Working paper UGA-25343
February 2026

Environmental taxation and carbon emissions reduction: Evidence from Kenya, Uganda, and Rwanda

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Environmental Taxation and Carbon Emissions Reduction: Evidence from Kenya, Uganda, and Rwanda

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Abstract

Global carbon dioxide emissions continue to rise despite increasing efforts to reduce them. Countries such as Kenya, Rwanda, and Uganda are experiencing rapid economic growth, urbanisation, and energy-intensive production processes that exacerbate carbon dioxide emissions. Although environmental taxes have been shown to reduce carbon dioxide emissions, empirical research supporting this in low-income countries is limited. As a result, it was necessary to determine whether environmental taxes affected per capita carbon dioxide emissions in Uganda, Rwanda, and Kenya from 2001 to 2022. The paper used a STIRPAT approach. The results showed a nonlinear relationship between environmental taxes and carbon dioxide emissions. When considering the aggregate effect, total environmental taxes can lower carbon dioxide emissions to a threshold of about 3.5% of GDP, while energy taxes show a threshold of 2.1% of GDP, and pollution taxes reduce carbon dioxide emissions only after reaching a threshold of 0.10% of GDP. It was also found that transport taxes are effective in reducing carbon dioxide emissions up to 0.88% of the GDP. Beyond these limits, increases in environmental taxes lead to diminishing marginal benefits from reducing carbon dioxide emissions. It was therefore concluded that the increase in existing environmental taxes to the thresholds deemed necessary to effectively reduce CO_2 emissions in Kenya, Uganda, and Rwanda.

Keywords: Environmental tax; carbon dioxide emissions; STIRPAT model; Kenya; Uganda; Rwanda; panel data; climate policy.

1. Introduction

Global carbon dioxide (CO2) emissions have risen from 6 billion metric tons in 1950 to 37.8 billion metric tons in 2024 (Crippa, 2025; IEA, 2025). CO2 emissions in 2024 reached 422.5 parts per million, an approximate 50% increase from pre-industrial levels. Additionally, average global temperatures increased by approximately 1.25°C over the last decade (2015-2024). During 2024, average temperatures had already approached 1.34°C, thus nearing the target set in the Paris Agreement established in December 2015 of 1.5°C, making 2024 the hottest year in recorded history (WMO, 2025). The increase of CO2 concentrations in our atmosphere presents a threat to our environment and to humanity, and indeed, CO2 is responsible for approximately 66% of Climate Change (Ritchie & Roser, 2020). Climate change contributes to repeated droughts, floods, changing precipitation patterns, water shortages, pollution, and food insecurity, threatening agriculture, the major source of livelihood, and the health of the people.

As environmental quality and sustainability become increasing concerns worldwide, the international community's focus on reducing CO2 emissions to counter the impending threat of climate change continues to grow. Consequently, multiple researchers have investigated the effectiveness of various strategies, including renewable energy implementation (Altın, 2024; Bilgili et al., 2016; Dong et al., 2020), improving energy efficiency (Clark et al., 2016; Mirza et al., 2022; Oyekale, 2024), creating carbon pricing systems (Andersson, 2019; Lin & Li, 2011; Pretis, 2022), and providing climate change education (Cordero et al., 2020; Misra & Verma, 2015) to reduce CO2 emissions and minimise the effects of climate change.

One policy tool increasingly discussed is environmental taxation. Environmental taxes are government-imposed charges on activities, products, or services that demonstrably harm the environment (Smith et al., 2010). They aim to correct market failures by taxing pollutants or environmentally harmful goods. Environmental taxes fall into four categories: energy taxes[1], transport taxes[2], pollution taxes[3], and resource taxes[4]. The seminal economic theory of Pigou

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[1] Energy taxes refer to total taxes charged on energy products such as fossil fuels and electricity, including those used in transportation, such as petrol and diesel.

[2] Transport taxes refer to taxes charged on the import of transport equipment, recurrent taxes on ownership, registration, or use of motor vehicles, and road use, but they exclude excise taxes on automotive fuel.

[3] Pollution taxes refer to taxes charged on ozone-layer depleting substances such as chlorofluorocarbons, carbon tetrachloride, chlorofluoromethanes, taxes on discharge of wastewater, taxes on packaging, such as plastic bags, on final disposal of solid waste, and other waste-related taxes, such as batteries and tires.

[4] Resource taxes refer to taxes imposed on water extraction, forest products, hunting, fishing, mining royalties, and excavation taxes, such as for sand and gravel (these do not include charges related to water supply).

(1920) proposed such taxes to correct externalities, yielding the first “dividend” of lower pollution and a second “dividend” of economic efficiency gains if revenues are recycled to cut distortionary taxes (Goulder, 1995a; Pigou, 2017; Polinsky & Shavell, 1982). Indeed, energy taxes, particularly on petrol and diesel, reduce fossil energy use and foster investments in cleaner technologies (Bilan et al., 2022; Schoder, 2023). Also, environmental taxes offer multiple benefits beyond climate goals: they raise domestic funds for expanding public expenditure. Secondly, enable developing countries to achieve both the Sustainable Development Goals (SDGs) and meet targets set in their Nationally Determined Contributions (NDCs) (Heine & Black, 2019). Environmental taxes have demonstrated that if well-designed, they can reduce emissions without harming growth. For instance, the World Bank, “State and Trends of Carbon Pricing 2022” report noted that environmental taxes cover approximately 23% of total global greenhouse gas (GHG) emissions worldwide (Bank, 2022).

Most existing studies on environmental taxes have been conducted in developed nations, with very few in developing nations. For instance, a recent study by Al Shammre et al. (2023) was conducted across 34 OECD countries to assess the impact of total environmental taxes, energy taxes, and pollution taxes on CO2 emissions from 1995 to 2019. The study concluded that each tax type has a significant negative impact on CO2 emissions at a defined threshold; these thresholds are as follows: 3.002% of GDP for total environmental taxes, 1.991% of GDP for energy taxes, 0.377% of GDP for pollution taxes, 0.170% of GDP for resource taxes, and 0.434% of GDP for transport taxes. Other work in the EU and developed countries suggests that taxes on fuels, electricity, and other harmful substances to the environment are correlated with lower CO2 emissions (Bashir et al., 2020; Doğan et al., 2022; Xie & Jamaani, 2022). However, evidence from developing countries is scarce. Moreover, Heine and Black (2019) clearly shows that environmental taxes have potential, but large gaps in environmental tax levels persist globally, especially in developing countries. Indeed, this explains why in developing countries, studies offer mixed and inconclusive findings (Akkaya & Hepsag, 2021; Telatar & Birinci, 2022). Furthermore, there is relatively limited empirical evidence regarding the impact of specific categories of environmental taxes on CO2 emissions, since nearly all of the previous studies in developing countries have examined the aggregate effect of environmental taxes with little attention being paid to possible variation across tax categories (Mehta & Derbeneva, 2024). As such, we do not yet know if developing countries that adopt similar tax policies will experience the same "double dividend" effects as those experienced in developed countries.

The paper thus aimed to fill that gap by empirically examining how specific environmental tax categories affect CO2 emissions in Kenya, Uganda, and Rwanda from 2001 to 2022. These three neighbours were selected based on data availability and because CO2 emissions in East Africa are rising at an alarming rate of 6.5% per year; together with Tanzania and Ethiopia, they account for over 80% of the region's total emissions (Sun et al., 2022). The study mainly focused on four tax categories: total environmental taxes and subcategories for energy, pollution, and transport. Resource taxes were excluded due to insufficient data. Environmental tax disaggregation helps policy thinkers in developing countries to identify the best instruments of CO2 emissions reduction, accounting for economic dynamism, and with consideration for the poor (United Nations, 2021). A visual trend from 2000 to 2021 shows that energy and total environmental taxes as a share of GDP have steadily declined, underscoring the urgency of evaluating their effectiveness (see Figure 1). Precisely, using the extended STIRPAT model, we aimed to answer three research questions: (Q1) Do higher environmental taxes reduce CO2 emissions? (Q2) Do the effects of environmental taxes differ by tax category: energy, pollution, and transport? Finally, (Q3) does the relationship between taxes and CO2 emissions have a turning point or threshold?

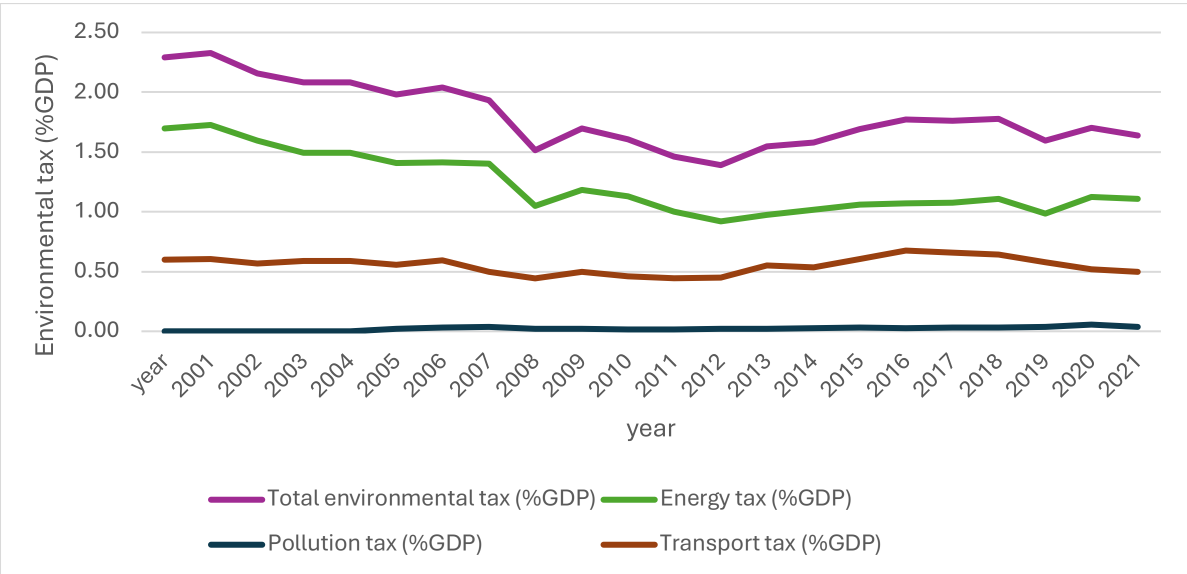

Figure 1 Trends in environmental tax revenue (% of GDP) for Kenya, Uganda, and Rwanda, 2000–2021. Source: Authors' calculations using OECD data[5].

The contribution of this study is novel in several ways. First, empirical evidence from developing countries: Kenya, Uganda, and Rwanda, added to existing research knowledge on

[5] Data on environmental taxes can be accessed on OECD website: https://shorturl.at/dareJ

the OECD and G7 countries (Al Shammre et al., 2023; Doğan et al., 2022). Second, the study helps policymakers understand the effects of various groups of environmental taxes on CO2 emissions in Kenya, Uganda and Rwanda, advancing the study by Mehta and Derbeneva (2024), which found that overall environmental taxes lower CO2 emissions in 13 African countries. Finally, the study aimed to provide policy-relevant evidence by estimating the "threshold" tax levels for minimising CO2 emissions via the quadratic STIRPAT specification. Adding threshold tax levels, the study indicates how far tax rates can rise without imposing excessive burdens on production and consumption.

The rest of the paper was structured as follows. The next section reviews relevant literature, both theoretical and empirical. Data and methodology follow Chapter 3, which describes the STIRPAT-based econometric model, data sources, and estimation procedure adopted by the study. The results and discussion section follows the methodology and presents descriptive statistics, correlations, regression results, and an interpretation and discussion of the findings in light of the theory. The paper concludes with policy recommendations and the study's limitations.

2. Literature Review

Environmental taxes have increasingly become a weapon in the battle to mitigate climate change and environmental degradation. The study was based on three theories: the Pigouvian Tax, the Green Paradox, and the Double Dividend Hypothesis. Environmental taxes can be grounded in the Pigouvian theory, first postulated by economist Pigou and later refined by Polinsky and Shavell (1982). According to this theory, taxes serve as a corrective measure for the differences between private and social costs arising from externalities (Pigou, 2017). From this perspective, people are affected by negative externalities arising from climate change, including elevated CO2 levels from pollution (Roach et al., 2019). Imposing environmental taxes can therefore help to reduce CO2 emissions for the greater good (Al Shammre et al., 2023; Guo & Wang, 2018).

Consistent with Pigouvian theory, the Double Dividend hypothesis argues that environmental taxes can achieve two dividends simultaneously: reduce emissions and enhance economic efficiency, on the condition that the revenues are recycled into less distortionary taxes, such as income or payroll taxes (Bovenberg & De Mooij, 1994; Goulder, 1995b; Pearce, 1991; Vona, 2021). Both developed and developing economies have supported the hypothesis that recycling revenues could reduce regressive effects and improve overall fiscal performance (Adom, 2025;

Domguia et al., 2024; Mehta & Derbeneva, 2024). More recent work underscores how extended environmental pricing and green innovation are self-reinforcing (Khan et al., 2025; Wei et al., 2025).

In contrast, the Green Paradox hypothesis highlights potential unintended consequences. According to Sinn (2015), the hint of government intervention with respect to future environmental taxes may stimulate resource owners to extract their fossil fuel stocks faster because of expected tighter controls. Such a supply-side response can worsen short-term emissions, indicating the key role of policy timing and credibility (Ulucak et al., 2020; Wolde-Rufael & Mulat-Weldemeskel, 2021). Empirical evidence indicates that once the expectation of the implementation of environmental taxes is raised, fossil fuel production increases within the OECD and BRICS nations (Aydin & Esen, 2018; Esen et al., 2021; Zaghdoudi & Maktouf, 2017).

There has been an emergence of empirical studies to complement and supplement theories that explain how environmental taxes affect greenhouse gas emissions and environmental degradation, with a growing body of evidence confirming their effectiveness in reducing carbon emissions. Doğan et al. (2022) demonstrate that environmental taxes significantly reduce CO2 emissions across G7 economies using panel cointegration and FMOLS methods, while Xie and Jamaani (2022) show, through quantile regression, that higher environmental taxes are consistently associated with lower CO2 emissions, particularly at higher pollution levels. Scholars have continued the discussion past a handful of boundaries. Environmental taxes have a significant reduction effect on carbon emissions in E7 nations (Tao et al., 2021). Additionally, Sarpong et al. (2023) align with the COP-26 agenda, supporting the view that environmental taxation is a positive factor in reducing CO2 emissions. Focusing on the empirical evidence conducted on particular nations, the situation is a more mixed bag, with Telatar and Birinci (2022) discovering little effect of environmental taxes on CO2 emissions in Turkey, while Akkaya and Hepsag (2021) found a null effect of fuel taxes on CO2 emissions in Turkey, both in the short- and long-run. According to Ocansey and Haywood-Dadzie (2025), a total of 105 research works were evaluated from 2014 to 2024, and it was revealed that environmental taxes are effective measures to mitigate CO2 emissions, although this depends on the tax system. On the whole, based on extensive research, it has been established that CO2 emissions are reduced with the use of environmental taxes; hence, the formulation of hypothesis one: Higher environmental taxes reduce CO2 emissions.

Another line of studies finds that the effectiveness of environmental taxes depends more on the type of tax rather than on the overall level of environmental taxes. For instance, Meireles et al. (2021) find that transport taxes, that is, car registry taxes, decrease CO2 emissions in the Mediterranean regions in the long run. Wolde-Rufael and Mulat-Weldemeskel (2021) find that CO2 emissions decrease as the amount of total taxes on the environment, energy, and transport increases. In opposition, Akkaya and Hepsag (2021) find that fuel taxes, implemented in Turkey, had little effect, while transport taxes led to more sustainability in the long run, as stated by Ahmad and Satrovic (2023). This has informed the formulation of the second hypothesis of the study: the effect of environmental taxes differs by tax category: energy, pollution, and transport taxes.

Recent literature has increasingly focused on nonlinearities and threshold effects, suggesting that carefully designed environmental taxes will not hamper production and consumption. For instance, it is clear from Zaghdoudi and Maktouf (2017) that in OECD countries, reductions in CO2 emissions occur only once a critical threshold tax rate is exceeded. Ulucak et al. (2020) report similar nonlinear patterns across BRICS, noting that too-low tax rates could trigger the Green Paradox and worsen outcomes. Esen et al. (2021) showed that a tax in the EU-15 nations tends to shrink ecological deficits when exceeding specific thresholds. The latest research, such as that by Al Shammre et al. (2023), identifies specific thresholds for the level of taxation within OECD economies: 3.002% of GDP for total environmental taxes, 1.991% for energy taxes, and 0.377% for pollution taxes. Domguia et al. (2024) support the increasing decarbonization impact in the industry and transport sectors when the tax-intensity threshold is crossed. Henceforth, the study adopted the third hypothesis: the relationship between environmental taxes and CO2 emissions is nonlinear, with a turning point or threshold.

According to the existing literature on environmental taxes and CO2 emissions, three gaps require further investigation. First, most studies investigate the effect of aggregate environmental taxes and provide a very narrow insight into how each category: energy taxes, pollution taxes, and transport taxes, affects CO2 emissions. Second, several studies have focused on linear effects, ignoring the nonlinear patterns that may influence the effectiveness of these taxes. Lastly, significant knowledge gaps exist in developing countries. For instance, Africa and other developing regions receive very little representation, as most studies are conducted in developed countries. This study bridges these gaps by providing evidence from Kenya, Rwanda, and Uganda.

3. Methodology

The analysis was guided by the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) framework. This model has its roots in the IPAT identity first introduced by Ehrlich and Holdren (1971) and was later advanced by Dietz and Rosa (1997) to allow hypothesis testing and flexible elasticities that overcame the deterministic limits of the IPAT identity. The STIRPAT model has now become a common framework for examining how environmental impacts are related to their underlying drivers (Al Shammre et al., 2023; Domguia et al., 2024; Ulucak et al., 2020). In its general form, the general STIRPAT model can be expressed as:

$$I_{it} = \alpha P_t^{\beta_1} A_t^{\beta_2} T_t^{\beta_3} \varepsilon_t, \tag{1}$$

where I_{it} denotes environmental impact, P represents population, A captures affluence, T denotes technology, and ε_t captures the error term. Taking natural logarithms yields the estimable log-linear form of equation (1):

$$\ln\, I_{it} = \alpha + \beta_1 \ln\, P_t + \beta_2 \ln\, A_t + \beta_3 \ln\, T_t + \varepsilon_t, \tag{2}$$

Following Chen et al. (2022) and Mehta and Derbeneva (2024), environmental impact was measured by carbon dioxide emissions per capita (CO2_pc); real GDP per capita (GDP_pc) was used as a proxy for affluence; urban population was used as a proxy for population (urb_share); and, lastly, energy intensity was used to represent technology (energy_int). Since the main objective of the study was to examine the role of fiscal policy on environmental impact, the study augmented equation (2) to add environmental taxation variables. Henceforth, environmental taxes capture policy-induced price signals affecting CO2 emissions (Mpofu, 2022; World Bank, 2022). This gives an extended empirical specification as:

$$co2\_pc_{it} = \alpha + \beta_1 gdp\_pc_{it} + \beta_2 energy\_int_{it} + \beta_3 urb\_share_{it} + \beta_4 tax_{it} + \varepsilon_{it}, \tag{3}$$

where tax_{it} represents environmental taxes. The study followed a panel data econometric model specification where i refers to the country and t refers to the time period. From the Pigouvian theoretical perspective, β_4 was expected to be negative. This is because environmental taxes introduce an extra cost, reflected in a higher price, which changes consumption and production behaviour, leading to reduced CO2 emissions.

Following growing empirical concern that environmental taxes have a nonlinear relationship with CO2 emissions (Al Shammre et al., 2023; Ulucak et al., 2020). Equation (3) was further extended to include a quadratic term by squaring the environmental taxes. Therefore, the quadratic specification can be written as:

$$co2\_pc_{it} = \alpha + \beta_1 gdp\_pc_{it} + \beta_2 energy\_int_{it} + \beta_3 urb\_share_{it} + \beta_4 tax_{it} + \beta_5 tax_{it}^2 + \varepsilon_{it}, \quad (4)$$

tax_{it}^2 allows the marginal effect of environmental taxation to vary with the level of taxation, and the marginal effect can be obtained by differentiating equation (4) with respect to the environmental tax. Thus, differentiating equation (4) with respect to the environmental tax leads to:

$$\frac{\partial co2\_pc_{it}}{\partial tax_{it}} = \beta_4 + 2\beta_5 tax_{it} \quad (5)$$

Setting equation (5) to zero yields the turning point, which can be expressed as follows:

$$tax^* = -\frac{\beta_4}{2\beta_5}, \quad (6)$$

tax^* represents the threshold at which the level of environmental taxation is predicted to reach its turning point, holding other factors constant. The nature of the tax–emissions relationship depends on the signs of β_4 and β_5. When $\beta_4 < 0$ and $\beta_5 > 0$, the relationship is U-shaped. In this case, increases in environmental taxation are associated with declining emissions up to the threshold tax^*, after which further increases are associated with rising emissions. Conversely, when $\beta_4 > 0$ and $\beta_5 < 0$, the relationship is inverted U-shaped. In the second case, increasing environmental taxation is associated with an initial increase in emissions up to the threshold tax^*, after which further increases are associated with decreasing emissions. If both coefficients are positive, the relationship is monotonically increasing; if both are negative, it is monotonically decreasing. Where both coefficients are zero, no systematic relationship is identified.

Consistent with Ewane and Ewane (2023) and Adeleye et al. (2023). A meaningful turning point requires that the linear and quadratic terms have opposite signs. For the emissions-minimising threshold to be empirically valid, three conditions must be satisfied: (i) both β_4 and β_5 must be statistically significant; (ii) $\beta_5 > 0$ to ensure convexity and the existence of a minimum; and (iii) the estimated tax^* must lie within the observed sample range. Under these conditions, tax^* characterises a data-consistent threshold in the long-run relationship between environmental taxation and per-capita carbon emissions.

Following the study's second hypothesis and to capture heterogeneity across categories, the analysis estimated separate models for each environmental tax category: total environmental taxes (env_tax), energy taxes (ener_tax), transport taxes (tra_tax), and pollution taxes (pol_tax). Each tax variable was entered individually in both linear and quadratic forms to avoid multicollinearity and to isolate category-specific effects.

Based on economic theory and the STIRPAT framework, the coefficient β_1 was expected to be positive, indicating that rising per capita income leads to greater consumption, more industries, and increased resource extraction, resulting in higher CO2 emissions. The coefficient β_2 was also expected to be positive, since higher energy use per unit of output implies greater fossil fuel dependence and higher CO2 emissions. The coefficient β_3 was expected to be positive because, as urbanisation advances, it can increase CO2 emissions through higher energy consumption, increased industrial activity, transportation, and construction of necessary infrastructure. The coefficient β_4 was expected to be negative, while β_5 was expected to be positive if diminishing returns or threshold effects are present (see equation 4). The study used publicly available data from the Organisation for Economic Co-operation and Development (OECD) and the World Bank's World Development Indicators (WDI) websites. The data covered the period from 2001 to 2022 to form a country-year panel. The names of the variables, their abbreviation, and sources are summarised in Table 1.

Table 1 Description and sources of variables

Abbreviation	Variable Description	Source
co2_pc	CO2 emissions (metric tons) per person	WDI
env_tax	Total environmental tax revenue (%GDP)	OECD
energy_tax	Energy tax revenue (%GDP)	OECD
Pol_tax	Pollution tax revenue (%GDP)	OECD
trans_tax	Transport tax revenue (%GDP)	OECD
energy_int	Energy intensity level of primary energy (MJ/$2021 PPP GDP)	WDI
gdp_pc	GDP per capita (constant 2015 US$)	WDI
urb_share	Urban population (% of total population)	WDI

Source: Authors' computation

Following Sohag et al. (2018), when dealing with panel data, selecting a suitable model depends on the number of cross-sections (N) and the number of years (T). This study adopted static panel models since $N<25$ and $T<25$. Further, for short panel time periods, the issue of stationarity becomes less important. In fact, according to Harris and Tzavalis (1999) and

Tzavalis (2002), when T is small, conventional unit root tests have lower statistical power and often yield incorrect results. Hence, it is not advisable to perform unit root tests when T is small; henceforth, the current study did not conduct unit root testing.

4. Results and Discussion

4.1 Descriptive Statistics

The descriptive statistics were summarised in Table 2 and underscore the differences in fiscal approaches to environmental management across Kenya, Uganda and Rwanda. The average level of total environmental taxes across the three countries is 1.8% of their GDP, ranging from 0.53% to 3.76% over 2001 to 2022. Energy taxes are the largest contributors to total environmental taxes, averaging 1.23% of GDP; transport taxes are the second-largest, averaging 0.55% of GDP; and pollution taxes are the third-largest, averaging 0.02% of GDP. In relation to the changes across the three countries, Kenya has the highest at 2.38% of GDP, followed by Uganda at 1.94% and Rwanda at 1.08%.

In addition, Kenya is the highest among the three countries in terms of GDP per capita and CO2 emissions, followed by Uganda and then Rwanda. Additionally, Kenya has the highest energy taxes at 1.32% of GDP; Uganda has the highest transport taxes at 1.73% of GDP; Rwanda has the lowest in all categories; and Uganda has the highest pollution taxes at 0.07% of GDP. Kenya also leads in the percentage of people living in urban areas, with a mean of 29.6%, followed by Uganda at 20.68%, and lastly Rwanda at 19%.

Table 2 Descriptive Statistics

Stat	co2_ pc	Env_tax	Energy tax	Pollution tax	Transport tax	Energy int.	GDP pc	Urban share
				Kenya				
N	22	22	22	22	22	21	22	22
Mean	0.32	2.38	1.32	0	1.06	5.23	1404.58	29.63
SD	0.06	0.68	0.62	0	0.16	0.25	179.83	3.55
Min	0.21	1.56	0.7	0	0.74	4.76	1169.14	20.44
Max	0.41	3.76	2.52	0	1.32	5.62	1747.53	31.87
				Rwanda				
N	22	22	22	22	22	22	22	22
Mean	0.09	1.08	0.64	0	0.45	5.22	632.99	18.98
SD	0.02	0.3	0.2	0	0.12	1.12	179.21	3.4
Min	0.07	0.53	0.23	0	0.27	3.51	358.45	16.55
Max	0.16	1.54	0.98	0	0.67	7.19	948.41	27.78
				Uganda				
N	22	22	22	22	22	22	22	22
Mean	0.12	1.94	1.73	0.07	0.15	10.87	768.45	20.67
SD	0.04	0.42	0.36	0.05	0.09	1.27	136.85	6.25
Min	0.06	1.39	1.24	0	0.07	9.52	519.46	11.9
Max	0.18	2.86	2.58	0.17	0.35	13.54	933.09	29.93
				Total				
N	66	66	66	66	66	65	66	66
Mean	0.18	1.8	1.23	0.02	0.55	7.14	935.34	23.09
SD	0.11	0.73	0.62	0.04	0.4	2.87	376.52	6.53
Min	0.06	0.53	0.23	0	0.07	3.51	358.45	11.9
Max	0.41	3.76	2.58	0.17	1.32	13.54	1747.53	31.87

Source: Authors' computation

4.2 Multicollinearity Test

Following Gujarati (2009), VIF has been used to assess multicollinearity. The rule of thumb is that a mean VIF of 10 or higher raises concerns about multicollinearity. Furthermore, the study has applied the pairwise correlation method described by Gujarati (2002). A rule of thumb is that values above 0.80 in the pairwise correlation matrix indicate serious multicollinearity. Results are shown in Table 3. They provide the correlation matrix of environmental taxes and the control variables.

Total environmental tax was found to be positive and highly correlated with energy tax (0.86), transport tax (0.48), GDP per capita (0.47), and urban share (0.43). The energy tax was positively correlated with energy intensity (0.58) and urbanisation (0.63). Also, the pollution tax was positively correlated with energy intensity (0.61) but negatively correlated with the transport tax (–0.60). The transport tax was highly positively correlated with GDP per capita

(0.77) but negatively correlated with energy intensity (–0.66). Also, GDP per capita was negatively correlated with the energy intensity (–0.41). Urban share was moderately correlated with the energy tax and pollution tax. Mean VIF was 4.32. Thus, multicollinearity was not considered a problem, as the VIFs were well below 10 and the correlations among the main independent variables were below 0.8.

4.3 Non-linear Relationship between Environmental Taxes and CO2 Emissions

In Figure 2, the LOWESS-smoothed graphs show the relationship between CO2 emissions and the four types of environmental taxes. The LOWESS curve was applied to test for a non-linear effect before introducing the threshold term into the model. In the first panel (I), the graph illustrates a non-linear association between the two variables, where total environmental taxes negatively influence CO2 emissions after a threshold is reached. The second panel (II) shows a similar non-linear association, with emissions declining above the threshold. In the third panel (III), which considers transport taxes, the result is mixed; initially, it follows a similar pattern. However, panel (III) generally shows that transport taxes do not affect CO2 emissions, no matter the taxation level. In the fourth panel (IV) on pollution taxes, the trend is steady and similar, with pollution taxes influencing CO2 emissions after a certain threshold. Therefore, the implication of these graphs is that there are non-linear relationships between environmental taxes and CO2 emissions, and that a threshold model is necessary to identify the fiscal threshold or turning point. These findings align with those in OECD countries, where environmental taxes reduce CO2 emissions only after the lower threshold is reached, but they become inefficient after the upper threshold is attained (Al Shammre et al., 2023).

4.4 Environmental Taxes and Carbon Dioxide Emissions

The strategy followed in the preceding section for estimating results was as follows: the study began by employing pooled OLS estimation. Following this, model misspecification was tested based on the Ramsey Reset Test (Ramsey, 1969). However, omitted-variable bias was found in the pooled OLS models. Subsequently, fixed and random effects were estimated, and the choice between them is based on the Hausman Test, which assesses violations of the orthogonality condition underlying RE estimation (Hausman, 1978). After selecting the fixed effects estimation method, the study further followed the deviations from classical assumptions that were remedied through an additional step of estimation based on the fixed effects weighted least squares with Driscoll-Kraay standard errors to address heteroskedasticity, serial correlation, and cross-sectional dependence common to panel data (Driscoll & Kraay, 1998).

To address endogeneity and obtain long-run estimates, the study used the fully modified ordinary least squares estimator developed by Pedroni (2001) as a robustness check. The study presented in Tables 4 to 7 the Ramsey RESET test, which rejected the pooled OLS specification; the Hausman test results, which favoured FE over RE; and post-estimation diagnostics following FE estimation that indicated serial correlation and heteroskedasticity in the residuals. Despite the above, we adopted the weighted FE estimator with Driscoll–Kraay standard errors, which account for cross-sectional dependence, autocorrelation, endogeneity, and heteroscedasticity, in order to robustify the inference before interpreting the coefficient estimates (see column 4).

Based on the results in Table 4, the preferred weighted fixed-effects model indicates that the linear coefficient on total environmental tax revenue is −0.0280 and was statistically significant at the 5% level. This implies that a 1-percentage-point increase in total environmental tax revenue as a % of GDP was associated with a 0.028 metric ton decrease in per capita CO2 emissions, holding GDP per capita, energy intensity, and urbanisation constant. In fully modified ordinary least squares (FMOLS), the linear term on total environmental tax revenue remains negative (−0.0415), and the squared term was positive and statistically significant (0.0060), implying a U-shaped relationship with an emission-minimising turning point around 3.45% of GDP. Substantively, this pattern suggests that increasing total environmental taxes was associated with emissions reductions of up to about 3.5% of GDP in the short and long run, after which marginal mitigation benefits diminish and may even reverse (see Table 4).

Energy and transport taxes exhibit nonlinear category patterns across estimators. For energy taxes, both weighted fixed effects and FMOLS report negative, highly significant linear coefficients (−0.0655 and −0.0696) and positive, significant quadratic coefficients (0.0154 and 0.0145), implying an emissions-minimising turning point between about 2.1% and 2.4% of GDP for the fixed-effects weighted least squares model (short run) and for the FMOLS model (long-run), respectively. These findings are consistent with a mechanism in which energy taxes directly shift relative fuel prices and induce efficiency improvements, but where additional increases beyond a defined threshold yield smaller incremental reductions and potentially offsetting behavioural or structural responses (see Table 5). Transport taxes show a similar U-shape relationship, with turning points around 0.75% of GDP for the fixed-effects weighted least squares model (short-run) and 0.88% of GDP for the FMOLS model (short-run). This implies that transport-related taxation can be effective in reducing carbon dioxide emissions by discouraging fuel use and increasing vehicle-efficiency incentives up to the turning point at about 0.88%, where incremental transport taxes face diminishing marginal returns. At this point, transport taxes shift activity patterns rather than reducing carbon dioxide emissions (see Table 6).

Based on the fixed-effects weighted least squares model results (short-run), the linear coefficient of pollution taxes was positive and significant (0.9187), while the quadratic term was negative and significant (−4.7263), implying an inverted-U relationship with a turning point approximating to 0.097% of GDP. The long-run results from the FMOLS model indicate that the turning point was around 0.024% of GDP. This implies that pollution-tax revenues initially correlate with higher CO2 emissions; however, the square of pollution taxes was associated with lower CO2 emissions. This implies that pollution taxes in Kenya, Rwanda, and Uganda may be particularly sensitive to measurement errors, small tax bases, and low tax levels, hence making them unreliable for reducing CO2 emissions (see Table 6).

The above findings are similar to threshold findings elsewhere. For instance, employing dynamic threshold models for the Organisation for Economic Co-operation and Development, Al Shammre et al. (2023) revealed that particular environmental taxes decrease CO2 emissions after surpassing upper thresholds of approximately 3% and 1.99%, and 0.377% for the total environmental tax, energy tax, and pollution tax, respectively, indicating a weak effect at a low tax intensity level and a strong effect after a regime switch.

Based on the results in Tables 4 to 7, GDP per capita, urbanisation, and energy intensity had a positive, statistically significant effect on CO2 emissions. This implied that, as expected, population, affluence, and technology are key determinants of environmental impact in the three countries as stipulated by the STIRPAT model (Dietz & Rosa, 1997; York et al., 2003). In this logic, income growth was likely to raise production and consumption levels, leading to increased energy demand, while energy intensity represents an economy's efficiency in using energy to produce output; thus, a higher energy intensity indicates a more carbon-intensive growth trajectory. Similarly, the positive association between urbanisation and CO2 emissions is consistent with the view that urban transition, especially in rapidly transforming economies, can elevate CO2 emissions through infrastructure build-out, increased mobility demand, construction activity, and higher commercial and residential energy use. Although urban form can eventually generate efficiency gains via density and public transport, the empirical literature indicates that urbanisation often increases energy consumption and CO2 emissions when planning, technology, and fuel mixes remain carbon-intensive (Liddle, 2014; Poumanyvong & Kaneko, 2010).

Taken together, these patterns imply that environmental taxation operates in a context where growth and structural transformation exert persistent upward pressure on CO2 emissions. Consequently, the substantive policy meaning of the tax–emissions relationship hinges on whether fiscal instruments produce mitigation effects that remain detectable after controlling for these dynamics, an issue repeatedly emphasised in empirical literature of carbon/energy pricing, where the effectiveness of taxation is frequently conditional on complementary structural and technological change (Andersson, 2019; Sterner et al., 1992).

5. Conclusions and Policy Recommendations

The study was based solely on a three-country panel covering Kenya, Rwanda, and Uganda for the period 2001–2022. The main focus of the study was to examine whether environmental taxes reduce carbon emissions, whether their effects differ across tax categories, and whether there are clear thresholds beyond which the marginal effect of environmental taxes starts diminishing. Across the models, total environmental taxes, energy taxes, and transport taxes consistently showed a non-linear relationship with CO2 emissions in which the linear tax term is negative, that is, a higher tax revenue share was associated with lower per-capita CO2, while the squared term is positive, implying that the marginal benefit of these taxes weakens and can reverse if there is increased taxation pressure.

The results of the present study suggest that not all environmental taxes reduce CO2 emissions. Indeed, the pollution tax was found to effectively and significantly reduce CO2 emissions when the level of taxation is high, that is, after squaring them for both the short-run and long-run. Thus, policymakers in the three countries cannot assume that any environmental tax will automatically reduce CO2 emissions; rather, environmental taxation must be carefully calibrated to achieve emission reduction goals, and policymakers should avoid one-size-fits-all approaches. The results also support the conclusion that environmental taxes have a nonlinear relationship with per-capita CO2 emissions in these countries, and their effect depends on the tax category under consideration. This implies that the marginal effect of an increase in environmental taxes diminishes once a certain threshold is reached and may even reverse beyond estimated thresholds. Specifically, for total environmental taxes, the turning point was reported at 3.5% in the short run and 3.45% of GDP in the long run. For energy taxes, the turning points were estimated at around 2.13% in the short run and 2.40% of GDP in the long run. For transport taxes, the turning points are around 0.75% for in the short-run and 0.88% of GDP in the long-run. By contrast, pollution tax results showed an inverted U-shaped relationship with CO2 emissions, with the turning point estimated at 0.1% of GDP in the short run and 0.02% of GDP in the long run, suggesting that current levels of pollution taxes do not significantly reduce CO2 emissions. Given the estimated thresholds, policymakers in Kenya, Uganda, and Rwanda should focus on scaling environmental taxes towards the turning points, as they offer the greatest environmental benefits by reducing CO2 emissions, and should also interpret the thresholds as practical "policy bands," not precise targets. Additionally, policymakers should focus on a specific category of environmental taxes to achieve the dual benefits of increased government revenue and improved environmental quality, as results show that the effects of environmental taxes vary by type.

Despite the key findings presented in this study, it is also worth noting potential limitations. First, the study considered a small number of countries due to limited data on environmental taxes and a small-T of only 22 years. This limited the use of advanced econometric methods, such as dynamic panel-data regression and the Generalised Method of Moments (GMM), to address potential pitfalls of static panel-data models, such as endogeneity and reverse causality. Therefore, future studies should consider using large samples to generalise the empirical findings. Secondly, environmental tax revenues can be influenced by macroeconomic conditions, commodity prices, and policy responses to changing CO2 emissions, so reverse causality and omitted shocks or variables cannot be ruled out.

Funding and Acknowledgments: This study was conducted under the International Growth Centre (IGC) Research Fellowship. The author gratefully acknowledges the IGC for research support and for facilitating the development of this work. The author also acknowledges Dr Sseruyange John and Dr Ssajjabi Vincent for their invaluable guidance during the conceptualisation of the research idea. Further appreciation is extended to Professor François Gerard for his guidance and mentorship throughout the research process.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data used in this study are publicly available from the OECD and the World Bank World Development Indicators. Replication files are available from the corresponding author upon reasonable request.

Conflicts of Interest: The author declares no conflict of interest.

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Appendix

Table 3 Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) env_tax	1.000						
(2) ener_tax	0.855	1.000					
	(0.000)						

(3) pol_tax	0.103	0.441	1.000				
	(0.409)	(0.000)					
(4) tra_tax	0.483	-0.038	-0.597	1.000			
	(0.000)	(0.760)	(0.000)				
(5) gdp_pc	0.467	0.064	-0.139	0.765	1.000		
	(0.000)	(0.609)	(0.267)	(0.000)			
(6) energy_int	0.170	0.582	0.610	-0.663	-0.407	1.000	
	(0.176)	(0.000)	(0.000)	(0.000)	(0.001)		
(7) urb share	0.434	0.630	0.302	-0.218	-0.191	0.301	1.000
	(0.000)	(0.000)	(0.014)	(0.079)	(0.124)	(0.015)	
Mean VIF	4.32						

Source: Authors' computation

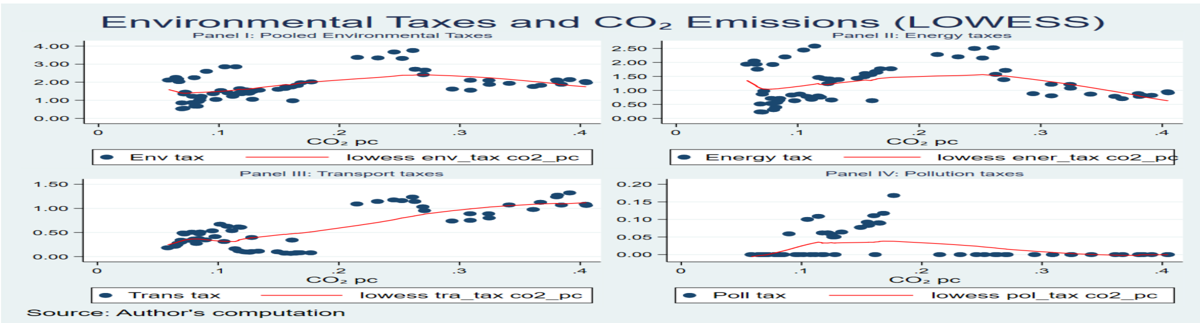

Figure 2 LOWESS Smoothing of Environmental Taxes on CO2 Emissions. Source: Authors' computation

Table 4 Total Environmental Taxes and Carbon Emissions Results

VARIABLES	(1) OLS	(2) FE	(3) RE	(4) FE (WLS)	(5) FMOLS
env_tax	-0.0599**	-0.0280	-0.0599**	-0.0280**	-0.0415***
	(0.0274)	(0.0200)	(0.0274)	(0.0127)	(0.0000)
env_taxsq	0.0117**	0.0035	0.0117**	0.004	0.0060***
	(0.0058)	(0.0044)	(0.0058)	(0.0030)	(0.0000)
gdp_pc	0.0003***	0.0002***	0.0003***	0.0002***	0.0003***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
energy_int	0.0024	0.0178***	0.0024	0.0178***	0.0085***
	(0.0017)	(0.0048)	(0.0017)	(0.0048)	(0.0000)
urb_share	0.0004	0.0029***	0.0004	0.0029***	0.0025***
	(0.0011)	(0.0010)	(0.0011)	(0.0010)	(0.0000)
linear					-0.0016***
					(0.0000)
Turning point				3.5	3.45
Constant	-0.0672***	-0.2035***	-0.0672***	-0.2035**	-0.0675***
	(0.0205)	(0.0659)	(0.0205)	(0.0753)	(0.0000)
Observations	65	65	65	65	64
R-squared	0.9501	0.8399			0.8611

RESET F-statistics	52.30[0.000]				
Number of countries		3	3	3	3
Hausman test		68.96[0.000]			
Heteroskedasticity test		5.980[0.113]			
Serial Correlation test		41.12[0.024]			
CD Test		-1.330[0.184]			
F-stat				100.8[0.000]	
Wald chi2			1123[0.000]		

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. CD refers to cross-sectional dependence. source: Authors' computation

Table 5 Energy Taxes and Carbon Dioxide Emissions Results

	(1)	(2)	(3)	(4)	(5)
VARIABLES	OLS	FE	RE	FE (WLS)	FMOLS
ener_tax	-0.1021***	-0.0655***	-0.1021***	-0.0655***	-0.0696***
	(0.0284)	(0.0232)	(0.0284)	(0.0194)	(0.0000)
ener_tax_sq	0.0291***	0.0154**	0.0291***	0.0154***	0.0145***
	(0.0094)	(0.0073)	(0.0094)	(0.0047)	(0.0000)
gdp_pc	0.0003***	0.0002***	0.0003***	0.0002***	0.0002***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
energy_int	0.0045***	0.0137***	0.0045***	0.0137***	0.0108***
	(0.0017)	(0.0046)	(0.0017)	(0.0042)	(0.0000)
urb_share	0.0013	0.0032***	0.0013	0.0032***	0.0035***
	(0.0011)	(0.0009)	(0.0011)	(0.0008)	(0.0000)
linear					-0.0014***
					(0.0000)
Turning point				2.13	2.40
Constant	-0.0829***	-0.1365**	-0.0829***	-0.1365*	-0.0942***
	(0.0167)	(0.0670)	(0.0167)	(0.0734)	(0.0000)
Observations	65	65	65	65	64
R-squared	0.9573	0.8553			0.8036
RESET F	39.64[0.000]				
Number of countries		3	3	3	3
Hausman test		62.74[0.000]			
Heteroskedasticity test		37.59[0.000]			
Serial Correlation test		42.07[0.023]			
CD test		-0.480[0.629]			
F-stat				67.39[0.000]	
Wald chi2			1323		

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. CD refers to cross-sectional dependence. source: Authors' computation

Table 6 Pollution Taxes and Carbon Emissions Results

VARIABLES	(1) OLS	(2) FE	(3) RE	(4) FE (WLS)	(5) FMOLS
pol_tax	-0.6121**	0.9187***	-0.6121**	0.9187***	0.0472***
	(0.2594)	(0.2631)	(0.2594)	(0.2821)	(0.0127)
pol_tax_sq	2.6950	-4.7263***	2.6950	-4.7263**	-1.0053***
	(1.9198)	(1.6401)	(1.9198)	(1.7203)	(0.0852)
gdp_pc	0.0002***	0.0003***	0.0002***	0.0003***	0.0002***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
energy_int	0.0033*	0.0299***	0.0033*	0.0299***	0.0050***
	(0.0018)	(0.0046)	(0.0018)	(0.0048)	(0.0001)
urb_share	0.0027**	0.0033***	0.0027**	0.0033***	0.0023***
	(0.0013)	(0.0009)	(0.0013)	(0.0009)	(0.0001)
linear					-0.0017***
					(0.0000)
Turning point				0.097	0.024
Constant	-0.1293***	-0.3779***	-0.1293***	-0.3779***	-0.0636***
	(0.0236)	(0.0553)	(0.0236)	(0.0595)	(0.0011)
Observations	65	65	65	65	64
R-squared	0.9520	0.8561			0.7019
RESET F	63.03[0.000]				
Number of countries		3	3	3	3
Hausman test		25.48[0.000]			
Heteroskedasticity test		1.980[0.576]			
Serial Correlation test		390.7[0.003]			
CD test		-0.610[0.540]			
F-stat				189.5[0.000]	
Wald chi2			1170		

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. CD refers to cross-sectional dependence. source: Authors' computation

Table 7 Transport Taxes and Carbon Emissions Results

	(1)	(2)	(3)	(4)	(5)
VARIABLES	OLS	FE	RE	FE (WLS)	FMOLS
tra_tax	0.0685	-0.1173**	0.0685	-0.1173***	-0.0751***
	(0.0474)	(0.0473)	(0.0474)	(0.0275)	(0.0015)
tra_tax_sq	0.0069	0.0665**	0.0069	0.0665**	0.0504***
	(0.0320)	(0.0261)	(0.0320)	(0.0239)	(0.0009)
gdp_pc	0.0002***	0.0003***	0.0002***	0.0003***	0.0002***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
energy_int	0.0046**	0.0212***	0.0046**	0.0212***	0.0035***
	(0.0020)	(0.0041)	(0.0020)	(0.0036)	(0.0001)
urb_share	0.0045***	0.0029**	0.0045***	0.0029*	0.0027***
	(0.0013)	(0.0011)	(0.0013)	(0.0016)	(0.0000)
linear					-0.0015***
					(0.0000)
Turning point				0.88	0.75
Constant	-0.1520***	-0.2480***	-0.1520***	-0.2480***	-0.0428***
	(0.0334)	(0.0550)	(0.0334)	(0.0526)	(0.0011)
Observations	65	65	65	65	64
R-squared	0.9575	0.8425			0.8291
RESET F	34.48[0.000]				
Number of countries	3	3	3	3	3
Hausman test		45.09[0.000]			
Heteroskedasticity test		3.790[0.285]			
Serial Correlation test		61.01[0.016]			
CD test		-1.810[0.071]			
F-stat				143.5[0.000]	
Wald chi2			1328		

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. CD refers to cross-sectional dependence. source: Authors' computation

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