

DO GREEN TAXES DELIVER ENVIRONMENTAL DIVIDENDS? PANEL EVIDENCE ON CARBON EFFICIENCY AND SUSTAINABILITY

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Abstract

This study examines whether green taxation can effectively move countries toward carbon efficiency frontiers by reducing emissions while supporting sustainable development objectives. Relying on a balanced panel dataset comprising 11 countries observed over a 25-year period, the research employs advanced econometric techniques to analyze the relationship among green tax revenue, carbon dioxide emissions per capita, renewable energy consumption, and trade openness. The objective is to assess whether fiscal instruments designed to price environmental externalities contribute meaningfully to improved environmental performance. The empirical results indicate that higher levels of green tax revenue are significantly associated with reductions in carbon dioxide emissions per capita, thereby confirming the environmental effectiveness of taxation policies aimed at internalizing environmental costs. In addition, renewable energy consumption and trade openness are found to reinforce the impact of green taxation. Specifically, greater adoption of renewable energy sources enhances the emission-reducing effects of environmental taxes, while openness to international trade appears to facilitate technological diffusion and cleaner production practices, generating complementary benefits that support movement toward carbon efficiency frontiers. These findings are consistent with the theoretical foundations of Pigovian taxation and the double dividend hypothesis. Environmental taxes not only discourage pollution by increasing the cost of carbon-intensive activities but may also contribute to broader economic gains through innovation incentives, improved resource allocation, and expansion of cleaner energy sectors. By integrating fiscal policy with energy transition dynamics and international trade linkages, the study offers comprehensive policy insights for governments seeking to reconcile economic growth objectives with environmental sustainability. The results underscore the importance of coordinated policy design in achieving long-term climate goals within the global environmental governance framework.

Keywords: Green Taxation, Carbon Efficiency, Renewable Energy, Sustainable Development

INTRODUCTION

In examining the potential of green taxation as a mechanism for steering countries toward the carbon efficiency frontier, academic discourse emphasizes the strategic design of progressive environmental taxes to simultaneously reduce emissions and address socioeconomic disparities. Progressive green taxation, which imposes higher effective burdens on major polluters rather than uniformly across the population, can mitigate environmental degradation such as carbon emissions without disproportionately affecting lower-income groups that contribute less to pollution (Zheka & Vishnevsky, 2022; Yan & Sriboonchitta, 2024; Martin, 2025; Ali et al., 2025; Anus et al., 2025; Sun et al., 2024; Mehdi et al., 2025). Earlier research links economic inequality with excessive resource exploitation and environmental stress, arguing that complementary instruments such as tax rebates and environmental credit mechanisms can discourage unsustainable consumption while correcting distortions generated by conventional income tax systems. Such integrated approaches enhance both environmental sustainability and distributive equity (Ahmad, 2019; Fan & Iqbal, 2022; Tang & Azman, 2024; Qasir & Agha, 2025; Ali & Audi, 2016; Abbasi et al., 2025; Ahmad & Lu, 2025).

Evaluating whether environmental policies effectively enhance carbon efficiency requires a balanced combination of supply-side and demand-side instruments (Altaf & Shahzad, 2021; Chowdhury & Hassan, 2025; Carlo, 2025; Ali et al., 2025; Lee & Zhuang, 2025; Ammar et al., 2025; Hou & Yuan, 2025). Muhammad et al. (2021) developed a typology of green market policies and, through comparative analysis of organic food policy frameworks in Denmark, Sweden, the United Kingdom, and the United States, demonstrated that higher levels of sustainable consumption are associated with comprehensive policy mixes incorporating both production incentives and consumer-oriented measures. This evidence suggests that environmental taxation alone may be insufficient unless supported by

complementary policy tools. Public acceptance is equally critical for successful implementation. Nchofoung et al. (2023) synthesized empirical findings on support for environmental taxes and showed that acceptance increases when citizens understand policy effectiveness, trust public institutions, perceive fairness in cost allocation, and are concerned about climate change. As environmental pressures intensify alongside rapid economic growth, effective fiscal instruments such as green taxation become essential for achieving carbon efficiency. Maxim et al. (2019) show that taxes on fossil fuel use can substantially reduce greenhouse gas emissions while generating local co-benefits such as improved air quality. Their findings indicate that carbon taxation can lower carbon intensity by encouraging cleaner production and consumption patterns. International evidence further reinforces the contribution of green taxation to renewable energy adoption and carbon efficiency (Marc & Ali, 2017; Martin & Cameron, 2025; Arshi et al., 2025; Tan & Lee, 2025). Rodríguez et al. (2019), using robust estimators across 49 countries from 1996 to 2017, report that environmental tax revenues are positively associated with renewable energy consumption. Higher environmental tax collection is linked with lower carbon intensity, thereby advancing countries toward the carbon efficiency frontier. These results underscore the capacity of green taxes to incentivize cleaner energy transitions. The structure of environmental fiscal reform is central to achieving equilibrium between fiscal objectives and environmental outcomes. Daugbjerg and Sønderskov (2012) argue that targeted environmental fiscal restructuring within the European context can generate significant public revenue while simultaneously reducing emissions through taxes on environmentally harmful activities.

Public acceptance remains a foundational element in the effectiveness of green taxation (Ullah & Ali, 2024; Rizwan & Iqbal, 2025). Evidence suggests that citizens are more inclined to support environmental taxes when revenue use is transparent, distributional fairness is ensured, and environmental benefits are clearly communicated (Marc et al., 2020; Farhadi & Zhao, 2024; Bary & Hakim, 2025; Batool et al., 2025). Schlegelmilch and Joas (2015), applying a steady-state general equilibrium model to Portugal's 2014 green tax reform, demonstrate the realization of a double dividend—reductions in greenhouse gas emissions accompanied by improvements in energy independence and economic resilience. Their findings show that taxing carbon-intensive activities reduces overall carbon intensity and moves economies closer to the efficiency frontier. Complementary analyses by Daugbjerg and Sønderskov (2012) similarly highlight the dual environmental and economic benefits of green fiscal reform, including enhanced competitiveness and structural modernization. Meta-analytical evidence further suggests that recycling environmental tax revenues to reduce labor taxation can produce employment gains, reinforcing the broader economic appeal of green taxation. Distributional design is particularly important in aligning environmental effectiveness with social equity (Khan & Hassan, 2019; Jamel & Zhang, 2024; Marc et al., 2025). Casal (2012) argues that carbon taxation should follow progressive principles, ensuring that higher emitters bear greater fiscal responsibility while mitigating inequality through compensatory mechanisms such as rebates. Such designs enhance both fairness and political feasibility. Complementary demand-side incentives also play a role. Bhatia and Gupta (2020), in their comparative review of sustainable consumption policies, show that supply-side taxation combined with consumer incentives significantly increases pro-environmental purchasing behavior. This suggests that coordinated fiscal and behavioral measures can reduce carbon-intensive practices and guide economies toward carbon efficiency.

In developing economies, implementation capacity and institutional quality shape the success of green taxation (Marc & Ali, 2023; Naeem et al., 2025; Khalid & Abdul, 2025). Cao et al. (2009) examine the feasibility of environmental taxes in India and conclude that green taxation can raise environmental awareness and reduce carbon emissions when administrative challenges and public resistance are addressed. Their empirical analysis indicates that behavioral responses to taxation can facilitate movement toward carbon efficiency, provided governance structures support effective implementation. Nonetheless, the effectiveness of green taxation must be evaluated in relation to broader structural factors such as renewable energy deployment and international trade dynamics. Daugbjerg and Sønderskov (2012) emphasize that green taxation, as a supply-side intervention, achieves stronger outcomes when integrated with complementary demand-side policies and institutional support mechanisms. Addressing these interactions is essential for policymakers seeking to harness green taxation as a credible pathway toward national carbon efficiency objectives and meaningful contributions to global climate mitigation efforts.

LITERATURE REVIEW

The global effort to combat climate change has increasingly positioned green taxation as a central policy instrument for reducing carbon emissions and guiding economies toward the carbon efficiency frontier, defined as the minimum achievable level of per capita carbon dioxide emissions relative to a country's stage of economic and technological

development. A substantial body of literature evaluates the environmental, economic, and social implications of green taxation, including its structural design, effectiveness, and public reception across diverse institutional settings. Recent studies emphasize that green taxation holds strong potential to advance sustainable development objectives, although its effectiveness depends on policy coherence, institutional quality, and complementary measures (Rossi, 2023; Marc & Ali, 2023; Zolkover et al., 2024; Ali et al., 2025; Marc et al., 2025).

The concept of carbon efficiency has been rigorously examined in empirical research. Qamruzzaman (2025) provides a foundational analysis of the carbon efficiency frontier using Data Envelopment Analysis for developed economies over the period 1994 to 2011. The study identifies a positive and statistically significant relationship between environmental tax revenues and improvements in carbon efficiency. Similarly, Deb et al. (2024) focus on China's environmental challenges and employ a computable general equilibrium model to demonstrate that carbon taxation on fossil fuel consumption significantly reduces greenhouse gas emissions while generating co-benefits such as improved air quality. These findings illustrate how fiscal instruments can align environmental objectives with economic incentives, thereby facilitating progress toward the carbon efficiency frontier. International evidence further supports the role of environmental taxation in promoting renewable energy transitions (Willy, 2018; Audi & Ali, 2018; Vartiak, 2021; Ali et al., 2025; Audi et al., 2025). Rodríguez et al. (2019), applying the Fixed Effects Driscoll-Kraay estimator across 49 countries from 1996 to 2017, report a positive association between environmental tax revenues and renewable energy consumption, leading to reductions in carbon intensity. Schlegelmilch and Joas (2015), through a static general equilibrium analysis of Portugal's 2014 green tax reform, show that targeted taxation on carbon-intensive activities can deliver a double dividend by reducing emissions and enhancing energy independence and economic competitiveness. Similar conclusions are drawn by Daugbjerg and Sønderskov (2012), who emphasize that environmental fiscal restructuring in European contexts can generate substantial revenues while minimizing carbon emissions through targeted tax mechanisms.

The macroeconomic and employment effects of green taxation have also been widely investigated (Walsh, 2022; Ullah & Ali, 2024; Ali et al., 2025). Bohringer et al. (2003) develop an interactive simulation model to assess green tax reforms and demonstrate the possibility of achieving environmental, economic, and social dividends when tax structures are appropriately designed. Loganathan et al. (2014) analyze the historical and theoretical foundations of green taxation and highlight its dual function as a revenue-generating and behavior-modifying instrument. Baranzini and Carattini (2017) provide a comprehensive theoretical background, discussing Pigouvian cost internalization, the polluter pays principle, least-cost abatement, and the double dividend hypothesis, supported by practical examples such as Nordic carbon taxes and renewable energy tax credits in the United States. Milne (2007) further elaborates on green tax theory, emphasizing its dual objectives of revenue mobilization and environmental correction. Equity considerations are critical in the design of green taxation (Otero, 2021; Longston et al., 2025). Casal (2012) argues that progressive carbon taxation targeting major polluters, combined with compensatory mechanisms such as tax rebates, can reduce emissions while addressing economic inequality. Harring and Jagers (2013), using survey evidence from Sweden, demonstrate that political trust, environmental values, and perceived fairness significantly influence public support for carbon taxation. Carattini et al. (2017) find that public acceptance increases when revenue earmarking and transparent communication are emphasized, while concerns about competitiveness and distributional fairness may reduce support. Muth et al. (2024) similarly show that revenue recycling mechanisms, including green spending and support for low-income households, enhance willingness to accept carbon taxation. Hjollund and Svendsen (2001) underscore the importance of political feasibility and lobbying dynamics in shaping green tax reforms, particularly under public choice considerations.

Administrative feasibility and institutional capacity also influence effectiveness (Ali et al., 2025). Smulders and Vollebergh (2001) argue that integrating carbon taxation within existing energy tax structures can reduce administrative burdens while maintaining environmental impact. De Miguel and Manzano (2011) use a dynamic general equilibrium framework to analyze gradual implementation of green tax reforms under the double dividend hypothesis, concluding that phased adjustments may minimize short-term efficiency losses while ensuring long-term environmental gains. Ciocirlan and Yandle (2003) provide a political economy perspective, showing that policymakers may prioritize revenue generation and competitiveness over environmental objectives, which can constrain optimal tax design. Gago and Labandeira (1999) propose integrating environmental taxation into broader fiscal systems to harmonize fiscal and environmental goals within a coherent reform structure. At the firm and sectoral levels, green taxation has been shown to stimulate sustainable transformation (Ali et al., 2025). Cheng et al. (2021) find that environmental taxes significantly increase green investment and reduce emissions among heavy-

polluting firms in China. Deb et al. (2023) demonstrate, using a Partial Least Squares Structural Equation Modeling approach, that green taxation positively influences corporate social responsibility across employee, customer, and community dimensions. Yang et al. (2024), applying a bidirectional fixed-effects model to Chinese provincial data from 2004 to 2021, show that green taxes promote green development and innovation, although resource constraints may crowd out comprehensive innovation. The interaction between green taxation, trade openness, and renewable energy adoption has also received growing attention (Arshad et al., 2025). Li et al. (2024), employing the Fully Modified Ordinary Least Squares method for BRICS countries from 1990 to 2021, find that green taxes and renewable energy consumption significantly reduce consumption-based carbon emissions, while trade openness may increase emissions. Ward and Cao (2012), using panel data and spatial lag models for Organization for Economic Cooperation and Development countries, identify both domestic institutional influences and international policy diffusion effects in shaping environmental taxation patterns. Degirmenci and Aydin (2024) support the load capacity curve hypothesis in Annex II countries, finding that green taxation, renewable energy, and green innovation enhance environmental sustainability. Sohail et al. (2023) analyze transportation taxation in BCIST economies using a nonlinear autoregressive distributed lag model and report that higher transport taxes reduce emissions in several emerging economies.

Distributional and intergenerational impacts are also significant (Sattar et al., 2025). Rausch and Yonezawa (2018) employ a dynamic general equilibrium model to examine the intergenerational incidence of carbon taxation in the United States, finding that future generations benefit most from revenue recycling through capital tax reductions. Liu and Hu (2020) similarly analyze intergenerational welfare effects and demonstrate that policy design features, including initial tax rates and revenue recycling mechanisms, shape long-term welfare outcomes. László (2021) highlights the underutilization of environmental taxation in the European Union, noting that environmental taxes accounted for only 2.4 percent of gross domestic product in 2019, with pollution taxes representing a minimal share, and argues for more comprehensive reform grounded in Pigouvian principles. Köppl and Schratzenstaller (2022) synthesize evidence from multiple jurisdictions and conclude that carbon taxation reduces emissions without harming economic growth when accompanied by appropriate revenue recycling.

Recent policy-oriented analyses further reinforce the strategic importance of green taxation. Zolkover et al. (2024) assess green taxation in the European Union, United States, and China during the period 2020 to 2024, concluding that environmental taxes stimulate renewable energy investment and industrial modernization, although developing economies face financing constraints. Ali et al., (2025), and Ali et al. (2023) review empirical studies from 36 jurisdictions and find that carbon taxes reduce emissions while maintaining competitiveness and employment under well-designed redistribution schemes. Collectively, the theoretical and empirical literature rooted in Environmental Taxation Theory and Pigouvian principles demonstrates that internalizing negative externalities through fiscal instruments can correct market failures, incentivize cleaner production and consumption, and facilitate progress toward carbon efficiency. While outcomes depend on policy design, institutional quality, public acceptance, and complementary measures, the cumulative evidence supports the expectation that environmental taxation contributes to lower carbon emissions. Accordingly, the following hypothesis is formulated:

H1: Higher green taxation revenue is associated with lower carbon dioxide emissions per capita.

METHODOLOGY

The study relies on secondary data obtained from established international databases and official government sources to ensure accuracy, consistency, and comparability across countries. The dataset consists of quantitative indicators related to green taxation revenues, carbon dioxide emissions per capita, renewable energy consumption, trade openness, and other relevant macroeconomic and environmental variables for a sample of 11 countries. The analysis covers the period from 2000 to 2024, providing a longitudinal time horizon of 24 years. This extended timeframe enables the identification of structural trends, policy shifts, and long-run dynamics associated with environmental fiscal reforms and their influence on carbon efficiency performance. A quantitative research design is employed to examine the relationship between green taxation and carbon efficiency. The study adopts an empirical framework grounded in environmental economics to evaluate how fiscal instruments aimed at internalizing environmental externalities affect carbon emission outcomes across different economic environments. By using panel data techniques, the analysis captures both cross-country heterogeneity and temporal variation, thereby allowing for a comprehensive assessment of how environmental taxation policies interact with renewable energy adoption, trade openness, and structural economic factors in shaping long-term carbon efficiency trajectories.

ANALYSIS

To empirically examine the relationship between green taxation and carbon efficiency, regression analysis will be conducted using STATA software. Given the panel structure of the dataset, panel data regression techniques will be applied to capture both cross-country heterogeneity and time-series dynamics over the study period. This methodological approach enables the model to control for unobserved country-specific characteristics, structural differences in economic development, and institutional variations that may influence environmental outcomes. By incorporating fixed effects or random effects specifications, the analysis will address potential omitted variable bias and ensure consistent parameter estimation. The panel regression framework further allows for the inclusion of relevant control variables such as renewable energy consumption and trade openness to isolate the independent effect of green taxation on carbon emissions per capita. Diagnostic procedures, including tests for heteroskedasticity, serial correlation, and cross-sectional dependence, will be performed to enhance the robustness of the estimations. Where necessary, robust standard errors will be employed to correct for potential econometric issues. This empirical strategy strengthens the validity of the findings and provides reliable insights into the direction and magnitude of the relationship between environmental fiscal policy and carbon efficiency performance, thereby supporting the theoretical propositions established in the literature on Pigouvian taxation and sustainable development.

RESULT AND DISCUSSION

Table 1: Descriptive Statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
CO2 emission	275	9.253833	4.200938	3.358967	21.01262
EnvTx	275	24.73788	1.782365	22.36563	29.80991
REC	275	14.55455	12.3502	.8	57.9
TOGDP	275	79.44878	41.55784	19.5596	191.9394

Table 1 summarizes the principal descriptive statistics for each variable in the dataset, based on 275 observations. It presents measures of central tendency, dispersion, and distributional range for the dependent variable, carbon dioxide emissions per capita, and for the independent and control variables, namely environmental tax revenue as a percentage of gross domestic product, renewable energy consumption as a percentage of total energy use, and trade openness as a percentage of gross domestic product. These statistics provide an initial understanding of the structure and variability of the panel dataset prior to econometric estimation.

Carbon dioxide emissions per capita record a mean value of approximately 9.25 metric tons, with a standard deviation of 4.20. This indicates a moderate degree of dispersion around the mean across countries and time periods. The minimum value of 3.36 and the maximum value of 21.01 reveal substantial cross-sectional and temporal variation in emissions levels. Such dispersion suggests heterogeneity in energy structures, industrial composition, and environmental policies among the sampled economies. The relatively wide range also implies that the dataset includes both comparatively low-emission and high-emission economies, which strengthens the suitability of the sample for examining differences in carbon efficiency performance.

Environmental tax revenue as a percentage of gross domestic product exhibits a mean of 24.74 percent and a comparatively low standard deviation of 1.78. This indicates a relatively stable distribution across the 275 observations. The values range from 22.37 percent to 29.81 percent, reflecting limited variation in the share of environmental tax revenue within national output across the sampled economies. The narrow dispersion suggests that green taxation structures are somewhat consistent within the panel, although even modest differences may generate measurable effects on emissions when assessed econometrically.

Renewable energy consumption presents a mean value of 14.55 percent of total energy use, accompanied by a relatively high standard deviation of 12.35. This indicates considerable heterogeneity in renewable energy adoption across the sample. The minimum value of 0.8 percent and the maximum of 57.9 percent demonstrate substantial disparities in energy transition progress. Some economies rely minimally on renewable sources, whereas others exhibit significantly higher penetration levels. The wide spread in this variable is economically meaningful, as it reflects structural differences in energy policies, technological capabilities, and resource endowments.

Trade openness, measured as a percentage of gross domestic product, records an average value of 79.45 percent with a large standard deviation of 41.56. The range extends from 19.56 percent to 191.94 percent, indicating pronounced variability. Such dispersion is consistent with the presence of both relatively closed economies and highly open economies within the panel. Values exceeding 100 percent are common for small and trade-dependent economies

where total imports and exports surpass domestic output. The substantial variation in trade openness suggests that it may play an important moderating or control role in the regression analysis.

Table 2: Correlation Matrix

	CO2 Emission	EnvTx	REC	TOGDP
CO2 Emission	1.0000			
EnvTx	0.0698	1.0000		
REC	-0.3431	-0.0850	1.0000	
TODGP	-0.2733	-0.6549	0.1059	1.0000

The correlation matrix presents the pairwise Pearson correlation coefficients among the study variables, offering preliminary insight into the strength and direction of linear associations prior to multivariate estimation. These coefficients range between minus one and positive one, where the sign indicates direction and the magnitude reflects the strength of the linear relationship. While correlation does not imply causation, the matrix provides useful diagnostic information regarding potential multicollinearity and expected relationships. The relationship between carbon dioxide emissions per capita and environmental tax revenue as a percentage of gross domestic product is positive but weak, with a coefficient of 0.0698. The absence of statistical significance suggests that, at the bivariate level, there is no meaningful linear association between green tax revenue and emissions. This indicates that environmental taxation alone does not exhibit a straightforward direct correlation with emissions in the raw dataset. However, this weak association may change once other explanatory variables are introduced in the regression framework, particularly when controlling for renewable energy consumption and trade openness. Carbon dioxide emissions and renewable energy consumption show a moderate negative and statistically significant correlation of minus 0.3431. This relationship aligns with theoretical expectations, as higher reliance on renewable energy sources typically reduces dependence on fossil fuels and consequently lowers emissions intensity. The magnitude of this coefficient suggests that renewable energy adoption plays a meaningful role in shaping carbon outcomes across the sample. The correlation between carbon dioxide emissions and trade openness is negative and statistically significant at minus 0.2733. Although the magnitude is moderate, the direction indicates that more open economies tend to exhibit lower emissions per capita within the sample. This finding may reflect technology transfer effects, access to cleaner production techniques, or structural specialization patterns that accompany integration into global markets. Nonetheless, the moderate strength suggests that trade openness interacts with other structural variables in determining emissions performance. The association between environmental tax revenue and renewable energy consumption is weakly negative at minus 0.0850 and statistically insignificant. This implies that there is no strong direct linear linkage between the level of environmental tax revenue and the share of renewable energy consumption in the descriptive data. The absence of significance indicates that the relationship may be indirect or mediated through other institutional or policy channels rather than immediate.

Environmental tax revenue and trade openness exhibit a strong negative and statistically significant correlation of minus 0.6549. This relatively large coefficient suggests a substantial inverse relationship between green tax revenue and trade openness in the sample. One possible interpretation is that economies with higher environmental tax burdens may be relatively less trade-intensive, or that structural economic differences exist between more open economies and those with higher environmental taxation ratios. The magnitude of this correlation warrants attention in regression analysis to assess potential multicollinearity concerns. Finally, renewable energy consumption and trade openness display a weak positive correlation of 0.1059, which is statistically insignificant. This indicates a slight tendency for more open economies to have higher renewable energy shares, although the relationship is not strong enough to be considered meaningful at the descriptive level. Overall, the correlation matrix suggests moderate relationships between emissions and key explanatory variables, with a particularly strong association between environmental tax revenue and trade openness that should be carefully considered in subsequent econometric modeling.

Table 3: Variance Inflation Factor (VIF)

Variable	VIF	1/VIF
TOGDP	1.76	0.568511
EncTx	1.75	0.570797
REC	1.01	0.988364

The Variance Inflation Factor results indicate a mean value of 1.51, which is substantially below commonly accepted threshold levels such as 5 or 10 that typically signal problematic multicollinearity. This outcome confirms that the

independent variables included in the regression model do not exhibit strong linear dependence among themselves. Consequently, the estimated coefficients are unlikely to suffer from instability or inflated standard errors due to collinearity concerns. From an econometric standpoint, this strengthens the reliability and interpretability of the regression results. Although environmental tax revenue and trade openness displayed a relatively strong negative correlation in the correlation matrix, the corresponding Variance Inflation Factor values remain within acceptable limits. This suggests that while these variables share some degree of association, the relationship is not sufficiently severe to distort the regression estimates. The slight elevation in their individual Variance Inflation Factor values is consistent with the earlier pairwise correlation findings but does not pose a threat to model validity. If the Variance Inflation Factor values had approached or exceeded critical thresholds, corrective measures such as variable transformation, mean-centering, or exclusion of redundant predictors might have been necessary. However, given the current diagnostics, the model demonstrates sound specification with respect to multicollinearity. Therefore, the regression analysis can proceed with confidence that the parameter estimates will reflect the independent contribution of each explanatory variable to carbon efficiency outcomes.

Table 4: Ordinary Least Squares

CO2 Emission	Coef.	Std. Err	t	P> t	[95% Conf. Interval]
EnvTx	-0.4715161	0.1697822	-2.78	0.006	-0.805776
REC	-0.109149	0.0186208	-5.86	0.000	-0.1458087
TOGDP	-0.0374355	0.0072964	-5.13	0.000	-0.518003
Cons	25.48096	4.615547	5.52	0.000	16.39407

The regression results demonstrate that environmental tax revenue exerts a statistically significant and negative effect on carbon dioxide emissions. The estimated coefficient of -0.4715 implies that a one percent increase in green tax revenue as a share of gross domestic product is associated with a reduction of approximately 0.47 metric tons of carbon dioxide emissions per capita. This magnitude is economically meaningful and provides empirical support for the proposition that environmental taxation functions as an effective policy instrument for internalizing environmental externalities. By raising the relative cost of carbon-intensive production and consumption, green taxes appear to incentivize firms and households to adopt cleaner technologies and energy-efficient practices, thereby contributing to measurable emission reductions. Renewable energy consumption also exhibits a highly significant and negative association with carbon dioxide emissions. The coefficient of -0.1091 indicates that a one percent increase in the share of renewable energy in total energy consumption corresponds to a decline of approximately 0.11 metric tons of emissions per capita. This finding is consistent with the theoretical expectation that renewable energy sources substitute for fossil fuels and reduce reliance on carbon-intensive energy inputs. The result reinforces the complementary role of energy transition policies alongside fiscal instruments in achieving environmental sustainability objectives.

Trade openness similarly displays a statistically significant negative coefficient of -0.0374 , suggesting that a one percent increase in trade openness as a share of gross domestic product is associated with a reduction of approximately 0.037 metric tons of emissions per capita. This outcome may reflect several underlying mechanisms, including the diffusion of environmentally friendly technologies, access to cleaner intermediate goods, improvements in production efficiency, and competitive pressures that encourage firms to adopt internationally recognized environmental standards. The result lends support to the argument that integration into global markets can facilitate environmental upgrading under appropriate regulatory frameworks. The constant term, estimated at 25.481, represents the baseline level of emissions when all explanatory variables are equal to zero. Although this parameter has limited direct economic interpretation in practical terms, it serves as a necessary component of the regression specification and captures the intercept of the estimated relationship.

Table 5: Fixed Effect Model

CO2 Emission	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
LEnvTx	-0.3820016	0.1804823	-2.12	0.035	-0.7374822
REC	-0.0948291	0.0200385	-4.73	0.000	-0.1342973
TODGP	-0.0332664	0.0078286	-4.25	0.000	-0.0486858
Cons	22.72691	4.941591	4.60	0.000	32.45995

The fixed-effects estimation provides further evidence regarding the dynamic relationship between environmental taxation and carbon dioxide emissions while accounting for unobserved country-specific heterogeneity. The

coefficient for lagged environmental tax revenue is -0.3820 and statistically significant, indicating that a one percent increase in green tax revenue in the previous period leads to a reduction of approximately 0.38 metric tons of carbon dioxide emissions per capita in the current period. The inclusion of the lagged term captures the delayed adjustment process associated with fiscal and regulatory policies. Environmental taxation typically requires time to influence production structures, consumption behavior, and technological adaptation. The smaller magnitude relative to the ordinary least squares estimate suggests that part of the earlier effect may have reflected cross-country structural differences that are now controlled through the fixed-effects specification. Renewable energy consumption continues to demonstrate a highly significant and negative association with emissions, with a coefficient of -0.0948 . This implies that a one percent increase in renewable energy use reduces carbon dioxide emissions by approximately 0.095 metric tons per capita. The persistence of both statistical significance and economic relevance after controlling for time-invariant country characteristics reinforces the robustness of the renewable energy channel. This result confirms that structural energy transition remains a key determinant of emission reductions, independent of country-specific institutional or geographic factors.

Trade openness also retains a statistically significant negative relationship with emissions, with an estimated coefficient of -0.0333 . A one percent increase in trade openness corresponds to a decline of approximately 0.033 metric tons of carbon dioxide emissions per capita. The slightly smaller magnitude compared to the ordinary least squares estimate indicates that the effect is primarily driven by within-country variation over time rather than cross-country differences. This suggests that changes in trade integration levels within a given country contribute to environmental performance improvements, potentially through technology diffusion, productivity gains, and integration into cleaner global value chains. The constant term, estimated at 22.727, reflects the baseline level of emissions after accounting for country-specific fixed effects. Although its direct interpretation remains limited, it incorporates the influence of unobserved structural characteristics unique to each country that remain constant over time. In comparison with the pooled ordinary least squares results, the fixed-effects estimates preserve both the direction and statistical significance of the explanatory variables while exhibiting slightly reduced magnitudes. This pattern indicates that the earlier model may have partially captured unobserved heterogeneity across countries. By eliminating bias arising from time-invariant country-specific factors, the fixed-effects specification enhances the credibility of causal inference. Overall, the findings confirm that green taxation, particularly with a lagged impact, contributes to emission reductions over time when renewable energy consumption and trade openness are jointly considered. For panel data analysis, the fixed-effects model provides a more robust framework, although formal model selection procedures such as the Hausman test remain appropriate to validate the preference for fixed effects over random effects.

DISCUSSION

This study provides a rigorous empirical assessment of green tax revenue as an instrument for reducing carbon dioxide emissions per capita, drawing upon a balanced panel of 11 countries over the period 2000 to 2024. By integrating renewable energy consumption and trade openness as control variables, the analysis captures the interdependent roles of fiscal policy, energy transition, and global economic integration in shaping environmental performance. The consistency of findings across both pooled ordinary least squares and fixed-effects specifications strengthens the credibility of the results. In both models, higher green tax revenue is associated with statistically significant reductions in carbon dioxide emissions, indicating that environmental taxation serves as an effective mechanism for altering production and consumption incentives in favor of cleaner outcomes. The inclusion of a lagged environmental tax variable in the fixed-effects framework further reveals that the impact of taxation is not instantaneous but unfolds over time, reflecting gradual technological adaptation, capital reallocation, and behavioral change among economic agents.

The observed negative relationship between green tax revenue and emissions is firmly grounded in Pigouvian tax theory, which advocates the correction of market failures through the internalization of negative externalities (Pigou, 1920). By increasing the cost of carbon-intensive activities, green taxes shift relative prices and incentivize firms to adopt low-emission technologies while encouraging households to adjust consumption patterns. In addition to environmental benefits, the results lend empirical support to the double dividend hypothesis, which suggests that environmental taxation can simultaneously reduce pollution and generate fiscal revenues that may be recycled to lower distortionary taxes or fund sustainable investments (Goulder, 1995). The persistent and robust negative association between renewable energy consumption and emissions further underscores the centrality of energy

transition policies in climate mitigation strategies. Greater reliance on renewable energy reduces dependence on fossil fuels, thereby directly lowering carbon intensity and advancing decarbonization objectives (Jacobson et al., 2017). Trade openness also emerges as a significant determinant of lower emissions within the sample. The negative coefficient suggests that deeper integration into international markets may facilitate access to advanced technologies, promote efficiency gains, and accelerate the diffusion of cleaner production processes. This finding aligns with environmental trade theories, particularly the technique effect component of the trade–environment nexus, which posits that openness can enhance environmental performance through technology transfer and productivity improvements (Grossman & Krueger, 1991). Nevertheless, the pronounced negative correlation between green tax revenue and trade openness raises an important policy consideration. While environmental taxation effectively curbs emissions, it may impose adjustment pressures on trade-exposed sectors, particularly in export-oriented economies. This potential trade-off highlights the importance of carefully calibrated policy design, including mechanisms such as border carbon adjustments or targeted support for affected industries, to reconcile environmental objectives with competitiveness concerns.

Relative to existing empirical literature, the multi-country and long-horizon structure of this study provides a broader perspective on the effectiveness of green taxation compared with single-country or short-term analyses (OECD, 2021). The application of fixed-effects estimation controls for unobserved, time-invariant country characteristics such as institutional quality, regulatory traditions, or cultural attitudes toward sustainability, thereby enhancing causal interpretation. Diagnostic tests indicate low multicollinearity among explanatory variables, ensuring stable and interpretable parameter estimates. At the same time, the relatively modest variation in green tax revenue across the sample suggests that stronger or more diversified fiscal instruments could potentially yield even more pronounced environmental outcomes. The findings also enrich the environmental Kuznets curve framework by demonstrating that deliberate fiscal interventions can accelerate the decoupling of economic growth from environmental degradation, potentially enabling countries to reach turning points in emissions earlier than predicted by traditional models (Panayotou, 1993). Furthermore, the results resonate with endogenous growth theory by illustrating how green taxation may stimulate innovation in clean technologies, thereby fostering long-term competitiveness and structural transformation (Romer, 1990). The interplay between trade openness and emissions contributes to the broader trade–environment literature by highlighting globalization as both a conduit for environmental improvement and a domain requiring coordinated policy responses.

From a policy perspective, the evidence supports the adoption of well-designed green tax systems, including carbon pricing and energy levies tailored to national economic structures. Effective revenue recycling strategies—such as investing in renewable energy infrastructure, subsidizing clean technology adoption, or protecting vulnerable households—can enhance both environmental effectiveness and social acceptability. The strong role of renewable energy consumption underscores the urgency of scaling up investments in clean energy systems, particularly in economies with low baseline adoption. Trade policies should be aligned with environmental objectives to harness the benefits of technology diffusion while mitigating risks of carbon leakage. International coordination under global climate frameworks can further promote harmonized fiscal measures and reduce competitive imbalances. Notwithstanding its contributions, the study is subject to certain limitations. The sample of 11 countries, while sufficient for panel estimation, may not fully capture the diversity of developing or less trade-integrated economies. Additionally, unobserved factors such as technological breakthroughs, institutional reforms, or shifts in environmental awareness could influence emission dynamics. Future research could expand the country coverage, employ dynamic panel estimators such as generalized method of moments to strengthen causal inference, and explore interaction effects between green taxation and complementary instruments such as subsidies or regulatory standards. Such extensions would deepen understanding of how fiscal policy can more effectively guide economies toward the carbon efficiency frontier.

CONCLUSIONS

This research provides compelling empirical evidence that green tax revenue functions as an effective instrument for reducing carbon dioxide emissions per capita, while renewable energy consumption and trade openness operate as important complementary channels. Drawing upon twenty-five years of panel data from eleven countries, the analysis demonstrates that fiscal policy can generate measurable environmental improvements even after controlling for country-specific heterogeneity and incorporating lagged effects that capture gradual policy transmission. The consistency of results across model specifications strengthens the credibility of the findings and confirms that environmental taxation is not merely symbolic, but capable of delivering sustained emission reductions over time.

The results reinforce foundational principles in environmental economics. The negative association between green tax revenue and emissions supports the Pigovian framework, which posits that taxation can internalize environmental externalities and realign private incentives with social welfare objectives. At the same time, the evidence is consistent with the double dividend hypothesis, suggesting that environmental taxation can reduce pollution while simultaneously generating public revenue that may be recycled to promote innovation, support clean energy investment, or ease distortionary fiscal burdens. The significant role of renewable energy consumption further confirms the importance of structural energy transformation in achieving long-term decarbonization. Trade openness, meanwhile, highlights the role of globalization in facilitating technological diffusion and efficiency gains that can contribute to environmental performance under appropriate policy conditions. From a theoretical standpoint, the findings contribute to the environmental Kuznets curve literature by demonstrating that proactive fiscal intervention can accelerate the decoupling of economic growth from environmental degradation, rather than waiting for income-driven structural transitions to occur naturally. The results also align with endogenous growth theory by illustrating how green taxation may stimulate innovation and technological upgrading in cleaner production processes, thereby supporting both environmental sustainability and long-term economic resilience.

In practical terms, the study underscores the necessity of integrated policy design. Green taxation alone is most effective when combined with policies that expand renewable energy capacity and maintain constructive engagement with international trade systems. Fiscal instruments should be carefully structured to avoid unintended competitiveness effects while maximizing incentives for low-carbon innovation. Revenue recycling mechanisms can enhance both equity and political feasibility, particularly when funds are directed toward renewable infrastructure, technological upgrading, or protection of vulnerable groups. Although the research is limited by its relatively small country sample and the constraints inherent in panel estimation techniques, it nevertheless offers a strong empirical foundation for sustained and coordinated climate policy. Policymakers are encouraged to implement scalable and equitable green tax frameworks, reinforce renewable energy deployment, and ensure that environmental and trade strategies operate in a complementary manner. Future research may broaden the sample to include more diverse economies, apply dynamic estimation approaches, or investigate interaction effects between taxation and other climate instruments to refine policy design further. Ultimately, the findings highlight the urgency of decisive fiscal and energy reforms. Well-calibrated green taxation, supported by renewable energy expansion and strategic trade integration, can meaningfully advance countries toward lower carbon intensity while strengthening economic adaptability. The implications extend beyond the countries studied, offering guidance for national governments and international institutions seeking to align economic policy with global climate commitments and long-term sustainability objectives.

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