

The impact of environmental tax and emission trading system on environmental quality in OECD countries

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Abstract

Achieving sustainability requires a coherent policy mix to address the climate change problem. To internalize the cost of carbon emissions resulting from the existing mode of production, central market-based mechanisms, such as carbon taxes and emissions trading systems (ETS), can be applied. Nevertheless, structural and technological context may affect their effectiveness. In this context, the present study tries to assess the impact of carbon pricing instruments on CO₂ emissions while explicitly accounting for the structural and technological framework by integrating energy intensity and the usage of low-carbon energy in the energy mix, using a dynamic panel approach based on the Generalized Method of Moments for 31 OECD countries over the period 1997-2020.

The results show that the implementation of carbon taxes or ETS does not have a statistically significant impact on emission reductions. However, combining the two instruments alongside a higher penetration of low-carbon energy sources leads to a significant decline in emissions. These findings suggest that the effectiveness of economic instruments should be combined with complementary structural and technological transformations. An integrated policy mix that simultaneously promotes energy efficiency and accelerates the transition toward low-carbon energy systems may be embedded with carbon pricing.

Keywords: emissions trading system, environmental taxes, generalized method of moments.

JEL classification: C13, H23, Q58

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1. Introduction

The goal of sustainable development encompasses three fundamental dimensions. As for the economic dimension, the focus is on the transition to green growth by upgrading the energy efficiency of industrial activities, promoting the adoption of renew-

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able energy, and reconfiguring the economic structure. Concerning the ecological dimension, the main objective is to preserve biodiversity and wisely manage limited resources. The social dimension emphasizes the continued protection of the environment to enhance human security. However, the current configuration of energy consumption, which has evolved since the Industrial Revolution, raises questions about its environmental consequences. To address these concerns, the International Renewable Energy Agency (2018) estimates that energy efficiency and adopting renewable energy could account for up to 90% of the necessary carbon mitigation measures.

In this sense, the Energy Information Administration highlighted that energy efficiency progress is crucial for the transition away from fossil fuels. In a pathway aligned with the IEA's scenario for achieving net-zero energy sector emissions by 2050 (EIA, 2024). Besides, World Energy Outlook (2025) advanced that renewables accounted for around one-fifth of electricity generation worldwide a decade ago and that this level has risen now to about one-third, reflecting cost reductions in renewable energy technologies and policy support in many markets.

To fulfill this energy transition, environmental policies must be implemented through environmental instruments. These instruments can be fundamentally categorized into three distinct groups: regulatory instruments, economic instruments, and informational instruments Vedung (2025).

Economic instruments have a key characteristic: they operate within market mechanisms. Their objective is to correct market prices by internalizing external costs, thus incentivizing actors to consider these aspects in their choices.

Unlike regulatory instruments, economic instruments influence the prices of goods by establishing financial incentives. They define criteria related to environmental costs and benefits, in the form of quotas, restrictions on specific products, or standards for products offered for sale.

Finally, a third group of tools emerges as informational instruments. Unlike regulatory and economic instruments, informational instruments do not impose prices or constraints on production. Indeed, by providing actors with information about the negative consequences of the products consumed, these instruments influence the decisions of consumers, who eventually integrate this information into their consumption choices.

The Organization for Economic Cooperation and Development (OECD) first introduced the polluter pays principle in 1972. This organization emphasized the importance of this principle as an essential tool for reducing pollution and encouraging sustainable development. In 1992, the United Nations Conference on Environment and Development declaration, also known as the Rio Declaration, identified the polluter pays principle as one of the 27 guiding principles of sustainable development.

The OECD report (1975) defines the "polluter pays principle" as that fact that the polluter should be charged with the cost of whatever pollution prevention and control measures are determined by the public authorities, whether preventive measures, restoration, or a combination of both. The implementation of this principle takes various forms, notably through the application of environmental taxes and the creation of emission quota trading systems.

The theoretical foundations of emissions trading were developed in the work of Montgomery (1972), who demonstrated that under competitive conditions, the tradable permits are cost-efficient. At the empirical level, Bayer and Aklin (2020)

showed that the EU ETS significantly reduces CO₂ emissions among regulated firms when supported by a reliable institutional framework.

According to OECD (2023), environmentally related tax bases comprise physical units that are directly linked to environmental pressures (e.g., emissions, pollutants). In the Pigouvian framework, environmental taxation is fixed according to a rule stipulating that the optimal corrective tax equals the marginal external damage of emissions. Recent contributions operationalize this principle by estimating the social cost of carbon through integrated assessment models and damage functions. These estimates provide quantitative benchmarks for carbon pricing consistent with marginal social damages and welfare maximization (Nordhaus, 2017; IMF, 2019; Rennert et al., 2022). Leading to optimal energy tax fixation.

Consequently, these economic methods incorporate environmental costs, or estimates of these costs, into market prices, creating a price signal to encourage economic actors to opt for more environmentally friendly products. Indeed, environmental tax increases the price of pollutants and energy-intensive products, leading enterprises to adopt energy-efficient equipment and to use renewable energies. As for Emissions Trading Systems, they operate by setting a cap on emissions and issuing tradable allowances, which are exchanged on the market, leading to a price signal that can encourage firms to adopt more efficient technologies if the abatement cost is lower than the market price.

Besides, Ji et al. (2022) stated that numerous theoretical discussions and quantitative simulations have shown that, under certain market assumptions, market-based instruments outperform command-based ones both in the scope of short-term economic costs and long-term dynamic incentives. Due to their effectiveness, the European Union actively supports the use of economic instruments and market mechanisms (Kosonen and Nicodemus, 2009).

Furthermore, the empirical literature studying the relationship between economic instruments used to resolve the climate change problem and environmental quality affords mixed evidence regarding their effectiveness in reducing CO₂ emissions. Furthermore, the distinction between policy adoption and emission coverage and the potential complementarity between carbon taxes and ETS have not been sufficiently assessed. Besides, the present study adopts a structured econometric strategy that distinguishes between the existing environmental tax revenues, emission coverage, and joint implementation of market-based instruments, while controlling for technological transition to lower-intensive and low-carbon technologies.

In this context, this paper aims to evaluate the impact of environmental taxation and emissions trading systems (ETS) on the environmental performance of 31 OECD countries from 1997 to 2020, with a specific focus on the proportion of CO₂ emissions covered by these instruments. Empirical evidence on their effectiveness remains mixed, highlighting the need for a more precise valuation. The present study contributes to the literature by quantifying the extent of emissions coverage under environmental taxes and ETS individually, while controlling for energy intensity improvements. Besides, it examines the simultaneous application of these instruments to assess whether broader coverage through concurrent implementation enhances environmental outcomes. Furthermore, this research tried to measure the impact of environmental tax measured by their related revenues as a percentage of GDP when controlling for energy intensity and low-carbon energy adoption. Employing a rigorous econometric

framework, this research provides a systematic analysis of both individual and combined policy measures, in terms of the generated revenues from environmental taxes on one side and the covered emissions by environmental taxes and ETS, offering insights for designing more effective and sustainable climate policies.

The rest of the paper is organized as follows: The first section presents the literature review. The second exposes the empirical investigation by presenting data description and the methodology applied. The third section highlights empirical results, and the last section concludes.

2. Literature review

In alignment with the overarching goal of climate change mitigation outlined in the Paris Agreement, nations have committed to a range of short-term, medium-term, and long-term targets aimed at reducing greenhouse gas (GHG) emissions. Both production and consumption activities are principal contributors to pollution and GHG emissions, which represent negative externalities that are not typically internalized in market prices. To address these externalities, governments may implement carbon pricing mechanisms such as carbon taxes or emissions trading systems (ETS), thereby incentivizing market participants to account for environmental costs. As noted by Chameides and Oppenheimer (2007), market-based instruments have emerged as pivotal tools in the international policy landscape for achieving emission reduction targets.

Among these instruments, ETSs have been widely adopted as market-based solutions to mitigate global warming and reduce carbon dioxide emissions (Ouyang et al., 2020). The European Union Emissions Trading Scheme (EU-ETS), launched in 2005, represents the first and most developed global carbon market. By early 2021, 24 operational ETSs worldwide covered approximately 16% of global GHG emissions (ICAP, 2021).

Several scholars, including Bushnell et al. (2013) and Schmalensee and Stavins (2017), have argued that ETSs represent the most cost-effective mechanism for reducing emissions, based on both economic and environmental performance. However, empirical evidence remains mixed. While some studies affirm the efficacy of ETSs in lowering emissions, others question their effectiveness. For instance, Kill et al. (2010) argue that ETSs may facilitate the redistribution of emission allowances from low-emitting to high-emitting countries, thereby undermining global emission reduction goals. Moreover, Ben-David et al. (2021) and Bartram et al. (2022) contend that carbon pricing instruments can result in unintended consequences, such as emissions leakage, due to regulatory arbitrage by firms relocating activities to less-regulated authorities.

The literature underscores the nuanced and context-dependent impact of ETSs, with existing studies pointing to both significant and inconsistent outcomes related to energy conservation and emissions abatement. Importantly, much of the empirical research has concentrated on developed economies, particularly Europe and the United States (Calel and Dechezleprêtre, 2016; Hoffmann, 2007), with relatively limited attention paid to developing nations (Xie et al., 2017). For instance, Clò et al. (2017), through the analysis of panel data from 29 European electricity markets between 1990 and 2012, found that the ETS had only a limited impact on emission reductions, largely due to the overallocation of permits.

Conversely, other studies present more favorable findings. Jung and Song (2023) demonstrated the effectiveness of ETs in reducing emissions across countries that adopted the mechanism. Similarly, Bian et al. (2024) evaluated the Chinese Carbon Emission Trading System (CETS) across 281 cities from 2006 to 2020, concluding that cities participating in CETS experienced greater progress in green development than those that did not.

Radulescu et al. (2025) examined the impact of carbon pricing and complementary factors – such as green technology, GDP, environmental taxes, green patents, renewable energy, and urbanization – on the ecological footprint of 26 EU member states during the 2011–2021 period. Their findings suggest that carbon pricing is effective in mitigating environmental pressures in upper quantile emission levels, but not in lower ones.

Parallel research also evaluates the role of environmental taxes as alternative or complementary instruments to ETs. Scholars such as Martin et al. (2014), Andersson (2019), and Metcalf (2019) have found that carbon taxes can be more effective than ETs in curbing emissions, a view supported by Ellerman et al. (2016).

The literature has extensively analyzed the impact of environmental taxes on energy efficiency and environmental quality, with mixed findings regarding the “double dividend” hypothesis. Some studies report positive environmental outcomes. For example, Wang et al. (2018) documented a 2.6% reduction in GHG emissions in Europe, a 10% reduction in waste production in Denmark, and a 5-15% decrease in air pollutants in the United States. Similarly, Hájek et al. (2019) employed multiple panel regression methods to assess the role of carbon taxes, allowance prices, household consumption, and renewable energy in the EU, highlighting the importance of carbon taxation in environmental protection and GHG mitigation.

Using system-GMM and quantile regression techniques, Bashir et al. (2020) found that environmental taxes, renewable energy, environmental technology, and financial development collectively contribute to emission reductions in OECD countries between 1995 and 2015. However, economic growth was shown to potentially counteract these environmental improvements.

He et al. (2021a) investigated the effects of environmental taxes on economic growth, energy use, and emissions in China, Finland, and Malaysia over the 1985-2014 period using an Autoregressive Distributed Lag (ARDL) panel analysis. The study found that taxes implemented in Finland and Malaysia were effective in reducing energy consumption and emissions, offering lessons for other developing countries. Similarly, Bashir et al. (2021) employed FMOLS, DOLS, and quantile regression models across 29 OECD countries (1994-2018), concluding that environmental taxes stimulate innovation in environmentally friendly technologies and contribute to emissions mitigation.

Additional support for the effectiveness of environmental taxation comes from Sarıgül and Topcu (2021), who found that such taxes had a statistically significant, albeit modest, impact on CO₂ reduction in Turkey between 1994 and 2015. Dogan et al. (2022) further analyzed the role of green growth policies and environmental taxation in 25 environmentally friendly countries between 1994 and 2018, using novel quantile regression methods. Their findings underscore the critical role of environmental taxes, renewable energy, and energy efficiency in reducing carbon emissions.

Nonetheless, some scholars question the universal effectiveness of environmental taxation. For example, Mardones and Flores (2018) highlight cases where these measures fail to significantly reduce emissions, suggesting a need for more nuanced policy design. Telatar and Birinci (2022) conducted a nonlinear analysis of Turkey's environmental tax policy from 1994 to 2019 and concluded that such taxes had no long-term impact on either the ecological footprint or CO₂ emissions, implying limited efficacy in curbing environmental degradation.

In examining the broader determinants of carbon emissions, it is important to integrate a comprehensive set of factors into the analysis to better understand their influence. The STIRPAT model, introduced by York et al. (2003), offers a robust framework for evaluating the effects of population, affluence, and technological development on environmental outcomes. Empirical studies, including those by Bargaoui et al. (2014) and Shafiei and Salim (2014), have confirmed that both population growth and increases in gross domestic product (GDP) are significant contributors to rising CO₂ emissions.

The role of technology in shaping emissions is often assessed through indicators related to industrial activities and energy consumption. Considerable scholarly attention has focused on improving the efficiency of fossil fuel use, motivated not only by concerns over long-term energy security but also by the imperative to reduce carbon emissions. Several studies have explored the connection between energy-related variables and CO₂ emissions. For instance, Aguir Bargaoui and Nouri (2017) analyzed how improvements in energy efficiency correlate with emission reductions, while Morales-Lage et al. (2016) highlighted how increased energy intensity and industrial output contribute to higher emission levels.

In the context of OECD countries, Tajudeen et al. (2018) conducted a two-stage analysis to evaluate the effects of energy efficiency on CO₂ emissions across 30 member countries over the period 1971-2015. Their findings indicate that gains in energy efficiency are associated with long-term emission reductions, averaging a 1.731% annual decline. Similarly, Yao et al. (2021a) investigated the interrelationships among technology, corruption, energy efficiency, and natural resource use in BRICS nations and 11 additional countries. Utilizing a combination of Data Envelopment Analysis (DEA) and the GMM estimator, their study underscored the importance of both institutional quality and energy efficiency in achieving environmental improvements.

Moreover, Yao et al. (2021b) expanded this line of inquiry by exploring the interactions among trade, energy efficiency, technological progress, foreign direct investment (FDI), and political institutions across various national contexts. Employing the Super-Slacks-Based Measure (Super-SBM) model alongside the GMM technique, their research revealed that technological advancement, institutional strength, and enhanced energy efficiency are pivotal in promoting sustainable economic growth while curbing carbon emissions.

3. Methodology and data

In this section, we will describe the applied methodology to analyze the impact of environmental taxes, the Emissions Trading Scheme, low-carbon energy, and en-

ergy efficiency on environmental quality in OECD countries. We will explain our choice of the dynamic panel method and the rationale behind using the system's two-stage GMM method.

3.1. Empirical model

The methodology used in the present paper is the Generalized Method of Moments (GMM), which accounts for the temporal dimension of our data. Indeed, this approach allows us to model relationships between variables over time and across countries to account for individual- and time-specific effects while addressing endogeneity biases in explanatory variables such as fossil fuel use, using instrumental variables generated by their lags.

Halkos (2003) highlights that the Generalized Method of Moments (GMM) estimation technique addresses issues of heteroscedasticity and provides estimates that are both unbiased and efficient. Blundell and Bond (1998), through Monte Carlo simulations, showed that the first-difference GMM estimator can yield biased results in finite samples when instruments are weak. To overcome this limitation, they introduced the system GMM approach, building on the level equation concept proposed by Arellano and Bover (1995). Their findings indicate that this alternative reduces both the finite sample bias and the asymptotic imprecision typically associated with the difference GMM estimator.

The reliability of the GMM method is contingent on two main assumptions. First, the instruments used must be valid, a condition tested using the Hansen or Sargan over-identification tests, as recommended by Blundell and Bond (1998). Second, there must be no autocorrelation in the error terms, which is checked using first- and second-order autocorrelation tests. The second-order test is particularly important, as first-differenced errors tend to be correlated at the first order, according to Levine et al. (2000). These characteristics make the system GMM estimator a suitable tool for evaluating OECD policy impacts on environmental performance – especially in areas like energy efficiency, environmental taxation, emissions trading systems (ETS), and the broader drivers of CO₂ emissions.

The objective of the dynamic panel data model proposed below is to determine the impact of environmental taxes, emissions trading schemes, low-carbon energy, and energy efficiency on environmental quality in OECD countries. Our empirical research is founded on a sample composed of a panel of 31 OECD countries, with annual data covering the period from 1997 to 2020. The choice of this time range is motivated by data availability.

3.2. Data description and data sources

Following a comprehensive analysis of existing research on the impact of environmental taxes, emissions trading schemes (ETS), and energy efficiency on environmental quality, we formulate the following hypotheses:

Assumption 1. Higher environmental taxes decrease carbon emissions by altering relative energy prices and incentivizing firms and households to adopt energy-efficient technologies or use lower-carbon energies.

Assumption 2. Emissions trading schemes (ETS) significantly contribute to CO₂ emissions reduction, based on previous research anticipating that ETS implementation will incentivize firms to invest in more sustainable practices to save on the cost of emission permits.

Assumption 3. Lower energy intensity is negatively associated with carbon emissions.

Assumption 4. Combining policies promoting energy efficiency, low-carbon energy forms, environmental taxes, and emissions trading schemes (ETS) will have a synergistic impact, amplifying the positive effects on environmental quality relative to the effect of each policy alone. The joint implementation of environmental taxes, ETS, energy intensity reduction, and low-carbon energy is expected to reduce carbon emissions.

We propose to estimate the following five models separately in order to confirm or refute our research hypothesis:

$$\text{Model 1: } \ln CO2_{i,t} = \beta_0 + \beta_1 \ln CO2_{i,t-1} + \beta_2 \ln EI_{i,t} + \beta_3 \ln Tax_{i,t} + \beta_4 \ln POP_{i,t} + \beta_5 \ln URB_{i,t} + \beta_6 \ln FF_{i,t} + \beta_7 \ln GDP_{i,t} + \mu_i + \theta_t + \varepsilon_{i,t}$$

$$\text{Model 2: } \ln CO2_{i,t} = \beta_0 + \beta_1 \ln CO2_{i,t-1} + \beta_2 \ln EI_{i,t} + \beta_3 \ln Tax_{i,t} + \beta_4 \ln POP_{i,t} + \beta_5 \ln URB_{i,t} + \beta_6 \ln FF_{i,t} + \beta_7 \ln GDP_{i,t} + \beta_8 \ln LLOWCARBON_{i,t} + \mu_i + \theta_t + \varepsilon_{i,t}$$

$$\text{Model 3: } \ln CO2_{i,t} = \beta_0 + \beta_1 \ln CO2_{i,t-1} + \beta_2 \ln EI_{i,t} + \beta_3 \ln LCARBONTAX_{i,t} + \beta_4 \ln POP_{i,t} + \beta_5 \ln FF_{i,t} + \beta_6 \ln GDP_{i,t} + \mu_i + \theta_t + \varepsilon_{i,t}$$

$$\text{Model 4: } \ln CO2_{i,t} = \beta_0 + \beta_1 \ln CO2_{i,t-1} + \beta_2 \ln EI_{i,t} + \beta_3 \ln LCARBONETS_{i,t} + \beta_4 \ln POP_{i,t} + \beta_5 \ln FF_{i,t} + \beta_6 \ln GDP_{i,t} + \mu_i + \theta_t + \varepsilon_{i,t}$$

$$\text{Model 5: } \ln CO2_{i,t} = \beta_0 + \beta_1 \ln CO2_{i,t-1} + \beta_2 \ln EI_{i,t} + \beta_3 \ln LCARBONTAXETS_{i,t} + \beta_4 \ln POP_{i,t} + \beta_5 \ln FF_{i,t} + \beta_6 \ln GDP_{i,t} + \mu_i + \theta_t + \varepsilon_{i,t}$$

Based on the literature insights, five model specifications are designed to assess the effectiveness of market-based environmental instruments gradually. Model 1 evaluates the separate effect of environmental taxes as measured by the environmental tax revenue percentage of GDP. Model 2 outspreads this basis by incorporating low-carbon energy to account for technological transition. Models 3 and 4 introduce emission coverage indicators for carbon taxes and ETS, respectively, to capture their policy impact. Finally, Model 5 studies the combined effect of carbon taxes and ETS coverage to assess complementarity between instruments while applying low-carbon energy.

The used data is collected from reliable sources such as the Organization for Economic Cooperation and Development (OECD) database, ourworldindata, and the

World Bank (World Development Indicators (WDI)). Our database and sources are summarized in Table 1 below:

Table 1 – Description and data sources

Variable	Variable definition	Abbreviation	Source
Urban population	Urban population (% of total population)	URB	https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS
Fossil fuel	Fossil fuel energy consumption (% of total)	FF	https://data.worldbank.org/indicator/EG.USE.COMM.FO.ZS
GDP per capita	GDP per capita (constant LCU)	GDP	https://data.worldbank.org/indicator/NY.GDP.PCAP.KN
Population	Population, total	POP	https://data.worldbank.org/indicator/SP.POP.TOTL
CO₂ emissions	Carbon dioxide (CO ₂) emissions excluding LULUCF per capita (t CO ₂ e/capita)	CO₂	https://data.worldbank.org/indicator/EN.GHG.CO2.PC.CE.AR5
Environmental tax	environmentally related tax revenues % of GDP	TAX	https://www.oecd.org/en/data/indicators/environmental-tax.html
Energy intensity	Primary energy consumption per GDP (kWh/\$)	EI	https://ourworldindata.org/grapher/energy-intensity?tab=table
CO₂ emissions covered by a carbon tax or emissions trading scheme	CO ₂ emissions covered by a carbon tax or emissions trading scheme as a percentage of the country's CO ₂ emissions	CARBON-TAXETS	https://ourworldindata.org/grapher/carbon-tax-trading-coverage
CO₂ emissions covered by a carbon tax	CO ₂ emissions covered by a carbon tax as a percentage of the country's CO ₂ emissions	CARBONTAX	https://ourworldindata.org/grapher/carbon-tax-trading-coverage?tab=line
CO₂ emissions covered by an emissions trading system	CO ₂ emissions covered by an emissions trading system as a percentage of the country's CO ₂ emissions	CARBONETS	https://ourworldindata.org/grapher/carbon-tax-trading-coverage?tab=line
Per capita consumption of low-carbon energy	Measured in kilowatt-hours per person. Low-carbon energy is the sum of nuclear and renewable primary energy	LOWCRBON	https://ourworldindata.org/grapher/per-capita-low-carbon-energy

Source: Author presentation

Table 1 presents an overview of the variables used in our research, including their definitions, measurement units, abbreviations, and data sources with links. Environmental pressure is proxied by CO₂ emissions that constitute the dependent variable. Carbon tax and emissions trading system (ETS) variables are introduced as variables capturing the implementation of market-based carbon pricing instruments. Energy intensity is included as an indicator reflecting the structural performance of the economy in terms of energy use. The low-carbon energy represents the degree of technological transition within the energy mix. Additional control variables, such as GDP per capita and population, urbanization, and fossil fuels are incorporated to account for scale, economic structure, and social effects, which may independently impact emission dynamics.

4. Results

4.1. Descriptive statistics

Before performing our model estimation, it is obvious to examine the descriptive statistics presented in Table 2.

Table 2 – Result of descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
URB	744	74.48535	10.89612	50.675	98.079
FF	744	1595.546	3934.466	29.40364	23576.99
GDP	744	41334.48	18278.08	10949.72	120647.8
POP	744	3.89e+07	5.90e+07	419450	3.32e+08
CO2	744	372807.9	943019.2	6928.3	5775807
TAX	744	2.402312	0.8631357	1.53	5.36
EI	744	1.443696	0.4963054	0.6488547	5.404991
CARBONTAXETS	744	31.00599	28.21035	0	93.81519
CARBONTAX	744	11.77872	21.22254	0	73.23335
CARBONETS	744	21.09633	21.88993	0	63.32411
LOWCARBON	744	12411.4	15757.2	17.96539	93578.22

Source: Our calculations under Stata

Descriptive data analysis for OECD countries from 1997 to 2020 reveals significant trends concerning environmental taxation, energy efficiency, and environmental quality. Urban population averages 74.49 with relatively small variation, indicating a relative stability in urban dynamics across OECD countries over the period considered. Fossil fuel energy consumption averages 1595.55, with significant dispersion represented by a standard deviation of 3934.47. This variability highlights substantial differences in fossil fuel dependence among OECD countries. GDP per capita averages 41334.48, with considerable variation, with a standard deviation of 18278.08, indicating significant differences in the level of economic development within OECD countries. Carbon dioxide emissions show a mean of 372807.9 CO₂ emissions in OECD countries. However, the high standard deviation (943019.2) highlights significant disparities between countries. Environmental tax has a mean of 2.40, with moderate variation illustrated by a standard deviation of 0.86. Energy intensity of consumption shows a mean of 1.44, with relatively low variation indicated by a standard deviation of 0.50, highlighting some stability in the energy efficiency level.

The results for CO₂ emissions covered by a carbon tax or an Emission Trading Scheme, and the combination of these two strategies, reveal respective averages of 11.78, 21.10, and 31.01, with high standard deviations indicating substantial variations in these environmental mechanisms' application.

Finally, the low-carbon energy consumption per capita standard deviation is 15757.2, illustrating the diversity of low-carbon energy sources adoption.

In conclusion, these statistics highlight the diversity of environmental and energy indicators within OECD countries over the period studied. They underscore the importance of considering this variability when analyzing the impact of environmental taxes, ETS, and energy efficiency on OECD's environmental quality.

Table 3 – Correlation matrix

	LCO2	LPOP	LGDP	LFF	LURB	LEI	LTAX	LCARBONTAXETS	LCARBONTAX	LCARBONETS	LLOWCARBON
LCO2	1.000										
LPOP	0.8396	1.0000									
LGDP	0.2123	0.1690	1.0000								
LFF	0.9917	0.8407	0.1494	1.0000							
LURB	0.3367	0.4164	0.5106	0.3058	1.0000						
LEI	-0.1918	-0.1175	-0.4514	-0.1940	0.0263	1.0000					
LTAX	-0.5147	-0.3345	-0.3609	-0.5089	-0.1786	0.0485	1.0000				
LCARBONTAXETS	0.1150	0.3671	0.3113	0.1087	0.1522	-0.3676	0.2513	1.0000			
LCARBONTAX	0.0996	0.2317	0.5836	0.0262	0.3035	-0.3232	0.0721	0.7271	1.0000		
LCARBONETS	-0.0263	0.2585	-0.0296	-0.0103	-0.0558	-0.1740	0.5115	0.8452	0.3882	1.0000	
LLOWCARBON	0.1211	0.1946	0.6442	0.0673	0.5141	-0.0539	-0.2371	0.2431	0.5635	-0.0144	1.0000

L denotes the natural logarithm of each variable

Source: Our calculations under Stata

Results of the correlation matrix highlight a high correlation between CO₂ and fossil fuel use, indicating that heavily dependent fossil fuel countries, such as coal, oil, and gas, show higher levels of CO₂ emissions, thus contributing to climate change.

The moderate positive correlation between urbanization and CO₂ emissions suggests that countries with higher urbanization, characterized by a concentration of population in urban areas, tend to emit more CO₂. This result can be attributed to an increase in energy demand to meet urban regions' needs, leading to an increase in CO₂ emissions.

The adverse correlation between energy intensity and CO₂ emissions indicates that countries that use energy more efficiently tend to emit less CO₂. Lower energy intensity reflects more efficient use of energy in economic production, which leads to lower CO₂ emissions.

The significant negative correlation between fossil fuel consumption and environmental tax suggests that nations that have implemented environmental tax policies are successful in reducing their dependence on fossil fuels. This reveals an inverse association between fossil fuel consumption and the implementation of tax measures to reduce CO₂ emissions. The moderate negative correlation between CO₂ emissions covered by an ETS and total CO₂ emissions indicates that countries im-

plementing specific environmental policies based on ETS contribute to reducing their CO₂ emissions.

Results of the correlation matrix presented in Table 3 highlight the importance of environmental tax, energy efficiency, and ETS in achieving CO₂ emissions reduction targets. However, it is essential to note that correlation does not necessarily imply causation, and further analyses would be needed to fully understand the dynamics underlying these relationships.

According to the correlation matrix, we can conclude that we are in the presence of a probable multicollinearity between several variables. Indeed, according to Gujarati (2004), a multi-collinearity problem exists if the correlation between the independent variables exceeds 0.80, which is the case for the results of our study. To further analyze the multicollinearity problem, we apply the variance inflation factor (VIF) test. This test measures the degree to which the explanatory variable can be explained by the other explanatory variables.

Thus, if the VIF is greater than 10, there is a multicollinearity problem (Neter et al., 1985). According to Table 4 below, all the explanatory variables have a VIF less than the critical value of 10, hence the absence of a multicollinearity problem. Thus, we can conclude that there are no extremely high levels of correlation requiring the use of measures that can overcome this problem.

Table 4 – VIF test estimates

Variable	VIF	1/VIF
LPOP	5.85	0.170898
LFF	5.52	0.180997
LGDP	3.40	0.294034
LCARBONTAXETS	2.72	0.367425
LLOWCARBON	2.44	0.410214
LURB	1.98	0.505336
LCARBONTAX	1.94	0.514211
LEI	1.77	0.564376
LTAX	1.58	0.633414
Mean VIF		3.02

Source: Authors' output from Stata

4.2. GMM estimation results

In this study, we estimate our models using the two-stage system GMM, developed by Arellano and Bover (1995) and Blundell and Bond (1998). Roodman (2009) confirmed that this method is more efficient and robust than other methods and that the statistical tests it allows are reliable. To ensure the validity of the method, we tested the instruments' validity using the Hansen test, first- and second-order autocorrelation using the Arellano-Bond test. These tests showed that the estimated models are valid. Consequently, our results are reliable. Table 5 below presents the estimated parameters and t-statistics.

Table 5 – Two-step system GMM estimation of the impact of environmental tax, ETS System, energy efficiency, and low carbon energy on CO₂ emissions for OECD countries

	Model 1	Model 2	Model 3	Model 4	Model 5
LCO _{2t-1}	0.122939 (2.65) **	0.0791706 (1.02)	0.063708 (0.52) **	0.0128558 (0.42)	0.2099423 (6.79) ***
LPOP	0.0434782 (0.44)	-0.0448849 (-0.40)	-1.409512 (-2.52)	-0.1526089 (-1.92) **	-0.1861102 (-3.03) ***
LGDP	-0.2936252 (-3.26) ***	-0.1884691 (-1.86) *	-0.1001533 (-1.18)	-0.2703996 (-7.27) ***	-0.2120903 (-9.31) ***
LFF	1.020806 (13.45) ***	0.9367323 (8.69) ***	0.6819503 (8.51) ***	1.016878 (34.10) ***	0.928704 (24.08) ***
LURB	0.4307252 (0.77)	0.8316417 (1.19) *			
LEI	-0.122216 (-2.87) ***	-0.0854369 (-1.69)	-0.0780486 (-1.63)	-0.0818503 (-4.21) ***	-0.1485873 (-7.31) ***
LTAX	-0.0083644 (-0.32)	-0.0155839 (-0.35)			
LCARBONTAXETS					-0.023715 (-3.18) ***
LCARBONTAX			-0.0291808 (-1.51)		
LCARBONETS				-0.0795126 (-1.50)	
LLOWCARBON		-0.1041972 (-2.65) **			
Constant	4.462919 (2.47) **	5.029379 (2.11) **	30.73739 (3.20) ***	10.83912 (6.75) ***	8.867992 (7.75) ***
Number of observations	706	706	250	419	490
Countries	31	31	17	27	30
Number of instruments	24	24	24	24	24
Hansen test	20.15 (0.213)	13.71 (0.548)	6.10 (0.992)	20.53 (0.248)	20.44 (0.252)
Arellano-Bond test AR (1)	-2.39 (0.017)	-1.70 (0.089)	-0.75 (0.456)	-1.79 (0.074)	-2.68 (0.007)
Arellano-Bond test AR (2)	-0.97 (0.333)	-1.26 (0.208)	-1.83 (0.068)	-0.94 (0.346)	-1.33 (0.184)

*, **, and *** indicate significance at 10%, 5%, and 1%

Source: Authors' output from Stata

Results of the overall models indicate that GDP per capita exerts a negative impact on emissions in OECD countries. Several structural and policy-related factors can explain this negative coefficient. Indeed, generally, structural economic transformation is associated with higher income levels. A tendency to switch from industrial, carbon-intensive to service and knowledge-based economies in OECD countries can be noticed. Furthermore, OECD countries implement environmental policies such as carbon pricing mechanisms and stricter emissions standards. Besides,

high-income economies possess greater financial capacity to invest in cleaner technologies, energy-efficient equipment, and infrastructure.

Model 1 estimation results display that energy intensity leads to CO₂ emissions reduction, confirming that the adoption of more energy-efficient equipment in these wealthy economies leads to a reduction of energy intensity and thereby decreases emissions levels. These findings support the necessity of the development of more energy-efficient technologies and disseminating them to less developed countries to amplify their positive impact on CO₂ reduction, and thereby improve environmental quality. Indeed, the OECD aims to help these countries implement policies to mitigate climate change. This policy adoption would reduce fossil fuel consumption, improve environmental quality, ensure energy security for the current generation, and preserve fossil resources for future generations. This positive effect of adopting energy efficiency was proven by Aguir-Bargaoui et al. (2014) for 151 countries over the period 1980-2010 and by Tajudeen et al. (2018) for 30 OECD countries over the period 1971-2015.

Furthermore, the estimated results suggest that past emissions contribute to increased actual emissions. Indeed, producing more emissions today leads to future environmental degradation. Fossil fuel use also contributes to this degradation. A 1% increase in fossil fuel consumption leads to a 1.0208% increase in CO₂ emissions. This result is consistent with the findings of other studies, such as that of Shafei and Ruhul (2013), who analyzed data from OECD countries between 1980 and 2011.

As for population, urban population, and environmental taxes variables, they do not significantly impact emissions.

The second model's estimates, focused on detecting the impact of low-carbon energy consumption, reveal a promising conclusion: the adoption of Low-carbon energy significantly reduces CO₂ emissions. The analysis shows that a 1% increase in low-carbon energy use leads to a -0.104% decrease in CO₂ emissions. This finding offers a positive outlook and encourages the active promotion of increased integration of low-carbon energy to improve environmental quality.

This conclusion aligns harmoniously with previous results by Jebli et al. (2016), Bilgili et al. (2016), and Paramati et al. (2017), thus consolidating the validity and consistency of our results with trends observed in the scientific literature.

As for Model three, we used a variable that measures the proportion of emissions subject to a carbon tax, rather than the level or rate of the tax itself. Results indicate that the level of carbon tax coverage in OECD countries does not have a statistically significant effect on CO₂ emissions. These results do not imply that carbon taxes are ineffective; however, they can give evidence that limited coverage may be insufficient to generate a measurable impact on emissions. The breadth of coverage and the magnitude of the tax rate applied may be revised in order to ameliorate the effectiveness of carbon taxes. Furthermore, this finding underscores the need to explore complementary approaches to achieve meaningful environmental objectives. Previous work by Mardones and Flores (2018) supports this perspective by highlighting the limitations of carbon taxes' impact on CO₂ emissions. Thus, broadening our understanding of environmental policies to design more effective and sustainable solutions is imperative.

The estimation of Model 4 highlights an interesting finding: the presence of ETS policy does not appear to exert a significant influence, as evidenced by its coefficient of -0.079 with a p-value of 0.732. This result indicates that the studied phenomenon,

namely the CARBONETS variable, does not have a statistically significant impact on CO₂ emissions.

This finding highlights the need to take a holistic approach in designing environmental policies and explore multiple mechanisms to achieve significant emission reductions.

The estimation of Model 5 reveals a significant finding: CO₂ emissions covered by a carbon tax or an ETS show a notable negative correlation, as indicated by a coefficient of -0.0237 and a p-value of 0.003. The negative correlation indicates that when CO₂ emissions are subject to a carbon tax or an ETS, CO₂ emissions tend to decrease. These findings support the idea that these instruments can help reduce greenhouse gas emissions. Aligning this observation with the findings of previous models, where other variables showed significant positive or negative correlations, it becomes clear that targeted policy implementation, such as carbon taxes or ETS, can be an effective lever to achieving environmental objectives. Thus, considering several variables, an integrated approach remains essential for sustainable environmental policy formulation.

The findings of this study significantly demonstrate the impact of several factors on CO₂ emissions, highlighting promising avenues for guiding environmental policies. Energy efficiency, low-carbon energy consumption, as well as the simultaneous implementation of a carbon tax and an Emissions Trading Scheme (ETS) policy, emerge as key elements that can positively influence emissions reductions.

These results are consistent with the findings of other studies on similar topics, reinforcing the idea that policies focused on improving energy efficiency, promoting low-carbon energy, and implementing carbon pricing mechanisms can play a crucial role in mitigating CO₂ emissions. However, the study highlights the inherent complexity of managing CO₂ emissions due to the simultaneous use of new policies and energy sources with fossil fuel consumption that contributes seriously to environmental quality deterioration.

This observation underscores the urgent need to reduce dependence on fossil fuels and adopt more sustainable alternatives. These findings call for an integrated approach to environmental policies. To achieve ambitious CO₂ emission reduction targets, governments should invest significantly in the research and development of more energy-efficient technologies. Actively encouraging renewable energy use and other low-carbon sources is also essential. Furthermore, carbon pricing schemes can play a key role in incentivizing more environmentally friendly behavior. This study highlights the need for a holistic approach, combining various policies and instruments, to effectively address the complexity of CO₂ emission challenges, while giving particular focus on reducing fossil fuel consumption due to its significant impact on environmental quality degradation.

In conclusion, holistic policies aimed at reducing fossil fuel consumption, improving energy efficiency, promoting sustainable economic growth, and implementing effective environmental policies are essential to address environmental challenges in OECD countries. An integrated approach that combines these different factors appears to be the key to progressing towards a greener and more equitable economy.

Two statistical tests are inherent to validate our estimates: the Hansen test for the validity of the instruments and the Arellano-Bond autocorrelation test. Indeed, Blundell and Bond (2000) stated that to test the validity of additional instruments, the

best practice when applying the GMM system is to use the Sargan difference test, which checks the validity of a subset of instruments. The Sargan difference test is, according to Roodman (2007), closely related to the Hansen test for the validity of the set of all used instruments. In the present study, we use the Hansen test to test the validity of all the instruments used. We consider the validity of p-instruments if the p-value is higher than 5%, and we accept the null hypothesis.

Regarding our estimated models, the p-values are all greater than 0.05, which allows us to accept the null hypothesis. Furthermore, the instruments used are valid. Therefore, the used instruments are not asymptotically correlated with the disturbances in the estimated models.

The Arellano-Bond statistical test, which tests the null hypothesis of the absence of first-order autocorrelation, is applied to the differenced residuals. The p-values of the models are higher than 5%, which shows that we can accept the null hypothesis of the absence of autocorrelation. These results do not affect the consistency of the results since it evaluates autocorrelation in differences. Several researchers have stated that the second-order error autocorrelation test AR (2) is more important because it allows us to detect autocorrelations at the level. The p-values are all greater than 5%. Then, a second-order autocorrelation is absent for all the models studied, which induces the robustness of our estimates.

5. Conclusion

This study studied the impact of economic instruments, which are market-based environmental policies, on CO₂ emissions in OECD countries during 1997-2020, using a dynamic panel framework estimated through system GMM.

Prominently, the results reveal that the existing level of emission coverage by an Emissions Trading Scheme (ETS) does not automatically translate into significant emission reductions. Similarly, carbon tax coverage alone does not appear sufficient to generate a measurable impact. However, the joint proportion of emissions effectively covered by carbon pricing instruments – carbon taxes and ETS – shows a statistically significant reduction in CO₂ emissions. This finding suggests that policy design, coverage breadth, and effective implementation matter more than the formal adoption of a single instrument. Carbon pricing mechanisms can be effective only by combining carbon taxes and ETS while controlling for energy intensity and using low-carbon energy.

The results confirm that improvements in energy intensity significantly decrease CO₂ emissions, revealing the central role of technological upgrading and energy-saving innovations in improving environmental quality. Likewise, the increased use of low-carbon energy sources exerts a statistically significant and negative effect on emissions, reinforcing the importance of accelerating the transition toward cleaner energy systems.

By dissimilarity, fossil fuel consumption remains a major driver of environmental degradation. Furthermore, economic growth appears negatively associated with emissions in some specifications. Several structural and policy-related factors can explain this negative coefficient. Undeniably, our studied sample is composed of OECD countries that are high and upper-middle-income countries that tend to switch from industrial, carbon-intensive to service and knowledge-based economies. Moreover, OECD countries already implement regulatory, economic, and informational instruments. De-

mographic variables and environmental tax, as measured by environmental tax revenues as a percentage of GDP, do not exhibit consistent statistical significance.

Post-estimation diagnostics support the validity and robustness of our findings. Indeed, the Hansen tests confirm the validity of the instruments used. Besides, there is no indication of first- or second-order autocorrelation as suggested by Arellano–Bond tests. Consequently, we can confirm the consistency of the estimators.

Overall, the evidence argues for three main policy implications. First, structural improvements in energy intensity and further low-carbon energy adoption. Second, carbon tax and ETS carbon coverage must be sufficiently widespread and rigorous to produce measurable environmental effects. Third, a coordinated and integrated strategy aimed at reducing fossil fuel dependence is needed to amplify the positive effect of environmental policies.

A coherent policy mix combining efficiency improvements, low-carbon energy expansion, and well-designed carbon pricing to ensure a sustainable coverage level seems essential for achieving sustained emissions reductions and evolving toward long-term carbon neutrality.

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