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Original Research

Reducing Air Pollution: Are Environmental Taxes Enough to Help the EU Member States Reach Climate Neutrality by 2050?

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Abstract

Recently, the European Union has officially announced that its' objective in terms of environmental policy is to achieve climate neutrality, including long-term low greenhouse gas emission, by 2050. In light of this, the current study aims to offer a new and updated perspective on the effectiveness of environmental taxes in reducing air pollution in the European Union. Firstly, cluster analysis is used to group the member states of the European Union according to characteristics that will make the research results more robust. Secondly, panel data dynamic error correction models were estimated for each cluster to assess the effect of environmental taxes (and other explanatory variables) on emissions of carbon dioxide on the one hand, and greenhouse gases in general on the other hand. The research looks at both short-run and long-run effects on air pollution. The results show a statistically significant negative long-run relationship between environment taxes and atmospheric pollutants emissions. However, this effect would happen with a certain delay and it would be short lived, which makes additional environment policy measures necessary to achieve the 2050 targets.

Keywords: environmental taxes, air pollution, climate neutrality, dynamic error correction model, European Union

Introduction

Protecting the environment is one of the main concerns of the European Union as it is stated in Article 3 of the Treaty on European Union. Furthermore, Article 191 of the Treaty on the Functioning of the European Union establishes combating climate change as one of the objectives of the European Union. The beginnings of the EU's environmental concerns can be traced back to 1973 when six Environmental Action Programs were decided upon. Even if they were not binding, they did mention goals and environmental policy strategies [1]. In many ways, these programs paved the way for environment protection legislation such as the NEC-Directive (2001/81) which set national emission limits for four pollutants and the 2003 Emission Trading Directive which set carbon dioxide emissions targets per each EU member state. These limits have been adjusted throughout the past two decades leading up to the EU's current climate targets for long-term low greenhouse gas emission [2].

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The objective of the EU is to achieve climate neutrality by 2050. This brings to the spotlight the discussion on how this objective could be achieved most efficiently. One widely used solution for reducing air pollution is the implementation of environmental taxes. The rationale behind environmental taxes is that pollution is a type of market failure due to the negative externalities attached to different activities (like transport) or the production process for certain goods (like energy). To correct this market failure, the external costs need to be internalized by including them in the price of the good or service. The definition of environmental taxes currently used by the European Environment Agency is the same as the one used by the UN: "a tax whose tax base is a physical unit (or a proxy of it) of something that has a proven, specific negative impact on the environment" [3]. In the European Union, the environmental taxes include four categories of taxes: energy taxes (including CO_2 taxes), transport taxes, pollution, and resource taxes.

In 2018, the total revenue collected from environment taxes across the EU was 324.6 billion EUR which represents 2.4% of the EU gross domestic product (GDP). Most of this came from energy taxes (77.7%) and the tax burden was shared almost equally between corporations and households. On average, in the EU, the revenue from environment taxes represents 6% of all revenue from taxes and social contributions with individual country percentages varying from 10.9% in Latvia to 4.4% in Luxembourg. Over the past two decades, the level of environmental taxes has changed very little both in terms of percentage of the EU GDP as well as in terms of percentage of total revenue from taxes and social contributions [4].

The research background on environmental taxes is quite diverse with several research directions. Some studies focus on providing an overview of environment taxes in the EU. Sterner and Köhlin talk about the high levels of environment taxes in the EU compared to the US and the diversity of issues regarding these taxes within the EU [5]. Other studies focus on comparative statistical analysis and provide detailed individual overviews of the types of environmental taxes and excise duties used by each EU member state [6-8].

The main research direction of interest for the current study is focused on the efficiency of environment taxes as a market-based instrument used by the governments to achieve pollution reduction goals [9, 10]. In 1996, authors Ekins, Andersen and Vos looked at 16 examples of environment taxes in different EU member states with the conclusion that some of these taxes seem to be environmentally efficient in achieving their objectives at a reasonable cost [11]. But since then, further analyses conducted regarding the efficiency of environment taxes seems to lead to conflicting conclusions.

Some authors clearly support the implementation of environmental taxes and they provide evidence of pollution-reducing efficiency of environmental taxes. Rapanos and Polemis analyzed a series of different environment tax level in Greece and concluded that an increase in these taxes to the maximum EU level would significantly restrict CO_2 emissions [12]. Morley studied the effectiveness of environmental taxes using panel data from the EU and Norway and found evidence of a significant negative relationship between environmental taxes and pollution [13]. Authors Hájek, Zimmermannová, Helman, and Rozenský evaluate the effectiveness of carbon taxes in the energy industries of a few EU member states (Sweden, Finland, Denmark, Ireland and Slovenia). The authors have found evidence of a significant relationship between the consumption of fossil fuels and greenhouse gases emissions and they conclude that carbon taxes are efficient in that an increase in the tax rate would lead to a reduction of greenhouse gases production [14]. In a recent study, authors Niu, Yao, Shao, Li, and Wang look at environment tax shocks and conclude that these can led to a reduction of carbon emissions in China [15].

However, other researchers seem to believe that the issue of environmental taxes efficiency is not as clear cut [16, 17]. Felder and Schleiniger argue that CO_2 taxes are not efficient by themselves, and they suggest a combination of a uniform CO_2 tax with differentiated labor subsidies as a better solution [18]. Aydin and Esen used dynamic panel threshold analysis to answer the question of whether environment taxes help reduce CO_2 emissions in 15 EU member states. Above the threshold level, the authors concluded that the effect of environmental taxes ranges from insignificantly positive to significantly negative [19]. Authors He, Ning, Yu, Xiong, Shen, and Jin use a panel auto-regressive distributed lag modelling approach to study the efficiency of environment taxes in 35 OECD countries and China. The authors find evidence that OECD countries with low industrial added value show "relatively good" short-term pollutant emission reduction effects for environmental taxes, but in China the provinces with high industrial added value are the ones with a better pollution reduction effect for the environmental taxes [20]. Other Chinese authors show that integrated policy mixes, in particular revenue from carbon taxes being used to reduce capital taxes or to provide a clean energy subsidy would improve the performance of carbon taxes in reducing carbon dioxide emissions [21].

Research studies published for single countries are equally unable to give a clear answer to the question of efficiency of environmental taxes in reducing air pollution. A study on the efficiency of environment taxes in the Czech Republic published by Nerudova and Solilovac concludes that these taxes are inefficient in terms of discouraging the purchase of goods that cause CO_2 emissions and that they are mainly used as a source of revenue for the government [22]. Authors Radulescu, Sinisi, Popescu, Iacob, and Popescu analyzed the environment tax policy in Romania using a vector error correction model and recommended granting environmental subsides instead of increasing environment taxes to achieve a reduction in pollutant emissions as well as economic growth [23]. Mardones and Baeza study the effectiveness of CO_2 taxes in three different Lantin America countries (Brazil, Mexico and Chile) and they conclude that the decrease in total emissions in those countries can be described as "heterogeneous" [24].

All in all, the research background does not provide a clear answer to the question of how efficient environmental taxes truly are in reducing pollutant gas emissions in the European Union. Because the EU has set climate neutrality as an objective to be reached by 2050 it is clear that further research is needed.

The current study aims to contribute to answering the question of how effective current environment taxes are as a tool for decreasing greenhouse gases emissions. There are three main contributions of this study to the existing literature: (1) an updated database with EU member states grouped according to similarities in environmental policy; (2) a research method which includes both short-run and long-run policy effects; (3) an analysis of alternative policy measures. Firstly, this study is conducted using data for the current 27 member states of the EU (excluding the UK) which offers an updated view on the issue of environment protection. Furthermore, country specific characteristics are acknowledged, and cluster analysis is used to group the countries with similar traits when it comes to pollution issues and current environment protection policies. Using clusters of member states leads to solutions with better applicability for each member state. Secondly, using error correction models as a research method allows for both long-run and short-run results to be analyzed and, consequently, the efficiency of environment taxes in the reduction of pollution can be viewed from different time perspectives. Finally, several other explanatory variables (such as the consumption of fossil fuels and the percentage of renewable energy in gross final energy consumption in transport) are included in the error correction models and they provide answers regarding alternative environmental policy measures.

Material and Methods

The environment has been an official area of policy for the European Union ever since 1993 (the Treaty of Maastricht). This has been reflected in a number of directives, programs and projects, including establishing a Sustainable Development Strategy in 2001 and, more recently, the Europe 2020 strategy for smart, inclusive and sustainable growth [25]. However, the implementation of any policy falls to individual member states, each with its unique business environment and challenges, each with its own economic strengths and weaknesses. Consequently, any study conducted for the EU as a whole focuses on the similarities between the member states and overlooks the differences.

Cluster Analysis

The first part of the current research will be dedicated to placing the member states into groups based on individual characteristics of the economy, national environmental policy and extent of environmental issues. The method used for grouping the EU countries is K-means cluster analysis which remains a very popular choice [26] in spite of being first proposed in the 1950s. Many improvements have been developed for this method [27] leading to various applications, including research on greenhouse gas emissions in EU countries [28, 29].

Briefly, K-means cluster analysis is used to group objects (countries, in this situation) based on information used to describe the characteristics of these objects. As a result, all countries with similar characteristics will be allocated to the same group (or cluster). Similarity is judged based on distance (Euclidean distance) to the center (or centoid) of each cluster. Since K, the number of clusters, must be specified, the analysis is run for different numbers of clusters and the best version is chosen.

The cluster analysis was run for the current 27 EU member states. Four variables were used to describe not only the level of economic activity in each EU member state, but also its environmental policy and

Table 1. Variables used for cluster analysis.

Symbol	Name of variable	Source
ECO_INNOV	Eco-innovation index	Eco-Innovation Observatory, Eurostat database - dataset code [T2020_RT200] time period 2010-2018
ENVIRON_TAXBURDEN	Environmental tax burden	Eurostat database - dataset code [T2020_RT320] time period 2008-2018
EC_GROWTH	Economic growth	Eurostat database - dataset code [TEC00115] time period 2008-2018
CO2_E_NEW_CARS	Average CO_2 emissions per km from new passenger cars	European Environment Agency (EEA), European Commission - Directorate-General for Climate Action (DG CLIMA) Eurostat database - dataset code [SDG_12_30] time period 2008-2018

its level of pollution (Table 1). The first variable used is the Eco-innovation index. The indicator is calculated as the unweighted mean of 16 sub-indicators which take into account areas such as eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency outcomes and socio-economic outcomes. The EU average is 100 and the indicator shows how each country compares to this average.

The second variable considered is the environmental tax burden calculated as percentage of GDP represented by environmental taxes. Therefore, the size of the economy is considered when deciding on the overall tax burden due to the environmental policy of the member state. Next, the level of economic growth was included as real GDP growth rate (volume). The calculation is based on a chain-linked series, where the GDP in current prices is adjusted for the prices of the previous year and so the effect of inflation on the indicator is eliminated. The final variable is a measure of the level of pollution - the average carbon dioxide (CO_2) emissions per kilometer by new passenger cars. It must be noted that the reported emissions are based on type-approval and can differ from actual emission of new cars.

A further step in the cluster analysis is to assess the level of correlation between the four variables in order to decide if they can all be included in the analysis [30]. This was done using a correlation matrix (Table 2). A weak negative correlation can be observed between the average CO_2 emissions per new car and the eco-innovation index, as well as with the environmental tax burden. Given that all correlations are either weak or insignificant, all four variables will be included in the cluster analysis.

The analysis was run for K ranging from 1 to 4 and the selection criteria was the Sum of Squared Error (SSE) calculated using Equation 1.

$$SSE = \sum_{i=1}^{K} \sum_{x \epsilon Ci} dist^2(x, m_i) \qquad (1)$$

...where $\boldsymbol{x}$ is an object in cluster C_i, $\boldsymbol{m_i}$ is the centroid (mean value) of cluster C_i and ***dist*** is the error in the distance. The smallest SSE will be chosen. After the cluster analysis, based on SSE values, the best choice was to group the EU member states into two clusters.

Cluster 1 can be described as including the more economically developed and technologically advanced countries in the EU. As a result, in this cluster there are countries with high values for the eco-innovation index (above 100) and low levels of average CO_2 emissions per kilometer for new passenger cars. The level of economic growth is also low which is specific to countries that are already considered to be developed economies. In addition, the level of environmental tax burden is low which is justified by the high level of tax revenue received from other sources (income taxes, consumption taxes). Again, this is a characteristic of developed economies. Cluster 1 includes the following countries: Belgium, Czechia, Denmark, Germany, Ireland, Spain, France, Italy, Luxembourg, the Netherlands, Austria, Portugal, Finland, and Sweden.

Cluster 2 is made up of the other 13 EU member states and its characteristics are the opposite of those described for Cluster 1. The number of countries in each cluster is almost equal to Cluster 1, which was one more reason for choosing to use two clusters. Most of the newer member states of the EU (joined in 2004 or later) were placed in Cluster 2. The only newer member state that was included in Cluster 1 was Czechia. This can be explained mainly due to two of the four variables: the eco-innovation index and the environmental tax burden. Czechia has been improving its eco-innovation index over the past 5 years, reaching a value of 100 in 2018 which puts it closer to the average for Cluster 1 than Cluster 2. As for the environmental tax burden, this has been almost 2% for the same past 5 years which is again in closer proximity to the average for Cluster 1.

Panel Data Regression

Panel data was used for each of the two clusters. Panel data is appropriate for this type of research as it allows the consideration of information for several variables calculated for different countries for a period of 19 years (2000-2018). This offers greater flexibility than time series or cross-sectional data would enable. All in all, the research conducted included 266 observations for Cluster 1 and 247 observations for Cluster 2.

The time period included in the analysis begins in 2000 because it was the year when the European

Table 2. Correlation matrix for cluster analysis variables.

	ECO_INNOV	ENVIRON_TAXBURDEN	EC_GROWTH	CO2_E_NEW_CARS
ECO_INNOV	1			
ENVIRON_TAXBURDEN	-0.058397	1		
EC_GROWTH	-0.050390	-0.177137***	1	
CO2_E_NEW_CARS	-0.264469***	-0.242404***	-0.098718	1

Note: ***indicates the statistical significance at 1% levels; **indicates the statistical significance at 5% levels; *indicates the statistical significance at 10% level

Table 3. Description of variables.

Variable	Explanation	Source
Carbon dioxide emissions (CO_2)	Total national emissions of carbon dioxide – tonnes per capita	European Environment Agency (EEA), Eurostat database - dataset code [env_air_gge]
Greenhouse gas emissions (GHG)	Total national emissions of greenhouse gas – tonnes per capita	European Environment Agency (EEA), Eurostat database - dataset code [env_air_gge]
Environmental tax (ENVIRON_TAX)	Environmental tax revenue as percentage of total revenues from taxes and social contributions	Eurostat database - dataset code [T2020_RT320]
Oil consumption (OIL_C)	Oil and petroleum products consumption (energy and non-energy) – tonnes per capita	Eurostat database - dataset code [nrg_cb_oil]
Fossil fuel consumption (FOS_FUEL_C)	Solid fossil fuels consumption – tonnes per capita	Eurostat database - dataset code [nrg_cb_sff]
Economic growth (GDP_GR)	Annual percentage growth rate of GDP	World bank database - World Development Indicators – code [NY.GDP.MKTP.KD.ZG]
Renewable energy sources in transport (REN_TRANSP)	Annual percentage of renewable energy in gross final energy consumption in transport	Eurostat database - dataset code [SDG_07_40]
Number of passenger cars (NO_CARS)	Number of petroleum and diesel engine passenger cars per 1000 people – natural logarithm	Eurostat database - dataset code [road_eqs_carhab]
Population of country (SIZE)	Size of the population of the EU member state – logarithm	Eurostat database - dataset code [demo_pjan]

Commission launched its Clean Air for Europe program and it set limit values for carbon monoxide and benzene in Directive 2000/69/EC. Furthermore, a proposal for a Directive on national emission ceilings for certain atmospheric pollutants was issued in February 2000. This was a significant step towards combating air pollution in the EU.

The main research variables considered for both clusters are carbon dioxide emissions, greenhouse gas emissions, environmental taxes, oil consumption and fossil fuel consumption. Addition variables included in the research are related to the size of the economy (economic growth and population) as well as passenger car usage and use of renewable energy in the transport sector. Table 3 includes further explanations of the variables used.

All data used was extracted from the Eurostat database or from the World bank database (see Table 3). To avoid problems related to different units of measurement and make the results more robust some variables were adjusted using logarithms or were converted in per capita values.

The variables chosen to be used in the analysis are closely linked to the research hypotheses. The main research question is that of the efficiency of environment taxes as market-based instruments to reduce the emissions of pollutants. Consequently, the first research hypothesis is stated below.

$\boldsymbol{H_1}$ – Environment taxes in the European Union directly lead to a reduction in the emissions of greenhouse gases in general and carbon dioxide in particular.

However, environment taxes are not the only tool available to governments aimed at reducing air pollution and there are many other factors that influence the emissions of atmospheric pollutants. All this has led to including several additional variables in the research which allow for further hypotheses to be tested.

$\boldsymbol{H_2}$ – The use of renewable energy in the transport sector has a significant impact in decreasing the emissions of greenhouse gases in general and carbon dioxide in particular.

$\boldsymbol{H_3}$ – The use of passenger cars with petroleum or diesel engines directly contributes to the increase of emissions of greenhouse gases in general and carbon dioxide in particular.

The other control variables are widely used in studies regarding the efficiency of environment taxes [12-20] and the expectation is that this research will confirm previous results. Therefore, the anticipated result is that the consumption of oil will have a significant positive effect on emissions of both carbon dioxide and greenhouse gases, in general. A similar effect is expected for the consumption of fossil fuel: the anticipated result is that the research will show a positive significant effect on the emissions of atmospheric pollutants.

Economic growth, which is measured using changes in the real gross domestic product (GDP), is expected to also have an effect on the emissions of pollutants. Usually, for a more economically developed country, there should be a smaller level of economic growth from one year to the next than for a less economically developed country. But the more developed countries also have higher levels of greenhouse gas and carbon dioxide emissions and more strict environment protection laws. All in all, it is difficult to form an expectation as to the impact of this variable on the emissions of atmospheric pollutants.

Finally, the size of the population should have a positive impact on the emissions of greenhouse gases and carbon dioxide, in particular. This expectation is based on the idea that a bigger population will lead to a higher level of consumption of goods and services that are produced using a process that involves emissions of atmospheric pollutants.

Before running any type of analysis, descriptive statistics were used for each cluster to identify any outliers or distortions in the data which could affect the robustness of the results (Table 4). Though most of the data showed no surprising values, some of the numbers required further investigation. For example, the maximum value for economic growth in Cluster 1 was above 25%. This is the value that Ireland reported in 2015 and it is a statistical fact though several analysts seem to agree it was due to an increase in Ireland's stock of productive assets as a large aircraft leasing company moved its headquarters to Ireland. It was speculated that the decision reflected Ireland's potential for tax avoidance practices more than its economic reality [31, 32]. The large negative values for economic growth for both clusters (Finland in Cluster 1 and Estonia in Cluster 2) were reported in 2009 and they were the effects of the global financial crisis which affected all the EU Member States.

A further item which required attention was the negative minimum value for CO_2 emissions in Cluster 1. This was reported by Sweden in 2016. In fact, Sweden reported negative values for the period 2015-2018. These values are due to two factors. The first one is the way the indicator is calculated as tonnes of CO_2 per capita for all sectors of the economy excluding land use, land use change and forestry (LULUCF). As these net removals had remarkably high values in Sweden and exceeded the emissions, the result was a negative number. This brings us to the second factor. In the past decades, Sweden has been one of the leading countries in terms of decreasing air pollution and CO_2 emissions. For example, it was one of the first countries to introduce and successfully implement a carbon tax in 1991 [33]. More recently, Sweden has committed to not have any net emissions of greenhouse gases by 2045 and achieve negative emissions afterward [34].

Table 5 shows the correlation matrix for the variables used in the analysis by cluster. There is a strong positive relationship between the consumption of

Table 4. Descriptive statistics.

Cluster 1					
Variable	Mean	Median	Max	Min	St. Deviation
CO_2	8.265286	8.048367	24.85759	-0.355283	4.495136
GHG	10.30947	9.954692	26.85298	0.862597	4.763322
ENVIRON_TAX	6.702762	6.345	10.75	4.32	1.53807
OIL_C	1.637378	1.342801	6.679678	0.780095	1.150471
FOS_FUEL_C	1.148006	0.59911	6.062082	0.120491	1.347526
GDP_GR	1.789725	1.954304	25.16253	-8.0746616	3.58597
REN_TRANSP	5.51161	5.173	29.696	0.04	4.952221
NO_CARS	6.219545	6.185179	6.536692	5.874931	0.138502
SIZE	7.085715	7.020357	7.91799	5.657973	0.561633
Cluster 2					
Variable	Mean	Median	Max	Min	St. Deviation
CO_2	5.551489	5.011314	13.28182	0.933886	2.766792
GHG	7.43022	6.71298	15.15703	2.9155072	2.723709
ENVIRON_TAX	8.302601	8.09	11.75	5.34	1.379651
OIL_C	0.765034	0.684359	1.95277	0.34073	0.312101
FOS_FUEL_C	1.809192	1.381318	6.558737	0.001155	1.835733
GDP_GR	2.627798	3.374687	11.8881	-14.81416	4.468515
REN_TRANSP	3.10241	2.521	8.542	0.053	2.265873
SIZE	6.724766	6.730231	7.581957	5.890048	0.455186

Table 5. Correlation matrix.

Cluster 1									
Variable	CO_2	GHG	ENVIRON_TAX	OIL_C	FOS_FUEL_C	GDP_GR	REN_TRANSP	NO_CARS	SIZE
CO2	1								
GHG	0.983607***	1							
ENVIRON_TAX	0.202774***	0.262984***	1						
OIL_C	0.785434***	0.750131***	-0.037367	1					
FOS_FUEL_C	0.172463**	0.162396**	-0.028772	-0.259175***	1				
GDP_GR	0.179474***	0.220362***	0.019321	0.129249	0.087954	1			
REN_TRANSP	-0.459713***	-0.478324***	-0.308496***	-0.178791***	-0.095391	-0.001367	1		
NO_CARS	0.316559***	0.225386***	-0.264374***	0.529863***	-0.220673***	-0.094794	0.152087**	1	
SIZE	-0.532403***	-0.568999***	-0.240550***	-0.717802***	0.161214**	-0.190446***	0.027433	-0.143858**	1
Cluster 2									
Variable	CO_2	GHG	ENVIRON_TAX	OIL_C	FOS_FUEL_C	GDP_GR	REN_TRANSP	SIZE	
CO2	1								
GHG	0.991965***	1							
ENVIRON_TAX	0.061225	0.064008	1						
OIL_C	0.506536***	0.491427***	0.176362**	1					
FOS_FUEL_C	0.204396***	0.200251***	0.129062*	-0.077068	1				
GDP_GR	0.002047	0.023014	-0.080389	-0.113602	-0.060060	1			
REN_TRANSP	-0.356693***	-0.374106***	-0.169814**	-0.373239***	0.041326	0.023957	1		
SIZE	-0.186349**	-0.183511**	-0.226718***	-0.581040***	0.616937***	0.051951	0.362887***	1	

Source: Author's calculations
*** indicates the statistical significance at 1% level
** indicates the statistical significance at 5% level
* indicates the statistical significance at 10% level

Table 6. Unit root tests.

Cluster 1								
Variable	Levin-Lin-Chu Test		Im-Pesaran-Shin Test		Augmented Dickey-Fuller Test		Phillips-Perron Test	
	Level	1st Difference	Level	1st Difference	Level	1st Difference	Level	1st Difference
CO_2	-1.7088**	-12.1297***	1.43658	-11.524***	16.5915	160.661***	13.2084	204.652***
GHG	-1.6865**	-11.1502***	1.87766	-10.8784***	13.8146	153.909***	12.6662	219.173***
ENVIRON_TAX	1.96586	-9.76962***	2.14157	-9.71352***	17.3605	136.207***	15.4193	128.661***
OIL_C	-3.682***	-12.0984***	-1.15643	-10.6968***	34.705	150.883***	13.8735	407.133***
FOS_FUEL_C	-0.69538	-13.5234***	1.73208	-12.0287***	22.0962	168.259***	25.38	222.415***
GDP_GR	-0.92963	-9.10768***	1.37093	-6.73902***	18.4364	94.2388***	13.1033	104.781***
REN_TRANSP	-0.43929	-10.8434***	1.50288	-8.21024***	24.0594	113.108***	29.8985	147.237***
NO_CARS	-1.4266*	-9.06082***	0.7829	-6.92636***	29.2271	99.8139***	27.4094	96.2148***
SIZE	2.73313	-2.52095***	5.58064	-2.18512**	36.8061	44.4952**	22.538	33.1401
Cluster 2								
Variable	Levin-Lin-Chu Test		Im-Pesaran-Shin Test		Augmented Dickey-Fuller Test		Phillips-Perron Test	
	Level	1st Difference	Level	1st Difference	Level	1st Difference	Level	1st Difference
CO_2	-1.24427	-8.9149***	-0.47847	-8.84202***	32.933	121.536***	43.037**	194.876***
GHG	-1.61482	-9.82434***	-0.58194	-9.56935***	32.3552	128.22***	35.3593	194.78***
ENVIRON_TAX	-1.45843*	-13.1519***	-1.64641**	-9.31092***	36.433*	110.313***	33.5283	116.451***
OIL_C	-1.55539*	-8.59058***	-1.10863	-7.47247***	37.414*	102.124***	21.0094	119.665***
FOS_FUEL_C	-0.35307	-12.4065***	0.77845	-10.4567***	18.7298	135.328***	24.8025	234.404***
GDP_GR	-1.21277	-6.81518***	0.84942	-4.61382***	22.7904	64.992***	17.3587	56.1589***
REN_TRANSP	0.00333	-5.72997***	2.14851	-4.73844***	15.7093	68.8821***	26.5101	53.5449**
SIZE	3.47226	-6.91753***	7.24827	-6.60051***	16.2358	125.61***	31.8732	186.072***

Source: Author's calculations
*** indicates the statistical significance at 1% level
** indicates the statistical significance at 5% level
* indicates the statistical significance at 10% level

oil and carbon dioxide and greenhouse gases emissions for both clusters. There is a weak correlation between the environmental tax and air pollutant emissions for Cluster 1, but there seems to be no significant relationship between the same variables for Cluster 2. Also, there is a significant negative relationship between the percentage of renewable energy in gross final energy consumption in transport and the emissions of carbon dioxide and greenhouse gases for both clusters.

For each cluster, the number of years included in the data set (19 years) exceeds the number of countries included in the cluster (14 countries in Cluster 1 and 13 countries in Cluster 2). Consequently, unit-root tests were run for each cluster to reduce the risk of errors in the regressions and in the analysis due to non-stationary data. Four unit-root tests were run for more accurate results: the widely used and rather classical unit-root tests proposed by Dickey-Fuller in 1979 and Phillips-Perron in 1988 as well as the more recent unit-root tests for panel data proposed by Levin-Lin-Chu in 2002 and Im-Pesaran-Shin in 2003 [35-38]. The results in Table 6 show that while most of the data is not stationary at level values, all data series are stationary at first difference for a significance level of 1%.

The unit-root tests performed lead to the overall conclusion that the series are integrated of the first order (they are non-stationary at level, but they are stationary at first difference). Therefore, a cointegration test is necessary to establish the existence of a stable long-run relationship between the variables which are to be included in the regression models. Table 7 shows the results for the cointegration test proposed by Kao in 1999 [39]. This test has a null hypothesis of "no cointegration" and uses the augmented Dickey-Fuller (ADF) statistic. The results allow the rejection of the null hypothesis at a significance level of 1% for Cluster 1, respectively at a significance level of 5% for Cluster 2. In other words, there is a long-run relationship between the variables for both clusters.

To sum up the results of the previous tests, the research variables are integrated of the first order and cointegration is present. This makes it appropriate to use an error correction model (ECM) in which deviations from the long-run equilibrium have an influence over short-run dynamics [40]. In this study, single equation dynamic error correction models were used to analyze the effect of several explanatory variables on carbon dioxide emissions and greenhouse gases emissions.

Equations (2) and (3) refer to Cluster 1 while the other two equations refer to Cluster 2. The variables included in the equations are as follows:

- CO_2 represents carbon dioxide emissions in country i in year t
- GHG represents greenhouse gas emissions in country i in year t
- ENVIRON_TAX represents the environmental tax revenue in country i in year t
- OIL_C represents the consumption of oil and petroleum products in country i in year t
- FOS_FUEL_C represents the consumption of fossil fuel in country i in year t
- GDP_GR represents the economic growth of country i in year t
- REN_TRANSP represents the use of renewable energy sources in the transport sector in country i in year t
- NO_CARS represents the use of petroleum and diesel fueled passenger cars in country i in year t
- SIZE represents the size of the population of country i in year t

$$\Delta CO2_{it}\sum_{j=1}^{p-1}\alpha_{ij}\Delta CO2_{i,t-1}+\sum_{j=0}^{q1-1}\beta_{ij}\Delta ENVIRON\_TAX_{i,t-j}+\sum_{j=0}^{q2-1}\gamma_{ij}\Delta OIL\_C_{i,t-j}+ \\ = \sum_{j=0}^{q3-1}\vartheta_{ij}\Delta FOS\_FUEL\_C_{i,t-j}+\sum_{j=0}^{q4-1}\rho_{ij}\Delta GDP\_GR_{i,t-j}+\sum_{j=0}^{q5-1}\sigma_{ij}\Delta REN\_TRANSP_{i,t-j}+ \\ \sum_{j=0}^{q6-1}\tau_{ij}\Delta NO\_CARS_{i,t-j}+\sum_{j=0}^{q7-1}\varphi_{ij}\Delta SIZE_{i,t-j}+\delta_1 CO2_{i,t-1}+\delta_2 ENVIRON\_TAX_{it}+\delta_3 OIL\_C_{it}+ \\ \delta_4 FOS\_FUEL\_C_{it}+\delta_5 GDP\_GR_{it}+\delta_6 REN\_TRANSP_{it}+\delta_7 NO\_CARS_{it}+\delta_8 SIZE_{it}+\mu_i+\varepsilon_{it} \tag{2}$$

$$\Delta GHG_{it}\sum_{j=1}^{p-1}\alpha_{ij}\Delta GHG_{i,t-1}+\sum_{j=0}^{q1-1}\beta_{ij}\Delta ENVIRON\_TAX_{i,t-j}+\sum_{j=0}^{q2-1}\gamma_{ij}\Delta OIL\_C_{i,t-j}+ \\ = \sum_{j=0}^{q3-1}\vartheta_{ij}\Delta FOS\_FUEL\_C_{i,t-j}+\sum_{j=0}^{q4-1}\rho_{ij}\Delta GDP\_GR_{i,t-j}+\sum_{j=0}^{q5-1}\sigma_{ij}\Delta REN\_TRANSP_{i,t-j}+ \\ \sum_{j=0}^{q6-1}\tau_{ij}\Delta NO\_CARS_{i,t-j}+\sum_{j=0}^{q7-1}\varphi_{ij}\Delta SIZE_{i,t-j}+\delta_1 GHG_{i,t-1}+\delta_2 ENVIRON\_TAX_{it}+\delta_3 OIL\_C_{it}+ \\ \delta_4 FOS\_FUEL\_C_{it}+\delta_5 GDP\_GR_{it}+\delta_6 REN\_TRANSP_{it}+\delta_7 NO\_CARS_{it}+\delta_8 SIZE_{it}+\mu_i+\varepsilon_{it} \tag{3}$$

$$\Delta CO2_{it}\sum_{j=1}^{p-1}\alpha_{ij}\Delta CO2_{i,t-1}+\sum_{j=0}^{q1-1}\beta_{ij}\Delta ENVIRON\_TAX_{i,t-j}+\sum_{j=0}^{q2-1}\gamma_{ij}\Delta OIL\_C_{i,t-j}+ \\ = \sum_{j=0}^{q3-1}\vartheta_{ij}\Delta FOS\_FUEL\_C_{i,t-j}+\sum_{j=0}^{q4-1}\rho_{ij}\Delta GDP\_GR_{i,t-j}+\sum_{j=0}^{q5-1}\sigma_{ij}\Delta REN\_TRANSP_{i,t-j}+ \\ \sum_{j=0}^{q6-1}\varphi_{ij}\Delta SIZE_{i,t-j}+\delta_1 CO2_{i,t-1}+\delta_2 ENVIRON\_TAX_{it}+\delta_3 OIL\_C_{it}+\delta_4 FOS\_FUEL\_C_{it}+ \\ \delta_5 GDP\_GR_{it}+\delta_6 REN\_TRANSP_{it}+\delta_7 SIZE_{it}+\mu_i+\varepsilon_{it} \tag{4}$$

$$\Delta GHG_{it}\sum_{j=1}^{p-1}\alpha_{ij}\Delta GHG_{i,t-1}+\sum_{j=0}^{q1-1}\beta_{ij}\Delta ENVIRON\_TAX_{i,t-j}+\sum_{j=0}^{q2-1}\gamma_{ij}\Delta OIL\_C_{i,t-j}+ \\ = \sum_{j=0}^{q3-1}\vartheta_{ij}\Delta FOS\_FUEL\_C_{i,t-j}+\sum_{j=0}^{q4-1}\rho_{ij}\Delta GDP\_GR_{i,t-j}+\sum_{j=0}^{q5-1}\sigma_{ij}\Delta REN\_TRANSP_{i,t-j}+ \\ \sum_{j=0}^{q6-1}\varphi_{ij}\Delta SIZE_{i,t-j}+\delta_1 GHG_{i,t-1}+\delta_2 ENVIRON\_TAX_{it}+\delta_3 OIL\_C_{it}+\delta_4 FOS\_FUEL\_C_{it}+ \\ \delta_5 GDP\_GR_{it}+\delta_6 REN\_TRANSP_{it}+\delta_7 SIZE_{it}+\mu_i+\varepsilon_{it}, \tag{5}$$

In the equations 2-5 the subscript letter *i = 1, 2, ..., 13/14* represents each of the 27 member states of the EU which were previously divided into two clusters. Subscript letter *t = 2000, 2001, ..., 2018* and it represents each year of the time period. The symbol Δ is the first order difference, μ_i allows for country specific effects and ε_{it} is the white noise. The coefficients α, β, γ, ϑ, ρ, σ, and φ reveal the short-run relationship between each explanatory variable and air pollutant emissions. The parameters δ 1 to 7 show the long-run relationship between each independent variable and the carbon dioxide emissions, respectively greenhouse gases emissions. A more detailed explanation of the variables included in the equations can be found in Table 3. The next section includes a presentation and discussion of the results.

Results and Discussion

Using the Engle and Granger 2-step approach, two dynamic error correction models were estimated for

Table 7. Kao cointegration test results.

Area of research	Dependent variable	ADF statistic	p-value
Cluster 1	CO_2	-7.435864***	0.0000
	GHG	-7.392864***	0.0000
Cluster 2	CO2	-1.733303**	0.0415
	GHG	-1.664671**	0.0480

Source: Author's calculations
*** indicates the statistical significance at 1% level
** indicates the statistical significance at 5% level
* indicates the statistical significance at 10% level

each cluster of EU member states. The models are described in Equations (2-5) above and the estimation results are presented and discussed below.

Research Results for Cluster 1

The research results obtained for Cluster 1 are shown in Table 8. Cluster 1 includes the EU member states that have a higher level of economic development and technological advancement. These countries are Belgium, Czechia, Denmark, Germany, Ireland, Spain, France, Italy, Luxembourg, the Netherlands, Austria, Portugal, Finland, and Sweden.

Research hypothesis 1 seems to only be confirmed for Cluster 1 with a one-year delay. In the short-run, the effect of environment taxes on emissions of pollutants is statistically significant, but positive. This shows that the "polluter pays" principal on which environment taxes are based, initially acts as a permission for economic actors to pollute the atmosphere as long as they pay the required tax. After a one-year delay the environment taxes become an effective tool in decreasing the emissions of both greenhouse gases in general and carbon dioxide in particular. An increase in the environment taxes by 1% should lead to a decrease of pollutant emissions by 0.19% for carbon dioxide and 0.18% for greenhouse gases. This confirms research hypothesis 1. However, perhaps the most concerning result is that after a two-years delay the environment taxes are no longer effective in the reduction of air pollution. The results show a coefficient that is no longer statistically significant. This leads to the conclusion that in the long-run environment taxes alone are not an effective solution for the problem of air pollutant emissions.

Another surprising result is regarding research hypothesis 2. Even with a two-years delay, the hypothesis cannot be confirmed as the effect of using renewable energy in the transport sector on pollutants emissions seems to be insignificant. Since Cluster 1 includes the most technologically advanced countries in the EU, one possible explanation is that renewable energy use in the transport sector is already at a level where it has diminished emissions of greenhouse gases as much as possible and further improvements in this area would not make a significant difference.

Hypothesis 3 is confirmed for emissions of carbon dioxide, but not for greenhouse gases in general. The impact of diesel and petroleum passenger cars for the countries in Cluster 1 is significant when it comes to carbon dioxide pollution. The results show that an increase of 1% in the number of these passenger cars per 1000 people would lead to a 1.3% increase in the level of carbon dioxide emissions.

The equation estimations also show that previous pollutant emissions have a significant long-run impact on current emissions for both carbon dioxide, in particular, and greenhouse gases in general. As far as the control variables are concerned, the research expectations are mostly confirmed by the results of the analysis. Consumption of oil and fossil fuel have a strong positive significant impact on the emissions of atmospheric polluting gases. Furthermore, the level of economic growth also has a positive impact on air pollution confirming the idea that one trade-off of achieving economic development is polluting gases emissions.

According to the results of this research study, the countries in Cluster 1 could use a reduction in the number of passenger cars with petroleum and diesel engines as an additional environmental policy measure to green taxes. This could be done by encouraging the ownership and use of electric cars. In fact, Norway has already implemented a strategy of promoting electrical cars by a combination of subsidies, tax exemptions and other driving privileges and this has proven successful in increasing the purchase and use of electrical vehicles. So, could this be the right solution for the EU member states in Cluster 1? There are published research studies [41, 42] that argue the costs of this approach and its implementation would be very high and that the effects on decreasing levels of air pollution would be too small to justify such costs.

In light of these studies, two other approaches to reducing the number of passenger cars with petroleum and diesel engines could prove effective for the EU member states in Cluster 1. The first approach is a short-term solution, and it would consist of restrictions for

Table 8. Research results for Cluster 1.

Explanatory Variables	Dependent Variables	
	CO_2	GHG
ENVIRON_TAX	0.214095***	0.200637**
	(2.713148)	(2.513696)
L1_ENVIRON_TAX	-0.189044**	-0.180163**
	(-2.341554)	(-2.223205)
L2_ENVIRON_TAX	-0.024970	-0.043879
	(-0.332244)	(-0.584068)
OIL_C	3.756338***	3.938779***
	(10.38266)	(10.59825)
FOS_FUEL_C	2.277129***	2.241009***
	(9.412612)	(9.181469)
GDP_GR	0.022704***	0.024841***
	(3.734484)	(4.059314)
L2_REN_TRANSP	-0.003905	-0.006110
	(-0.443451)	(-0.688829)
L2_CO2	0.048605	_
	(1.357577)	
L3_CO2	0.083205**	_
	(2.605276)	
L2_GHG	_	0.055107
		(1.556066)
L3_GHG	_	0.078000**
		(2.428318)
NO_CARS	1.321770*	1.150666
	(1.757148)	(1.528300)
SIZE	-26.75645***	-29.04685***
	(-3.117153)	(-3.327892)
L1_ECM	-0.689055***	-0.662597***
	(-10.50429)	(-10.22651)
R-sq. (adjusted)	**0.78**	**0.78**
F statistic	**51.8630*** **	**53.007*** **
No countries	**14**	**14**

Source: Author's calculations using Eviews
Note: An explanation of research variables is available in Table 3; t-statistic values in ()
*** indicates the statistical significance at 1% level
** indicates the statistical significance at 5% level
* indicates the statistical significance at 10% level

the purchase and use of diesel and petroleum passenger cars. Such an approach could yield results as current lockdown measures and travel restrictions due to the coronavirus pandemic have seen level of air pollution decrease spectacularly. The second solution is a long-term one: supporting research to improve electrical cars and make their use more cost effective.

Research Results for Cluster 2

According to the cluster analysis run previously, Cluster 2 includes the EU member states which are less technologically and economically developed. Specifically, Cluster 2 includes the following 13 countries: Bulgaria, Estonia, Greece, Croatia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Romania, Slovenia, and Slovakia. The research results for Cluster 2 are presented in Table 9.

Research hypothesis 1 is only confirmed for Cluster 2 with a two-years delay. The initial effect of the environment taxes on emissions of greenhouse gases in general and carbon dioxide in particular is the same as for Cluster 1: a positive relationship which shows the perception of those who owe environment taxes that as long as the taxes are paid, they are allowed to pollute the atmosphere. After one year, there seems to be no direct impact of environment taxes on pollutant emissions as the research shows a coefficient that is not statistically significant. After a two-years delay, however, the research shows that a 1% increase in environment taxes will lead to a 0.081% decrease in carbon dioxide emissions and a 0.08% decrease in overall emissions of greenhouse gases. This confirms hypothesis 1 in the long-run. But since the value of the coefficient is relatively small, the question of how significant an impact environment taxes can make still remains.

The use of renewable energy in the transport sector has a statistically significant impact of reducing atmospheric pollution in the countries included in Cluster 2. Therefore, hypothesis 2 is confirmed with a one-year delay. The results show that an increase of the percentage of renewable energy used in the transport sector by 1% should lead to a decrease in the emissions of both carbon dioxide and greenhouse gases in general, by 0.05%. The value of the decrease might not seem high, but if we compare it with the impact of the environment taxes with a two-year delay, then we can say that hypothesis 2 is confirmed for Cluster 2. Research hypothesis 3 could not be confirmed for Cluster 2.

Similarly to the research results obtained for the EU member states included in Cluster 1, in the countries included in Cluster 2 previous emissions of pollutants have a long-run effect on current level of air pollution both for carbon dioxide and for greenhouse gases in general.

The expectations regarding the control variables are confirmed for Cluster 2. The level of consumption of oil and fossil fuel both have a positive statistically significant impact on pollutant emissions. Looking at the result, the consumption of oil impacts air pollution

Table 9. Reserach results for Cluster 2.

Explanatory Variables	Dependent Variables	
	CO_2	GHG
ENVIRON_TAX	0.079338**	0.085211**
	(2.277188)	(2.232832)
L1_ENVIRON_TAX	-0.028406	-0.037723
	(-0.928725)	(-1.128207)
L2_ENVIRON_TAX	-0.081392**	-0.080536**
	(-2.534410)	(-2.306377)
OIL_C	2.72810***	2.882613***
	(5.251967)	(5.266281)
FOS_FUEL_C	0.943043***	0.976075***
	(13.48757)	(12.27213)
GDP_GR	0.030998***	0.035058***
	(5.680603)	(6.006681)
L1_REN_TRANSP	-0.055854***	-0.053360***
	(-3.062369)	(-2.690126)
L1_CO2	0.202841***	_
	(3.190428)	
L1_GHG	_	0.209018***
		(3.309997)
SIZE	-21.76146**	-25.66266***
	(-2.423707)	(-2.698468)
L1_ECM	-0.507851***	-0.542681***
	(-6.037043)	(-6.584477)
R-sq. (adjusted)	**0.71**	**0.69**
F statistic	**20.279*** **	**18.728*** **
No countries	**13**	**13**

Source: Author's calculations using Eviews
Note: An explanation of research variables is available in Table 3; t-statistic values in ()
*** indicates the statistical significance at 1% level
** indicates the statistical significance at 5% level
* indicates the statistical significance at 10% level

much more than the consumption of fossil fuel as the estimated coefficient is three times higher for the first explanatory variable. Economic growth also seems to have a positive impact on atmospheric pollutants emissions, the same as for Cluster 1.

Furthermore, the results for the EU member states included in Cluster 2 show that an additional measure to environmental taxes should be the increase of the percentage of renewable energy used in the transport sector. However, this might prove difficult and expensive to put into practice because Cluster 2 includes countries with a lower level of the eco-innovation index that might not be able to afford the costs of adjusting the transport sector to renewable energy sources.

Another discussion point is regarding a potential increase in the level of environment taxes. Given the ambitious objectives set by the European Union in terms of environment policy for 2050, would increasing environmental taxes be a solution for achieving these targets for air pollution? This research study has shown a statistically significant negative long-run relationship between environment taxes and emissions of carbon dioxide as well as greenhouse gases in general. Therefore, an increase in environmental taxes should have the desired effect. However, the results of this study also show that this effect would happen with a certain delay (depending on the country) and it would be short lived. Consequently, additional measures and further adjustments of environmental policy would be necessary to achieve the 2050 targets.

The current study has two clear advantages: (1) it offers a fresh and updated view on the efficiency of environmental taxes in reducing air pollution in the European Union and (2) it looks at additional policy measures. The goal is to provide policymakers with information regarding the combination of policy tools which should be implemented in order to achieve the 2050 goal of climate neutrality. The difficulty for the policymakers lies in the fact that any effects of environmental policy measures appear with some delay and this makes reliable and continuous research all the more important.

In terms of limitations of the current research results, one aspect that needs to be mentioned is related to the way in which the member states of the EU report data regarding environmental taxes to the European Environment Agency. In spite of a common definition of environmental taxes, which includes four categories of taxes: energy taxes, transport taxes, pollution taxes, and resource taxes, some of the member states only provide aggregate data for pollution and resources taxes, according to Eurostat. To address this, the current research only looks at environmental taxes as a whole. Which leads to a second limitation: the conclusions would be more accurate and more useful if a similar analysis could be run for pollution taxes alone. However, the data to do this is not currently available.

Conclusions

The main focus of this research was to contribute to answering the question of efficiency of environment taxes in reducing air pollution in the European Union. For both clusters, the research shows that in the short-run environment taxes would not deter economic actors from engaging in the production or consumption of goods and services that lead to emissions of atmospheric pollutants. In fact, it would seem that paying the environment taxes acts as a sort of permission granted to pollute the environment. This is not entirely surprising given existing literature highlighting issues in the implementation of the polluter-pays principle [43] as well as suggestions for improvements of the principle based on characteristics of the economic environment of the country where it is used [44, 45].

As far as long-run conclusions are concerned, this research study shows that environment taxes contribute to reducing air pollution with a one-year delay for the countries in Cluster 1 and with a two-year delay for the countries in Cluster 2. This could prove to be an important consideration for policymakers when deciding on measures that could lead to achieving climate neutrality in the EU by 2050. Moreover, the long-run effect of environment taxes in decreasing level of pollutant gases emissions is not very strong if we consider the relatively small value of the estimated coefficients. This leads to a particularly important conclusion in terms of environmental policy: environment taxes alone are not enough to reduce air pollution and they need to be complemented and supported by other measures. Two such additional tools are suggested by the results of this study: the increase of the percentage of renewable energy used in the transport sector and a reduction in the number of passenger cars with petroleum and diesel engines.

An additional conclusion that can be drawn based on the current study is that "one size does not fit all" even when it comes to countries that have set common objectives in terms of environment policy. Since environment taxes do not seem to be efficient enough to reach the 2050 goal of climate neutrality, a country-by-country analysis could pinpoint specific government intervention tools to complement environment taxes and enhance their effect. Consequently, a further research direction could be running the same type of analysis for each individual member state of the EU.

Conflict of Interest

The author declares no conflict of interest.

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