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Environmental fiscal policy and greenhouse gas emissions in the EU-27: Evidence from a dynamic panel GMM model

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Abstract. This paper examines the effects of environmental fiscal policy variables on greenhouse gas (GHG) emissions in the EU-27 from 2009 to 2023. The Arellano and Bond difference GMM estimator is used to address potential endogeneity and persistence of GHG emissions. The panel model is estimated using the total GHG emissions as the dependent variable, while energy taxes, transport taxes, and government environmental protection expenditure serve as independent variables. The results indicate significant persistence in GHG emissions. Energy taxes and government environmental protection expenditure have a negative and statistically significant effect on emissions in both the short run and the long run, confirming the effectiveness of these fiscal instruments in reducing emissions. However, transport taxes show a positive and significant relationship with emissions, suggesting that their current structure, which is linked primarily to vehicle ownership rather than fuel consumption, is not effective in reducing emissions. Robustness checks using population as a control variable and CO_2 emissions as an alternative dependent variable confirm the stability of these results. The findings suggest that energy taxes and environmental expenditures are effective fiscal instruments for reducing emissions in the EU, while the design of transport taxes requires reconsideration to improve their environmental effectiveness.

Keywords: dynamic panel GMM, environmental expenditures, environmental taxation, european union, greenhouse gas emissions

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1. Introduction

Over the past few decades, increased living standards have improved well-being but have also placed great pressure on natural ecosystems, resulting in increased CO_2 emissions, biodiversity loss, and environmental imbalances. Balancing economic growth with environmental sustainability remains an economic policy concern [6]. Handoyo [22] points out that effective public governance plays a key role in shaping national environmental outcomes and determining how well governments respond to environmental challenges. According to Batini et al. [5], spending that helps reduce greenhouse gas emissions can significantly boost economic growth while supporting environmental sustainability.

While fiscal measures can promote employment and production, their environmental consequences differ due to differences in resource allocation and the incorporation of sustainability objectives. Consequently, governments often face the challenge of creating fiscal strategies that support economic growth without threatening environmental sustainability. Environmental outcomes largely depend on the extent to which fiscal frameworks support clean technologies, energy efficiency, and green innovation [7]. Consequently, integrating sustainable environmental objectives into the global policy framework has become one of the priorities, together with economic development and social equity. According to the Kunming–Montreal Global Biodiversity Framework, governments should align fiscal and financial activities with global biodiversity and environmental sustainability goals [38].

Recently, in 2023, the EU's greenhouse gas footprint amounted to 9.0 tonnes of CO_2 equivalents per capita [12]. Regarding total environmental tax revenue in the EU, it was €341.5 billion in 2023, representing 2% of EU GDP and 5.1% of total EU government revenue from taxes and social contributions. Taxes on energy accounted for more than three-quarters of total revenues from environmental taxes (76% of the total), followed by taxes on transport (19%) and pollution and resources (5%) [13]. Moreover, the total general government expenditure on environmental protection in the EU was €142 billion and accounted for 0.8% of GDP in 2023 [14].

Previous empirical studies have examined the relationship between fiscal policy and environmental quality, focusing mainly on aggregate environmental taxes and CO_2 emissions [21, 37, 29]. This paper contributes to previous research in several ways. Firstly, it examines both the revenue side (environmental taxes) and expenditure side (government environmental protection expenditure) of fiscal policy, providing a more comprehensive view of fiscal instruments. Secondly, this research disaggregates tax revenues into energy, transport, and pollution/resource taxes. Thirdly, this research uses an overall measure, namely total greenhouse gas emissions, which includes CO_2, CH_4, N_2O, and F-gases, rather than focusing solely on CO_2 emissions, unlike the common literature [21, 37, 29]. While CO_2 from fossil fuels remains the dominant greenhouse gas, accounting for 73.7% of global GHG emissions in 2023, the remaining share is also important: methane contributes 18.9%, nitrous oxide 4.7%, and fluorinated gases 2.7% [25]. Importantly, non-CO_2 gases are increasing rapidly. Between 1990 and 2023, F-gas emissions increased by 294%, CH_4 by 28.2%, and N_2O by 32.4% [25]. Furthermore, the European Climate Law sets binding targets for reductions in total GHG emissions, not CO_2 alone [9]. To ensure comparability with the existing literature, CO_2 emissions are used as an alternative dependent variable in the robustness checks. Moreover, this research uses the most recent available data (2009–2023), capturing post-COVID recovery and recent EU climate policy developments under the European Green Deal. Finally, the dynamic panel model is estimated using the difference GMM estimator of Arellano and Bond [1] to address potential endogeneity and persistence in GHG emissions, in line with Okombi and Ndoum Babouama [33].

After the introduction, the literature review provides relevant empirical research on the role of fiscal policy in environmental sustainability, followed by the empirical part, providing data, methods, results, and discussion. Finally, the main conclusions are provided with research limitations and perspectives for future research.

2. Literature review

López et al. [30] examined how fiscal spending affects the environment in 38 selected countries and outlined the importance of the allocation of spending. When governments allocate more spending towards public goods like education, healthcare, and environmental protection, pollution tends to decrease. However, they outlined that simply increasing total government spending without changing allocation does not reduce pollution. Halkos and Paizanos [21] analysed fiscal policy impact on CO_2 emissions in the United States between 1973 and 2013. Using a Vector Autoregression model, they found that higher government spending can lower emissions from both production and consumption, while tax cuts financed by deficits increase consumption-related emissions. Their findings suggest that the environmental impact of fiscal policy depends on its design, with spending measures showing a more favourable impact than tax cuts. Savranlar et al. [37] analysed the influence of environmental taxes on CO_2 emissions in EU-27 countries using a panel vector autoregression (PVAR) approach, finding that an increase in environmental taxes reduces CO_2 emissions by 0.14%. Leitão [29] investigated the impact of environmental taxes on CO_2 emissions in 38 OECD countries from 1995 to 2022, employing FMOLS, DOLS, quantile regression, and System GMM estimation.

Okombi and Ndoum Babouama [33] analyse the relationship between environmental taxation and inclusive green growth in developing countries from 2000 to 2021 using the System GMM estimator and outline that environmental taxes promote inclusive green growth. The study further demonstrates that institutional quality positively moderates this relationship. Kohlscheen et al. [28] analysed 121 countries using dynamic panel regressions and found that an increase in carbon taxes by $10 per ton of CO_2 reduces CO_2 emissions per capita by 1.3% in the short run and 4.6% in the long run, providing robust evidence for the effectiveness of carbon pricing mechanisms.

Regarding single-country research, Katircioglu and Katircioglu [26] outlined that in Turkey, government spending and tax revenues are cointegrated with CO_2, and the increase in fiscal aggregates is related to lower emissions in the long-run. Moreover, Erdogan [8] empirically examines how green fiscal policy instruments, renewable energy use, and economic growth affect environmental degradation in Germany using the Autoregressive Distributed Lag (ARDL) approach. The study uses the load capacity factor as a comprehensive indicator of environmental sustainability. The findings indicate that economic growth and renewable energy consumption improve environmental quality, while environmental taxes do not significantly contribute to reducing environmental degradation. In contrast, environmental protection expenditures have a positive impact on sustainability, suggesting that expenditure-based fiscal instruments may be more effective than tax-based instruments in achieving environmental goals. Nguyen and Duong [31] analysed the effects of fiscal policy on environmental quality in Vietnam between 1990 and 2022 using a nonlinear ARDL framework and pointed to asymmetric long-run and short-run effects on CO_2 emissions. Specifically, increased government spending significantly reduces CO_2 emissions, while a contraction in public spending increases emissions. Nguyen and Duong [31] attribute the reduction in emissions to Vietnam's expansionary spending on sectors such as education, healthcare, and social welfare, which have lower carbon intensity compared to the manufacturing sector or consumption-driven service sector. In contrast, fiscal contractions are found to decrease investments in green infrastructure.

However, the effectiveness of environmental taxes may depend critically on their design. In the EU, transport taxes are ownership-based, linked to vehicle registration and possession, while taxes on transport fuels are classified under energy taxes [11]. Pigato and Hayde [34] noted that higher registration taxes may discourage new vehicle purchases, leading consumers to retain older, more polluting vehicles. Similarly, Aydin and Bozatli [3] found that transport taxes increase air pollution in countries with the highest transport tax revenues, and Ptak et al. [35] argued that the environmental impact of transport taxes can be relatively limited.

To summarise, the reviewed literature points to several gaps. Most empirical studies examine the effect of aggregate environmental taxes on CO_2 emissions, without distinguishing between tax categories that differ in design and incentive structure. The expenditure side of environmental fiscal policy remains largely underexplored, with only a few studies analysing government spending [30, 21, 8, 31]. Furthermore, under the Eurostat classification, transport taxes consist exclusively of ownership-based levies, while fuel taxes are classified under energy taxes [11]. However, this distinction has rarely been exploited in panel data studies to separately assess the environmental effectiveness of ownership-based and usage-based taxation. This research contributes to filling these gaps using disaggregated fiscal data and total GHG emissions for the EU-27.

3. Data and sample

The dependent variable is greenhouse gas (GHG) emissions, retrieved from Eurostat [15], measured in million tonnes of CO_2 equivalent. The indicator includes carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (hydrofluorocarbons, perfluorocarbons, nitrogen trifluoride, and sulphur hexafluoride), excluding Land Use, Land-Use Change and Forestry (LULUCF), as well as emissions from international aviation and maritime transport. Using each gas's individual global warming potential (GWP), emissions are integrated into a single indicator expressed in CO_2 equivalents [15]. As a robustness check, CO_2 emissions without other emissions are also used as an alternative dependent variable [19].

The independent variables refer to both the revenue and expenditure sides of environmental fiscal policy. The revenue side is represented by transport taxes and energy taxes measured in million euros [16]. The pollution taxes were excluded from modelling due to data limitations. Three EU member states reported zero pollution tax revenues: Germany throughout the entire sample period (2009–2023), Greece from 2009–2017, and Luxembourg in 2009. Hence, including pollution taxes would exclude Germany from the analysis, introducing selection bias. Moreover, as previously mentioned, pollution taxes account for a relatively small share of total revenues from environmental taxes, which was 5% in 2023 [13]. Nevertheless, it should be acknowledged that the exclusion of pollution taxes may affect the generalisability of the findings if countries that levy higher pollution taxes differ systematically in their emission patterns. Transport taxes (TRATAX) include taxes related to the ownership and use of motor vehicles and also cover taxes on other transport equipment, such as aircraft and related transport services. Energy taxes (NRGTAX) refer to taxes on energy products used for both transport and stationary purposes. The most important energy products for transport purposes are petrol and diesel. Energy products for stationary use include fuel oils, natural gas, coal, and electricity. CO_2 taxes are included under energy taxes [16]. It should be noted that under the Eurostat classification of environmental taxes, taxes on transport fuels such as petrol and diesel are included under energy taxes, while transport taxes consist of ownership-based levies such as vehicle registration and annual vehicle taxes [11]. Therefore, the difference between NRGTAX and TRATAX in this paper relates to separation between usage-based and ownership-based taxation in the Eurostat methodology.

Concerning the expenditure side, the government expenditure on environmental protection (ENVEXP) is available at the Eurostat [17] database on general government expenditure by function. Environmental protection expenditure covers government spending on waste management, wastewater management, pollution abatement, protection of biodiversity and landscape, and other environmental protection activities [17].

Furthermore, GDP (2015=100), available at Eurostat [18], was first considered as a control variable, but due to high multicollinearity with the fiscal policy variables, it was not included in the model. The correlation coefficient between GDP and energy tax revenues is very high ($r = 0.98$), between GDP and environmental expenditure is $r = 0.96$, and for GDP and transport taxes, $r = 0.89$. For robustness check, population (POP) is included in alternative specification as control variable. Population is retrieved from Eurostat [20] and measured in thousands of persons.

All fiscal variables (NRGTAX, TRATAX, ENVEXP) are measured in million euros and deflated to real values using the implicit GDP deflator, 2015=100, available at Eurostat [18]. Table 1 provides variable description, as well as data sources with Eurostat codes.

The model estimation is conducted on a panel dataset of 27 European Union member states (EU-27) from 2009 to 2023. The descriptive statistics of data prior to logarithmic transformation is provided in Table 2.

Greenhouse gas emissions (GHG) show substantial variation across EU countries, with an average value of 138.37 million tonnes of CO_2 equivalent and a wide range from 1.90 to 934 Mt

Variable	Description	Source	Eurostat code
GHG	GHG emissions (million tonnes of CO_2 equivalent)	Eurostat [15]	sdg_13_10
CO_2	Carbon dioxide emissions (million tonnes)	Eurostat [19]	env_air_gge
NRGTAX	Energy taxes (million euro)	Eurostat [16]	env_ac_tax
TRATAX	Transport taxes (million euro)	Eurostat [16]	env_ac_tax
ENVEXP	General government expenditure on environmental protection (million euro)	Eurostat [17]	gov_10a_exp
POP	Population on 1 January (thousands of persons)	Eurostat [20]	demo_gind

Table 1: *Variable description and data sources.*

Variable	Mean	Std. Dev.	Min	Max	CV (%)
GHG	138.37	192.17	1.90	934.00	138.9
CO_2	109.85	155.22	1.40	762.00	141.3
NRGTAX	9,542.10	15,842.17	86.62	75,195	166.0
TRATAX	2,117.31	2,874.75	6.42	11,250	135.8
ENVEXP	3,858.94	6,038.64	-38.10	28,936	156.5
POP	16,400,000	21,700,000	410,926	83,200,000	132.3

Table 2: *Descriptive statistics of selected variables.*

CO_2e. This reflects differences in the size and industrial structure of EU economies. Energy tax revenues (NRGTAX) have the highest average among fiscal variables (€9.5 billion) and exhibit considerable variability across countries, while transport tax revenues (TRATAX) are substantially lower on average (€2.1 billion), reflecting the smaller share of transport taxes in overall environmental tax revenues in the EU. Environmental protection expenditure (ENVEXP) averages €3.9 billion, but also shows notable variation across countries. High coefficients of variation point to heterogeneity in emissions levels, environmental taxation and environmental spending, as well as population across EU member states. Moreover, the minimum value of ENVEXP (-38.10 million euros) which corresponds to Estonia in 2010, is negative. In the ESA 2010 accounting framework [10], negative values in government expenditure by function can occur due to netting in the transaction classifications.

For model estimation, all variables are transformed using natural logarithms, the first-differenced log variables represent approximate growth rates, and the estimated coefficients are interpreted as elasticities. Table 3 shows the results of the Im–Pesaran–Shin (IPS) panel unit root test. The IPS test examines the null hypothesis that all panel series contain a unit root [24].

Variable	IPS (level)	p-value	IPS (1st diff.)	p-value
LNGHG	5.368	1.000	-8.510^{***}	0.000
$LNCO_2$	-0.795	1.000	-8.636^{***}	0.000
LNNRGTAX	0.257	0.601	-8.215^{***}	0.000
LNTRATAX	-0.455	0.325	-7.203^{***}	0.000
LNENVEXP	-1.038	0.150	-7.927^{***}	0.000
LNPOP	-0.413	1.000	-0.767	0.221

Table 3: *Panel unit root tests (Im–Pesaran–Shin). Note:* *** $p < 0.01$.

All variables except LNPOP are non-stationary in levels but stationary in first differences, i.e. integrated of order one, I(1). Population, which is not stationary in first differences, is included as an exogenous control variable for robustness check of the baseline model. The first-difference GMM estimator is used in model estimation, which is explained in the next section.

4. The empirical model

In line with the dynamic panel data literature [4], the following dynamic model is estimated as a baseline model:

$$y_{i,t} = \rho y_{i,t-1} + \mathbf{X}'_{i,t}\boldsymbol{\beta} + \alpha_i + \varepsilon_{i,t}, \quad |\rho| < 1, \tag{1}$$

where $y_{i,t} = \text{LNGHG}_{i,t}$ denotes the natural logarithm of greenhouse gas emissions for country i at time t, $\mathbf{X}_{i,t}$ is a vector of explanatory variables (LNNRGTAX, LNTRATAX, LNENVEXP), α_i represents time-invariant country-specific fixed effects, and $\varepsilon_{i,t}$ is the idiosyncratic error term with $E(\varepsilon_{i,t}) = 0$ and $E(\varepsilon_{i,t}\varepsilon_{j,s}) = 0$ for $i \neq j$ or $t \neq s$. The fiscal policy variables (energy taxes, transport taxes, and environmental protection expenditure) are treated as endogenous, as fiscal revenues and expenditures may simultaneously impact and be impacted by emission levels.

Model (1) is the baseline specification with total GHG emissions as the dependent variable. To assess the robustness of the baseline results, three alternative model specifications are estimated. Model (2) extends the baseline by including the total population as a control variable:

$$y_{i,t} = \rho y_{i,t-1} + \mathbf{X}'_{i,t}\boldsymbol{\beta} + \gamma \ln(\text{POP})_{i,t} + \alpha_i + \varepsilon_{i,t}. \tag{2}$$

Model (3) uses CO_2 emissions instead of total GHG emissions as the dependent variable, with the same set of explanatory variables as in Model (1), while Model (4) uses CO_2 emissions as the dependent variable and includes population as a control variable. Table 4 presents the estimation results for all four models.

The fiscal policy variables (LNNRGTAX, LNTRATAX, LNENVEXP) and the lagged dependent variable are treated as endogenous and instrumented using their own lagged levels from periods $t-2$ to $t-4$. Population, when included, is treated as strictly exogenous, meaning it is assumed to be uncorrelated with the idiosyncratic error term at all leads and lags: $E[\ln(\text{POP})_{i,s} \cdot \varepsilon_{i,t}] = 0$ for all s and t. Population dynamics are related to demographic processes that are not influenced by changes in greenhouse gas emissions. In the GMM estimation framework, strictly exogenous variables instrument themselves, appearing in both the regressor and instrument matrices, rather than being instrumented by their own lags as is the case for endogenous variables [36].

In the first-differenced equation estimated by the Arellano–Bond procedure, population enters in its differenced form, serving as its own instrument without requiring additional lags. This distinction is reflected in the instrument count: 12 instruments in Models (1) and (4), and 13 instruments in Models (2) and (3), where the additional instrument corresponds to the population variable.

The presence of the lagged dependent variable $y_{i,t-1}$ creates correlation with the fixed effects α_i, hence OLS and fixed effects estimators are biased and inconsistent [32]. To address this endogeneity problem, the first-difference GMM estimator proposed by Arellano and Bond [1] is used.

First-differencing baseline model equation (1) eliminates the fixed effects:

$$\Delta y_{i,t} = \rho \Delta y_{i,t-1} + \Delta \mathbf{X}'_{i,t}\boldsymbol{\beta} + \Delta\varepsilon_{i,t}. \tag{3}$$

However, the differenced lagged dependent variable $\Delta y_{i,t-1} = (y_{i,t-1} - y_{i,t-2})$ is correlated with the differenced error $\Delta\varepsilon_{i,t} = (\varepsilon_{i,t} - \varepsilon_{i,t-1})$ through the term $y_{i,t-1}$. Arellano and Bond [1] propose using lagged levels of the dependent variable as instruments, exploiting the following moment conditions:

$$E[y_{i,t-s}\,\Delta\varepsilon_{i,t}] = 0, \quad s \geq 2;\ t = 3, \ldots, T. \tag{4}$$

Similarly, if the explanatory variables $\mathbf{X}_{i,t}$ are potentially endogenous, their lagged values can serve as instruments:

$$E[\mathbf{X}_{i,t-s}\,\Delta\varepsilon_{i,t}] = 0, \quad s \geq 2;\ t = 3, \ldots, T. \tag{5}$$

The problem that arises in GMM estimation is instrument proliferation. Following Roodman [36], the instrument matrix is collapsed, which reduces the number of instruments while maintaining consistency. By collapsing the instrument matrix, the number of instruments is below the number of cross-sectional units (27 countries), which is in line with the recommendations of Roodman [36] and Baltagi [4]. Without collapsing, the number of instruments would exceed the number of cross-sections, potentially leading to overfitting and weakening the Hansen test of overidentifying restrictions.

The two-step GMM estimator, which uses the residuals from a first-step consistent estimator to construct an optimal weighting matrix, is used. However, two-step standard errors are known to be downward-biased in finite samples. Hence, the Windmeijer [39] finite-sample correction is used to obtain reliable inference.

The validity of the GMM estimator is assessed through the Arellano–Bond test for serial correlation and the Hansen [23] J-test. The dynamic specification allows computation of both short-run and long-run effects. The short-run elasticity is given directly by the coefficient β, while the long-run elasticity is computed as [4]:

$$\text{Long-run elasticity} = \frac{\beta}{1-\rho}. \tag{6}$$

5. Estimation results and discussion

The dynamic panel dataset comprises 27 EU member states from 2009 to 2023. After first-differencing, which eliminates the first period, and the use of lagged levels from $t-2$ as instruments, which eliminates an additional period, the total number of observations is 349. Following Roodman [36], the instrument matrix is collapsed to limit the number of instruments. Lagged levels of greenhouse gas emissions, energy taxes, transport taxes, and environmental protection expenditure from periods $t-2$ to $t-4$ are used as instruments. To avoid biased standard errors, Windmeijer-corrected standard errors are used for the two-step GMM estimator [2, 27].

As previously mentioned, to assess the robustness of the baseline model, three alternative model specifications are estimated. In addition to Model (1), Model (2) includes total population as a control variable, while Model (3) uses CO_2 emissions as the dependent variable, and Model (4) uses CO_2 emissions as the dependent variable and population as control variable. Table 4 presents the estimation results for all four models.

In the baseline model, the coefficient on the lagged dependent variable ($\rho = 0.580$) is significant with a p-value of 0.000, and points to persistence in GHG emissions. In dynamic panel models, the inclusion of a lagged dependent variable captures such dynamic behaviour and allows the estimation of both short-run and long-run effects [4]. Current emission levels are strongly influenced by past emission levels, pointing to the persistence of emissions. Thus, changes in emissions adjust slowly over time. The estimated coefficient below one also points to partial adjustment dynamics. Long-run coefficients on fiscal variables are therefore calculated in line with equation (6).

In the baseline model, the energy taxes have a significant negative effect on emissions, with a short-run elasticity of −0.39 and a long-run elasticity of −0.93. This implies that a 1% increase in energy taxes reduces emissions by 0.39% in the short run and 0.93% in the long

Variable	**(1) GHG**	**(2) GHG + POP**	**(3) CO_2 + POP**	**(4) CO_2**
Lagged dependent variable	0.580^{***}	0.367^{**}	0.376^{**}	0.586^{***}
	(0.134)	(0.143)	(0.140)	(0.126)
ln(NRGTAX)	-0.392^{***}	-0.586^{***}	-0.605^{***}	-0.433^{***}
	(0.134)	(0.157)	(0.184)	(0.150)
ln(TRATAX)	0.411^{**}	0.508^{***}	0.618^{***}	0.453^{**}
	(0.156)	(0.153)	(0.171)	(0.175)
ln(ENVEXP)	-0.371^{***}	-0.373^{***}	-0.445^{***}	-0.414^{***}
	(0.108)	(0.129)	(0.139)	(0.128)
ln(POP)	–	-0.729^{*}	-0.673	–
		(0.385)	(0.441)	

Table 4: *Two-step difference GMM estimation results. Source: Author's calculation, Stata 15.0.*

Notes: standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. *Two-step difference GMM with Windmeijer (2005) corrected standard errors.*

run, which points to the effectiveness of energy taxation as an environmental policy instrument. As noted in Section 1, energy taxes account for approximately 76% of total environmental tax revenues in the EU [13]. This empirical result emphasises the important role of energy taxes for environmental sustainability. The negative significant impact is in line with the literature on environmental taxation impact [37, 28].

However, regarding transport taxes, the coefficient is also statistically significant, but positive, indicating that a 1% increase in transport taxes increases emissions by 0.41% in the short run and 0.98% in the long run. This result is unexpected and should be interpreted with caution. In the EU, transport taxes are linked to vehicle ownership and use, rather than directly to fuel consumption. As noted in Section 3, the Eurostat classification assigns fuel taxes to the energy tax category, while transport taxes are ownership-based [11]. The positive coefficient on TRATAX, therefore, specifically reflects the effect of ownership-based taxation, while the negative coefficient on NRGTAX captures the effect of usage-based energy taxation, including taxes on transport fuels. In 2023, households accounted for about 66.5% of total transport tax revenues, pointing to the connection between transport taxes and private vehicle ownership [13]. Transport taxes mainly include vehicle registration and similar charges, which may have only a limited effect on emissions. As outlined in Section 1, transport taxes account for only about 19% of total environmental tax revenues in the EU, compared with 76% for energy taxes [13]. Their relatively small revenue share, together with the structure discussed above, may explain the finding that they do not reduce emissions. National patterns also differ across countries. In Ireland, Malta, and Austria, most transport taxes are paid by households, while in Slovakia and Czechia, a larger share is paid by businesses, particularly in the services sector. This points to differences in transport habits, tax structures, and vehicle ownership across the EU [13]. Higher registration taxes may decrease new vehicle purchases but can also impact the decision to delay buying a new car or to purchase a used vehicle instead, increasing the share of older and more polluting vehicles [34]. Therefore, transport tax revenues may reflect the level of transport activity rather than reducing emissions. According to Ptak et al. [35], the environmental impact of fuel or transport taxes can be relatively limited. Similarly, Aydin and Bozatli [3] found that transport taxes increase air pollution for the whole panel of the ten countries with the highest transport tax revenues, concluding that transport taxes are not effective in reducing air pollution and that the structure of transport taxes should be changed. Erdogan [8] found that environmental taxes do not serve as an effective green fiscal policy tool in Germany.

Concerning government environmental expenditures, it has a significant negative effect, indicating that 1% increase in environmental expenditures decreases emissions by 0.37% in the short run and 0.88% in the long run. This result is in line with López et al. [30], who stated that the allocation of government spending towards public goods such as environmental protection reduces pollution. Similarly, Halkos and Paizanos [21] found that higher government spending lowers emissions, with spending measures showing a more favourable environmental impact than tax-based instruments. Nguyen and Duong [31] confirmed that increased government spending significantly reduces CO_2 emissions in Vietnam. Furthermore, Batini et al. [5] concluded that green spending multipliers can significantly boost economic growth while supporting environmental sustainability.

The robustness check results confirm the stability of the baseline results in terms of signs and statistical significance of fiscal variables. Energy taxes and environmental protection expenditure consistently show statistically significant negative impacts on emissions, while transport taxes maintain their statistically significant positive impact on emissions. The population variable shows a marginally significant negative coefficient in Model (2) with GHG emissions (p-value = 0.069).

Long-run elasticities are presented in Table 5 and confirm the short-run results. Energy taxes and environmental protection expenditure reduce emissions in the long-run, while transport taxes remain positively associated with emissions.

Variable	**(1) GHG**	**(2) GHG + POP**	**(3) CO_2 + POP**	**(4) CO_2**
NRGTAX	−0.933	−0.926	−0.969	−1.045
TRATAX	0.979	0.802	0.991	1.093
ENVEXP	−0.883	−0.589	−0.713	−1.000

Table 5: *Long-run elasticities.*

The diagnostic tests are consistent across all models and confirm the adequacy of all model specifications, as reported in Table 6. The AR(1) test is significant, which is expected in first-differenced models, and the AR(2) test is insignificant, indicating that second-order autocorrelation is not present. Moreover, the Sargan test and Hansen test do not reject the null hypothesis for all models, which confirms instrument validity. The number of instruments remains relatively small (12 or 13, depending on the model) compared to the number of countries (27), preventing instrument proliferation.

Statistic	**(1) GHG**	**(2) GHG + POP**	**(3) CO_2 + POP**	**(4) CO_2**
Observations	349	349	349	349
Countries	27	27	27	27
Instruments	12	13	13	12
AR(1) p-value	0.018	0.051	0.059	0.015
AR(2) p-value	0.474	0.581	0.446	0.372
Sargan test p-value	0.208	0.329	0.373	0.346
Hansen test p-value	0.416	0.570	0.598	0.508

Table 6: *Model diagnostic tests' results.*

These results provide several important implications for the design of environmental fiscal policy in the European Union, particularly regarding the balance between tax-based and expenditure-based fiscal instruments. Both environmental taxation and protection expenditures contribute to emission reductions in the European Union. In particular, energy taxes and environmental expenditures are more effective in reducing emissions, while the current structure of transport taxes may limit their environmental effectiveness.

6. Conclusion

This paper assesses the impact of environmental fiscal policy instruments on greenhouse gas emissions in the EU-27 using difference GMM estimation from 2009 to 2023. The analysis provides an assessment of the impact of both the revenue and expenditure sides of environmental fiscal policy. The revenue side is represented by energy and transport taxes, while the expenditure side refers to government environmental protection expenditures.

The energy taxes have a significant negative effect on GHG emissions, with a 1% increase in energy taxes reducing emissions by 0.39% in the short run and 0.93% in the long run. Given that energy taxes account for approximately 76% of total environmental tax revenues in the EU, this finding underlines their importance in environmental policy. Government environmental protection expenditure also shows a significant negative effect on emissions, with short-run and long-run elasticities of -0.37 and -0.88, respectively. This suggests that expenditure-based fiscal instruments are effective in achieving environmental objectives. However, transport taxes exhibit a significant positive relationship with emissions, indicating that a 1% increase in transport taxes is associated with a 0.41% increase in emissions in the short run. This counterintuitive result can be explained by the structure of transport taxes in the EU, which are primarily related to vehicle ownership and registration rather than directly to fuel consumption or emissions.

These results are robust to the inclusion of population as a control variable and to the use of CO_2 emissions as an alternative dependent variable and have important policy implications for the design of environmental fiscal policy in the European Union. First, the negative and statistically significant impact of energy taxes on greenhouse gas emissions confirms that energy taxation is the most effective fiscal instrument on the revenue side for decreasing emissions. Given that energy taxes represent the largest share of environmental tax revenues in the EU, strengthening energy taxation could further support environmental sustainability. Second, the significant negative effect of government expenditure on environmental protection emphasizes the importance of public investment in environmental sustainability. This suggests that fiscal policy should not rely solely on taxation measures, but should also use expenditure-based instrument aimed at environmental protection. Finally, the positive relationship between transport taxes and emissions suggests that the current structure of transport taxation may not provide a sufficiently strong environmental incentive. Under the Eurostat methodology, transport taxes are exclusively ownership-based, while fuel taxation is captured by energy taxes [11]. The contrasting signs of the two tax variables confirm that usage-based taxation (energy taxes) effectively reduces emissions, whereas ownership-based taxation (transport taxes) does not. The positive coefficient on transport taxes therefore does not imply that all transport-related taxation is ineffective, but rather that the ownership-based component does not contribute to emission reductions. Policymakers may therefore consider restructuring ownership-based vehicle taxes to incorporate stronger emission-related criteria. Such reforms could better align transport taxation with environmental objectives and improve its effectiveness in reducing emissions.

The limitation of the study is that the model does not account for potential heterogeneity across member states in terms of economic development, energy mix, or institutional quality. Moreover, pollution taxes are not included in the analysis due to data constraints. Future research could extend this analysis by incorporating pollution taxes, as well as examining heterogeneous effects across different groups of EU member states. Additionally, future work could explore the inclusion of country-specific time trends, particularly as longer time series become available.

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