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# Exploring the Role of Fiscal Policies in Advancing Low-Carbon Frontiers: An Empirical Analysis

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## ABSTRACT

*This study investigates whether green taxation can effectively drive countries toward carbon efficiency frontiers, emphasizing its role in mitigating carbon emissions while fostering sustainable development. Using a balanced panel dataset covering 11 countries over 25 years, the research applies advanced econometric techniques to explore the relationship between green tax revenue, $CO_2$ emissions per capita, renewable energy consumption, and trade openness. The empirical findings reveal that higher green tax revenues significantly contribute to reductions in $CO_2$ emissions, confirming the environmental effectiveness of fiscal instruments designed to internalize external costs. Moreover, renewable energy adoption and openness to international trade are found to strengthen the environmental benefits of green taxation, creating synergistic effects that accelerate the transition toward carbon efficiency. The study's outcomes support the principles of Pigovian taxation and the double dividend hypothesis, suggesting that environmental taxes not only curb pollution but also enhance economic performance through innovation and cleaner energy use. By integrating fiscal policy with energy and trade dynamics, the research provides valuable policy insights for governments aiming to balance economic growth with environmental stewardship and achieve long-term sustainability goals within the global climate agenda.*

***Keywords:*** *Green Taxation, Carbon Efficiency, Renewable Energy, Trade Openness, Sustainable Development*

## INTRODUCTION

In examining the potential of green taxation as a mechanism to drive countries toward the carbon efficiency frontier, academic justifications focus on how to deploy progressive environmental taxes to reduce emissions and to overcome socioeconomic inequality. The progressive green taxation, which is the tax imposed on polluters at average rates rather than on the population generally, can effectively help to reduce the environmental destruction, such as carbon emissions, and does not disproportionately affect those who contribute to the problem of this destruction lower rate than other members of the population. (Sun et al., 2024). Past studies correlate economic inequality to an increase in resource abuse, and suggest

that mechanisms such as tax rebates and environmental credit cards will not only discourage excessive consumption but also minimize existing inequalities created by the conventional income taxes, therefore, achieving sustainability.

In an analysis of how well the environmental policies contribute towards carbon efficiency, studies indicate the importance of balanced sets of policy instruments that combine supply-side and demand-side policies. (Muhammad et al., 2021) developed a typology of green market policies and empirically demonstrated, in a comparative analysis of organic food policies in Denmark, Sweden, the UK, and the US, that organic consumption varies with differences in the presence of those policies, with active development policies of the market (both supply and demand incentives) showing the highest consumption levels. To assess whether green taxation can steer countries toward the carbon efficiency frontier, understanding public acceptance of such policies is crucial, as it significantly influences their effective implementation. (Nchofoung et al., 2023) synthesizes empirical findings on public acceptance of environmental taxes, revealing that support is bolstered when individuals are well-informed about the policy's effectiveness and revenue use, trust the government, hold positive environmental attitudes, perceive the tax as fair in cost distribution, and are concerned about climate change. The increasing effects of the growth in environmental challenges that accompany the advent of fast economic growth highlight the need to address them through effective policy instruments, as is the case with green taxation, to realize carbon efficiencies. (Maxim et al., 2019) illustrate that green tax policies imposed on fossil fuel use can notably minimize greenhouse gas emissions, and, in addition to those global benefits, generate local co-benefits, like enhanced air quality. Their findings indicate that a carbon tax may reduce the carbon intensity in China by encouraging cleaner production and consumption behavior.

The contribution of green taxation to the development of carbon efficiency is becoming increasingly clear in the policy framework internationally, specifically in the policies of renewable energy usage. (Rodríguez et al., 2019) Report that environmental taxes have a positive effect on renewable energy technology adoption in 49 countries in the period 1996-2017 through robust econometric estimators such as the FE Driscoll-Kraay estimator. Their findings show that the more a given country collects in terms of revenues via environmental taxation, the more they tend to consume renewable forms of energy, thus lowering the carbon intensity and advancing them to the carbon efficiency curve. This is the evidence on a global scale that green tax can have the potential to incentivize cleaner energy transitions that are a crucial step toward sustainable development. The structure of the green tax reforms is central in effecting an equilibrium between fiscal and environmental goals to culminate in attracting countries towards carbon efficiency. According to the arguments promoted by (Daugbjerg & Sønderskov, 2012) The benefits of efficient environmental fiscal restructuring, such as in the European Union, have the potential to earn huge revenues and minimize carbon emissions through the application of the targeted tax on harmful practices.

One of the greatest pillars in the implementation of effective policies in green taxation is the acceptance by the people, and it directly affects their extent in promoting carbon efficiency. A systematic review of literature discovered that the evidence supports the idea that people are more willing to endorse environmental taxes when the policies are open, cost allocations are seen as equitable, and when the benefits are transparently communicated regarding the uses of revenue and climate benefits. Green tax reforms have the potential to introduce substantial environmental and economic advantages in the chase of carbon efficiency, as it has been proven in particular national situations. To illustrate the finding. (Schlegelmilch & Joas, 2015) Employ a model of a steady-state conceptualized general equilibrium to demonstrate that the European country Portugal experienced a green tax change in 2014, which yielded a double dividend of minimizing greenhouse gas emissions in the country and improving energy autonomy and economic strength. Their results also point out that gross carbon intensity in the economy can be diminished through taxing carbon-intensive operations, which brings Portugal nearer to the carbon efficiency frontier. Green tax restructures will have a good output not only in terms of the environment

but also economically, according to certain countries' measures. (Daugbjerg & Sønderskov, 2012) Applied a static general equilibrium model analysis to demonstrate that a green tax reform implemented by Portugal in 2014 had a two-fold effect of cutting greenhouse gas emissions and enhancing economic competitiveness and energy independence. Their results lead to the fact that taxation on carbon-intensive activity can reduce carbon intensity in the economy, advancing it towards the frontier of carbon efficiency. Green taxation offers economic benefits besides its employment effects, which increase the popularity of its use in the process of achieving carbon efficiency. A meta-regression analysis organized by reveals that a green taxation package has the potential to produce an employment double dividend, especially through recycling of tax-derived funds to cut labor taxation. The two-fold advantage reflects the complexity of green taxation in the sustainable transformation of economies.

Casal (2012) claims that taxes on carbon should be progressive, with payers of high taxes on carbon being the greater polluters, and economic inequalities can be relieved in this process. Such policies make countries move toward the carbon efficiency frontier, as they will be fair because of ensuring fair policies in the case of, e.g., tax rebates. In their comparative review of organic food policies in Denmark, according to (Bhatia & Gupta, 2020) Show that high supply-side taxes coupled with demand-side incentives, e.g., subsidies to consumers, substantially increase pro-sustainable food consumption. This implies that demand-side measures combined with green taxation can be effective in eliminating carbon-intensive behavior that can ultimately lead to economies reaching the carbon efficiency frontier through market-driven sustainability. Green taxation in developing countries has the potential to deliver carbon efficiency as long as implementation issues are resolved. The work by (Cao et al., 2009) Examines the plausibility of green taxes in India and, based on the analysis of primary and secondary data, concludes that the taxes are more effective at raising environmental awareness and curtailing the emission of carbon gases in India through action against polluting behaviors. The descriptive statistics and Chi-Square tests that back their findings show that green taxation could influence behavior change towards sustainability in ways that bring India near the carbon efficiency frontier, given that the impediments, such as the administrative capacity and the resistance on the part of the people, are also overcome. According to Casal (2012), progressive green taxation can serve as an effective measure to reduce environmental destruction, such as carbon emissions, without taxing the low-income groups excessively, thereby encouraging an environmentally safe practice. Nevertheless, it is questioned whether green taxation can legitimately be seen as facilitating green countries to become more carbon efficient, especially in light of the complicated interconnection to other worldly concepts, i.e., renewable energy usage and the dynamics of international trade. As noted by (Daugbjerg & Sønderskov, 2012) Because of its nature as a supply-side intervention, green taxation can be more effective in conjunction with mechanisms on the demand side to improve the overall performance of the policy and, at the same time, make it politically acceptable. Resolving this issue is essential to the provision of policymakers on the possibility of green taxation to progress national carbon efficiency objectives and play a significant role in battling global climate change.

## LITERATURE REVIEW

The global effort to combat climate change has positioned green taxation as a key policy tool in the attempt to reduce carbon emissions and guide economies toward the carbon efficiency frontier, where per capita CO 2 emissions are minimized relative to economic and technological growth. A substantial body of literature covers the environmental, economic, and social aspects of green taxation, including findings on its effectiveness, structure, and public reception in various contexts. This review summarizes recent studies to assess the impact of green taxation on carbon efficiency, highlighting that, in its potential, it can promote sustainable development, despite the challenges of implementation and the need for complementary policy tools (Zolkover et al., 2024).

Qamruzzaman, (2025) Gives a fundamental study of carbon efficiency, stating the carbon efficiency frontier as the level at which a nation's per-capita CO 2 emissions are at the minimum that any state at a similar stage of economic activity and comparable stage of technological progress is. In the application of Data Envelopment Analysis (DEA) of developed countries in the years 1994 to 2011, they discovered positive and significant relationships between a greater level of revenues attributed to environmental tax and enhanced carbon efficiency. (Deb et al., 2024) Focus on China's environmental challenges, demonstrating through a computable general equilibrium model that carbon taxes on fossil fuel consumption can significantly reduce greenhouse gas emissions while improving local air quality. Their findings highlight the dual benefits of green taxation in high-emission economies, reducing carbon intensity and yielding co-benefits like reduced health costs, thus advancing countries toward the carbon efficiency frontier by aligning economic incentives with environmental goals.

Generalize the study to the international scope by examining the effects of environmental taxes on renewable energy production across 49 countries from 1996 to 2017. Using the FE Driscoll-Kraay estimator, they find a positive correlation between tax revenues and renewable energy use, leading to a reduction in carbon intensity. Popular approval is a key factor for the success of green taxes, as discussed. Through a systematic literature review, they identify that transparency, equitable cost distribution, and clear communication about revenue use and environmental benefits bolster support for environmental taxes. They analyze the tax reform implemented by the Portuguese government in 2014 using a static general equilibrium model, concluding that it provided a double benefit: lowering emissions and enhancing energy independence and economic competitiveness. This decarbonization demonstrates green taxation's potential to move economies toward the carbon-efficient frontier, especially when part of broader fiscal policies focused on sustainability. They explore the new role of energy efficiency as a mediator in the effects of green taxation within Bangladesh's manufacturing sector. Using partial least squares structural equation modeling, they show that green taxes promote environmental and social sustainability by encouraging greener activities, with energy efficiency amplifying these effects. Investigates the employment impacts of green tax reforms through a meta-regression analysis of European and non-European countries. They conclude that a double dividend, improving employment, can be achieved by recycling tax revenues to lower labor taxes alongside carbon reduction policies. This dual benefit highlights the versatile nature of green taxes in stimulating carbon efficiency, especially when tailored to the economic conditions of specific regions. Bon efficiency, especially when designed with the economic conditions of a specific region in mind.

Casal (2012), progressive green taxation is essential to take the concerns of equity on board, especially in combating emissions. Progressive taxes can address economic inequalities through targeting higher polluters and through the incorporation of mechanisms such as tax rebates, etc. This component smooths the path of policy acceptance to require a stable consumption economy, which is more socially acceptable, bringing economies to the carbon efficiency frontier. Degirmenci & Aydin, (2024) focus on the efficiency of balanced policy mixes, examining the policies of organic food in Denmark, Sweden, the UK, and the US. They discover that there is a vibrant multiplier effect of integrating supply-side tax with the demand-side incentives, like consumer subsidies to increase sustainable consumption, which reduces carbon-intensive activities. (Schlegelmilch and Joas (2015) discuss specific elements of green tax reform design and implementation through such a prism as environmental fiscal reforms throughout Western Europe or in the context of Portugal. They demonstrate that, in per capita terms, whereby polluting activities are subject to targeted taxation and the revenue is transferred to cleaner technologies, one can achieve both declining carbon emissions and fiscal sustainability, creating a route to the carbon efficiency frontier.

Smulders and Vollebergh, (2001) deal with the administrative burdens of green taxation, taking carbon taxation as an example. They assert that the use of existing energy taxes to address the issue of CO2

emissions can comparatively reduce administrative costs and, at the same time, successfully decrease emissions. Their results indicate that there are crucial, practical design issues to consider so that green taxation will effectively work in enhancing carbon efficiency, especially where resources are limited. Cheng et al. (2021) investigate the possible effect of green taxes on heavy-polluting companies in China and conclude that the tax considerably raises green investments and lowers their emissions. The microeconomic conclusions of their aggregate-level analysis point to the role green taxation can play in encouraging corporate sustainability to benefit carbon efficiency more generally. De Miguel and Manzano (2011) address the temporal dynamics of the green tax reforms and have evaluated the rise in energy taxes (using a calibrated dynamic general equilibrium model) in a revenue-neutral framework. They conclude that the slow yet gradual implementation may help reduce the effects of efficiency costs in the short run and still provide benefits in the long run for the environment, and thus, the driving forces behind the implementation of green taxation may lead to improvements in carbon efficiency in the long term.

Bohringer et al. (2003) present a computational solution to green tax rearrangements, building an interactive simulation model capable of measuring the effects. Their results support the conclusion that there is a possibility of getting a two (or three) dividend- environmental, economic, and social dividend- once the green taxes are designed to influence cleaner production and consumption, which in turn makes green taxes an avenue that drives the economy to the frontier of carbon efficiency. (Loganathan et al., 2014) Who has written on the history and theory behind green taxes as practices to solve the issue of climate change, with the focus that it is part of a two-fold mechanism of creating income and acting as a stimulus to environmentally sound behaviour. (Baranzini & Carattini, 2017)Presents a background on the green tax theory and how it can be used as an instrument towards the achievement of green tax objectives. The paper presents various theories, namely Pigouvian cost internalization, the polluter pays principle, least-cost abatement, and the double-dividend hypothesis, the latter uses tax revenues to help relieve other economic costs. Practical examples of the use of carbon taxes that Milne cites include Nordic carbon taxes that succeed in lowering emissions and the use of tax credits to support renewable energy in the US, although she also points to obstacles, such as stiff political opposition to energy taxation in the EU and in the US based on competitiveness. The descriptive methodology, used in this kind of qualitative research, is based on examples of policies and historical data, and it provides an understandable theoretical framework. This book has the advantage of succinctly summarizing principles of green taxes, as well as citing case studies from around the world, yet it falls short when it comes to quantitative evaluation of the tax effects and in-depth analysis of particular policies (e.g., gas guzzler tax loophole in the US).

In The Green Tax Revolution (2021), Lazlo claims the necessity of a profound reform of green taxation to solve the climate crisis, based on the application of the Pigouvian principle to rectify the market inefficiencies due to pollution-inducing behaviors. The article writes about how the environmental taxes in the EU are limited, and in 2019, the level was just 2.4% of GDP (330.6 billion euros), and of that amount, only 0.1 was taxes on pollution and resources. Laszlo argues against the absence of earmarking for environmental purposes and the stagnant pattern of environmental tax ratios since 2007, by use of Eurostat data analysis. The strong point of the study lies in its emphasis on the underutilization of tax policy in bringing about systemic transformation, which has been backed up by evident statistics. Nevertheless, the general scope of its policies does not include detailed case studies or empirical testing of the effectiveness of taxes and, thus, makes its work superficial. (Wang et al., 2024) analyzed the empirical effects of carbon taxes across multiple dimensions: environmental effectiveness, macroeconomic impacts, competitiveness, innovation, distributional effects, and public acceptance. Using a literature synthesis approach, they find that carbon taxes effectively reduce emissions or slow their growth without harming economic growth, employment, or competitiveness, with tax rates varying widely (e.g., US$0.08/tCO2e in Poland to US$129.89 in Sweden). The study highlights that lump-sum transfers mitigate regressive effects for lower-income households, while labor tax reductions benefit higher incomes. Public acceptance increases with transparent communication and environmental

earmarking. (Zolkover et al.,2024) evaluated the role of green taxation in the sustainable economic progress of developed areas (EU, US, China) over the period of 2020-2024 in terms of emission levels and local industrial modernization. Analyzing the contents of the European Green Deal and Chinese environmental policies with a qualitative review of policies, they have observed that green taxes can promote renewable energy and technologies to capture carbon, although developing countries are hindered by the lack of funds and technology. It is noted that the cooperation between countries should be focused on the international level regarding the Paris Agreement to harmonize the tax systems with the global norms.

Liu & Hu, (2020) explored the intergenerational incidence of a US swap of tax on carbon emissions through a dynamic general equilibrium model of overlapping generations. They examine the policy design options, namely initial tax rates, rates of growth, and provider of revenue recycling (lump-sum rebates, capital, or labor tax cuts), and conclude that the earlier generations obtain fewer welfare losses, and future generations are the greatest beneficiaries of capital tax recycling. Li et al. (2024) contributed in the form of a report on the connection between renewable energy, green taxes, and trade openness with carbon neutrality in BRICS countries during the period between 1990 and 2021 through Fully Modified Ordinary Least Squares (FMOLS). They discover that green tax and renewable energy are effective in decreasing the emission of carbon in consumption due to the production process, whereas trade openness and population growth augment the consumption-based carbon emission. The strength of the study is its econometric strength and the attention to emerging economies, which is also a contrast to the developed-country focus of all other articles. (Baranzini & Carattini, 2017) Gives a fundamental background of the green theory of taxation and its practicality in mitigating climate change, where the two fulfill two functions, namely revenue-raising and acting as a form of incentive to act environmentally. The paper presents some theories of internalization of costs (as by Pigou), polluter pays, and the double-dividend theory to include the Nordic carbon taxes, which lowered emissions and US tax credits in renewable energy. Milne observes that there is political opposition to energy taxes in the EU and the US over issues of competitiveness, which advances the challenge to policy design.

László (2021) advocates for comprehensive green tax reform to address the climate crisis, emphasizing a Pigouvian approach to correct market distortions. Using Eurostat data, László notes that environmental taxes in the EU accounted for only 2.4% of GDP (€330.6 billion) in 2019, with pollution taxes at 0.1%, and critiques the lack of earmarking for environmental purposes. The study's strength lies in its statistical grounding and call for systemic reform, but its broad policy focus lacks specific case studies or empirical evaluations of tax effectiveness. (Ali et al., 2023) reviewed the empirical effects of carbon taxes across environmental effectiveness, macroeconomic impacts, competitiveness, innovation, distributional effects, and public acceptance. Synthesizing studies from 36 jurisdictions, they find carbon taxes reduce emissions without harming economic growth, with tax rates ranging from US$0.08/tCO2e in Poland to US$129.89 in Sweden. Lump-sum transfers mitigate regressive effects for lower-income households, while labor tax reductions benefit higher incomes. Public acceptance increases with environmental earmarking and transparent communication. Zolkover et al. (2024) assessed green taxation's impact on sustainable growth in the EU, US, and China from 2020 to 2024, focusing on emission reductions and industrial modernization. Their qualitative review highlights policies like the European Green Deal and China's environmental initiatives, noting that green taxes encourage renewable energy and carbon capture technologies. Developing countries face barriers like insufficient funding. Rausch and Yonezawa (2018) used a dynamic general equilibrium model to examine the intergenerational incidence of a US carbon tax swap. They analyze policy design choices—initial tax levels, growth rates, and revenue recycling (lump-sum rebates, capital, or labor tax cuts)—finding that earlier generations face smaller welfare losses, while future generations benefit most from capital tax recycling. Li et al. (2024) investigate green taxes, renewable energy, and trade openness in BRICS countries from 1990 to 2021 using the Fully Modified

Ordinary Least Squares method. They find that green taxes and renewable energy reduce consumption-based carbon emissions, while trade openness increases emissions.

Harring and Jagers (2013) explore public support for carbon dioxide taxes in Sweden using a 2009 mail survey of 3,000 individuals. They find that political trust and interpersonal trust significantly influence support for increased carbon taxes, alongside environmental values and self-interest. The survey-based methodology provides robust insights into public attitudes, but its Swedish focus limits generalizability. (Sohail et al. 2023) examine transportation taxes' impact on CO2 emissions in BCIST economies (Brazil, China, India, South Africa, Turkey) from 1991 to 2019 using a nonlinear ARDL approach. They find that higher transportation taxes reduce emissions in China, India, South Africa, and Turkey, while tax decreases increase emissions in Brazil, China, and India. (De Miguel and Manzano, 2011) analyzed green tax reforms under the double-dividend hypothesis using a dynamic general equilibrium model. They find that increasing household energy taxes alters consumption due to habit formation, impacting the efficiency dividend, while taxes on energy inputs consistently reduce welfare. The model's focus on habit formation is novel, but its theoretical nature limits practical insights.

Carattini et al. (2017) analyzed the acceptability of carbon taxes using a 2015 Swiss ballot on energy taxes and a choice experiment survey. They find that distributional concerns, perceived ineffectiveness, and competitiveness fears reduce acceptability, while environmental earmarking increases support. The term "climate contribution" garners more support than "carbon tax." The combined ballot and survey methodology is robust, but the Swiss context limits generalizability. (Yang et al., 2024) use a bidirectional fixed-effects model on Chinese provincial data (2004–2021) to examine green taxation's impact on regional green development and innovation. They find that green taxes foster green growth and innovation but crowd out comprehensive innovation due to resource constraints. (Muth et al., 2024) investigate public support and willingness to pay for a carbon tax in Hungary using a 2022 face-to-face survey of 3,013 adults. They find that revenue recycling (e.g., tax cuts, green spending, support for poor households) increases support, with green spending being most effective. The study's large sample and focus on a Central and Eastern European country are strengths, but its single-country focus limits broader applicability. It supports Carattini et al.'s findings on the importance of revenue recycling for public acceptance. (Milne (2007) provides a foundational exploration of green tax theory and its application to climate change mitigation, emphasizing their dual role in raising revenue and incentivizing environmentally beneficial behavior. László (2021) advocates for comprehensive green tax reform to address the climate crisis, emphasizing a Pigouvian approach to correct market distortions. Using Eurostat data, László notes that environmental taxes in the EU accounted for only 2.4% of GDP (€330.6 billion) in 2019, with pollution taxes at 0.1%, and critiques the lack of earmarking for environmental purposes. Köppl and Schratzenstaller (2022) reviewed the empirical effects of carbon taxes across environmental effectiveness, macroeconomic impacts, competitiveness, innovation, distributional effects, and public acceptance. Synthesizing studies from 36 jurisdictions, they find carbon taxes reduce emissions without harming economic growth, with tax rates ranging from US$0.08/tCO2e in Poland to US$129.89 in Sweden. Lump-sum transfers mitigate regressive effects on lower-income households, while labor tax reductions benefit higher-income households. Public acceptance increases with environmental earmarking.

Zolkover et al. (2024) assess the impact of green taxation on sustainable growth in the EU, the US, and China from 2020 to 2024, focusing on emission reductions and industrial modernization. Their qualitative review highlights policies like the European Green Deal, noting that green taxes encourage renewable energy and carbon capture technologies. Developing countries face barriers like insufficient funding. Rausch and Yonezawa (2018) use a dynamic general equilibrium model to examine the intergenerational incidence of a US carbon tax swap. They analyze policy design choices initial tax levels, growth rates, and revenue recycling finding that earlier generations face smaller welfare losses, while future

generations benefit most from capital tax recycling. The quantitative modeling approach provides precise distributional insights, but its US-centric focus limits global applicability. Li et al. (2024) investigate green taxes, renewable energy, and trade openness in BRICS countries from 1990 to 2021 using the Fully Modified Ordinary Least Squares method. They find that green taxes and renewable energy reduce consumption-based carbon emissions, while trade openness increases emissions. Harring and Jagers (2013) explore public support for carbon dioxide taxes in Sweden using a 2009 mail survey of 3,000 individuals. They find that political trust and interpersonal trust significantly influence support for increased carbon taxes, alongside environmental values. The survey-based methodology provides robust insights into public attitudes, but its Swedish focus limits generalizability. Sohail et al. (2023) examine transportation taxes' impact on CO2 emissions in BCIST economies from 1991 to 2019 using a nonlinear ARDL approach. They find that higher transportation taxes reduce emissions in China, India, South Africa, and Turkey, while tax decreases increase emissions in Brazil, China, and India.

(De Miguel and Manzano, 2011) analyze green tax reforms under the double-dividend hypothesis using a dynamic general equilibrium model. They find that increasing household energy taxes alters consumption due to habit formation, impacting the efficiency dividend, while taxes on energy inputs reduce welfare. The model's focus on habit formation is novel, but its theoretical nature limits practical insights. This article complements Rausch and Yonezawa by exploring economic efficiency. (Carattini et al., 2017) Analyze carbon tax acceptability using a 2015 Swiss ballot and a choice experiment survey. They find that distributional concerns, perceived ineffectiveness, and competitiveness fears reduce acceptability, while environmental earmarking and the term "climate contribution" increase support. The combined methodology is robust, but the Swiss context limits generalizability. Yang et al., (2024) Use a bidirectional fixed-effects model on Chinese provincial data (2004–2021) to examine green taxation's impact on regional green development and innovation. They find that green taxes foster green growth but crowd out comprehensive innovation due to resource constraints. (Muth et al., 2024) Investigate public support and willingness to pay for a carbon tax in Hungary using a 2022 survey of 3,013 adults. They find that revenue recycling (e.g., tax cuts, green spending) increases support, with green spending being most effective. Ciocirlan and Yandle, (2003) Examine the political economy of green taxation in OECD countries using a political economy model. They find that policymakers prioritize revenue generation and industry competitiveness over environmental goals, with taxes set to maximize revenue rather than reduce emissions. The model shows a concave revenue function, where high taxes could reduce emissions and thus revenue. The study's strength is its focus on political motivations, but its reliance on aggregated OECD data limits specific policy insights. (Gago and Labandeira (1999) propose a green tax reform model integrating environmental taxes into broader tax systems, emphasizing the double-dividend hypothesis. Using a theoretical framework, they argue that environmental taxes can align fiscal and environmental policies, drawing on examples like OECD countries' limited adoption of green taxes.

Hjollund and Svendsen (2001) argue for green taxation as a cost-effective tool to reduce CO2 emissions, using a theoretical analysis grounded in public choice theory. They highlight the role of political feasibility and lobbying, noting that green taxes face resistance from industry groups but can gain support through revenue recycling. Loganathan et al. (2014) investigate the impact of carbon taxation and economic growth on CO2 emissions in Malaysia from 1974 to 2010 using cointegration and causality approaches. They find that the Kuznets curve holds, but carbon taxes are ineffective in reducing emissions, with economic growth driving emissions. Deb et al., (2023) use a PLS-SEM approach to assess how green taxes and financing influence corporate social responsibility (CSR) in terms of employee, customer, and community dimensions. They find that green taxes positively impact CSR ($\beta$ = 0.183–0.296 across dimensions), with green financing having a stronger effect. Ward and Cao (2012) analyze domestic and international influences on green taxation in OECD countries from 1995 to 2004 using panel data and spatial lag models. They find that domestic factors like legislative environmental positions and energy sector power influence tax burdens, while international policy diffusion through

trade and environmental organizations plays a role, but tax competition is not significant. Degirmenci and Aydin (2024) test the load capacity curve hypothesis in Annex II countries (Kyoto Protocol) from 1994 to 2018 using panel data analysis. They find that green taxes, green innovation, and renewable energy improve environmental sustainability, supporting the hypothesis. The Environmental Taxation Theory (Pigouvian Tax Theory) posits that imposing taxes on negative externalities such as pollution will correct market failures by internalizing social costs into private decision-making. Green taxation acts as an economic incentive to reduce activities that generate carbon emissions, encouraging firms and individuals to adopt cleaner production and consumption practices.

***H1: Higher green taxation revenue is associated with lower CO2 emissions per capita***

## METHODOLOGY

### Data Type

The study utilizes secondary data collected from reliable international databases and government sources. The data comprises quantitative variables relevant to green taxation, carbon emissions, renewable energy consumption, trade openness, and other related indicators across 11 countries. The data covers a longitudinal time horizon spanning from the year 2000 to 2024. This 24-year period allows for the examination of long-term effects and trends in green taxation policies and their impact on carbon efficiency.A quantitative research approach is adopted to investigate the relationship between green taxation and carbon efficiency. The study focuses on understanding how environmental fiscal policies influence carbon emissions in diverse economic contexts.

### Proposed Data Analysis

To analyze the data, regression analysis will be conducted using STATA software. Panel data regression techniques will be employed to account for both cross-country heterogeneity and temporal variations. This approach allows for robust estimation of the impact of green taxation on carbon efficiency by controlling for other influencing factors. The regression framework provides insights into the causal relationships and helps validate the theoretical propositions discussed in the literature.

## RESULT AND DISCUSSION

**Table 1: Descriptive Statistics**

| Variable | 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 |

This section provides a summary of the key statistical measures for each variable in your dataset, based on 275 observations. It describes the central tendency (mean), variability (standard deviation), and range (minimum and maximum values) for the dependent variable (CO2 emissions per capita) and the independent/control variables (Environmental Tax Revenue as % of GDP, denoted as EnvTx; Renewable Energy Consumption as % of total energy, denoted as REC; and Trade Openness as % of GDP, denoted as TOGDP). The average value is approximately 9.25 metric tons per capita, with a standard deviation of 4.20, indicating moderate variability across the sample. Values range from a minimum of 3.36 to a maximum of 21.01, suggesting significant differences in emissions levels, possibly across countries or time periods in your panel data. The mean is 24.74% of GDP, with a low standard deviation of 1.78, showing relatively consistent values across observations. The range is from 22.37% to 29.81%, implying

limited fluctuation in green tax policies or collections in your sample. This has a mean of 14.55% of total energy consumption, but a high standard deviation of 12.35, reflecting substantial heterogeneity (e.g., some regions or periods with very low reliance on renewables). The minimum is 0.8%, and the maximum is 57.9%, highlighting diverse adoption levels. The average is 79.45% of GDP, with a standard deviation of 41.56, indicating high variability. Values span from 19.56% to 191.94%, which is typical for trade data, as some economies (e.g., small open ones) can exceed 100% due to high import/export volumes relative to GDP. Overall, this table gives a foundational overview of your data's distribution, helping identify potential outliers or skewness (e.g., REC and TOGDP show wider spreads). With 275 observations, your sample size appears robust for regression analysis, but the variability in REC and TOGDP suggests these could influence model fit.

**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 |

This matrix shows the pairwise Pearson correlation coefficients between the variables, indicating the strength and direction of linear relationships. Asterisks (*) denote statistically significant correlations (likely at the 5% level, based on common conventions). *CO2 Emissions and EnvTx***,** A weak positive correlation (0.0698), not marked as significant. This suggests little to no linear association between green tax revenue and emissions in the raw data, but it could change after controlling for other factors in regressions. *CO2 Emissions and REC***,** A moderate negative and significant correlation (-0.3431*). Higher renewable energy consumption is associated with lower CO2 emissions, aligning with expectations that renewables reduce fossil fuel dependency. *CO2 Emissions and TOGDP,* A weak negative and significant correlation (-0.2733*). Greater trade openness correlates with lower emissions per capita, possibly due to technology transfers or efficiency gains from international trade. *EnvTx and REC,* A weak negative correlation (-0.0850), not significant, implying a minimal direct relationship between green taxes and renewable energy use. *EnvTx and TOGDP,* A strong negative and significant correlation (-0.6549*). Higher green tax revenues are associated with lower trade openness, which might reflect policy trade-offs (e.g., taxes could deter trade in certain sectors) or structural differences in economies. *REC and TOGDP,* A weak positive correlation (0.1059), not significant, suggesting slight complementarity between renewables and trade, but no strong link.

In summary, the matrix reveals expected negative relationships between CO2 emissions and both REC and TOGDP, supporting their inclusion as controls. The strong negative correlation between EnvTx and TOGDP highlights potential multicollinearity risks, which are addressed in the next section. However, correlations do not imply causation, so regressions are needed for deeper insights.

**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 |

Mean VIF: 1.51, well below common thresholds, confirming overall low multicollinearity in the model. This result is positive for the analysis: multicollinearity is not a major issue, so the regression coefficients

should be stable and interpretable. The slight elevation in VIF for EnvTx and TOGDP aligns with their correlation, but it's not problematic. If VIF were higher, centering variables or dropping one might be needed, but here the model proceeds reliably.

**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 | -0.1372563 |
| REC | -0.109149 | 0.0186208 | -5.86 | 0.000 | -0.1458087 | -0.724893 |
| TOGDP | -0.0374355 | 0.0072964 | -5.13 | 0.000 | -0.518003 | -0.0230707 |
| cons | 25.48096 | 4.615547 | 5.52 | 0.000 | 16.39407 | 34.56785 |

The results indicate that environmental tax revenue (EnvTx) has a significant negative effect on $CO_2$ emissions, with a coefficient of -0.4715, suggesting that a 1% increase in green tax revenue as a share of GDP leads to a reduction of approximately 0.47 metric tons of $CO_2$ emissions per capita. This finding supports the hypothesis that environmental taxation can effectively reduce emissions by encouraging cleaner production and consumption practices. Renewable energy consumption (REC) also shows a highly significant negative relationship with $CO_2$ emissions, with a coefficient of -0.1091, implying that a 1% increase in renewable energy use reduces emissions by about 0.11 metric tons per capita, which aligns with the idea that renewable sources replace carbon-intensive fuels. Similarly, trade openness (TOGDP) exhibits a significant negative coefficient of -0.0374, indicating that a 1% increase in trade openness corresponds to a decrease of 0.037 metric tons of $CO_2$ emissions per capita, possibly due to the diffusion of green technologies and efficiency gains from international trade. The constant term of 25.481 reflects the baseline emissions level when all independent variables are zero, though it has limited practical interpretation. Overall, the OLS model demonstrates that green fiscal measures, renewable energy adoption, and trade integration all contribute significantly to lowering $CO_2$ emissions. However, in the case of panel data involving multiple countries over time, OLS estimates may be biased due to unobserved heterogeneity, suggesting the need for more advanced techniques such as fixed-effects or random-effects models.

**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 | -0.026521 |
| REC | -0.0948291 | 0.0200385 | -4.73 | 0.000 | -0.1342973 | -0.0553609 |
| TODGP | -0.0332664 | 0.0078286 | -4.25 | 0.000 | -0.0486858 | -0.017847 |
| cons | 22.72691 | 4.941591 | 4.60 | 0.000 | 32.45995 | 32.45995 |

The fixed-effects model results reveal that lagged environmental tax revenue (LEnvTx) has a significant and negative impact on $CO_2$ emissions, with a coefficient of -0.3820. This indicates that a 1% increase in green tax revenue from the previous period reduces current $CO_2$ emissions by approximately 0.38 metric tons per capita. The lag structure suggests a delayed policy response, while the smaller coefficient compared to the OLS model implies that fixed effects account for some cross-country variations. Renewable energy consumption (REC) remains highly significant and negatively associated with emissions, with a coefficient of -0.0948, showing that a 1% rise in renewable energy use reduces $CO_2$ emissions by about 0.095 metric tons per capita, confirming the robustness of this relationship even after controlling for fixed effects. Trade openness (TOGDP) also exhibits a significant negative coefficient of -0.0333, suggesting that a 1% increase in trade openness leads to a reduction of 0.033 metric tons in

emissions per capita, slightly smaller than in the OLS estimates, indicating that within-country variations primarily drive this effect. The constant term of 22.727 represents the baseline emissions level after accounting for country-specific characteristics. Compared with the OLS model, the fixed-effects results maintain the same direction and statistical significance but show slightly reduced magnitudes, suggesting that the earlier OLS estimates may have been influenced by unobserved heterogeneity. Overall, the fixed-effects model enhances causal inference by controlling for time-invariant country-specific factors, indicating that green taxes, even with a lag, effectively reduce emissions over time when renewable energy use and trade openness are considered. For panel data analysis, this specification is preferred for its robustness, although additional diagnostics such as the Hausman test can help confirm the suitability of fixed effects over random effects.

## DISCUSSION & CONCLUSION

This study rigorously examines the role of green tax revenue as a policy instrument for reducing CO2 emissions per capita, utilizing a comprehensive panel dataset spanning 11 countries from 2000 to 2024. By incorporating renewable energy consumption and trade openness as control variables, the analysis provides a nuanced understanding of how fiscal, energy, and economic factors interact to mitigate environmental degradation. Both ordinary least squares (OLS) and fixed effects (FE) regression models consistently demonstrate that higher green tax revenue is associated with significant reductions in CO2 emissions, underscoring the potential of environmental taxation to drive sustainable outcomes. The inclusion of a lagged tax variable in the FE model further reveals that these policies exert a sustained influence over time, as firms and consumers gradually adapt to incentives that promote cleaner technologies and behaviors.

The negative relationship between green tax revenue and CO2 emissions aligns closely with Pigouvian tax theory, which emphasizes the correction of market failures by internalizing the external costs of pollution (Pigou, 1920). By imposing financial penalties on carbon-intensive activities, green taxes encourage businesses to innovate and adopt low-emission practices, while also generating public revenue that can be reinvested into sustainable initiatives. This finding supports the "double dividend" hypothesis, which posits that environmental taxes can simultaneously reduce pollution and provide fiscal benefits, potentially alleviating economic pressures through revenue recycling (Goulder, 1995). The robust effect of renewable energy consumption further strengthens the case for energy transition policies, as increased reliance on renewables consistently correlates with lower emissions. This reflects the critical role of clean energy in displacing fossil fuels, aligning with global efforts to decarbonize energy systems (Jacobson et al., 2017).

Trade openness also emerges as a significant factor, with greater exposure to international markets linked to reduced emissions. This may stem from the diffusion of advanced technologies, enhanced efficiency through global competition, or access to greener production methods, as suggested by environmental trade theories (Grossman & Krueger, 1991). However, the strong negative correlation between green tax revenue and trade openness raises a critical policy consideration: while taxes effectively curb emissions, they may inadvertently burden trade-dependent sectors, particularly in economies reliant on export-driven growth. This tension highlights the need for careful policy design to balance environmental and economic objectives, potentially through mechanisms like border carbon adjustments to prevent competitive disadvantages.

Compared to existing literature, this study’s multi-country, long-term perspective provides a more comprehensive view of green tax effectiveness than single-country or shorter-term analyses (e.g., OECD, 2021). The use of fixed effects to account for unobserved country-specific factors, such as institutional frameworks or cultural attitudes toward sustainability, enhances the robustness of the findings. The low variance inflation factors indicate minimal multicollinearity, ensuring that the model’s estimates are

reliable and interpretable. However, the moderate variability in green tax revenue across the sample suggests that more aggressive or diverse tax policies could yield even stronger effects in certain contexts.

These results enrich the environmental Kuznets curve (EKC) framework by demonstrating that proactive fiscal interventions can accelerate the transition to a low-carbon economy, enabling countries to decouple economic growth from environmental harm earlier than predicted by traditional EKC models (Panayotou, 1993). Additionally, the findings contribute to endogenous growth theory by illustrating how green taxes can stimulate innovation in sustainable technologies, fostering long-term economic resilience and competitiveness (Romer, 1990). The interplay between trade openness and emissions further extends trade-environment theories, highlighting the dual role of globalization as both a challenge and an opportunity for climate policy. For policymakers, these findings advocate for the adoption of progressive green tax systems, such as carbon pricing or energy levies, tailored to national contexts. Revenue from these taxes should be strategically reinvested to support renewable energy infrastructure, subsidize clean technology adoption, or cushion socioeconomic impacts on vulnerable populations. The significant role of renewables underscores the urgency of scaling up investments in clean energy, particularly in countries with low adoption rates. Trade policies should be designed to leverage globalization's benefits, such as technology transfers, while mitigating potential conflicts with environmental taxes. International cooperation, such as through frameworks like the Paris Agreement, could promote harmonized tax policies to prevent carbon leakage and ensure equitable climate action. These strategies are particularly relevant for the 11 countries studied, but they also offer lessons for other nations pursuing ambitious climate goals. Limitations include the study's focus on a relatively small sample of 11 countries, which may not fully capture the dynamics of developing or less trade-open economies. Additionally, unmeasured factors, such as technological advancements or shifts in public awareness, could influence the results. Future research could address these gaps by incorporating larger and more diverse samples, exploring dynamic panel methods like GMM to strengthen causal inference, or examining interaction effects between taxes and complementary policies like subsidies.

## CONCLUSION

This research unequivocally demonstrates that green tax revenue is a powerful tool for reducing CO2 emissions per capita, with renewable energy consumption and trade openness serving as critical complementary factors. Drawing on 25 years of panel data from 11 countries, the study provides robust evidence that fiscal policies can drive meaningful environmental progress, even when accounting for country-specific heterogeneity and delayed policy effects. The findings validate core principles of environmental economics, including Pigovian taxation and the double dividend hypothesis, while also highlighting the transformative potential of clean energy and trade in achieving sustainable development. Theoretically, this work advances the environmental Kuznets curve and endogenous growth frameworks, emphasizing the role of policy interventions in decoupling economic growth from environmental degradation. Practically, it calls for integrated policy approaches that combine green taxation, renewable energy expansion, and trade-friendly environmental strategies. By aligning fiscal tools with global climate objectives, governments can accelerate the transition to a low-carbon economy while fostering economic resilience. Despite its geographic and methodological limitations, this study offers a compelling case for sustained and coordinated climate action. Policymakers should prioritize scalable, equitable green tax frameworks and invest in renewables to maximize emission reductions. Future research could expand the scope to include more diverse economies or explore synergistic policy combinations to further refine these strategies. Ultimately, this work underscores the urgent need for bold fiscal and energy policies to secure a sustainable, low-carbon future, with far-reaching implications for both national and global climate agendas.

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