“Environmentally related taxes and their influence on decarbonization of the economy”

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ENVIRONMENTALLY RELATED TAXES AND THEIR INFLUENCE ON DECARBONIZATION OF THE ECONOMY

Abstract

Environmental taxes ensure sustainable development, but their fiscal and environmental effectiveness differs for countries with different socio-economic characteristics. This study aims to compare the impact of environmental tax revenues on economy's decarbonization (measured through carbon productivity – the ratio of GDP to carbon dioxide emissions) in different countries, considering their green technologies development and carbon emissions. The paper analyzed OECD and World Bank statistical data for 38 OECD countries for 2002–2021 using linear panel regression models with fixed and random effects (using Hausman test and STATA 18). To identify explicit and latent patterns of this influence, which are common to certain countries, this analysis did not consider each country separately but targeted clusters, distinguished by Ward and Sturges methods based on the effective tax rate on carbon emissions, total environmental tax revenues, total carbon emissions, and carbon productivity. The positive influence of environmental tax revenues on the economy's decarbonization level has been confirmed for 29 countries (four from six clusters). The effect is the largest for the USA (an increase in tax revenues by 1% leads to an increase in carbon productivity by 0.9% on average) and the smallest – for the cluster including Austria, Belgium, Canada, Costa Rica, Czechia, Estonia, France, Germany, Hungary, Iceland, Korea, Lithuania, New Zealand, Poland, Portugal, Slovakia, Spain, and the Great Britain (increase – 0.1%). The negative impact was confirmed for nine countries (two from six clusters): Denmark, Finland, Israel, Latvia, and Sweden (decrease – 0.3%) and Greece, Italy, the Netherlands, and Slovenia (decrease – 0.21%).

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INTRODUCTION

Decarbonization of the economy is a key direction of international and national policies to overcome global challenges caused by climate change and the negative impact of carbon emissions on the environment, people's well-being, and socio-economic and sustainable development. Reducing and stabilizing the concentration of gases depends on agreed policies at all levels of government – local, regional, national, and international, strong partnerships and close attention at the global level to achieve the goals of the Paris Agreement (UN, 2015), which requires structural changes to overcome carbon dependence and decarbonization of the economy. In this regard, the main instruments of climate and economic policy are updated, such as a clear carbon price and the gradual elimination of all fossil fuel subsidies (OECD, 2017). Emission pricing, carbon taxes, and incentives aim to reduce emissions at the lowest possible cost (OECD, n.d.e). Effective management, leadership, and innovative approaches are also critical to achieving these and other goals (Zomchak & Nehrey, 2022; Gentsoudi, 2023; Oe et al., 2023; Olaniyan & Adepeju, 2023; Pakhnenko & Kuan, 2023).

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All over the world, countries are still far from fully utilizing the potential of policies and tools to decarbonize the economy. However, experts, scientists, and policymakers, comparing various instruments of influence, are inclined to the opinion that no instrument is clearly superior to the rest. Therefore, the emphasis should be on a strategic integrated approach (emissions pricing, norms and standards, policies to promote the redistribution of capital, labor, and innovation in favor of low-carbon activities) (D'Arcangelo et al., 2022). Among the complex of these instruments, an important place is also given to environmentally related taxes, i.e., fees levied on a physical unit of an object that has a proven negative impact on the environment (a gallon of gasoline, a passenger flight, or a ton of waste sent to a landfill) (IMF, n.d.).

National policies are characterized by both differences and similarities in taxation mechanisms, tax rates and revenues, and efficiency level. This actualizes the issue of the cluster approach when the influence of environmentally related taxes on the decarbonization of the economy is checked and estimated.

1. LITERATURE REVIEW

EU's modern green policy is oriented toward sustainable European development and involves the assessment of the parameters of the national ecosystems of the EU member states (Kuzior et al., 2022a; Davydenko et al., 2022). Thus, the need to reduce carbon dioxide emissions by reducing energy consumption is emphasized (Kuzior et al., 2022b). The impact of renewable energy on greenhouse gas emissions is an urgent issue. Kwilinski et al. (2024) used regression models with lags to confirm that an increase in annual investment in off-grid renewable energy by USD 1 million leads to a decrease in CO_2 by 1.18 kt and N_2O by 1.102 kt. For the global development of renewable energy technologies, governments must understand their impact on changing the scale of environmental pollution. Skowron et al. (2023) concluded the interdependence of renewable energy production and CO_2 emissions.

Sustainable development, green brand, and eco-friendly approaches are a priority scientific direction toward the balance of economic growth, social justice, and environmental protection to solve urgent global challenges (Lyeonov et al., 2021; Starchenko et al., 2021; Bhandari, 2023; Titenko et al., 2023; Oe & Yamaoka, 2023). The focus is on the current state and problems of implementing the concept of sustainable development of industrial regions, violations of environmental requirements by industrial enterprises, and non-compliance with environmental standards (Kuzior, 2010; Sotnyk, 2012; Kuzior & Lobanova, 2020; Naseer et al., 2023). In addition, the concept of development and environmental protection is considered at the intersection with security (Didenko et al., 2020; Didenko et al., 2021).

Along with economic and social development, ecological development plays an important role in ensuring sustainable development (Chygryn et al., 2023). Sotnyk (2016) analyzed problems and prospects of energy efficiency and decarbonization of economy. Kurbatova et al. (2019), Kuzior et al. (2021), Boiko et al. (2023), and Chygryn and Shevchenko (2023) confirmed a stable trend in the growth of demand for renewable energy. Artyukhova et al. (2022) discovered a positive relationship between renewable energy consumption, GDP per capita, and foreign direct investment.

Vakulenko et al. (2023) analyzed the concept of a carbon-neutral economy. Carbon taxes are recognized as an effective means of mobilizing significant domestic resources for sustainable development. However, despite their advantages, some scholars investigated potential negative impacts on poverty and inequality. Dorband et al. (2022) suggest that lower-income households will bear a lower consumption burden from carbon pricing than higher-income households.

Heine and Black (2018) argue that well-designed environmental taxation is particularly valuable in developing countries, where it can reduce emissions, increase domestic revenues, and create positive welfare impacts. However, despite significant potential, large gaps in environmental tax levels persist around the world, especially in developing countries (Patel et al., 2023; Storonyanska et al., 2023; Davydenko et al., 2023). The dynamics of environmental tax revenues are inferior to the dynamics of general tax revenues in GDP, and in this regard, attracting additional funding and financial outsourcing is an option (Koval et al., 2023; Njegovanović, 2023; Oliinyk et al., 2023; Vytvytska et al., 2023).

Leonov et al. (2022) and Timilsina et al. (2021) put attention on an economy with significant informality, where a carbon tax can bring fiscal co-benefits that will improve economic performance in addition to reducing carbon emissions. Tiutiunyk et al. (2022), Zolkover et al. (2022), Tiutiunyk et al. (2023), Mazurenko et al. (2023a), and Mazurenko et al. (2023b) assessed the impact of shadow evasion by taxpayers, including environmental taxes, on the level of competitiveness of the tax system.

Bilan et al. (2020) and Bozhenko et al. (2023) studied the "pollution-shadow economy" chain while assessing the impact of individual factors and the level of carbon intensity of the gross domestic product (GDP). They also focused on the dependence of the carbon intensity of GDP on the level of shadowing of the economy and the size of tax payments. Ziabina and Acheampong (2023), Ziabina et al. (2023a), and Ziabina et al. (2023b) characterized the chain of waste management, fiscal and financial policy for green development, and energy balance transformation.

Melnyk and Kubatko (2012, 2013) and Melnyk et al. (2016) investigated different instruments and practices in the context of the EU experience for Ukraine to adapt the economy to green innovations. Special attention was paid to regional differentiation (Mentel et al., 2018). Doğan et al. (2022) investigated the impact of an environmental tax on carbon dioxide emissions for the G7 countries from 1994 to 2014. They proved that environmental taxes effectively reduce emissions for these countries and suggested redistributing tax revenues to research and development of sustainable technology programs. Burns et al. (2021) studied carbon tax scenarios in the case of Pakistan and identified that a USD 20 carbon tax could reduce emissions by 36% by 2050. The impact on GDP could also be positive if carbon tax revenues were used to reduce reliance on highly distortive taxes. Letunovska et al. (2021), Matvieieva and Hamida (2022), Vostrykov and Jura (2022), and Matvieieva et al. (2023) also quantify the co-benefits of improved health and productivity. Singh and Pandey (2023) described India's experience in achieving Sustainable Development Goals. Rafique et al. (2022) examined the role of environmental taxes in the growth of the ecological footprint in 29 OECD countries. They showed that environmental taxes, economic growth, foreign direct investment, urbanization, energy use, industrialization, and renewable energy sources significantly affect the long-term ecological footprint.

At the same time, the impact of environmentally related taxes on the decarbonization of the economy has not been comprehensively studied. Determining the impact in terms of individual clusters formed based on specific indicators in the context of the study requires special attention.

Therefore, the purpose of this study is to compare the impact of environmentally related tax revenue on carbon productivity in identified clusters within OECD member countries depending on their similar explicit and implicit features related to effective carbon rate, total environmentally related tax revenue, carbon dioxide emission, and carbon productivity.

2. METHODS

This study employed cluster and regression analysis and economic and mathematical modeling using MS Excel and STATA 18. Cluster analysis was based on Ward's and Sturges methods using previously normalized data (Ward, 1963; Kaufman & Rousseeuw, 1990; Scott, 2009; Blank, 2016).

The number of clusters within which the impact of environmental taxes on the decarbonization of the economy is analyzed using Sturges' rule (formula) (Blank, 2016):

$$n = 1 + 3.322 \cdot \lg N, \tag{1}$$

where n is the number of clusters; N is the number of research objects.

Ward's method was chosen for cluster analysis (Ward, 1963). It belongs to the hierarchical ap-

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proach when groups are combined based on the measure of the distance between them to maximize the objective function. When the sum of squared errors is small, the data are close to the cluster means, and there is a cluster of similar units. At each clustering step, the linkage centroid (mean value) joins the groups whose means are the closest. The centroid of the group is the component average and can be interpreted as the center of gravity of the group (Kaufman & Rousseeuw, 1990; Stata, n.d.b).

Since the input data have different dimensions, there is a need for preliminary data normalization. For this purpose, the minimum and maximum values and normalized values were generated accordingly for each indicator, using STATA 18 tools and the following formula:

$$normal\_I = \frac{I - \min\_I}{\max\_I - \min\_I}, \qquad (2)$$

where I is a value of certain indicator; min_I, max_I, *normal_I* are accordingly minimum, maximum, and normalized value of certain indicator.

To determine the influence of environmentally related taxes on decarbonization of economy, linear regression models for panel data estimation with fixed and random effects were built, in particular with estimations within each formed cluster (Allison, 2009; Baltagi, 2013; Schunck, 2013). The model specification was chosen based on Hausman test result (Hausman, 1978).

Research sample includes all 38 OECD members countries for 20 years from 2002 to 2021 based on statistical data of OECD and the World Bank. The following indicators were considered:

- Effective Carbon Rates (ECR) (OECD, n.d.b);
- Environmentally Related Tax Revenue: total value (T) (OECD, n.d.c);
- Carbon Dioxide emission (C) (OECD, n.d.a);
- GDP, current USD (GDP) (World Bank, n.d);
- Carbon Productivity as the ratio of GDP to Carbon Dioxide Emission (CP);
- Environment-related technologies (patents) as a percentage of technologies (EP) (OECD, n.d.d).

3. RESULTS AND DISCUSSION

When studying environmental taxes and their impact on the decarbonization of the economy, attention should be paid to the Effective Carbon Rate (*ECR*). It describes the amount of taxes and tradable permits that actually set the price of carbon emissions resulting from emission permit prices, fuel excises, and carbon taxes and how countries price carbon emissions according to the cost of carbon (OECD, n.d.e). Sixty euros per ton of CO2 was stated by the OECD to be a mid-range estimate of carbon costs in 2020 and a low estimate for 2030 (the average cost estimate for carbon emissions in 2030 is projected as 120 euros). These control estimates are given according to the OECD methodology, which is the basis for calculating the ECR. Accordingly, a price of 60 euros or more in all emissions (100%) shows that the country is effective in achieving the goal of the Paris Agreement to decarbonize the economy. An ECR of 100% means that the country values all carbon emissions at or above the cost of carbon, while a 0% level, on the contrary, indicates that the country does not put a price on carbon emissions (OECD, n.d.b; OECD, n.d.e; OECD, 2021). Besides, countries with a high score tend to emit less than countries that score almost no emissions. In many countries, emissions are not measured at all, and 90% are estimated at a price of less than 30 euros per ton.

Figure 1 shows the results of a comparative analysis of ECR in OECD member countries in 2021.

Leading countries with high scores (Greece, Luxemburg, Germany, Ireland, Slovenia, and Norway) emit less carbon dioxide per unit of GDP and are better prepared for the decarbonization of the economy. The average ECR is 51.97%.

The other significant indicator of the decarbonization of the economy is Carbon Productivity. Stabilizing the concentration of gases in the atmosphere depends on the implementation of the effective and adopted policy of the country and its

Source: OECD (n.d.b).

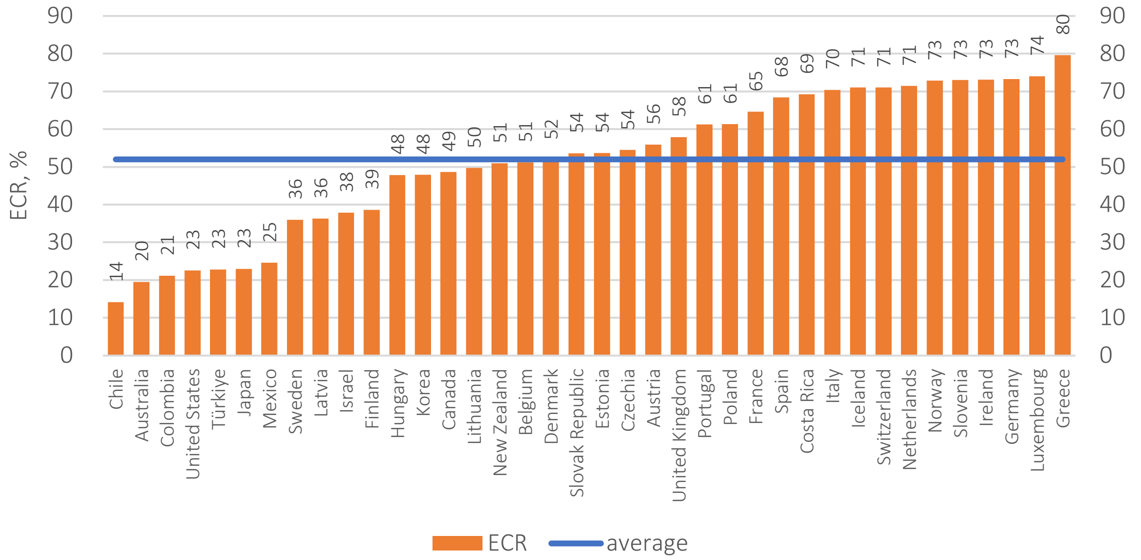

Figure 1. Comparative analysis of ECR in OECD member countries in 2021

ability to separate the growth of emissions from economic growth and reduce the overall level of emissions. The achievement of the economy's decarbonization goals can be assessed by trends in emissions productivity in terms of production and demand, the so-called footprint, and the level of decoupling between emissions and economic growth (OECD, 2017).

This study calculated this indicator as a ratio of GDP to Carbon Dioxide Emission (OECD, n.d.a; World Bank, n.d). Figure 2 shows the formed rating of OECD member countries according to Carbon Productivity in 2021.

The average carbon productivity is 6,772,483 USD/thousands of tons of CO2. The resulting value for

Source: OECD (n.d.a) and World Bank (n.d).

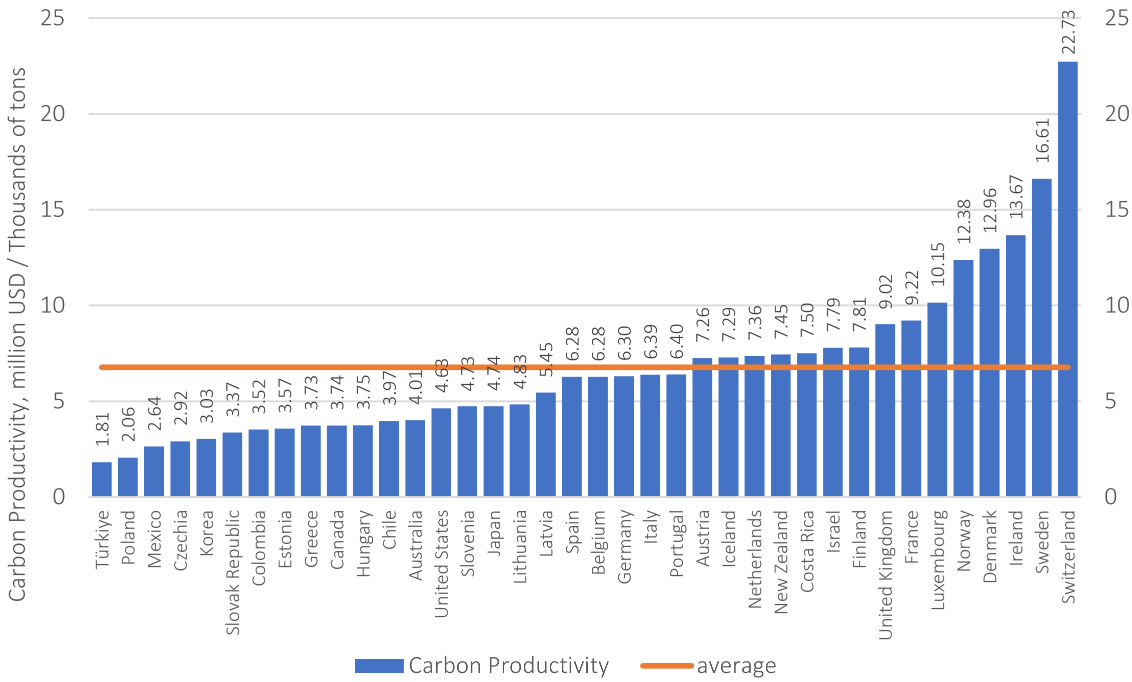

Figure 2. Rating of OECD member countries according to Carbon Productivity in 2021

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each country reflects the economic value (in terms of GDP) per unit of emissions and shows the relative gap between economic activity and carbon emissions. Switzerland, Sweden, Ireland, Denmark, and Norway have the highest level of Carbon Productivity. In general, the carbon productivity of the economies of the OECD countries is characterized by a positive trend since emissions increased at a lower rate than real GDP (relative decoupling), for example, in Türkiye, Korea, or Estonia; some countries showed a reduction in emissions in absolute terms (absolute decoupling), for example Sweden and Denmark.

At the same time, OECD countries have differences regarding leadership in this or that indicator of the efficiency of decarbonization of the economy, as well as regarding the level of environmentally related taxes in general and on an individual basis. Therefore, it is advisable to conduct a cluster analysis within the OECD member countries to determine which of these countries have similarities or differences, including hidden features. Moreover, one needs to trace the data structure in the context of the studied indicators of the policy of decarbonization of the economy and environmental taxation and group them into homogeneous clusters for further study of the impact of environmentally related taxes on decarbonization of the economy within the defined clusters. Table 1 shows normalized input data.

Table 1. Normalized input data

Country	Effective Carbon Rate	Total Environmentally Related Tax Revenue	Carbon Dioxide Emission	Carbon Productivity
Australia	0.0909	0.2938	0.0766	0.1051
Austria	0.6364	0.5375	0.0124	0.2605
Belgium	0.5606	0.3313	0.0183	0.2136
Canada	0.5303	0.1719	0.1061	0.0921
Chile	0.0000	0.1469	0.0152	0.1031
Colombia	0.1061	0.0000	0.0173	0.0819
Costa Rica	0.8333	0.4688	0.0010	0.2722
Czechia	0.6061	0.5156	0.0185	0.0528
Denmark	0.5758	0.7281	0.0055	0.5329
Estonia	0.6061	0.5594	0.0014	0.0841
Finland	0.3788	0.6125	0.0068	0.2869
France	0.7727	0.5375	0.0631	0.3543
Germany	0.8939	0.3250	0.1343	0.2147
Greece	1.0000	1.0000	0.0107	0.0917
Hungary	0.5152	0.5344	0.0090	0.0927
Iceland	0.8636	0.3844	0.0000	0.2620
Ireland	0.8939	0.1781	0.0068	0.5671
Israel	0.3636	0.5594	0.0118	0.2861
Italy	0.8485	0.7781	0.0664	0.2190
Japan	0.1364	0.2219	0.2105	0.1400
Korea	0.5152	0.6563	0.1186	0.0584
Latvia	0.3333	0.7625	0.0007	0.1738
Lithuania	0.5455	0.4156	0.0021	0.1443
Luxembourg	0.9091	0.1969	0.0010	0.3988
Mexico	0.1667	0.1313	0.0983	0.0395
The Netherlands	0.8636	0.8000	0.0271	0.2653
New Zealand	0.5606	0.1750	0.0061	0.2694
Norway	0.8939	0.3469	0.0074	0.5052
Poland	0.7121	0.6250	0.0651	0.0118
Portugal	0.7121	0.5656	0.0072	0.2193
The Slovak Republic	0.6061	0.4313	0.0063	0.0746
Slovenia	0.8939	0.9094	0.0019	0.1398
Spain	0.8182	0.3938	0.0451	0.2136
Sweden	0.3333	0.4156	0.0070	0.7073
Switzerland	0.8636	0.3500	0.0064	1.0000
Türkiye	0.1364	0.3281	0.0893	0.0000
The United Kingdom	0.6667	0.4469	0.0686	0.3445
The United States	0.1364	0.0188	1.0000	0.1349

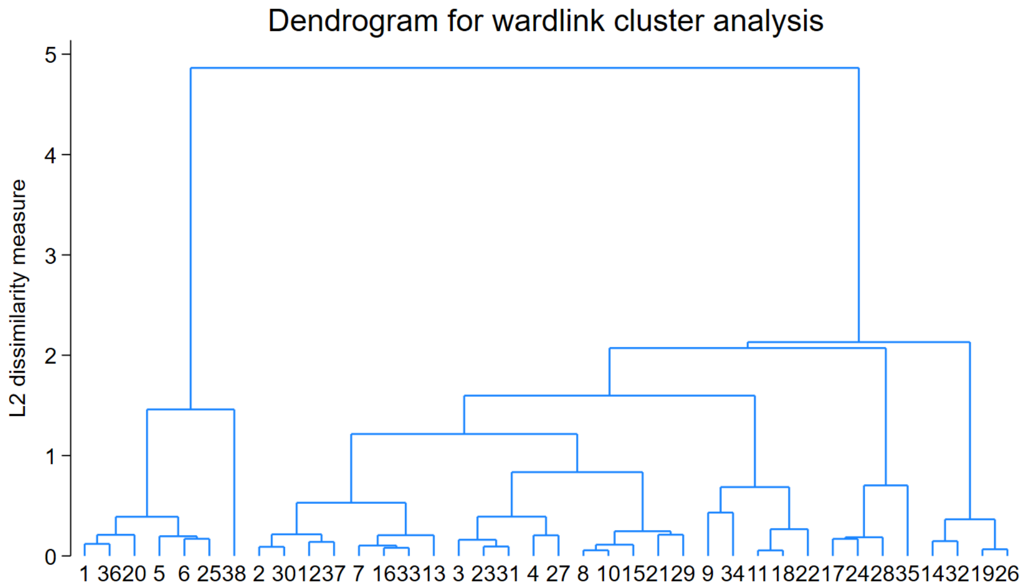

Figure 3. Dendrogram for Ward link cluster analysis

The number of countries in the sample is 38, and the optimal number of clusters is equal to six, according to Sturges' rule (formula 1).

A dendrogram for Ward link cluster analysis graphically represents information about which observations are grouped together at different levels of similarity/dissimilarity (Figure 3).

In the lower part of the dendrogram, observation objects are located. Vertical lines extend upwards for each observation, and at different values of similarity/dissimilarity, these lines are connected to the lines of other observations by a horizontal line. The observations continue to be combined until they are grouped together at the top of the dendrogram. The height of the vertical lines and the range of the axis of dissimilarity make it possible to visually come to a conclusion about the strength of clustering. The longer the vertical lines, the clearer the division into groups. Accordingly, these groups (clusters) are well separated from each other, and vice versa: the shorter these lines, the less the groups differ from each other (Stata, n.d.a).

Figure 4 shows descriptive characteristics of cluster analysis obtained with STATA 18 tools.

The first cluster includes six countries (15.79%), the second – one (2.63%), the third – 18 (47.37%),

```
. cluster generate group = groups(6), name(wardlink) ties(error)

. tabulate group
```

group	Freq.	Percent	Cum.
1	6	15.79	15.79
2	1	2.63	18.42
3	18	47.37	65.79
4	5	13.16	78.95
5	4	10.53	89.47
6	4	10.53	100.00
Total	38	100.00	

```
. tabstat normal_ECR normal_T normal_C normal_CP, by(group)

Summary statistics: Mean
Group variable: group
```

group	normal~R	normal_T	normal_C	normal~P
1	.1060606	.1869792	.0845299	.0782684
2	.1363636	.01875	.9999999	.1349141
3	.6641414	.4486111	.0379601	.1797098
4	.3969697	.615625	.0063691	.3973981
5	.8901515	.2679687	.0053884	.6177685
6	.9015152	.871875	.0265334	.1789269
Total	.5757576	.4435033	.061842	.2371861

Figure 4. Descriptive characteristics of cluster analysis

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the fourth – five (13.16%), the fifth – four (10.53%), and the sixth – four (10.53%) countries from the studied sample of OECD countries. Table 2 gives detailed information about the country's distribution in the formed clusters.

Table 2. The country's distribution in the formed clusters

Country	Wardlink_ id	Wardlink_ ord	Wardlink_ hgt	Cluster number
Australia	1	1	.12025448	1
Austria	2	36	.21052964	3
Belgium	3	20	.39069144	3
Canada	4	5	.1962087	3
Chile	5	6	.17104519	1
Colombia	6	25	1.4597184	1
Costa Rica	7	38	4.8637896	3
Czechia	8	2	.09085352	3
Denmark	9	30	.21533129	4
Estonia	10	12	.13995642	3
Finland	11	37	.530109	4
France	12	7	.1038702	3
Germany	13	16	.08085599	3
Greece	14	33	.20681819	6
Hungary	15	13	1.2148513	3
Iceland	16	3	.16140315	3
Ireland	17	23	.09378371	5
Israel	18	31	.39167302	4
Italy	19	4	.20585238	6
Japan	20	27	.83512836	1
Korea	21	8	.0564451	3
Latvia	22	10	.11215978	4
Lithuania	23	15	.24632232	3
Luxembourg	24	21	.21165128	5
Mexico	25	29	1.5976438	1
The Netherlands	26	9	.43222565	6
New Zealand	27	34	.68615254	3
Norway	28	11	.0554685	5
Poland	29	18	.26660719	3
Portugal	30	22	2.071556	3
The Slovak Republic	31	17	.17011865	3
Slovenia	32	24	.18622285	6
Spain	33	28	.70321426	3
Sweden	34	35	2.1310492	4
Switzerland	35	14	.14780853	5
Türkiye	36	32	.36507033	1
The United Kingdom	37	19	.06626396	3
The United States	38	26	.00000000	2

Table 3 presents the generalized results of the division of 38 OECD countries into clusters depending on effective carbon rates, total environmentally related tax revenue, carbon dioxide emission, and carbon productivity.

Table 3. Generalized results of country clustering

Cluster number	Countries name
1	Australia, Chile, Colombia, Japan, Mexico, Türkiye
2	United States
3	Austria, Belgium, Canada, Costa Rica, Czechia, Estonia, France, Germany, Hungary, Iceland, Korea, Lithuania, New Zealand, Poland, Portugal, the Slovak Republic, Spain, the United Kingdom
4	Denmark, Finland, Israel, Latvia, Sweden
5	Ireland, Luxembourg, Norway, Switzerland
6	Greece, Italy, the Netherlands, Slovenia

Linear regression models for panel data estimation with fixed and random effects were built to confirm the impact of environmentally related taxes (based on the total value of Environmentally Related Tax Revenue) on decarbonization of economy (based on indicator of Carbon Productivity calculated as the ratio of GDP to Carbon Dioxide Emission) (Allison, 2009; Baltagi, 2013; Schunck, 2013).

The data were previously normalized. First, it is checked whether the random effects specification is appropriate for the individual-level effects in the model, and a fixed-effects regression model is built that captures all time-constant individual-level effects. Table 4 shows the results of the linear regression model with fixed effects for the countries panel of cluster 1 (six countries).

This model is assumed to be consistent with the true parameters, so the results using save estimates are stored under a fixed name.

Next, a random effects model is chosen as a fully efficient specification of the individual effects, assuming that they are random and normally distributed. Table 5 shows the results of the linear regression model with random effects for the countries panel of the first cluster.

After that, the scores are compared with the previously saved results using the Hausman test (Hausman, 1978); the results are given in Figure 5.

The obtained results indicate that the initial hypothesis that individual-level effects are ade-

Table 4. Linear regression model with fixed effects for countries panel of cluster 1

CP	Coefficient	Std. err.	t	P > t [95%]	[95% conf. interval]
T	.2629242	.1711718	1.54	0.127	–.076264 .6021125
C	–.8389338	.4045547	–2.07	0.040	–1.640586 –.0372816
EP	–.4428869	.1341959	–3.30	0.001	–.7088051 –.1769686
_cons	.5200991	.1788643	2.91	0.004	.1656676 .8745307
sigma_u .21358256, sigma_e .155452 F test that all u_i = 0: F(5, 111) = 6.64, Prob > F = 0.0000 Prob > F = 0.0001					

Note: CP – Carbon Productivity as the ratio of GDP to Carbon Dioxide Emission; T – total value of Environmentally Related Tax Revenue; C – Carbon Dioxide emission; EP – Environment-related technologies/patents.

Table 5. Linear regression model with random effects for countries panel of cluster 1

CP	Coefficient	Std. err.	t	P > t [95%]	[95% conf. interval]
T	.2783505	.1524735	1.83	0.068	–.0204921 .5771931
C	–.3567042	.1638777	–2.18	0.030	–.6778987 –.0355098
EP	–.4450853	.1283387	–3.47	0.001	–.6966245 –.193546
_cons	.3660913	.1302821	2.81	0.005	.1107431 .6214395
sigma_u .13008094, sigma_e .155452 Prob > chi2 = 0.0000					

quately modeled by the random effects model is accepted. So, it was concluded that an increase in the total value of environmentally related tax revenue by 1% leads to an increase in carbon productivity by 0.28% on average (with a level of statistical significance of 93.2%). Moreover, this result indicates a positive impact in the context of decarbonization of the economy. At the same time, an increase in carbon dioxide emissions by 1% leads to a decrease in carbon productivity by 0.36% (with a level of statistical significance of 97%).

Analogous commands and tools were applied to the country panels of the rest of the formed clusters, except for the second cluster, which included only one country (the USA), and accordingly, in this case, a linear regression model was built for the time series. Table 6 shows the generalized results of the regression analysis with distribution into clusters.

```
. . hausman fixed ., sigmamore

                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |     fixed          .          Difference       Std. err.
-------------+----------------------------------------------------------------
          nT |   .2629242     .2783505       -.0154263        .0760768
          nC |  -.8389338    -.3567042       -.4822296        .3678783
         nEP |  -.4428869    -.4450853        .0021984         .037088
------------------------------------------------------------------------------
                          b = Consistent under H0 and Ha; obtained from xtreg.
           B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

    chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
            =   1.97
Prob > chi2 = 0.5780
```

Figure 5. Results of Hausman test to determine the specification of linear regression model for countries panel of the first cluster

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Table 6. The generalized results of the regression analysis to confirm the impact of environmentally related taxes (Environmentally Related Tax Revenue) on the decarbonization of the economy (Carbon Productivity)

Cluster	Cluster's membership of countries	Model specification	Model adequacy	Statistical significance level	Interpretation of the impact
1	Australia, Chile, Colombia, Japan, Mexico, Türkiye	Random-effects linear regression (panel data estimation)	Prob > chi2 = 0.0000	93.2%	1% ↑T → 0.28% ↑ CP
2	The United States	Linear regression	R-squared = 0.9602 Prob > F= 0.0000	100%	1% ↑T → 0.9% ↑ CP
3	Austria, Belgium, Canada, Costa Rica, Czechia, Estonia, France, Germany, Hungary, Iceland, Korea, Lithuania, New Zealand, Poland, Portugal, the Slovak Republic, Spain, the United Kingdom	Random-effects linear regression (panel data estimation)	Prob > chi2= 0.0000	97.5%	1% ↑T → 0.1% ↑ CP
4	Denmark, Finland, Israel, Latvia, Sweden	Fixed-effects linear regression (panel data estimation)	Prob > F = 0.0000	99.5%	1% ↑T → 0.3% ↓ CP
5	Ireland, Luxembourg, Norway, Switzerland	Fixed-effects linear regression (panel data estimation)	Prob > F = 0.0000	100%	1% ↑T → 0.51% ↑ CP
6	Greece, Italy, the Netherlands, Slovenia	Fixed-effects linear regression (panel data estimation)	Prob > F = 0.0000	98.7%	1% ↑T → 0.21% ↓ CP

For four out of six clusters identified in the research process, the investigated impact was confirmed. The impact of environmentally related taxes (Environmentally Related Tax Revenue) on the decarbonization of the economy (Carbon Productivity) is positive. In the other two clusters (the fourth and the sixth), this impact was not confirmed. This can be explained by differences in the policies and a shift in emphasis in favor of greater use and, accordingly, a more significant impact of other instruments compared to the one under study. Besides, quantitative estimates of impact vary from cluster to cluster. The maximum positive impact occurs in the second (the USA) and the fifth cluster (Ireland, Luxembourg, Norway, and Switzerland).

This study has several limitations. First, the sample of countries is limited to the list of OECD members. Secondly, the study period was 20 years. In further research, these parameters can be expanded.

Youssef et al. (2023) sought to confirm the role of environmental taxes in environmental results. However, they focused on a different sample of countries, in particular on the countries of the European Economic Area, as well as a different toolkit and methods than this study (cross-sectional autoregressive distributed lag model and dynamic common correlated effects). Their study found a negative correlation between environmental taxes and CO2 emissions, emphasizing the more significant effect of changes in production capacity on reducing these emissions. In contrast, this study found positive effects of tax policies on carbon productivity in most countries, which are at the heart of both economic growth and emissions.

Kamalu and Binti Wan Ibrahim (2023) studied the impact of an environmental tax on decarbonization targeting 25 developing countries from 1993 to 2019 (compared to this study that sampled 38 countries for 2002–2021). Their results showed that an environmental tax contributes to full decarbonization and that an environmental tax policy can reduce CO2 emissions, correct environmental externalities, and generate revenue.

Also traditional in the scientific literature are conclusions about "double dividends" in the ecological economy from environmental taxes, which contribute both to the reduction of emissions of pollutants and to the increase of GDP and/or economic efficiency from the use of environmental tax revenues (Parry, 2015). This current study quantitatively assessed the positive impact of the tax, including on the volume of emissions (in the example of the first cluster).

Criqui et al. (2019) comparatively analyzed carbon taxation in three countries – Sweden, Canada, and France. They showed that carbon taxes, when implemented, do have the intended effect. However, different positions in terms of achievements, challenges, and results highlight the need to consider the social and political conditions for the adoption and effective implementation of such economic instruments. These conclusions fully correspond to the findings of this current study since, in different clusters, there are both different quantitative dimensions of the effect and the opposite nature of the effect in some of them.

As for clustering done by Vasylieva et al. (2020), they defined four groups using Ward's hierarchical method but also considering other relevant indicators and determining relationships between changes in tax revenues from energy, transport, environmental taxes on pollution, and GDP growth rates. In contrast, this study identified the links with carbon productivity, which covers not only GDP change but also changes in carbon dioxide emissions.

CONCLUSION

The research purpose was to compare the impact of environmentally related tax revenue on carbon productivity in identified clusters within OECD member countries depending on their similar explicit and implicit features related to effective carbon rate, total environmentally related tax revenue, carbon dioxide emission, and carbon productivity.

Thirty-eight OECD member countries were divided into six clusters. For four of six identified clusters (29 countries), the positive impact of environmentally related tax revenue on carbon productivity was confirmed. The maximum positive impact occurs in the USA (cluster 2), where an increase in tax revenues by 1% leads to an increase in carbon productivity by 0.9% on average (statistical significance is 100%). The smallest is shown by cluster 3, including Austria, Belgium, Canada, Costa Rica, Czechia, Estonia, France, Germany, Hungary, Iceland, Korea, Lithuania, New Zealand, Poland, Portugal, Slovakia, Spain, and the Great Britain (increase – 0.1%, statistical significance – 97.5%). In cluster 1 (Australia, Chile, Colombia, Japan, Mexico, and Türkiye), an increase in the total value of environmentally related tax revenue by 1% leads to an increase in carbon productivity by 0.28% on average (with a level of statistical significance of 93.2%), and in cluster 5 (Ireland, Luxembourg, Norway, and Switzerland) – by 0.51% (statistical significance is 100%).

In two of the six clusters, the studied impact was negative (nine countries). In clusters 4 (Denmark, Finland, Israel, Latvia, and Sweden) and 6 (Greece, Italy, the Netherlands, and Slovenia), the positive impact was not confirmed. An increase in the total value of environmentally related tax revenue by 1% leads to a decrease in carbon productivity by 0.3% and 0.21%, respectively. This can be explained by differences in the policies of these countries and a shift in emphasis in favor of greater use and more significant impact of other instruments.

The obtained results can become the basis for further research of the internal causes, factors, and common and distinctive features in the identified clusters, where a different direction of influence of revenues from environmental taxes on the level of carbon productivity, in particular positive and negative influence, was revealed. Further research should also be devoted to a detailed study of this influence on a global sample, as well as the clustering of countries, not only taking into account the increase in the sample size but also the dynamics of the transition between clusters in different historical periods. This will help identify effective tools and policies for the decarbonization of the economy and sustainable development.

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