic, legislative, and political influences, such as COVID-19 recovery, increases in investments, the launch of the "NextGenerationEU" recovery programs that required that at least 37% of funds be allocated to climate and environmental goals, and the implementation of the European Green Deal preparing member states to reduce emissions by 55% by 2030 **[24]**.

As stated by Zhan et al. **[6]** and Georgieva **[9]**, the environmental protection expenditure subcategory, expenditure on pollution abatement, is the most affected expenditure category by climate tax policies. It is directly tied to expenditure to mitigate the negative effects of climate change. According to Cleveland **[25]** and Eurostat **[13]**, public expenditure on pollution abatement is rather directed toward the other 05 cogof subcategories, of which public expenditure on waste management and water management is the most voluminous. However, in this context, Cleveland **[25]** mentions that countries exhibit very different priorities in environmental protection, which is mirrored in the structure of public expenditure on environmental protection. As noted by Barrell et al. **[28]**, higher environmental protection expenditures do not necessarily lead to better environmental conditions. According to Martínez Córdoba et al. **[29]**, the environmental policy depends on whether the country is developed or developing. Findings presented in Ercolano and Romano **[30]** indicate that there is no convergence in environmental protection expenditure within EU countries.

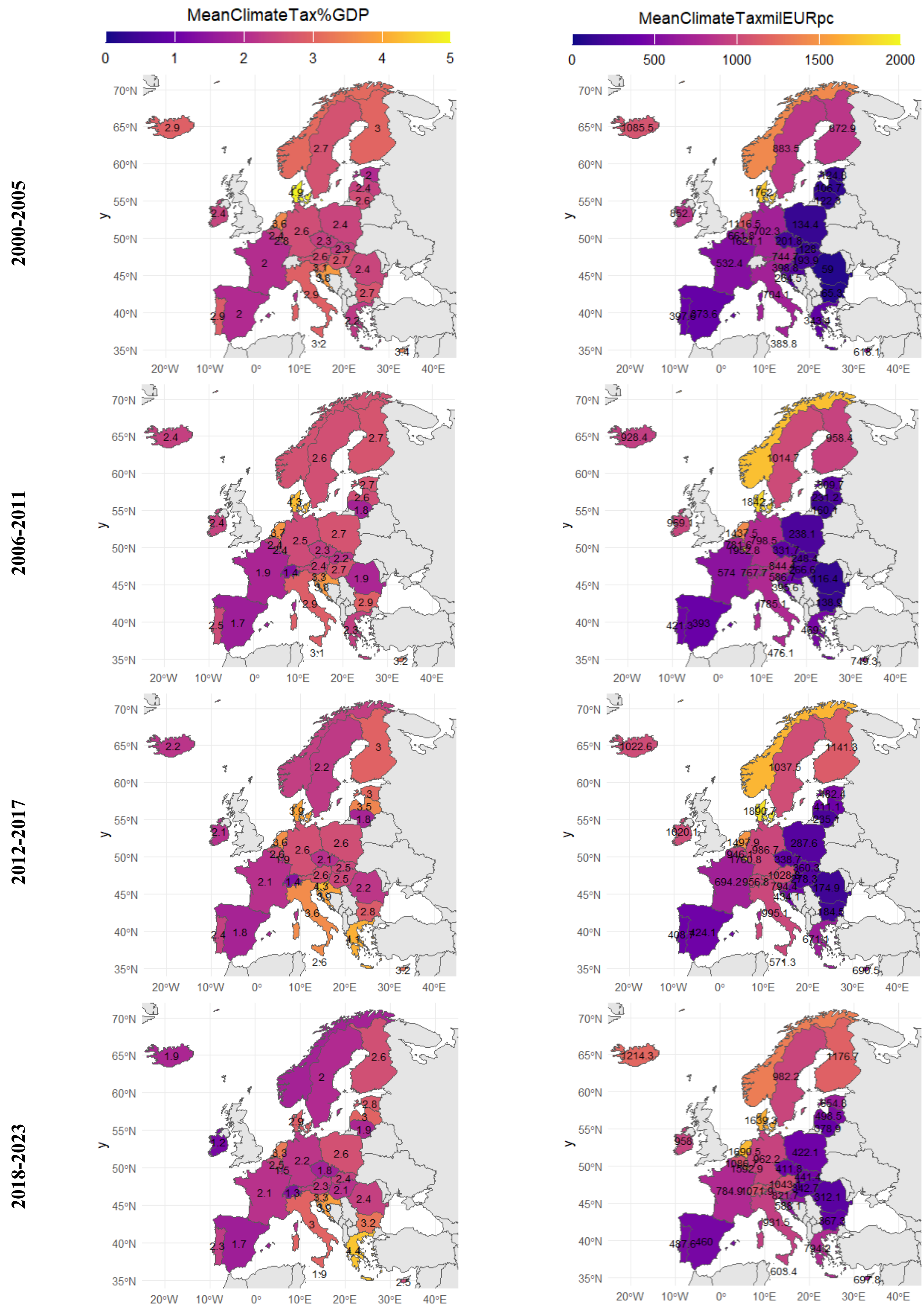

Figure 2 Climate taxes in European countries.

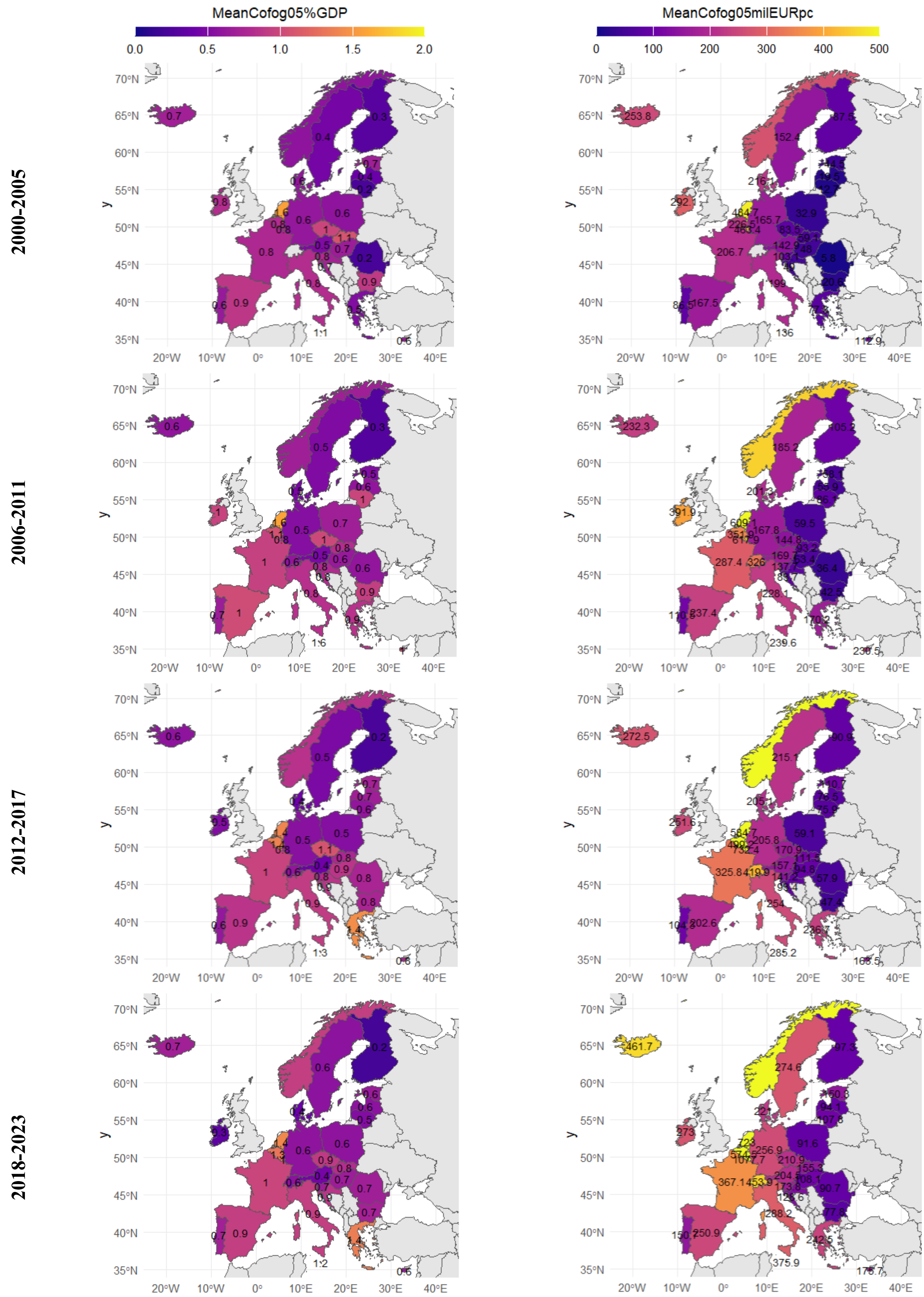

Figure 3 Environmental protection expenditures in European countries.

Figure 4 presents the classification of the researched countries into clusters based on four variables. In all cases, the Elbow and Silhouette tests indicate that two clusters are optimal in each sub-period. Based on the cluster analysis results, certain patterns are evident. A smaller cluster is created in each period with permanent members such as the Netherlands, Denmark, and Croatia, and just a few countries join this cluster:

- 1st subperiod, it is the Netherlands, Denmark, Croatia + Norway, Malta, Iceland, and Cyprus,
- 2nd subperiod, it is the Netherlands, Denmark, Croatia + Malta, and Cyprus,
- 3rd subperiod, it is the Netherlands, Denmark, Croatia + Cyprus, Estonia, Italy, Latvia, Greece, and Slovenia,
- 4th subperiod, it is the Netherlands, Denmark, Croatia + Estonia, Italy, Latvia, Greece, Slovenia, and Bulgaria.

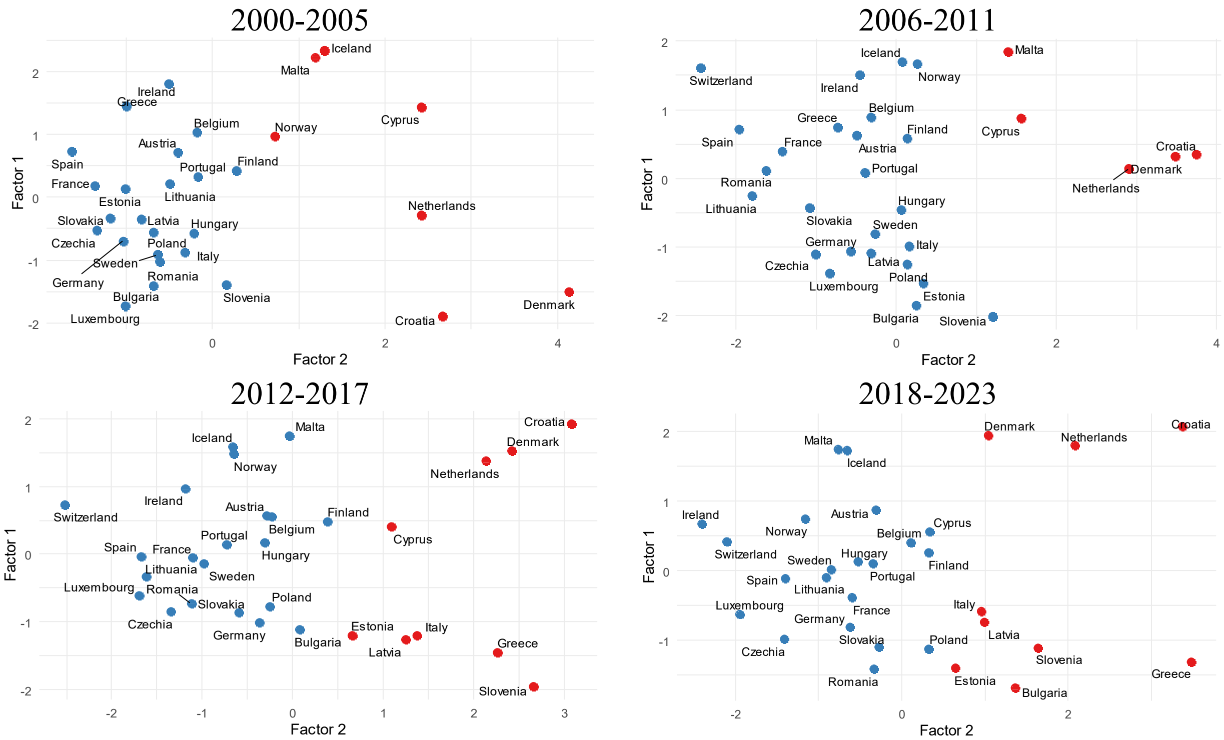

Figure 4 Cluster analysis.

Classifying countries into clusters allows us to observe different patterns in climate tax revenues. This aspect is incorporated into the next step of the regression analysis. The baseline model for both clusters is estimated first, then the sample is divided by cluster membership, and the estimations are rerun. The same procedure is repeated for different expressions of dependent and independent variables (% of GDP, % of total, millions EUR pc).

Table 2 projects the results of the regression analyses with the dependent variable defined as public expenditure on environmental protection (COFOG 05). Table 3 presents the results of the regression analyses, with the dependent variable defined as public expenditure on pollution abatement, a subcategory of public expenditure on environmental protection (COFOG 05.3).

The results shown in Table 2 are somewhat ambiguous due to the frequent lack of statistical significance for the explanatory variables. On the other hand, the results demonstrate that the expression of the variables matters, and the sub-period´s economic conditions matter as well, while their interconnection is expected. In the analyses, as mentioned hereinbefore, two sub-periods contain external shocks. These structural breaks are evident as periods of crisis (2006-2011 and 2018-2023) and as substantial changes in EU environmental policy (2018-2023). Periods of economic contraction typically necessitate fiscal policy adjustments. Drops in tax revenues and deceleration in GDP growth require solutions focused on stabilization and redistribution to support the economy. This leads to changes in the volume and structure of public expenditure in corresponding fields, while environmental protection expenditures remain marginal. The combination of multi-crises and periods of environmental policy changes in line with the EU goals in the subperiod 2018-2023 crowds out the effect of increasing environmental protection expenditures (as discussed in the results shown in Figure 1).

In the sub-period 2000-2005, climate tax revenues positively affect environmental protection expenditures, while the beta estimates are statistically significant only for variables expressed in millions of EUR per capita, not relative to GDP or total amounts reported in given fiscal categories.

In the sub-period 2006-2011, there is a discrepancy in the observed results, which, of course, could be explained by the global financial crisis that hampered the economies of EU countries during this period. As shown in the columns on % of GDP and % of total, the relationship between climate tax revenues and environmental protection expenditures is negative and statistically significant. In the case of expression based on millions of EUR per capita, the relation is positive and statistically significant, when results are not affected by the changes in the GDP or total tax revenue and public expenditure in times of crisis.

In the sub-period 2012-2017, climate tax revenues positively affect environmental protection expenditures, while the beta estimates are again statistically significant only for variables expressed in millions of EUR per capita in the full sample of countries and in cluster 1 (the smaller, red cluster, see Figure 4).

In the sub-period 2018-2023, the sign of the beta estimate turns negative across all estimations, while it is statistically significant for variables expressed as % of GDP and total. However, another crisis occurred in this sub-period with evident declines in the GDP. Besides, the new EU programming period began in 2021, when the EU´s goals addressed several challenges in the economic recovery after the multicrisis and in environmental protection, e.g., NextGenerationEU recovery programs and the European Green Deal **[24]**.

Table 2 Estimation results – dependent variable – government spending on environmental protection (COFOG 05).

		Full sample	**Cluster 1**	**Cluster 2**	**Full sample**	**Cluster 1**	**Cluster 2**	**Full sample**	**Cluster 1**	**Cluster 2**
Period	**Control variables**		**%GDP**			**%of Total**			**milEURpc**	
2000-2005	N	0.0064 (0.8855)	0.0125 (0.8259)	-0.0028 (0.9698)	-0.0255 (0.4531)	0.0130 (0.7629)	-0.0854 (0.1251)	0.1897 (< 0.0001) ***	0.2174 (< 0.0001) ***	0.1650 (< 0.0001) ***
	Y	0.0037 (0.9332)	0.0116 (0.8361)	-0.0106 (0.8876)	-0.0296 (0.3806)	0.0054 (0.9001)	-0.0859 (0.1330)	0.1794 (< 0.0001) ***	0.2043 (< 0.0001) ***	0.1297 (0.0005) ***
2006-2011	N	-0.1845 (0.0034) ***	-0.2084 (0.0044) ***	-0.0748 (0.4828)	-0.3434 (< 0.0001) ***	-0.3692 (< 0.0001) ***	-0.1286 (0.3014)	0.1513 (< 0.0001) ***	0.1539 (0.0002) ***	0.1295 (0.1571)
	Y	0.1912 (0.0026) ***	-0.2273 (0.0023) ***	-0.1016 (0.4510)	-0.3159 (< 0.0001) ***	-0.3443 (< 0.0001) ***	-0.2028 (0.1346)	0.1627 (< 0.0001) ***	0.1628 (0.0001) ***	0.1762 (0.1308)
2012-2017	N	0.0188 (0.7777)	0.1183 (0.2128)	-0.0756 (0.4206)	0.0416 (0.3970)	0.0729 (0.2716)	-0.0028 (0.9685)	0.0739 (0.0083) ***	0.1026 (0.0013) ***	-0.0668 (0.2699)
	Y	-0.0046 (0.9355)	-0.0391 (0.6418)	-0.0551 (0.5269)	0.0428 (0.3840)	0.0604 (0.3556)	-0.0367 (0.6330)	0.1319 (< 0.0001) ***	0.1465 (< 0.0001) ***	0.0371 (0.5432)
2018-2023	N	-0.0552 (0.0023) ***	-0.0649 (0.0126) **	-0.0491 (0.0840) *	-0.0358 (0.0084) ***	-0.0579 (0.0004) ***	-0.0179 (0.4629)	-0.067 (0.1621)	-0.1192 (0.094) *	-0.0135 (0.8180)
	Y	-0.0550 (0.0018) ***	-0.0766 (0.0028) ***	-0.0490 (0.0803) *	-0.0330 (0.0100) **	-0.056 (0.0005) ***	-0.0201 (0.3752)	-0.0481 (0.3286)	-0.0946 (0.2103)	-0.0076 (0.8980)

Note: Beta estimates presented with p-values in parentheses. *** denotes the significance level 0.01, ** 0.05, an d * 0.1. Y – control variables included; N – control variables not included.

The results shown in Table 3 are the same as those presented in Table 2. Again, the way the variables are expressed matters. However, a systematic relationship between climate tax revenue and environmental protection expenditure is observed when variables are expressed as a percentage of GDP and total, rather than in millions of EUR per capita. Again, the results for the full sample resemble those for Cluster 1.

In the sub-period 2000-2005, climate tax revenues positively affect environmental protection expenditures in all estimations except for cluster 2.

In the sub-period 2006-2011, there is a turnover: the relationship between climate tax revenues and environmental protection expenditures is negative and statistically significant, except for variables expressed in millions of EUR per capita, which are in line with our previous findings presented in Table 2.

In the sub-period 2012-2017, the relationship between climate tax revenues and environmental protection expenditures is not statistically significant.

In the sub-period 2018-2023, the signs of the beta estimates are negative across all estimations, again, in line with our previous findings presented in Table 2.

Table 3 Estimation results – dependent variable – government spending on pollution abatement (COFOG 05.3).

		Full sample	**Cluster 1**	**Cluster 2**	**Full sample**	**Cluster 1**	**Cluster 2**	**Full sample**	**Cluster 1**	**Cluster 2**
Period	**Control variables**	**%GDP**			**%of Total**			**milEURpc**		
2000-2005	N	0.0386 (0.0392) **	0.0535 (0.0581) *	0.0249 (0.2770)	0.0002 (0.0593) *	0.0001 (0.3046)	0.0002 (0.0180) **	0.0098 (0.0782) *	0.0184 (0.0167) **	0.0025 (0.7797)
	Y	0.0438 (0.0096) ***	0.06834 (0.0067) **	0.0260 (0.2289)	0.0002 (0.0139) **	0.0002 (0.1279)	0.0002 (0.0190) **	0.0061 (0.2376)	0.0145 (0.0392) **	-0.0071 (0.4087)
2006-2011	N	-0.1491 (0.0032) ***	-0.1811 (0.0032) ***	-0.0092 (0.5623)	-0.0021 (< 0.0001) ***	-0.0024 (< 0.0001) ***	0.0000 (0.7080)	0.0124 (0.5851)	0.0111 (0.6708)	0.0225 (0.1294)
	Y	-0.1487 (0.0036) ***	0.1828 (0.0037) ***	-0.0135 (0.5033)	-0.0021 (< 0.0001) ***	-0.0025 (< 0.0001) ***	0.0000 (0.9232)	0.0179 (0.4463)	0.0166 (0.5410)	0.0263 (0.1842)
2012-2017	N	0.0289 (0.3236)	-0.0156 (0.7131)	0.0688 (0.0913) *	0.0001 (0.4458)	0.0000 (0.9092)	0.0004 (0.2931)	-0.0106 (0.4206)	-0.0129 (0.4221)	0.0004 (0.9854)
	Y	0.0256 (0.3808)	-0.0504 (0.2464)	0.0446 (0.2973)	0.0002 (0.4548)	0.0000 (0.9905)	0.0000 (0.9942)	-0.0027 (0.8561)	-0.0014 (0.9381)	0.0096 (0.7036)
2018-2023	N	-0.0555 (0.0003) ***	-0.0399 (0.0255) **	-0.0684 (0.0242) **	-0.0005 (< 0.0001) ***	-0.0005 (< 0.0001) ***	-0.0005 (0.0298) **	-0.0967 (< 0.0001) ***	-0.1218 (0.0006) ***	-0.0638 (0.0145) **
	Y	-0.05659 (0.0004) ***	-0.0516 (0.0071) ***	-0.0718 (0.0188) **	-0.0005 (< 0.0001) ***	-0.0005 (< 0.0001) ***	-0.0005 (0.0176) **	-0.0989 (0.0001) ***	-0.1308 (0.0006) ***	-0.0634 (0.0166) **

Note: Beta estimates presented with p-values in parentheses. *** denotes the significance level 0.01, ** 0.05, and * 0.1. Y – control variables included; N – control variables not included. Bulgaria was excluded from the estimations due to data unavailability for the COFOG 05.3 expenditure category.

The results are partially consistent with those of Famulska et al. **[2]** and Knežević and Pavlović **[5]**, which assume a positive relationship between environmental tax revenues and environmental protection expenditures. However, the results are sensitive to the period specification, which reveals several turnovers in the relationship and indicates a nonlinear pattern, supporting the findings of Esen et al. **[7]**. However, the reason is different. According to Esen et al. **[7]**, people pollute and destroy the environment less only after a certain threshold in the level of environmentally related taxes, so climate taxes should be well-designed and optimal. Similarly, the research by Aydin and Esen **[33]** examines the threshold in the relationship between climate taxes and pollution levels. In our results, the non-linear relationship is driven by periods of crisis that hamper economies and shift policy away from environmental improvement toward countercyclical government interventions, as well as by other external factors, such as changes in environmental policy, mainly adopted in EU countries.

Another issue is that differences in the variables in the question are country-specific, as noted in Famulska et al. **[2]**; thus, the trends in climate tax revenues are not universal. Besides, the overall economic development of the countries is important Stern **[10]**, He et al. **[11]**, when more developed countries with higher economic growth rates implement environmental improvements as suggested Stern **[10]**. As mentioned by Liobikienė et al. **[4],** environmental taxes induce investment in abatement technologies, whereas Oates **[3]** warns about the simple increase in public spending. In line with statements of Oates **[3]**, Zhan et al. **[6]** warn about the use of additional revenue to pay for the public deficit and public debt without any impact on the environment or without the revenue-recycling effect discussed in work Oates **[3]**. Additionally, authors Kinyar and Bothongo **[14]** note the role of government environmental spending when "polluters" tend to behave as free riders. Finally, the uniform approach to environmental policies is questionable, as Chen et al. **[8]** argue that countries need customized environmental tax policies to mitigate climate vulnerability and to spend public resources effectively in line with the United Nations Sustainable Development Goals **[31]**. Additionally, according to Caglar and Yavuz **[32]**, environmental protection is a public good whose provision should be tailored to local circumstances, specifics, and needs.

In conclusion, the literature on environmentally related public spending supports increasing this category of public expenditures because it improves the country's environmental performance **[34]**. Additionally, as noted by Wen et al. **[35]**, increased environmental protection expenditures demonstrate the government´s interest in the environment and improve citizens' well-being, as climate change has various social and economic impacts **[36]**. The government's commitment to environmental issues is considered fundamental **[29]**, and both environmental protection expenditures and climate taxes play an important role in shaping environmental policies, as noted by Akdag et al. **[1]** and Bozatli and Akca **[37]**. However, Dahmani **[12]** recommends refining environmental tax systems and boosting investment in sustainable technological innovations. Lower costs due to already modernized infrastructure occur after large projects are completed. Operating costs for environmental services (e.g., wastewater treatment and waste management) decreased as newer technologies became more efficient.

CONCLUSION

Industries in food and agriculture, together with the energy industry, are the major emitters, and climate taxes affect their operations through carbon taxes, methane levies, and nitrogen fertilizer taxes. However, the government can recycle public revenue generated by climate taxes for environmental protection expenditures, aiming to correct market failures such as negative externalities and to support activities that create positive externalities. As pollution becomes more expensive under climate taxes, innovation becomes more attractive, encouraging low-emission production methods and driving product reformulation. Nevertheless, the fiscal bridge between climate taxes and environmental protection depends on the government's tax and environmental policy goals. Thus, it is not automatically established, and its intensity varies within countries. This study investigates the relationship between climate-related taxation and environmental protection expenditures. The underlying expectation of a statistically significant positive relationship between climate tax revenues and environmental protection spending rests on the assumption that when countries introduce climate taxes to mitigate the adverse effects of climate change, they should also allocate the revenue generated to environmental protection. The regression analysis is conducted on a sample of 30 European countries over the period 2000–2023, comprising the 27 current member states of the European Union as well as Norway, Iceland, and Switzerland. To account for potential cross-country heterogeneity, the sample is divided into subsamples using cluster analysis, and the overall time span is segmented into subperiods to capture disturbances from economic and non-economic shocks. The results of the regression analysis are ambiguous and presented in a descriptive rather than causal manner. Tests of the expected positive relationship between climate tax revenues and environmental protection expenditures reveal several reversals in the direction of the association. These correspond to periods of crisis that constrained national economies and prompted a shift away from environmentally oriented policies toward countercyclical government interventions, as well as to other external influences, such as changes in environmental policy, particularly those adopted within the European Union. These findings point to the dominance of macro-fiscal constraints limiting the environmentally related public expenditures. However, the failure of climate tax earmarking might also play a role when shaping environmentally oriented public policies. The research contributes to filling a gap in the literature which bridges the climate tax revenues and environmental protection expenditures. Research limitations lie in the sample composition, as the adoption of the EU´s environmental programmes does not bind non-EU members. Another limitation is the different types of structural breaks presented in the monitored period. Exogenous shocks, such as crises, bring declines in GDP. Breaks at the beginnings and ends of EU programming periods often bring changes in the direction of policy targeting. Further research on the nexus of climate taxes and environmental protection expenditures will face challenges in the current dynamic geopolitical environment, including energy supply, fiscal stress in public budgets, and the need for place-based solutions to mitigate the negative impacts of climate change, which prevent countries from adopting general measures.

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Contact Address:

Lenka Maličká
Affiliation: Technical University of Košice, Faculty of Economics, Department of Finance, Němcovej 32, 040 01 Košice, Slovakia
Tel.:00421 55 602 32 84
E-mail: lenka.malicka@tuke.sk
ORCID: https://orcid.org/0000-0002-5706-5695
Author contribution: conceptualisation, methodology, software, validation, formal analysis, investigation, resources, data curation, writing – original draft, writing – review & editing, visualisation.

Corresponding author: **Lenka Maličká**

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