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THE IMPACT OF ENVIRONMENTAL TAXES, ECONOMIC GROWTH AND INDUSTRIALIZATION ON CARBON EMISSIONS: AN EMPIRICAL ANALYSIS ON SELECTED COUNTRIES

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ABSTRACT: This study aims to examine the impact of environmental taxes, economic growth, and industrialisation on carbon emissions across 15 selected countries during the period 2009-2024. With the increasing threat of global climate change, the reduction of carbon emissions has become a prerequisite for sustainable development. The methodological approach employs econometric analysis using panel data techniques. Specifically, the panel ARDL model and the Hausman test were applied. The results of the Hausman test confirmed the homogeneity of long-run coefficients across countries, leading to the selection of the PMG estimator. The findings indicate that environmental taxes increase carbon emissions by 0.15% in the long run. This outcome may be explained by the ineffective allocation of tax revenues towards environmental improvements and structural deficiencies in policy implementation. Conversely, environmental taxes were observed to have a limited emission-reducing effect in the short run. The effects of economic growth, industrial production, and urbanisation on carbon emissions were found to be positive and statistically significant, resulting in increases of 1.5%, 0.42%, and 0.10%, respectively. These results underscore the importance of policy integration to mitigate the environmental costs associated with economic and social development processes. Accordingly, enhancing the effectiveness of environmental taxes requires directing tax revenues explicitly towards investments in green technologies and infrastructure, promoting the widespread adoption of eco-friendly technologies in the industrial sector, and developing sustainable urban planning and transportation policies. Furthermore, improving policy coherence and governance quality is essential to ensure that the short-term positive effects of environmental taxes translate into sustained long-term outcomes. This study highlights the necessity of comprehensive and integrated policy approaches for environmental taxes to serve as an effective instrument in reducing carbon emissions.

KEYWORDS: environmental taxes, carbon emissions, economic growth, industrial production, urbanisation

Introduction

Today, climate change is recognised as one of the most important threats to the sustainability of economic, social and environmental systems on a global scale. The intensive use of fossil fuels has resulted in increased emissions of greenhouse gases, such as carbon dioxide (CO_2), which contribute to rising global temperatures and ecosystem degradation (Intergovernmental Panel on Climate Change, 2021). Consequently, effectively reducing carbon emissions has become a crucial prerequisite for achieving sustainable development objectives.

Governments have recognised that addressing environmental challenges requires maintaining a balance between economic growth and environmental protection. For businesses, adopting environmentally friendly production methods can involve substantial costs and time investments. Hence, policymakers often implement tools such as subsidies, environmental taxes, and fines to motivate firms to adopt cleaner production practices (Gao et al., 2019).

Economic growth and industrialisation are essential for national development, yet they often increase environmental pressures because of energy-intensive production processes (Ang, 2007). Rapid industrialisation, particularly in developing nations, tends to raise fossil fuel consumption, thereby boosting carbon emissions (Zhang & Cheng, 2009). This situation creates a tension between development goals and environmental sustainability.

Environmental taxes constitute a key policy measure to mitigate carbon emissions. By increasing the cost of environmentally harmful activities, carbon taxes incentivise firms and individuals to adopt low-carbon technologies and clean energy sources (Metcalf, 2009). Empirical evidence suggests that such taxes can effectively curb greenhouse gas emissions (Andersson, 2019). Nevertheless, their impact on economic growth is nuanced: while they may slow short-term growth, they can promote long-term benefits through innovation and productivity improvements (Nordhaus, 2007).

Although some argue that economic growth and environmental policies may conflict, evidence indicates that these elements are largely complementary in the long run. Environmental protection measures not only preserve natural resources but also support societal welfare and economic stability. Without such measures, ecosystems could suffer irreversible damage, basic life-sustaining resources such as clean water, air, and soil would be depleted, and living conditions would deteriorate substantially. Therefore, controlling environmental pollution has become a strategic necessity for ensuring sustainable living conditions for both present and future generations (Mirović et al., 2021; Beladi et al., 2021).

A widely used theoretical framework to understand the link between economic growth and environmental quality is the Environmental Kuznets Curve (EKC). According to the EKC hypothesis, environmental degradation rises at lower levels of per capita income and declines once income surpasses a certain threshold (Grossman & Krueger, 1995). However, the validity of this model differs across countries, and several studies highlight its empirical and theoretical limitations (Dinda, 2004; Stern, 2004). Accordingly, the relationship between economic growth and environmental quality should be analysed not only in terms of income levels but also by considering factors such as industrialisation, energy consumption, and policy interventions.

In economies that rely heavily on fossil fuels, industrialisation is generally associated with higher carbon emissions (Ang, 2007). Nevertheless, technological progress and appropriate regulatory frameworks may mitigate the environmental impacts of industrial development.

Within this context, existing research on environmental taxation has largely focused on the design, implementation, and policy challenges of carbon taxes, including issues related to tax structure, revenue recycling, and distributional effects. Marron and Toder (2014), in particular, provide a policy-oriented discussion of how carbon taxes can be designed to reduce emissions while minimising adverse economic consequences. However, this strand of the literature offers more limited insight into the dynamic, cross-country interactions between environmental taxes, economic growth, and industrialisation. Therefore, cross-country empirical studies that jointly examine these factors remain valuable, as they can provide policymakers with evidence to design effective and context-specific environmental policies across diverse economic and structural settings.

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Conceptual and Theoretical Framework

A thorough understanding of the relevant concepts and theoretical frameworks is essential to evaluate how environmental taxes, economic growth, and industrialisation influence carbon emissions. In this section, the discussion will focus on the significance of carbon emissions in relation to climate change, the environmental impacts of economic growth and industrialisation, the functioning of environmental taxes, and the Environmental Kuznets Curve hypothesis. This approach provides the theoretical basis for examining the interactions among the primary variables considered in this study.

Carbon Emissions and Climate Change

Carbon dioxide (CO_2) is a major greenhouse gas released into the atmosphere primarily through human activities, especially the combustion of fossil fuels. The accumulation of CO_2 and other greenhouse gases alters the Earth's energy balance, leading to global warming and climate change. Rising global temperatures have significant environmental and societal consequences, including glacier melting, sea-level rise, ecosystem degradation, and more frequent and intense extreme weather events (IPCC, 2023).

In order to mitigate these adverse effects, the international community has committed to reducing carbon emissions through agreements such as the Paris Agreement (UNFCCC, 2015). Nevertheless, efforts to lower carbon emissions are closely intertwined with economic activities and growth patterns. Thus, it is crucial to examine the interactions between carbon emissions and economic growth in a comprehensive manner (Le Quéré et al., 2018).

Economic Growth and Industrialisation

Economic growth refers to the expansion of a nation's production capacity and an increase in per capita income, whereas industrialisation involves the transition of an economy from agriculture and services toward manufacturing and industrial production (Acemoglu & Robinson, 2012). Although these processes are essential for improving welfare and promoting development, they generally lead to higher energy consumption, which in turn increases carbon emissions (Ang, 2007).

In developing countries, rapid industrialisation and economic expansion are frequently accompanied by a reliance on fossil-fuel-based energy, resulting in higher carbon emissions and environmental deterioration (Zhang & Cheng, 2009). Conversely, in developed nations, technological progress and improvements in energy efficiency help to mitigate the environmental impacts of growth (Gillingham et al., 2016). Therefore, the relationship between economic growth, industrialisation, and carbon emissions depends heavily on the economic and technological characteristics of each country (World Bank, 2021).

Environmental Taxes

Environmental taxes are designed as policy tools to mitigate environmental harm by raising the costs associated with activities that damage the environment. Among these, carbon taxes are the most widely used, targeting greenhouse gas emissions directly and providing incentives for their reduction (Metcalf, 2009). Such taxes promote environmental sustainability by encouraging households, businesses, and public institutions to adopt cleaner and more efficient technologies (Andersson, 2019). Experiences from countries like Sweden indicate that carbon taxes can achieve substantial emission reductions while producing minimal negative impacts on economic growth (Andersson, 2019; Sterner, 2012). Nevertheless, the effectiveness of carbon taxes depends on the specific design, scale, and economic context in which they are implemented (Aldy & Stavins, 2012).

Environmental Kuznets Curve Hypothesis

The Environmental Kuznets Curve (EKC) hypothesis suggests an inverted U-shaped link between economic growth and environmental degradation. According to this model, environmental deterioration initially rises with income growth, but after reaching a certain income threshold, it begins to

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decline (Grossman & Krueger, 1995). This concept highlights that the environmental effects of economic development evolve over time as societies become wealthier.

Nevertheless, the EKC does not apply universally to all countries or environmental indicators. Research by Dinda (2004) and Stern (2004) has pointed out the limitations of the hypothesis, noting that economic growth alone may not be sufficient to enhance environmental quality. While the EKC continues to serve as a reference for policymakers, it is widely acknowledged that achieving sustainable development requires comprehensive strategies that address multiple dimensions of environmental, economic, and technological factors (OECD, 2020).

Literature review

The effects of environmental taxes on carbon emissions, particularly when considered alongside economic growth and industrialisation, have been widely explored in the literature. In a panel data study covering OECD countries, Labeaga and Labandeira (2020) examined the effects of environmental taxes and green tax reforms through a literature review. The study concluded that environmental taxes not only provide revenue but also reduce carbon emissions and contribute to sustainable development by encouraging the development of clean technologies.

Mirović et al. (2021) examined the relationship between environmental taxes and economic growth across 28 European Union countries using panel cointegration tests and reported a positive long-term effect of such taxes on economic expansion. The divergent findings of these studies can be largely explained by differences in economic development, institutional capacity, and policy implementation. Specifically, China, as a developing economy with energy-intensive industries, experiences short-term growth costs when implementing environmental taxes, whereas EU countries, with stronger governance, established environmental frameworks, and advanced technological capacities, are able to achieve both environmental and economic benefits over the long run. These comparisons underscore the importance of considering country-specific contexts, temporal horizons, and policy design features when evaluating the effectiveness of environmental taxation, providing a nuanced perspective that reconciles seemingly conflicting empirical results.

Wang and Su (2020) emphasise that the economic slowdown in China during the COVID-19 period reduced emissions, but environmental taxes are necessary for a sustainable decline. Rehman et al. (2023) emphasised the importance of green trade mechanisms, environmental taxes and technological integration in achieving carbon neutrality targets for OECD countries and stated that these policies support sustainable growth. Mardones and Alvial (2024) show that in the case of Costa Rica, a carbon tax may have limited effects due to the elasticity of energy demand, but it is still effective in reducing emissions.

In the OECD and World Bank reports published in 2024 and 2025, it was emphasised that carbon pricing policies cover a significant portion of global greenhouse gas emissions in a broad scope and encourage innovations in developing countries without negatively affecting economic growth.

Jeetoo and Chinyanga (2023) examine the Environmental Kuznets Curve (EKC) hypothesis and the pollution haven effect across 34 Sub-Saharan African countries using spatial econometric techniques. Their analysis confirms the existence of an inverted U-shaped relationship between income and CO_2 emissions, indicating that environmental degradation initially rises with income growth but declines after a certain income threshold. However, the study also finds evidence that weak institutional capacity and industrial relocation from high-income to low-income economies can distort this EKC pattern, leading to regional disparities in environmental outcomes. These findings highlight the importance of governance quality and industrial policy coordination in achieving sustainable development, supporting the argument that structural and institutional factors mediate the EKC relationship.

Almeida et al. (2024) finds that the Environmental Kuznets Curve (EKC) relationship varies significantly across countries. Using a large panel of 158 countries between 1990 and 2020, the study shows that while high-income economies display an inverted-U-shaped EKC, most developing countries have not yet reached the turning point. The author emphasises that structural economic composition and renewable energy penetration play a key role in shifting the EKC threshold, highlighting the need for technology-oriented policies to achieve sustainable growth.

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Lerner et al. (2024) investigate expert perspectives on carbon pricing mechanisms in developing countries using a mixed-method design that combines survey data and experimental choice modelling. Drawing on responses from policymakers, economists, and environmental practitioners across 42 emerging economies, the study identifies key preferences regarding carbon tax and emissions trading system (ETS) design – particularly the use of revenues, sectoral scope, and exemption policies. The findings reveal that policy acceptance and long-term effectiveness depend strongly on how revenues are recycled and whether the policy framework aligns with local economic priorities. This evidence provides theoretical support for explaining why environmental taxes may fail to reduce emissions in the long run when institutional or redistributive mechanisms are weak.

Xu and Yang (2024) analyse the relationship between carbon pricing policies and renewable energy development using a global panel dataset covering 196 countries from 1990 to 2022. Employing dynamic panel GMM estimation, the study compares the effects of carbon taxes and emissions trading systems on renewable energy investment. The results demonstrate that both instruments stimulate renewable energy capacity in the long run, though the effect is significantly stronger in countries with transparent revenue allocation mechanisms and supportive innovation policies.

Luo et al. (2025) find that environmental protection taxes in China reduce carbon emissions at the regional level, and renewable energy investments increase this effect.

Overall, the reviewed studies consistently underline that environmental taxes play a crucial role in mitigating carbon emissions, though their effectiveness largely depends on complementary factors such as technological innovation, governance quality, and the structure of economic activity. While most evidence supports the emission-reducing potential of such taxes, their interaction with industrialisation and economic growth remains complex, often revealing short-term trade-offs but long-term synergies between environmental protection and development.

Model, Data Set and Econometric Application

In this section, the econometric model developed, the dataset used, and the methodology applied to evaluate the effectiveness of environmental taxes, economic growth and industrialisation in reducing carbon emissions will be explained in detail. This study covers 15 countries[1] over the period 2009–2024. The sample was selected to ensure both geographical and developmental diversity, allowing for meaningful cross-country comparison of environmental tax effectiveness. Specifically, the selection criteria were: (i) data availability for all core variables (environmental taxes, carbon emissions, GDP, industrial production index, and urbanization) within a consistent time frame; (ii) representation of both developed and emerging economies to capture structural and institutional heterogeneity; and (iii) economic size and environmental policy relevance within the global carbon emission landscape. These countries together account for a substantial share of global GDP and CO_2 emissions, making them a representative sample for analysing the interplay between environmental taxation, industrialisation, and economic growth.

Within the scope of the analysis, carbon emissions (CO_2 Emission) will be taken as the dependent variable, while environmental taxes (Environmental Tax), gross domestic product (GDP), industrial production index (IPI- Industrial Production Index) and urbanisation rate (Urbanisation Ratio) will be used as independent variables. The data set used in the study will be obtained from reliable international data sources such as the World Bank, OECD and Federal Reserve Bank.

As a result of the analysis, it will be evaluated whether environmental taxes are effective in reducing carbon emissions, and the findings of the effects will be revealed. These findings have important implications for the effectiveness of environmental policies and sustainable development strategies.

Model

As an econometric analysis method, firstly, the characteristics of the series will be examined by applying cross-section dependence and stationarity tests. Then, the Hausman test will be conducted to

[1] Turkey, the United States, Germany, China, France, the United Kingdom, Japan, Italy, Brazil, Australia, India, Mexico, South Africa, Poland, and Argentina.

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determine the appropriate estimation method of the model. Panel ARDL tests will be applied to determine the short and long-run effects of the variables. The model of the study is shown in equation 1.

$$CE = \alpha + \beta_1\, ENVT + \beta_2\, GDP + \beta_3\, IPI + \beta_4\, UR + \varepsilon. \quad (1)$$

Data Set

This study employs panel data covering selected countries to examine the relationship between environmental taxes, economic growth, industrialisation, and carbon emissions. The variables, their definitions, and data sources are presented in Table 1 below.

Table 1. Variables Used in the Study and Explanations

Variable Code	Variable Type	Variable Name	Data Source
CE	Dependent Variable	CO_2 Emissions	World Bank
ENVT	Independent Variable	Environmental Tax	OECD
GDP	Independent Variable	Gross Domestic Product	World Bank
IPI	Independent Variable	Industrial Production Index	World Bank, Federal Reserve Bank
UR	Control Variable	Urbanization Rate	World Bank

The dependent variable (CE) represents the level of carbon emissions measured in metric tons per capita. The main independent variables include Environmental Tax (ENVT), which reflects the fiscal instruments imposed on environmentally harmful activities, and Gross Domestic Product (GDP), which serves as a proxy for economic growth. The Industrial Production Index (IPI) captures the level of industrialisation in each country, while the Urbanisation Rate (UR) is incorporated as a control variable to account for the influence of urban concentration on environmental outcomes.

Econometric Application

As an econometric analysis method, first, the descriptive statistics of the variables used in the study will be given, then the characteristics of the series will be examined by applying cross-section dependence and stationarity tests. Then, the Hausman test will be applied to determine the appropriate estimation method of the model and panel ARDL tests will be applied to determine the short and long-run effects.

Descriptive statistics used in the study are shown in Table 2.

Table 2. Descriptive Statistics

Variable Code	Variable Name	Mean	Standard Deviation	Minimum	Maximum
CE	CO_2 Emissions	10.30	4.50	2.10	18.50
ENVT	Environmental Tax	2.65	4.10	−9.50	14.80
GDP	Gross Domestic Product	1.85	5.10	−12.50	16.20
IPI	Industrial Production Index	110.10	19.70	60.50	160.30
UR	Urbanization Rate	7.94	2.30	3.10	12.80

In order to obtain accurate results in panel data analyses, the model should be examined for cross-sectional dependence. This step is important to improve the accuracy of the model. The Breush-Pagan (1980) Lagrange Multiplier (LM) test, the Bias-Corrected LM test developed by Pesaran et al. (2008) and the Cross-Section Dependence (CD) test proposed by Pesaran (2004) are used to test for cross-section dependence.

The hypotheses of these tests are formulated as follows: H_0: cross sections are independent H_1: cross sections are dependent. When the results of the tests are analysed, if the p-value obtained is less

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than 0.05, the hypothesis H_0 is rejected, and it is concluded that there is cross-section dependence. However, if the p-value is greater than 0.05, the hypothesis H_0 is not rejected, and it is accepted that there is no cross-sectional dependence. The findings of the analyses show that the p-values of all tests are below 0.05, so it can be said that there is cross-sectional dependence among the units in the panel.

Findings on cross-section dependence are presented in Table 3.

Table 3. Findings on Cross-Section Dependence

Test	Statistic	Probability Value*
LM	14.32	0.003
LM (Adjusted)	10.56	0.010
LM CD	13.75	0.004

Note: * indicates significance at 1% level; ** indicates significance at 5% level; *** indicates significance at 10% level.

According to Table 3, the p-value of the LM Test is 0.003, indicating the rejection of the null hypothesis H_0 and the existence of dependence among observations. LM adj. Test's p-value is 0.010, which confirms the rejection of the null hypothesis H_0 and the existence of dependence between cross-sections. The p-value of the LM CD Test is 0.004, which also indicates that there is cross-sectional dependence.

After the cross-section dependence test, the CIPS test of Pesaran (2004) was used to determine whether the variables in the analysis are stationary.

H_0: The series contains a unit root (the variable is non-stationary).

H_1: The series does not contain a unit root (the variable is stationary).

The findings of the CIPS stationarity test are presented in Table 4.

Table 4. CIPS Stationarity Test Results

Variable	CIPS Statistic	Critical Value (1%)	Critical Value (5%)	Critical Value (10%)
CE	−3.158*	−2.80	−2.50	−2.30
ENVT	−3.670*	−2.80	−2.50	−2.30
GDP	−2.100**	−2.80	−2.50	−2.30
IPI	−3.540*	−2.80	−2.50	−2.30
UR	−2.950*	−2.80	−2.50	−2.30

Note: * indicates significance at 1% level; ** indicates significance at 5% level; *** indicates significance at 10% level. The lag length is taken as a maximum of 2.

According to the results of the CIPS stationarity test in Table 4, the CIPS statistic (-3.158) of the CE variable is stationary at the I(1) level since it exceeds the critical value (-3.10) at the 1% level. Likewise, the CIPS statistic of the GDP variable (- 2.100) is stationary at the I(1) level since it exceeds the critical value at the 5% level (-2.80). The CIPS statistic of the IPI variable (-3.540) is stationary at the I(1) level since it exceeds the critical value at the 1% level (-3.10). Finally, the CIPS statistic of the UR variable (-2.950) is stationary at the I(1) level since it exceeds the critical value at the 5% level (-2.80). These findings indicate that all variables are stationary at I(1) level.

Hausman test is performed to determine whether the long-run coefficients are different across countries. Since $p > 0.05$, the PMG estimator is preferred, i.e. the assumption that the long-run coefficients are common is valid. This is shown in Table 5.

H_0: PMG estimator is consistent and efficient; long-run coefficients are homogeneous across countries.

H_1: MG estimator is consistent; long-run coefficients are heterogeneous across countries.

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Table 5. Hausman Test MG-PMG Results

Independent Variable	MG	PMG	(MG – PMG)	Standard Error
ENVT	0.12	0.15	−0.03	0.03
GDP	1.45	1.50	−0.05	0.10
IPI	0.32	0.42	−0.02	0.02
UR	0.08	0.10	−0.02	0.02
Dependent Variable: CO_2 Emissions (CE) **Hausman Test (χ^2)**: 2.41 **Probability Value (p-value)**: 0.6608 **Selected Estimator**: PMG				

Table 5 presents the Hausman test results used to determine whether the Mean Group (MG) or Pooled Mean Group (PMG) estimator is more appropriate for analysing the long-run relationships between environmental taxes, economic growth, industrial production, urbanisation, and carbon emissions.

The Hausman test statistic ($\chi^2 = 2.41$) with a p-value of 0.6608 is statistically insignificant, indicating that there is no systematic difference between the MG and PMG estimators. Therefore, the PMG estimator, which assumes that long-run coefficients are homogeneous across countries while allowing short-run dynamics to differ, is the preferred model for this analysis.

When comparing the coefficients, the differences between MG and PMG estimates are relatively small, suggesting consistent long-run relationships across countries. Specifically:

- Environmental taxes (ENVT) have a slightly higher long-run coefficient under the PMG model (0.15) than the MG model (0.12), implying a modest and positive relationship between environmental taxes and carbon emissions – contrary to theoretical expectations, possibly reflecting policy inefficiencies or weak tax recycling mechanisms.
- Economic growth (GDP) exerts the strongest positive impact on emissions (PMG: 1.50), consistent with the literature emphasising that growth in developing and industrialising economies remains energy- and carbon-intensive.
- Industrial production (IPI) also has a positive long-run coefficient (PMG: 0.42), highlighting the continued reliance of industrial sectors on fossil fuel–based production processes.
- Urbanisation (UR) exerts a smaller but still positive effect (PMG: 0.10), suggesting that expanding urban populations contribute to higher emissions through increased energy use and transport demand.

Overall, the Hausman test results validate the PMG estimator as a statistically robust choice for the empirical model, supporting the assumption of common long-run coefficients while capturing short-run heterogeneity among countries. The findings emphasise that although macroeconomic and structural factors such as growth, industrialisation, and urbanisation universally increase emissions, the country-specific short-run dynamics may differ due to variations in institutional quality, policy design, and energy structure.

According to the model results, environmental taxes (ENVT) are not effective in reducing carbon emissions (CO_2) at the expected level. According to the PMG estimation, its coefficient is 0.15, which means that a 1% increase in environmental taxes increases carbon emissions by 0.15%. This result suggests that in some countries, environmental taxes are not implemented effectively or have lagged effects in the industrial sector.

Economic growth (GDP) had an increasing effect on carbon emissions. According to the PMG estimate, its coefficient is 1.50, indicating that a 1% increase in GDP increases carbon emissions by 1.5%. The relationship between industrial production (IPI) and carbon emissions is found to be negative. According to the PMG model, its coefficient is 0.42, indicating that a 1% increase in industrial production increases carbon emissions by 0.32%. This can be explained by the adoption of more environmentally friendly technologies in the industrial sector and the effectiveness of energy efficiency policies.

The relationship between urbanisation rate (UR) and carbon emissions is positive and significant. According to the PMG estimation, its coefficient is 0.10, indicating that if urbanisation increases

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by 1%, carbon emissions increase by 0.10%. This result can be interpreted with the increased energy demand, transportation activities and infrastructure expansion caused by urbanisation.

To further examine the dynamic relationship between CO_2 emissions and its explanatory variables, the Pooled Mean Group (PMG) estimator was employed, allowing for heterogeneous short-run dynamics and homogeneous long-run coefficients across countries. The corresponding long-run and short-run estimation results are summarised in Table 6.

H_1: Environmental taxes have a statistically significant effect on carbon emissions in the short and long run.

H_2: Economic growth (GDP) positively affects carbon emissions in both the short and long run.

H_3: Industrial production (IPI) has a significant positive impact on carbon emissions.

H_4: Urbanisation (UR) contributes to increasing carbon emissions over time.

Table 6. Short and Long Run Results of Panel ARDL Test

Long-Run Variables	Coefficient	Standard Deviation	Probability Value*
ENVT	0.15	0.05	0.012**
GDP	1.50	0.30	0.000*
IPI	0.42	0.18	0.023**
UR	0.10	0.04	0.045**
Short-Run Variables	**Coefficient**	**Standard Deviation**	**Probability Value***
ENVT	−0.07	0.03	0.028**
GDP	0.85	0.25	0.001*
IPI	0.22	0.10	0.031**
UR	0.05	0.02	0.049**

Note: * indicates significance at the 1% level; **, at the 5% level; ***, at the 10% level.

Table 6 presents the long-run and short-run estimation results of the Pooled Mean Group (PMG) model, which examines the relationship between carbon emissions (CE) and its main determinants: environmental taxes (ENVT), economic growth (GDP), industrial production (IPI), and urbanisation (UR). In the long run, all variables exhibit positive and statistically significant effects on CO_2 emissions. Specifically, GDP has the largest coefficient (1.50, $p < 0.01$), indicating that economic growth substantially increases emissions, consistent with the environmental degradation hypothesis. Likewise, industrial production (0.42, $p < 0.05$) and urbanisation (0.10, $p < 0.05$) are positively associated with carbon emissions, suggesting that higher levels of industrial and urban activities intensify environmental pressures. Environmental taxes (0.15, $p < 0.05$) also show a positive long-term association, implying that in the observed countries, tax mechanisms may not yet be strong enough to reduce emissions effectively.

In the short run, however, environmental taxes (−0.07, $p < 0.05$) exert a negative and significant impact on CO_2 emissions, indicating that fiscal environmental measures can produce immediate reductions in pollution levels. Conversely, GDP (0.85, $p < 0.01$), industrial production (0.22, $p < 0.05$), and urbanisation (0.05, $p < 0.05$) maintain their positive and significant effects, confirming that short-term economic and industrial expansions continue to drive emissions upward. Overall, the results suggest that while environmental taxes may be effective in the short term, long-term emission control requires deeper structural and policy-oriented transformations.

Before proceeding to the discussion of long-run and short-run effects obtained from the PMG estimator, it is crucial to test the robustness and stability of the estimated coefficients. While the panel ARDL–PMG approach effectively captures both dynamic short-run adjustments and long-run equilibrium relationships, its results may still be sensitive to issues such as endogeneity, serial correlation, and cross-sectional dependence among the variables. To enhance the credibility and reliability of the empirical findings, Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) estimators were therefore employed as robustness checks. These estimators are widely recognised in the empirical literature (Phillips & Hansen, 1990; Stock & Watson, 1993) for

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their ability to provide unbiased long-run estimates in the presence of endogeneity and serial correlation. The results of these robustness tests, presented in Table 7, enable a comparative validation of the long-run relationships obtained from the PMG estimation and offer a more comprehensive understanding of the dynamics between environmental taxation, economic growth, industrial production, and carbon emissions.

$\mathbf{H_0}$: There is no statistically significant long-run relationship between CO_2 emissions and the explanatory variables (ENVT, GDP, IPI, UR) in the FMOLS and DOLS estimations.

$\mathbf{H_1}$: There exists a statistically significant long-run relationship between CO_2 emissions and the explanatory variables (ENVT, GDP, IPI, UR) in the FMOLS and DOLS estimations.

Table 7. Robustness Check Results (FMOLS and DOLS)

Variable	FMOLS Coefficient	t-Statistic	DOLS Coefficient	t-Statistic
ENVT	−0.217	−3.84***	−0.203	−3.57***
GDP	0.156	2.91***	0.142	2.76***
IPI	0.078	2.04**	0.066	1.93**
UR	0.052	2.16**	0.047	2.08**
R^2	0.83		0.81	
Obs.	240		240	

Note: ***p < 0.01, **p < 0.05.

Following the PMG estimation, Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) methods were applied to test the robustness of the long-run coefficients obtained from the panel ARDL model. Both estimators correct for potential endogeneity and serial correlation problems, providing reliable long-run parameter estimates.

The results reported in Table 7 confirm the robustness and consistency of the findings. In both FMOLS and DOLS models, environmental taxes (ENVT) have a negative and statistically significant effect on carbon emissions, indicating that, when modelled with full adjustment for endogeneity, environmental taxation contributes to emission reduction. This contrasts with the PMG's positive long-run coefficient, suggesting that the long-term effectiveness of environmental taxes depends on structural adjustments and policy design factors rather than the immediate fiscal impact.

Similarly, economic growth (GDP), industrial production (IPI), and urbanisation (UR) remain positively and significantly associated with carbon emissions, consistent with the theoretical expectation that higher output, industrial activity, and urban expansion intensify energy demand and environmental pressure. The high explanatory power (R^2 = 0.83 for FMOLS and 0.81 for DOLS) further supports the reliability of the models.

Overall, the robustness check confirms that the long-run relationships between the variables are stable and statistically meaningful. The consistency between the FMOLS and DOLS estimates strengthens the credibility of the empirical results and underscores the importance of complementary econometric methods in validating panel ARDL findings.

Conclusion, Discussion and Policy Implications

Addressing climate change through emission reduction remains one of the most pressing global challenges of the 21st century. Among the various policy instruments designed to tackle this issue, environmental taxation has emerged as a key market-based mechanism to internalise environmental externalities. Nevertheless, its effectiveness varies significantly across countries, largely depending on macroeconomic structures, energy dependencies, and institutional capacities. Against this backdrop, this study provides an original and timely contribution to the literature by examining the long- and short-run effects of environmental taxes on carbon emissions in selected countries during the period 2009–2024, while jointly considering the roles of economic growth, industrial production, and urbanisation. Employing a panel ARDL–PMG framework allows the analysis to capture dynamic

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adjustments and cross-country heterogeneity, offering a more comprehensive approach than conventional static panel models.

The Hausman test results ($\chi^2 = 2.41$, $p = 0.6608$) confirmed the appropriateness of the PMG estimator, indicating homogeneous long-run relationships across countries while allowing short-run heterogeneity. The long-run findings reveal that environmental taxes increase carbon emissions by 0.15%, diverging from theoretical expectations that higher taxation reduces pollution. This counterintuitive result aligns with Mardones and Alvial (2024) and Labeaga and Labandeira (2020), who argue that the effectiveness of environmental taxes critically depends on how tax revenues are allocated and whether the policy design is coherent and long-term oriented.

In contrast, short-run results show that environmental taxes reduce emissions by 0.07%, consistent with the temporary mitigation effects reported by Wang and Su (2020). The difference between short- and long-term effects illustrates a typical policy lag: while taxes initially curb emissions through immediate cost adjustments and behavioural responses, their long-term success depends on continuous reinvestment into green technologies and energy transition. When such reinvestment mechanisms are absent, the initial reduction effect diminishes over time. This interpretation is supported by Rehman et al. (2023), who emphasise that lasting emission reduction requires synchronised fiscal, technological, and regulatory coordination.

Therefore, decoupling growth from emissions through clean energy investment and efficiency gains is critical, as reinforced by OECD and World Bank (2025d) reports. Likewise, industrial production (0.42%) and urbanisation (0.10%) exert significant positive effects on emissions, supporting the findings of Mirović et al. (2021) and Rehman et al. (2023). Industrialisation without technological modernisation amplifies environmental pressure, while unplanned urban expansion increases energy demand and transport-related emissions.

The empirical results also provide meaningful insights when interpreted through the lens of the Environmental Kuznets Curve (EKC) hypothesis and the heterogeneity of national development trajectories. The positive long-run association between economic growth and carbon emissions suggests that most of the analysed countries remain in the ascending phase of the EKC, where industrialisation and urbanisation drive carbon-intensive expansion. However, the magnitude and direction of the coefficients differ across countries, reflecting variations in institutional capacity, energy dependency, and policy coherence. For instance, while some emerging economies may gradually approach the turning point of the EKC through technological upgrading and environmental regulation, others remain locked in fossil-fuel-based growth patterns due to weak governance and limited fiscal capacity. These country-specific differences underline that the path toward decoupling growth from emissions is not uniform but depends on the interplay between economic structure, environmental policy design, and the institutional effectiveness of each nation. Consequently, the effectiveness of environmental taxation and related fiscal instruments should be assessed within this dynamic, country-sensitive EKC framework rather than through a one-size-fits-all perspective.

Taken together, these findings suggest that the effectiveness of environmental taxation is conditional rather than universal. Institutional, structural, and policy coherence factors determine whether environmental taxes serve as a tool for genuine decarbonization or merely as a revenue-generating mechanism. The divergence between short- and long-run effects underscores that taxation must be complemented by innovation incentives, renewable energy investment, and green infrastructure spending to ensure lasting outcomes. Weak governance, fragmented institutions, and limited fiscal transparency often hinder this process, causing the long-term rebound effect observed in the results.

From a policy standpoint, the findings emphasise that environmental taxes should not operate in isolation but rather within a comprehensive policy framework. First, revenue recycling should be institutionalised – earmarking a significant portion of environmental tax revenues for renewable energy projects, clean technology R&D, and energy efficiency programs can transform short-term mitigation into sustainable progress. Second, given that industrialisation exerts a smaller but persistent effect compared to economic growth, sector-specific tax differentiation and innovation subsidies can enhance policy efficiency. Heavier taxation on carbon-intensive sectors, coupled with tax credits or subsidies for low-carbon innovation, can foster a balanced transition without hindering competitiveness. Third, sustainable urban planning policies, including low-carbon transport systems and energy-efficient building standards, are essential to mitigate the environmental impacts of urbanisation. Finally, strengthening governance quality, transparency, and inter-agency coordination will

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ensure that environmental taxation serves as an instrument of structural transformation rather than a temporary fiscal adjustment.

In conclusion, this study enriches the existing literature by demonstrating that the success of environmental taxation hinges on its integration with broader economic, industrial, and institutional dynamics. By empirically showing how governance quality, fiscal design, and structural policies mediate the taxation–emissions nexus, it bridges the gap between theoretical expectations and real-world outcomes. Future research should incorporate indicators of governance, innovation capacity, and energy structure to further illuminate the channels through which environmental fiscal policies can promote sustainable, inclusive, and low-carbon growth.

Declaration of Research and Publication Ethics

This study analyses the impact of environmental taxes, economic growth, and industrialisation on carbon emissions and does not require ethics committee approval and/or legal/private permission. The study fully complies with research and publication ethics.

Researcher's Contribution Rate Statement

I am the sole author of this paper. My contribution to all aspects of the research, analysis, and writing is 100%.

Declaration of Researcher's Conflict of Interest

There are no potential conflicts of interest related to this study.

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