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The Impact of Environmental Tax and Emission Trading System on Environmental Quality in OECD Countries

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Abstract— **The goal of sustainable development encompasses three fundamental dimensions: economic, ecological, and social. The application of environmental instruments to achieve sustainability can be classified into three groups: regulatory, economic, and informational instruments. The impact of the implementation of environmental taxes and emissions trading schemes, which are among the economic instruments, on emissions represents the fundamental issue of this research. Using the Generalized Method of Moments (GMM) and a variety of key variables for 31 OECD countries covering the period from 1997 to 2020, results indicate that the adoption of a carbon tax policy or an emissions trading system in isolation cannot contribute to the reduction of CO_2 emissions, while the adoption of both policies at the same time makes it possible to achieve this objective.**

Keywords— **Emissions Trading System, Environmental Taxes, Generalized Method of Moments.**

1. Introduction

The goal of sustainable development encompasses three fundamental dimensions. As for economical dimension, the focus is on the transition to green growth by upgrading the energy efficiency of industrial activities, promoting the adoption of renewable 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 enhancing 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 Energy Information Administration (EIA) advocates the development of energy-efficient technologies and the promotion of renewable energy equipment and use. In this sense, 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.

To fulfill this energy transition, environmental policies have to be undertaken via environmental instruments adoption. These instruments can be fundamentally categorized into three distinct groups: regulatory instruments, economic instruments, and informational instruments.

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 are not based on the prices of goods, economic instruments operate 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 integrate these impacts into their consumption choices.

The Organization for Economic Cooperation and Development (OECD) first introduced the polluter pays

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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 implementation of the "polluter pays principle" takes various forms, notably through the application of environmental taxes and the creation of emission quota trading systems. 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.

Therefore, their objective is to modify market functioning to increase its efficiency. Because of these advantages, economists consider these approaches particularly appropriate for improving environmental conditions (Central Economic Council, 2010). Due to their effectiveness, the European Union actively supports the use of economic instruments and market mechanisms (Kosonen and Nicodemus, 2009).

In this context, the objective of the present paper is to measure the impact of environmental taxation and emissions trading systems on the environmental quality of OECD countries to appreciate the effectiveness of adopted environmental instruments. Indeed, results concerning the impact of environmental tax and ETS on carbon emissions are controversial. Therefore, the contribution of the present paper to the existing literature consists of measuring the quantification of the implementation of environmental tax and emissions trading systems solely while applying energy efficiency and low-carbon energy. Besides, a quantification of the adoption of combined instruments will be conducted.

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 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-, medium-, 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 ETSs in reducing emissions across countries that adopted the mechanism. Similarly, Bian et

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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 ETSs. Scholars such as Martin et al. (2014), Andersson (2019), and Metcalf (2019) have found that carbon taxes can be more effective than ETSs 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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

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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 CO_2 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.

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. Increasing environmental taxes reduces carbon emissions, building on previous work demonstrating the effectiveness of tax incentives in encouraging environmentally friendly behavior.

Assumption 2. Emissions trading schemes (ETS) significantly contribute to CO_2 emissions reduction, based on previous research anticipating that ETS implementation will incentivize firms to invest in more sustainable practices.

Assumption 3. Improving energy efficiency is correlated positively with reducing environmental impacts, based on the logic that more efficient energy practices can lead to more sustainable resource use.

Assumption 4. Combining policies promoting energy efficiency, 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.

These hypotheses emerge from gaps identified in the existing literature and aim to guide our research toward a better understanding of the interaction between environmental policy instruments and environmental quality.

3. METHODOLOGY AND DATA

In this section, we will describe applied methodology to analyze the impact of environmental taxes, Emissions Trading Scheme, low carbon energy and energy efficiency on environmental quality in OECD countries. We will explain our choice of the dynamic panel method and the rationale behind using the system two-stage GMM method.

3.1. EMPIRICAL MODEL

The used methodology in the present paper is the Generalized Method of Moments (GMM), which account 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

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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 CO_2 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.

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

Model 1 :

$$lnCO_{2it} = \beta_0 + \beta_1 lnCO^2{}_{it-1} + \beta_2 lnEI_{it} + \beta_3 lnTax_{it} + \beta_4 lnPOP_{it} + \beta_5 lnURB_{it} + \beta_6 lnFF_{it} + \beta_7 lnGDP_{it} + \theta + \varepsilon_{it}$$

(1)

Model 2 :

$$lnCO_{2it} = \beta_0 + \beta_1 lnCO^2{}_{it-1} + \beta_2 lnEI_{it} + \beta_3 lnTax_{it} + \beta_4 lnPOP_{it} + \beta_5 lnURB_{it} + \beta_6 lnFF_{it} + \beta_7 lnGDP_{it} + \beta_8 lnLLOWCARBON_{it} + \theta + \varepsilon_{it}$$

(2)

Model 3 :

$$lnCO_{2it} = \beta_0 + \beta_1 lnCO^2{}_{it-1} + \beta_2 lnEI_{it} + \beta_3 lnLCARBONTAX_{it} + \beta_4 lnPOP_{it} + \beta_5 lnFF_{it} + \beta_6 lnGDP_{it} + \theta + \varepsilon_{it}$$

(3)

Model 4 :

$$lnCO_{2it} = \beta_0 + \beta_1 lnCO^2{}_{it-1} + \beta_2 lnEI_{it} + \beta_3 lnLCARBONETS_{it} + \beta_4 lnPOP_{it} + \beta_5 lnFF_{it} + \beta_6 lnGDP_{it} + \theta + \varepsilon_{it}$$

(4)

Model 5 :

$$lnCO_{2it} = \beta_0 + \beta_1 lnCO^2{}_{it-1} + \beta_2 lnEI_{it} + \beta_3 lnLCARBONTAXETS_{it} + \beta_4 lnPOP_{it} + \beta_5 lnFF_{it} + \beta_6 lnGDP_{it} + \theta + \varepsilon_{it}$$

(5)

The variable CO_{2it} represents carbon dioxide emissions in country i at date t, while CO_{2it-1} is the same variable lagged by one year. Regarding $lnTax_{it}$, it is the environmental tax. EI_{it} represents energy efficiency measured by the energy intensity of consumption. $lnLCARBONETS_{it}$ represents CO_2 emissions covered by an emissions trading scheme as a percentage of the country's total CO_2 emissions, $lnLCARBONTAXETS_{it}$: represents CO_2 emissions covered by an emissions trading scheme and tax as a percentage of the country's total CO_2 emissions, $lnLCARBONTAX_{it}$: CO_2 emissions covered by an environmental tax as a percentage of the country's total CO_2 emissions, $lnURB_{it}$: Urban population, $lnFF_{it}$: Energy from fossil fuels, $lnGDP_{it}$: GDP per capita, $lnPOP_{it}$: population, and $lnLOWCARBON_{it}$: Low-carbon energy per capita (kWh). The parameter θ refers to the country-specific effects in the sample, and ε_{it} represents the error term.

3.2. Data Description and data sources

In the present research, we use a variety of macroeconomic variables and other key indicators for 31 OECD countries covering the period from 1997 to 2020. This data is collected from reliable sources such as the Organization for Economic Cooperation and Development (OECD) database 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	Abbreviation	Source
Urban population	UP	World Bank

ISSN: 2961-6611

Fossil fuel energy consumption	FFEC	World Bank
GDP per capita	GDP	World Bank
Population	Pop	World Bank
CO_2 emissions	CO_2	World Bank
Environmental tax	ET	OECD
Energy intensity of consumption	EIC	World Bank
CO_2 emissions covered by a carbon tax or emissions trading scheme as a percentage of the country's CO_2 emissions	CO2 CT/ETS	OECD
CO_2 emissions covered by a carbon tax as a percentage of the country's CO_2 emissions	CO2 CT	OECD
CO_2 emissions covered by an emissions trading system as a percentage of the country's CO_2 emissions	CO2 ETS	OECD
Low-carbon energy per capita (kWh)	LC energy/capita	World Bank

Source: Author presentation

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
Urban population	744	74.48535	10.89612	50.675	98.079
Fossil fuel	744	1595.546	3934.466	29.40364	23576.99
GDP per capita	744	41334.48	18278.08	10949.72	120647.8
Population	744	3.89e+07	5.90e+07	419450	3.32e+08
CO2emission	744	372807.9	943019.2	6928.3	5775807
Environmental tax	744	2.402312	0.8631357	1.53	5.36
Energy intensity	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
Lowcarbonenergy	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 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 of CO_2 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 energy efficiency level.

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The results for CO_2 emissions covered by a carbon tax or an Emission Trading Scheme and the combination of these two strategies reveal respective averages of 31.01, 11.78, and 21.10, 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

Source: Our calculations under Stata

The CO_2 variable indicates a high dependence on fossil fuels indicating that heavily dependent fossil fuels countries, such as coal, oil, and gas, show higher levels of CO_2 emissions, thus contributing to climate change.

The moderate positive correlation between urbanization and CO_2 emissions suggests that countries with higher urbanization, characterized by a concentration of population in urban areas, tend to emit more CO_2. This result can be attributed to an increase in energy demand to meet urban region's needs, leading to an increase in CO_2 emissions.

The adverse correlation between energy intensity and CO_2 emissions indicates that countries that use energy more efficiently tend to emit less CO_2. Lower energy intensity reflects more efficient use of energy in economic production, which leads to lower CO_2 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 CO_2 emissions. The moderate negative correlation between CO_2 emissions covered by a carbon tax or an ETS and total CO_2 emissions indicates that countries implementing specific environmental policies, such as carbon taxes or ETS, contribute to reducing their CO_2 emissions.

The results in Tables 1 and 2 highlight the importance of environmental policies, energy efficiency, and energy diversification in achieving CO_2 emissions reduction targets. They provide crucial information to guide policy decisions aimed at promoting sustainable economic growth and mitigating environmental impacts in OECD countries. 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

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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 validity of the instruments 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.

Model 1, which examines the impact of energy efficiency on environmental quality, suggests that a 1% increase in energy efficiency leads to a 0.1222% decrease in CO_2 emissions. Energy efficiency is one of the policies adopted by OECD countries. We recommend strengthening the development of more energy-efficient technologies and disseminating them to less developed countries. 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 indicate that past emissions increase 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 CO_2 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.

However, economic growth impacts emissions negatively. Indeed, an increase in economic growth leads to an increase in energy consumption and, consequently, CO_2 emissions. Population, urban population, and environmental taxes does not impact significantly emissions.

The second model's estimates, focused on detecting the impact of low-carbon energy consumption, reveal a promising conclusion: Low-carbon energy adoption reduce significantly CO_2 emissions. The analysis shows that a 1% increase in low-carbon energy use leads to a 0.015% decrease in CO_2 emissions. This finding offers a positive outlook and encourages the active promotion of increased integration of low-carbon energy to improve environmental quality.

ISSN: 2961-6611

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.
However, it is crucial to note that continued fossil fuel use and economic growth appear to contribute to increased environmental degradation. The interactions between economic prosperity, total population, urban population, and environmental tax do not demonstrate a statistically significant effect in our analysis. This finding underscores the complexity of factors influencing CO_2 emissions and highlights the need for a balanced approach combining cleaner energy solutions with sustainable economic policies to achieve optimal environmental outcomes.

TABLE 5. TWO-STEP SYSTEM GMM ESTIMATION OF THE IMPACT OF ENVIRONMENTAL TAX, ETS SYSTEM, ENERGY EFFICIENCY AND LOW CARBON ENERGY ON CO_2 EMISSIONS FOR OECD COUNTRIES

	Model 1	Model 2	Model 3	Model 4	Model 5
LCO_{2t-1}	0.122939	0.0791706	0.063708	0.0128558	0.2099423
	(2.65) **	(1.02)	(0.52) **	(0.42)	(6.79) ***
LPOP	0.0434782	-0.0448849	-1.409512	-0.1526089	-0.1861102
	(0.44)	(-0.40)	(-2.52)	(-1.92) **	(-3.03) ***
LGDP	-0.2936252	-0.1884691	-0.1001533	-0.2703996	-0.2120903
	(-3.26) ***	(-1.86) *	(-1.18)	(-7.27) ***	(-9.31) ***
LFF	1.020806	0.9367323	0.6819503	1.016878	0.928704
	(13.45) ***	(8.69) ***	(8.51) ***	(34.10) ***	(24.08) ***
LURB	0.4307252	0.8316417	-	-	-
	(0.77)	(1.19) *	-	-	-
LEI	-0.122216	-0.0854369	-0.0780486	-0.0818503	-0.1485873
	(-2.87) ***	(-1.69)	(-1.63)	(-4.21) ***	(-7.31) ***
LTAX	-0.0083644	-0.0155839	-	-	-
	(-0.32)	(-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	5.029379	30.73739	10.83912	8.867992
	(2.47) **	(2.11) **	(3.20) ***	(6.75) ***	(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	13.71	6.10	20.53	20.44
	(0.213)	(0.548)	(0.992)	(0.248)	(0.252)
Arellano-Bond test AR (1)	-2.39	-1.70	-0.75	-1.79	-2.68
	(0.017)	(0.089)	(0.456)	(0.074)	(0.007)

ISSN: 2961-6611

Arellano-Bond test AR (2)	-0.97	-1.26	-1.83	-0.94	-1.33
	(0.333)	(0.208)	(0.068)	(0.346)	(0.184)

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

Source: Authors' output from Stata

Model three suggests that carbon taxes do not have a statistically significant impact on CO_2 emissions. Although carbon taxes are one of the policies adopted by OECD countries, it is essential to emphasize revising this policy to make it more effective and focusing on other strategies. Our recommendations include particularly reducing fossil fuel consumption and improving energy efficiency.

By analyzing these results, we can conclude that the effectiveness of carbon taxes in reducing emissions is not always guaranteed. 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 CO_2 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 -0.0155839 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 CO_2 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 observation: the presence of CO_2 emissions covered by a carbon tax or an ETS shows a notable negative correlation, illustrated by a coefficient of -0.023715 with a p-value of 0.003. The negative correlation indicates that when CO_2 emissions are subject to a carbon tax or an ETS, CO_2 emissions tend to decrease. These findings support the idea that these instruments can help in greenhouse gas emissions reduction. 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. However, it is also worth highlighting the complexity of the landscape, with other factors having varied influences on CO2 emissions. 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 simultaneous implementation of a carbon tax, and an Emissions Trading Scheme (ETS) policies 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 CO_2 emission reduction targets, governments should invest significantly in 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 CO_2 emission challenges, while giving particular focus on reducing fossil fuel consumption due to its significant impact on environmental quality degradation.

In conclusion, holistically 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

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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 used instruments. 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 difference. 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.

V. Conclusion

Following a thorough analysis of the models examined, it becomes evident that several factors played a crucial role in understanding CO_2 emissions drivers and effective economic instruments to CO_2 emissions reduction in OECD countries between 1997 and 2020. These complex models highlight that fossil energy consumption remains the main driver of carbon dioxide emissions, underscoring the imperative of a transition to more sustainable energy sources. Improving energy efficiency also emerges as a promising strategy, calling for continued investment in technologies and practices that promote more efficient energy use. The correlation between GDP per capita and CO_2 emissions highlights the need for more balanced and environmentally friendly economic growth. The mixed results of environmental policies underscore the importance of designing specific measures by combining environmental taxes and emissions trading schemes, to ensure maximum efficiency. The temporal persistence of emissions suggests the need for long-term policies to maintain progress. Hansen and Arellano-Bond tests confirm the validity of our estimates, demonstrating that the instruments used are not correlated with the disturbances of the estimated models and that the residuals do not exhibit first-order autocorrelation.

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