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Do environmental taxes and renewable energy consumption play a role in climate change mitigation? International evidence from developing economies

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ABSTRACT

Climate change and environmental degradation are largely attributed to increased carbon dioxide emissions (CO₂). This study investigates the effectiveness of environmental taxes and renewable energy consumption on reducing CO₂ emissions in 36 developing countries from 1994 to 2018, using the Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) panel data methodology. Our findings indicate that renewable energy consumption plays a crucial role in lowering CO₂ emissions, underscoring the need for increased investment in renewable energy infrastructure and technological advancements. Conversely, environmental taxes do not have a significant impact on emissions reduction in these countries, possibly due to inadequate implementation and institutional constraints. These findings suggest that policies promoting renewable energy, such as subsidies, incentives, and investments in research and development, are crucial for achieving meaningful emission reductions. Therefore, international efforts may be more effective by providing financial support and technological assistance rather than emphasizing environmental taxes, which may not be suitable for developing nations.

Introduction

One of the most pressing issues of the twenty-first century is the rapid shift in climate patterns. While its severe consequences can still be mitigated, it requires concerted efforts to reduce greenhouse gas emissions and combat environmental pollution. Policymakers, academics, and researchers are increasingly focused on the challenges posed by climate change, environmental degradation, and global warming. The primary causes of these problems are energy-related, primarily due to the reliance on fossil fuels such as coal, oil, and petroleum, which contribute significantly to greenhouse gas (GHG) emissions. In response to these concerns, various policy measures have been implemented, including regulatory directives, economic incentives, and taxes aimed at curbing environmental harm and reducing carbon emissions (Shahzad, 2020). Many countries made new commitments during the UN climate conference in Glasgow (2021) known as COP26 to address climate change, environmental pollution and greenhouse gas emission (Dogan et al., 2022). However, the pressing question is how these countries are set to achieve environmental pollution reaction goals and targets.

International agreements, such as the Paris Climate Agreement, highlight the importance of enforcing environmental regulations and promoting green technologies to tackle greenhouse gas emissions. These efforts include a range of strategies, such as regulatory controls, environmental taxation, carbon pricing mechanisms, and the development of energy-efficient technologies (Rafique et al., 2022). Environmental taxes are widely recognized as powerful tools to decrease pollution from energy use, effectively lowering the ecological footprint while ensuring both environmental sustainability and economic efficiency. These tax policies are part of broader efforts to combat climate change, targeting the reduction of air pollutants, water contamination, and waste disposal, among other environmental challenges. Scholars proved that there is an interdependence between the entire environmental tax system and socioeconomic development factors and energy consumption, which should be addressed to mitigate the impact of global climate change (Bashir et al., 2022). Several countries have undertaken certain climate change and environmental pollution mitigation measures designed to address the interaction between the environment and the economy. A primary approach is the adoption of environmental taxes by which

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revenues from these taxes are allocated to the promotion of a sustainable economy based on nature conservation and greener production (Miceikiene et al., 2018). Historically, policymakers have leaned towards using command and control instruments rather than environmental taxes to regulate polluting activities (Baumol and Oates, 1988; Bluffstone, 2003). However, with the escalating issues of climate change and environmental degradation, there is a pressing need to reconsider policy approaches. This includes addressing challenges in financing and creating new regulations, especially in regions severely affected by climate change. Recognizing the severity of these issues, governments worldwide are now seeking and developing more effective means of controlling and limiting pollution. This shift towards more proactive environmental policies reflects a growing awareness of the critical need to address these global challenges.

The growing concern over environmental pollution and its effects on social and economic life has underscored the need for more independent research. In this paper, we aim to assess two key tools for climate change mitigation—environmental taxes and renewable energy consumption—and their effectiveness in developing countries. While these policies have been widely implemented in developed nations, their impact and applicability in developing countries remain less clear. Developing countries often face challenges, including limited financial resources, technological constraints, and pressing socio-economic priorities such as poverty alleviation and infrastructure development. These factors can significantly hinder the successful implementation of climate policies that have proven effective in more advanced economies.

The remainder of this paper is organized as follows: Section 1 starts by exploring the central theoretical and empirical research on the impact of CO₂ emissions on climate change, highlighting the relationship between environmental degradation and greenhouse gas emissions. It then examines the interaction between environmental taxes and renewable energy consumption, emphasizing their effect on climate change. Section 2, details the econometric approaches utilized in this research and provides an overview of the data used. Section 3, presents the outcomes of the study, comparing the effectiveness of environmental taxes and highlighting the contribution of renewable energy consumption in addressing climate change in developing nations. Section 4, discusses the findings and implications of the study.

1. Literature review

The world has been subject to global warming patterns caused by anthropogenic emissions of greenhouse gases, particularly CO₂ from fossil fuel combustion as well as from non-CO₂ greenhouse gases such as Methane (CH₄), Nitrous Oxide (N₂O) and Ozone-Depleting substances (ODS) all of which significantly contribute to climate change (Montzka et al., 2011). At present, although the main focus of climate policy has been to reduce fossil fuel consumption, a large cut in CO₂ emissions alone will not abate climate change (Ripple et al., 2014) unless attention is shifted to focus on the source of methane (CH₄) emissions emanating from ruminants, the fossil fuel industry, landfills, biomass burning and rice production.

Developing nations have increasingly become major sources of carbon emissions and are facing severe depletion of their natural resources. Approximately 80 % of biodiversity loss in these regions can be attributed to the energy and agriculture sectors. Major contributors include deforestation, inefficient agricultural methods, and widespread environmental contamination, which together accelerate ecological degradation and threaten biodiversity (Zhang et al., 2022). Additionally, environmental pollution and degradation result from issues related to fossil fuel combustion for power generation and transportation, soil degradation, and air, soil, and water pollution (Cottrell and Falcão, 2018).

All these issues indicate that climate change is a potential crisis that will hit developed and developing countries. However, developed countries are responsible for much higher emissions in absolute and per-

capita terms, but any approach to reduce the concentration of greenhouse emissions requires the participation of both developed and developing countries (Cantore and Padilla, 2010). If CO₂ emission growth continues unchecked in countries, the international objectives for controlling climate change will fail (Heine and Black, 2019). To avoid the release of polluting substances, efforts designed to curb climate change are underway, but no size fits all approach can fix the climate dilemma nor is there a reliable technology that could sequester CO₂ from fossil-fuel combustion emissions (Bellido-Arregui, 2003).

Chandio et al. (2024) point out that emission scenarios, such as those developed by the Intergovernmental Panel on Climate Change (IPCC), are based on forecasts of population growth, economic expansion, energy consumption, carbon intensity of energy, and transportation-related CO₂ emissions (Davis et al., 2010). The environmental impact grows as CO₂ emissions, a key byproduct of economic activities, are recognized as a major pollutant. However, as economies develop, stricter regulations on industrial pollution are implemented, and the demand for higher environmental quality rises alongside increasing income levels (Acharyya, 2009). The association between GDP and CO₂ emission has shown a strong positive linear correlation. This indicates as GDP increases; CO₂ emissions also increase proportionally. This CO₂ emission is a product of emission increase in electricity production, manufacturing and mining sectors. Farhani and Ben Rejeb (2012) discovered a short-term causal relationship between, economic growth, CO₂ emissions and energy consumption, indicating that higher energy consumption can contribute to both income growth and increased CO₂ emissions (Shikwambana et al., 2021). When assessing the effects of GDP growth, energy consumption, and population growth on CO₂ emissions, the results indicate that per capita energy consumption and per capita GDP contribute to an increase in carbon emissions. However, population growth does not appear to have a notable effect on per capita CO₂ emissions (Begum et al., 2015). Cederborg and Snöbohm (2016) confirm the relationship between GDP per capita and per-capita CO₂ emissions, yet no tuning point is found at which emission starts to decrease when reaching a high enough GDP. Indeed, market economy mechanisms are not enough to lower the missions and therefore, legal regulations are needed to mitigate environmental degradation. Research on the relationship between economic growth, renewable energy consumption, and CO₂ emissions, incorporating human capital, has produced insightful findings. Mahmood et al. (2019) suggest that the interaction between renewable energy consumption and income levels influences CO₂ emissions. Their study also found that while trade openness tends to increase emissions, human capital plays a mitigating role in reducing them. In this context, the connection between renewable energy use, GDP, and CO₂ emissions is frequently analyzed to assess progress toward sustainable development and to address environmental challenges (Lu, 2017; Koçak and Şarkgüneşi, 2017).

Sadiq et al. (2023), employing a panel cross-sectional augmented ARDL approach demonstrates that both renewable energy consumption and effective control of corruption play significant roles in reducing emissions over the long term. However, the presence of policy uncertainty poses a challenge to achieving environmental sustainability. Li et al. (2023) highlight a negative correlation between renewable energy usage and per capita carbon emissions, implying that expanding renewable energy use helps reduce environmental pressures. As the consumption of renewable energy grows, its beneficial impact on reducing carbon emissions becomes increasingly evident, suggesting that further development of renewable energy sources is essential for mitigating environmental harm. Conversely, the relationship between renewable energy and CO₂ emissions is widely studied, but challenges remain in understanding the full impact of energy use on emissions. Some studies have found a unidirectional link between energy consumption and CO₂ emissions, others suggest a bidirectional relationship, while some reveal no clear causality at all (Abban et al., 2022).

Since the 1980s, the use of renewable energy has become a key factor in promoting environmental sustainability, with its adoption growing

steadily in both emerging and developed economies (Wei et al., 2023). In fact, due to technology, renewable energy has become possible and led to contributing to the financial efforts (Zakari et al. 2023; Hashemizadeh et al., 2023). With growing recognition of renewable energy's importance in curbing environmental degradation, numerous countries have launched diverse policy measures to encourage energy efficiency and the use of renewable energy technologies (Sarkar and Singh, 2010). Emphasis has been placed on the introduction of biofuels to enhance renewable energy consumption. Furthermore, various policy measures, including tax credits, have been adopted to encourage greater investment in energy technologies (Bashir et al., 2022).

The major negative effects of climate change and rapid environmental degradation have caught scholars' attention, prompting theoretical and empirical investigations into environmental quality, efficiency, and policy instruments (Onofrei et al., 2017). Consequently, policymakers in several nations are crafting policies to address environmental challenges, with a particular interest in environmental taxation as a strategy to reduce CO₂ emissions (Morley, 2012). Recent literature explores the nexus between environmental taxes and CO₂ emissions, emphasizing their role as central policy instruments for combating environmental degradation (Morley, 2012; Heine and Black, 2019; Ulucak et al., 2020; Wolde-Rufael and Mulat-Weldemeskel, 2021).

Ulucak et al. (2020) used the panel smooth transition regression approach to examine the non-linear effects of environmental taxes on CO₂ emissions. They controlled patents, economic growth, and environmental technologies, and determined the threshold levels endogenously. Their findings suggest that environmental taxes decrease CO₂ emissions at higher levels of globalization. In contrast, Aydin and Esen (2018) describe asymmetrical relationships, identifying thresholds for various environmental taxes, including energy taxes, environmental taxes, and transport taxes. The authors reveal that when these thresholds are exceeded, the effect of environmental taxes on CO₂ emissions changes from insignificantly positive to significantly negative. They suggest that environmental taxes are levied only when carbon dioxide concentrations surpass a harmful threshold. It is also shown that the concentration of carbon dioxide decreases as the rate of environmental taxes increases (Sundar et al., 2016).

In a different direction, Morley (2012) finds that environmental taxes have a significantly negative effect on pollution. His study reveals that energy-heavy industries have had a limited influence on the success of pollution reduction policies. The results imply that the effectiveness of environmental taxes largely depends on how they integrate within the broader tax system, with the greatest impact seen when these taxes constitute a significant proportion of total tax revenues. Environmental taxes are theoretically considered particularly effective when targeting specific areas of concern, such as energy consumption in industries including road transport, aviation, and waste management (Fullerton et al., 2008).

As effective as it looks, environmental taxes are seen as a wide policy tool in countries toolbox that reduce pollution, achieve sustainability development goals, and reverse climate change. By including production factor costs in the market process, environmental taxes help to internalize environmental damage (Bozatli and Akca, 2023). Environmental taxes have been used to influence behavior since the taxes generate revenue that is used to promote environmental protection (Piciu and Trică, 2012). When carefully designed, specific taxes can both mitigate environmental damage and generate revenue. This revenue can then be allocated to reducing other types of taxes and establishing a trust fund dedicated to environmental initiatives (Fullerton, 1996). Wolde-Rufael, and Mulat-Weldemeskel, (2022) demonstrate that environmental taxes play a dual role in reducing CO₂ emissions and boosting renewable energy adoption. The findings support the idea that environmental taxes, along with renewable energy, are effective measures for improving environmental quality. Therefore, fostering sustainability can be achieved by increasing environmental taxes, expanding

investment in renewable energy, and decreasing the use of non-renewable energy sources.

However, while economic theory often champions carbon pricing for its cost-efficiency in reducing emissions political and economic realities undermine its practicality. Finon (2019) highlights that carbon taxes face significant political economy constraints in emerging economies, such as heightened social inequality and the need to protect energy-intensive industries from international competition. The regressive nature of such taxes, disproportionately affecting lower-income groups, further exacerbates resistance (Jenkins, 2014; Baumgärtner et al., 2017). Additionally, the limited institutional capacity in many developing nations complicates the implementation and monitoring of pricing mechanisms Finon (2019). Instead, non-pricing instruments, such as regulatory measures, efficiency standards, and subsidies for low-carbon technologies, are argued to be more suitable (Tvinneim and Mehling, 2018).

2. Data and methodology

This section presents a quantitative study that investigates the effects of environmental taxes on CO₂ emissions and examines the role of renewable energy consumption in reducing CO₂ emissions as part of strategies for climate change mitigation. This study is set to study 36 countries. Argentina, Bolivia, Brazil, Bulgaria, Chile, Colombia, Cote d'Ivoire, Cyprus, Czechia, Dominican Republic, Ecuador, Greece, Guatemala, Honduras, Hungary, Jamaica, Latvia, Lithuania, Malaysia, Malta, Mexico, Nicaragua, Panama, Paraguay, Peru, Philippines, Poland, Romania, Slovak Republic, Slovenia, South Africa, Türkiye, Uruguay, Cameroun. Data was extracted from the Organization for Economic Cooperation and Development (OECD) database (OECD, 2020). The study is limited to 36 countries due to data availability. Additionally, data for some measures are only available for the period between 1994 and 2018. The study employs a CS-ARDL panel data approach. The adoption of the CS-ARDL framework has several advantages compared to traditional regression methods, especially in managing slope heterogeneity, cross-sectional dependence, and endogeneity (Chudik et al., 2017). The CS-ARDL approach mitigates the impact of unobserved common factors by using the panel ARDL model based on the Pesaran (2006) technique, which treats the lagged dependent variable as a weakly exogenous variable. This method replaces the unobserved factors with cross-section averages of the observed variables and their lags, effectively accounting for cross-sectional dependence under the assumptions of parameter endogeneity and slope heterogeneity. Additionally, it can generate robust estimates, regardless of the integration order of the variables, and addresses sample selection bias.

Our four models, aiming to study the effectiveness of environmental taxes and renewable energy, are as follows:

Model 1

$$LCO2k_{it} = \beta_0 + \beta_1 LTAXTR_{it} + \beta_2 LRENW_{it} + \beta_3 LENER_{it} + \beta_4 LGDPC_{it} + \beta_5 POP_{it} + \varepsilon_{it} \quad (1)$$

Model 2

$$LCO2k_{it} = \beta_0 + \beta_1 LTAXGDP_{it} + \beta_2 LRENW_{it} + \beta_3 LENER_{it} + \beta_4 LGDPC_{it} + \beta_5 POP_{it} + \varepsilon_{it} \quad (2)$$

Model 3

$$LCO2perc_{it} = \beta_0 + \beta_1 LTAXTR_{it} + \beta_2 LRENW_{it} + \beta_3 LENER_{it} + \beta_4 LGDPC_{it} + \beta_5 POP_{it} + \varepsilon_{it} \quad (3)$$

Model 4

$$LCO2perc_{it} = \beta_0 + \beta_1 LTAXGDP_{it} + \beta_2 LRENW_{it} + \beta_3 LENER_{it} + \beta_4 LGDPC_{it} + \beta_5 POP_{it} + \varepsilon_{it} \quad (4)$$

These models have been meticulously developed to assess the interactions between environmental taxes, renewable energy, and their resulting impact on CO₂ emissions over a period of 25 years. Among these variables, LCO2kt represents the natural logarithm of CO₂ emissions (kt), while LCO2perc represents the natural logarithm of CO₂ emissions per capita, providing an alternative measure for robustness. LRENW – Log Renewable Energy Consumption (% of Total Final Energy Consumption). This indicator, serves as a proxy for renewable energy-based policies. Higher values indicate a greater reliance on renewable energy sources relative to total final energy consumption, reflecting the effectiveness and implementation of such policies. LENRG – Log Energy Consumption, Fossil Fuel: Energy use (Kg of oil equivalent per capita) represents the energy consumption that is sourced from fossil fuels. This is an important metric to monitor as fossil fuel consumption is directly related to greenhouse gas emissions. LTAXTR – Log Share of Environmental Taxes in Total Tax Revenues: This refers to the total environmental tax revenues generated. Such taxes can be levied on activities or products that harm the environment, like carbon emissions, to reduce harmful activities and generate revenue for environmental initiatives. A robustness measure was also considered: LTAXGDP – Log Share of Environmental Taxes in GDP: This is the ratio of environmental tax revenues to the country's Gross Domestic Product (GDP). It provides insight into how significant environmental tax policies are in the overall economy. LGDPC – Log GDP per Capita: This is the natural logarithm of GDP per capita. It measures the average economic output per person if a nation's total economic production is evenly divided among its citizens. Taking the logarithm can help in analyzing the relative economic growth and development of regions or countries. LPOP – Log Population which the natural logarithm of the population is created. This transformation can be useful when comparing growth rates across countries with vastly different population sizes.

3. Results and analysis

3.1. Stationarity and CS-ARDL

While panel data offers numerous advantages, a significant concern identified in recent studies is Cross-Sectional Dependence in the residuals. This issue arises due to the interconnected nature of global economies (De Hoyos and Sarafidis, 2006). Consequently, residuals in panel data are often correlated across cross-sectional units, driven by omitted common factors, shared shocks, spatial influences, externalities, and unobserved components (Pesaran, 2006). To address this, the Pesaran CD test is included (Pesaran, 2004, 2006).

Given the time series nature of our panel data, it is essential to verify the stationarity of the variables. Recent advancements in panel unit root testing have introduced innovative methods to enhance the accuracy and reliability of the results. First-generation unit root tests, like those by Levin et al. (2002) and Im et al. (2003), do not account for cross-sectional dependence (CSD), which can result in inaccurate conclusions. In contrast, second-generation unit root tests consider CSD, providing more reliable results for determining the integration order of panel data variables (Pesaran, 2007). To evaluate cross-sectional dependence (CD) in the series, Cross-sectional Augmented Dickey-Fuller (CADF) panel unit root test is used. This test estimates the following regression:

$$\Delta y_{it} = \alpha_i + \beta_1 y_{it-1} + \lambda_i \bar{y}_{t-1} + \Phi_i \Delta \bar{y}_{it} + \varepsilon_{it} \quad (5)$$

where \bar{y}_{t-1} represents the lagged variable cross-sectional average, and $\Delta \bar{y}_{it}$ denotes the first difference cross-sectional average of the variable. We apply the CIPS test introduced by Pesaran (2007). This test involves calculating the cross-sectional average of t-ratios as follows:

$$CIPS = \frac{1}{N} \sum_{i=1}^N t_i(N, T) \quad (6)$$

In this equation $t_i(N, T)$, represents the Cross-sectional ADF (CADF).

Our baseline model, a panel CS-ARDL (cross-sectionally augmented auto regressive distributed lag) is specified as follows:

$$y_{it} = \alpha_i + \sum_{k=1}^p \beta_k y_{it-k} + \sum_{j=0}^q \theta_j x_{it-j} + \sum_{l=0}^{pr} \gamma_l \bar{y}_{t-l} + \sum_{m=0}^{qr} \delta_m \bar{x}_{t-m} + \varepsilon_{it} \quad (7)$$

y_{it} is the dependent variable for entity i at time t . α_i is the entity-specific intercept. y_{it-k} represents the lagged values of the dependent variable. x_{it-j} represents the lagged values of the independent variables. \bar{y}_{t-l} is the cross-sectional average of the dependent variable across all entities at time $t-l$. \bar{x}_{t-m} is the cross-sectional average of the independent variable (s) across all entities at time $t-m$. β_k , θ_j and δ_m are the coefficients to be estimated. ε_{it} is the error term.

In order to investigate both the long- and short-run relationship between the variables in the different models, we represent the CS-ARDL baseline model in its error correction model form (ECM) as follows:

$$\begin{aligned} \Delta y_{it} = & \alpha_i + \Phi_i (y_{it-1} - \beta_0 - \sum_{j=0}^q \theta_j x_{it-j}) + \sum_{k=1}^{p-1} \lambda_k y_{it-k} + \\ & \sum_{j=0}^{q-1} \delta_j \Delta x_{it-j} + \sum_{l=0}^{pr} \gamma_l \bar{y}_{t-l} \\ & + \sum_{m=0}^{qr} \delta_m \bar{x}_{t-m} + \varepsilon_{it} \end{aligned} \quad (8)$$

where Δy_{it} represents the change in the dependent variable (LCO2kt or LCO2perc). Φ_i is the speed of adjustment coefficient, indicating how quickly deviations from the long-run equilibrium are corrected. The expression $(y_{it-1} - \beta_0 - \sum_{j=0}^q \theta_j x_{it-j})$ captures the long-run relationship, where x_{it} (LTAXGDP or LTAXR, LRENW, LENER, LGDP, LPOP) is a vector of independent variables. The coefficients λ_k , δ_j , γ_l and δ_m represent the short-term coefficients of the dependent and independent variables. Additionally, \bar{y}_{t-l} and \bar{x}_{t-m} denote the changes in the cross-sectional means of the independent and dependent variables, respectively.

Table 1 presents the summary statistics for various environmental, economic, and demographic variables across 900 observations. The average log CO₂ per capita (LCO2perc) is 1.021, with a standard deviation of 0.950, signifying a moderate spread around the mean, and it ranges from −1.497 to 2.509. The average log CO₂ emissions in kilotonnes (LCO2kt) is 10.333, with a standard deviation of 1.474, indicating a considerable spread, and it ranges from 7.664 to 13.145. The data on log energy consumption (LENRG) reveals an average of 7.185, with a relatively smaller spread as indicated by a standard deviation of 0.692, and it ranges from 5.794 to 8.410. The log GDP per capita (LGDPC) showcases a mean of 9.217 and a standard deviation of 0.699, suggesting consistent economic conditions among the observations, with values ranging from 7.457 to 10.458. The log population (LPOP) has a mean of 16.085, indicating a wide range of population sizes in the dataset, from smaller regions to highly populous ones, and it ranges from 11.130 to 19.131. Total environmental tax revenues (LTAXTR) have a

Table 1
Summary statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
LCO2perc	900	1.021032	0.9503151	−1.496663	2.508515
LCO2kt	900	10.33343	1.473513	7.663877	13.14534
LENRG	900	7.184896	0.6920702	5.794064	8.409945
LGDPC	900	9.216952	0.6986828	7.456977	10.45824
LPOP	900	16.08475	1.546924	11.12951	19.13098
LTAXTR	900	1.853803	0.6843566	−0.8915981	3.04785
LTAXGDP	900	0.3173699	0.8649809	−3.218876	1.667707
LRENW	900	2.814564	1.151682	−2.407946	4.457945

mean of 1.854, but interestingly, the minimum value is negative (−0.892), suggesting possible rebates or negative taxes in some regions or periods, and it ranges up to 3.048. Environmental taxes as a share of GDP (LTAXGDP) average around 0.317, but again we observe negative values, possibly indicating areas or times when environmental credits exceeded taxes, and it ranges from −3.219 to 1.668. The log renewable energy consumption (LRENW) has a mean of 2.815, with a large standard deviation of 1.152, indicating significant variability, and it ranges from −2.408 to 4.458.

Table 2 presents the results of the cross-sectional dependence (CSD) tests, highlighting significant CSD across most variables. The CD-test statistics and corresponding p-values indicate highly significant cross-sectional dependence at the 1 % level for multiple variables, with one variable showing significant dependence at the 10 % level. These results confirm that common factors or interactions exist across different cross-sections of the data, necessitating control for CSD in subsequent analyses to avoid biased results. This finding is consistent with the literature on macro panel data analysis, which emphasizes the importance of accounting for CSD to produce reliable and accurate inferences (Baltagi and Hashem Pesaran, 2007; Pesaran, 2007; Sarafidis et al., 2009; Pesaran, 2015; Pesaran, 2021).

Besides addressing the cross-section dependence problem, this study further employs the heterogeneity diagnostic to assess the impact of cross-sectional heterogeneity on the coefficient slope. Table 3 explores the findings of the slope heterogeneity test. The probability values for both adjusted Delta statistics in all models are less than 1 %, indicating strong significance. Consequently, the null hypothesis (H0) of homogeneous slope coefficients is rejected. This rejection confirms that the panel empirical findings could be misleading if the homogeneity assumption is maintained for the candidate series. Methodologically, the results from table 3 indicate that there are issues of cross-sectional dependence and slope heterogeneity in the panel data. This recognition is crucial for applying more appropriate tests for stationarity, cointegration, and long-run estimations.

The next step in panel data evaluation is to test the stationarity of the variables. We performed 1st generation and 2nd generation unit root tests. Table 4 presents the results of the stationarity tests for various variables using the Cross-sectional Augmented Dickey-Fuller (CADF) and Cross-sectional Im, Pesaran, and Shin (CIPS) methods, both at the level and first-difference forms. The results indicate that at the level I (0), most variables exhibit non-stationary behavior. Specifically, variables such as LCO2perc, LCO2kt, LENRG, LPOP, and LGDPC have test statistics at the level that do not meet the significance threshold. However, the tax variables (LTAXTR and LTAXGDP) show significant results even at the level. Upon taking the first differences I (1), the test statistics become highly significant, demonstrating that the variables become stationary. For instance, the CADF and CIPS statistics for LCO2perc improve significantly at the first difference, both becoming significant at the 1 % level. Similarly, LRENW, which was insignificant at the level, shows a substantial shift to strong significance at the first difference, confirming its stationarity. The same pattern is observed for other variables, with all first-difference statistics indicating strong significance.

Table 2
Cross-sectional dependence test results.

Variable	CD-test	p-value
LCO2perc	8.107***	0.000
LCO2kt	18.868***	0.000
LRENW	1.86 *	0.063
LENRG	16.39***	0.000
LPOP	41.073***	0.000
LGDPC	108.703***	0.000
LTAXTR	8.635***	0.000
LTAXGDP	4.77***	0.000

Note: ***, ** and * significant value at 1% denote significant value at 5% and 10% respectively.

Table 3
Pesaran and Yamagata (2008) test for slope heterogeneity.

	Model 1	
	Delta	P-value
adj	17.489***	0.000
	21.477***	0.000
	Model 2	
adj	Delta	P-value
	17.795***	0.000
	21.853***	0.000
adj	Model 3	
	Delta	P-value
	17.468***	0.000
adj	21.452***	0.000
	Model 4	
adj	Delta	P-value
	17.489	0.000
	21.477	0.000

H0: slope coefficients are homogenous.

Note: ***, ** and * significant value at 1% denote significant value at 5% and 10% respectively.

Table 4
Unit root tests.

	CADF		CIPS	
	Level	1st-difference	Level	1st-difference
LCO2perc	−1.357	−2.750***	−1.752	−4.234***
LCO2kt	−1.388	−2.787***	−1.823	−4.243***
LRENW	3.615	−8.670***	−2.009	−4.296***
LENRG	−1.598	−2.669***	−1.903	−4.246***
LPOP	−1.919	−2.273***	−1.114	−2.398 ***
LGDPC	−1.906	−2.128***	−1.268	−3.108***
LTAXTR	−2.180***	−3.235***	−2.123**	−4.133***
LTAXGDP	−2.240***	−3.390***	−2.129**	−4.239***

Note: ***, ** and * significant value at 1% denote significant value at 5% and 10% respectively.

This transformation from non-stationarity at the level to stationarity at the first difference suggests that all variables under consideration follow the stationary property after differencing once I (1). Considering these results, it is suggested to use Westerlund cointegration and CS-ARDL approaches.

Table 5 presents the results of the Westerlund cointegration test across the four different models, examining whether long-run relationships exist among the variables. Each model is evaluated using two statistics, Dh-g (Group Panels) and Dh-p (All Panels), both of which show strong significance levels. The Dh-g statistics consistently indicate significance at the 1 % level across all models, suggesting robust evidence of cointegration. Similarly, the Dh-p statistics demonstrate significance at the 5 % level, further confirming the presence of long-run relationships among the variables. These findings highlight the validity of the models in capturing the long-term equilibrium connections, emphasizing the necessity of considering cointegration in the analysis.

Table 6 presents the results of the Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) for our four models, examining both long-run and short-run relationships between various economic and environmental variables in developing countries. In the long run, LGDPC shows a strong positive and significant association with the dependent variables across all models, indicating that GDP per capita is closely linked to increased carbon emissions (Sadiq et al., 2023). This relationship aligns with the Environmental Kuznets Curve (EKC) hypothesis (Kuznet), which posits that in the early stages of economic development, pollution and emissions increase as countries prioritize industrial growth and economic expansion. Developing nations, in their efforts to boost GDP, often depend heavily on fossil fuels and energy-intensive sectors, which contribute to increased carbon emissions. However, as these countries advance economically and reach higher income

Table 5

Westerlund cointegration test results.

	Model 1		Model 2		Model 3		Model 4	
	Statistic	P-value	Statistic	P-value	Statistic	P-value	Statistic	P-value
Dh-g	-2.74***	0.003	-2.76***	0.002	-2.75***	0.003	-2.75***	0.003
Dh-p	-1.66**	0.047	-1.71**	0.042	-1.66**	0.047	-1.70**	0.043

Note: ***, ** and * significant value at 1% denote significant value at 5% and 10% respectively.

Table 6

Results of CS-ARDL.

	Model 1	Model 2	Model 3	Model 4
Long Run				
LGDPG	0.3330022*** (0.1136771)	0.3124354*** (0.1148811)	0.3261673*** (0.1084028)	0.3226878*** (0.1090715)
LPOP	−0.8826885** (0.4770611)	−0.8680146 (0.6817535)	0.0467141 (0.523616)	0.1203759 (0.7587556)
LENRG	0.584096*** (0.0846221)	0.5724075*** (0.0907906)	0.5509529*** (0.0765931)	0.535268*** (0.0825317)
LTAXTR	0.0021161 (0.0053766)		0.0013697 (0.0045337)	
LTAXGDP		0.0081103 (0.0374651)		0.0007307 (0.031662)
LRENW	−0.5952127*** (0.1380187)	−0.5920543*** (0.1344995)	−0.5653142*** (0.1239085)	−0.5807909*** (0.1248459)
Short Run				
ECM	−1.007456*** (0.033081)	−1.018208*** (0.0372845)	−1.008341*** (0.033477)	−1.019528*** (0.0373685)
LGDPG	0.3305724*** (0.1087367)	0.3258716*** (0.1096636)	0.3261673*** (0.1084028)	0.3089666*** (0.1138569)
LPOP	−0.904515* (0.5195772)	−0.8393753 (0.7495573)	0.0467141 (0.523616)	0.0787197 (0.6871967)
LENRG	0.5516988*** (0.0764999)	0.536845*** (0.0825392)	0.5509529*** (0.0765931)	0.5701536*** (0.0906661)
LTAXTR	0.0014535 (0.0045345)		0.0013697 (0.0045337)	
LTAXGDP		0.0010404 (0.0317687)		0.0075677 (0.0371452)
LRENW	−0.5640907*** (0.1239397)	−0.5792875*** (0.1249332)	−0.5653142*** (0.1239085)	−0.5939287*** (0.1345295)
Observations	900	900	900	900
Country	36	36	36	36

Note: ***, ** and * significant value at 1% denote significant value at 5% and 10% respectively.

(.) Represent Standard Error.

thresholds, a stage many have yet to achieve—they are likely to invest in greener technologies and enforce tougher environmental policies, which may ultimately result in lower emissions. The significant positive coefficients for LGDPC suggest that developing countries in the studied period are still in the phase where economic growth drives up carbon emissions. LGDPC maintains its positive and significant relationship with carbon emissions in the short run, mirroring the long-run results. This indicates that economic activities continue to drive up emissions even in the short term.

LPOP, representing population growth, shows mixed results. In Model 1, it has a significant negative relationship with carbon emissions, suggesting that in some contexts, population growth may be associated with lower per capita emissions (Usman et al, 2022; Zakari et al 2023). However, in the other models, LPOP does not show a significant impact. LENRG, or fossil energy consumption, consistently demonstrates a significant positive relationship with carbon emissions in both the long and short run. This finding is expected, as energy consumption is a primary driver of carbon emissions, especially in developing countries that predominantly rely on fossil fuels. The high significance and positive coefficients underscore the crucial role of energy use in influencing emissions as highlighted by (Zhang and Khan, 2024). As developing countries industrialize and urbanize, their energy demands increase, leading to higher carbon emissions unless there is a shift towards cleaner energy sources. The persistent significance of LENRG in both timeframes highlights the need for these countries to adopt energy-efficient technologies and diversify their energy mix to include more renewable sources. The results are in line with Usman et al. (2022). Therefore, these results are expected given the established link between carbon emissions and energy use.

The tax variables, LTAXTR and LTAXGDP, do not exhibit significant long-run effects on carbon emissions, highlighting that tax measures alone may not have a direct long-term impact on emissions reduction in developing countries. These findings are consistent with [Pretis \(2022\)](#)

and support the arguments of [Eskander and Fankhauser \(2020\)](#) that climate policies have struggled to achieve large-scale effectiveness. This insignificance suggests that environmental tax policies in developing and emerging countries between 1994 and 2018 might not have been high enough or are still in the early stages of implementation. [Finon \(2019\)](#) explains that carbon pricing is often ineffective in developing countries due to economic, social, and political constraints. These constraints lead to implicit caps on environmental taxes, weakened by exemptions and free allowances. This results in much lower carbon pricing levels compared to developed economies where these taxes are more effective. Additionally, energy-intensive industries in developing countries, facing international competition, strongly oppose carbon pricing, fearing competitive disadvantages. The tax variables show no significant short-run impact on emissions, further suggesting that tax measures may require additional supportive policies to be effective in developing countries. This reinforces the idea that standalone tax policies might not be sufficient to achieve desired environmental outcomes ([Tvinnereim and Mehling, 2018](#)).

LRENW, representing renewable energy, shows a significant negative relationship with carbon emissions across all models, the results align with those found by (Zhu et al., 2024). This underscores the critical importance of renewable energy-based policies in effectively reducing emissions in developing countries. The consistent negative coefficients for LRENW indicate that increasing the share of renewable energy in the energy mix can significantly mitigate carbon emissions. The significance of LRENW emphasizes the need for policies that promote the adoption and expansion of renewable energy infrastructure. LRENW continues to exhibit a significant negative relationship with carbon emissions in the short run, reinforcing the immediate benefits of renewable energy in reducing emissions.

Overall, the results from the CS-ARDL test across the four models emphasize the limited direct impact of tax measures on emissions and highlight the substantial role of renewable energy in achieving both

immediate and long-term reductions in carbon emissions in developing countries. The findings also indicate that placing excessive emphasis on carbon pricing as a central element of climate policies in developing countries demonstrates an overdependence on theoretical economic models. This perspective is inherently flawed, as it fails to adequately consider real-world conditions. (Finon, 2019).

4. Discussion and policy implications

This study focused on the impact of environmental taxes and renewable energy consumption in reducing CO₂ emissions in developing countries. The findings highlight that the connection between these policy tools and their effects on the environment is not straightforward. Different measures, like environmental taxes and renewable energy consumption, have varied impacts, making it clear that a one-size-fits-all approach does not work. Notably, renewable energy consumption emerges as a robust and consistent factor in reducing CO₂ emissions, suggesting that investments in renewable energy infrastructure and technology are crucial for achieving significant environmental benefits. This suggests that policies encouraging the development and adoption of renewable energy sources are crucial. Such policies might include subsidies for renewable energy projects, incentives for businesses and households to adopt renewable technologies, and investments in research and development to lower the costs and improve the efficiency of renewable energy systems. On the other hand, the study finds that environmental taxes, while theoretically sound as mechanisms to internalize the external costs of pollution, do not uniformly result in significant emissions reductions in developing countries. This lack of significant impact can be attributed to several factors. Firstly, the implementation of these taxes in developing countries may be inadequate, either in terms of the tax rate being too low or the tax base being too narrow. Additionally, there may be institutional and economic constraints that limit the effectiveness of these taxes, such as tax evasion, administrative inefficiencies, or exemptions granted to certain industries. Other challenges may include economic constraints, where high tax rates could impact low-income populations, and political challenges, where there may be resistance from powerful industrial sectors. Therefore, while environmental taxes are a potentially powerful tool in developed countries, their design and implementation in developing countries require careful consideration to balance economic growth, social equity, and environmental sustainability. Furthermore, there is often pressure from international institutions for developing countries to implement environmental taxes as part of global climate change mitigation efforts. However, this pressure may overlook the economic and social challenges faced by these nations. Instead of emphasizing the adoption of environmental taxes, it may be more beneficial for international institutions to provide increased financial support and technological assistance. More financial aid could help developing countries invest in renewable energy projects and infrastructure without placing additional economic burdens on their populations.

While this study makes significant contributions, it has several limitations. It focuses solely on CO₂ emissions, neglecting other significant environmental pollutants such as methane (CH₄), nitrogen oxides (NO_x), sulfur oxides (SO_x), and volatile organic compounds (VOCs). Furthermore, while it evaluates the role of environmental taxes, it does not differentiate between various types of these taxes (e.g., carbon taxes, energy taxes, transportation taxes), which can have varied impacts depending on their design, implementation, and enforcement.

Future research could explore a broader range of environmental metrics, differentiate between various types of environmental taxes, and compare their impacts across regions. It could also examine the role of fiscal policy, particularly in deploying subsidies for renewable energy consumption and prioritizing public investment in research and development to counter climate change. Such state-led interventions can stimulate demand, increase innovation, and create green jobs.

Emphasizing proactive government action is essential to address market failures and guide the economy toward a low-carbon future.

CRedit authorship contribution statement

Ayoub Rabhi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ismail Soujaa:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Formal analysis, Data curation, Conceptualization. **Brandon Parsons:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Abban, O. J., Hongxing, Y., Nuta, A. C., Dankyi, A. B., Ofori, C., & Cobbinah, J. (2022). Renewable energy, economic growth, and CO₂ emissions contained Co-movement in African oil-producing countries: A wavelet-based analysis. *Energy Strategy Reviews*, 44, Article 100977.
- Acharyya, J. (2009). FDI, growth and the environment: Evidence from India on CO₂ emission during the last two decades. *Journal of Economic Development*, 34(1), 43.
- Aydin, C., & Esen, Ö. (2018). Reducing CO₂ emissions in the EU member states: Do environmental taxes work? *Journal of Environmental Planning and Management*, 61 (13), 2396–2420.
- Baltagi, B. H., & Hashem Pesaran, M. (2007). Heterogeneity and cross section dependence in panel data models: Theory and applications introduction. *Journal of Applied Econometrics*, 22(2), 229–232.
- Bashir, M. F., Ma, B., Bashir, M. A., Radulescu, M., & Shahzad, U. (2022). Investigating the role of environmental taxes and regulations for renewable energy consumption: Evidence from developed economies. *Economic Research-Ekonomska Istraživanja*, 35 (1), 1262–1284.
- Baumgärtner, S., Drupp, M. A., Meja, J. N., Munz, J. M., & Quaas, M. F. (2017). Income inequality and willingness to pay for environmental public goods. *Journal of Environmental Economics and Management*, 85, 35–61.
- Baumol, W. J., & Oates, W. E. (1988). *The theory of environmental policy*. Cambridge University Press.
- Begum, R. A., Sohag, K., Abdullah, S. M. S., & Jaafar, M. (2015). CO₂ emissions, energy consumption, economic and population growth in Malaysia. *Renewable and Sustainable Energy Reviews*, 41, 594–601.
- Bellido-Arregui, M. (2003). *Environmental taxes and global warming*.
- Bluffstone, R. A. (2003). Environmental taxes in developing and transition economies. *Public Finance and Management*, 3(1), 143–175.
- Bozatli, O., & Akca, H. (2023). The effects of environmental taxes, renewable energy consumption and environmental technology on the ecological footprint: Evidence from advanced panel data analysis. *Journal of Environmental Management*, 345, Article 118857.
- Cantore, N., & Padilla, E. (2010). Equality and CO₂ emissions distribution in climate change integrated assessment modelling. *Energy*, 35(1), 298–313.
- Cederborg, J., & Snöbom, S. (2016). Is there a relationship between economic growth and carbon dioxide emissions? *Semantic Scholar*.
- Chandio, A. A., Gokmenoglu, K. K., Dash, D. P., Khan, I., Ahmad, F., & Jiang, Y. (2024). Exploring the energy-climate-agriculture (ECA) nexus: A roadmap toward agricultural sustainability in Asian countries. *Environment, Development and Sustainability*, 1–27.
- Chudik, A., Mohaddes, K., Pesaran, M. H., & Raissi, M. (2017). Is there a debt-threshold effect on output growth? *Review of Economics and Statistics*, 99(1), 135–150.
- Cottrell, J., & Falcão, T. (2018). A climate of fairness: environmental taxation and tax justice in developing countries.
- Davis, S. J., Caldeira, K., & Matthews, H. D. (2010). Future CO₂ emissions and climate change from existing energy infrastructure. *Science*, 329(5997), 1330–1333.
- De Hoyos, R. E., & Sarafidis, V. (2006). Testing for cross-sectional dependence in panel data models. *The Stata Journal*, 6(4), 482–496.
- Dogan, E., Hodžić, S., & Fatur Šikić, T. (2022). A way forward in reducing carbon emissions in environmentally friendly countries: The role of green growth and environmental taxes. *Economic research-Ekonomska istraživanja*, 35(1), 5879–5894.
- Eskander, S. M., & Fankhauser, S. (2020). Reduction in greenhouse gas emissions from national climate legislation. *Nature Climate Change*, 10(8), 750–756.
- Farhani, S., & Ben Rejeb, J. (2012). Energy consumption, economic growth and CO₂ emissions: Evidence from panel data for MENA region. *International Journal of Energy Economics and Policy*, 2(2), 71–81.

- Finon, D. (2019). Carbon policy in developing countries: Giving priority to non-price instruments. *Energy Policy*, 132, 38–43.
- Fullerton, D. (1996). Why have separate environmental taxes? *Tax Policy and the Economy*, 10, 33–70.
- Fullerton, D., Leicester, A., & Smith, S. (2008). Environmental taxes (No. w14197). National Bureau of Economic Research.
- Hashemizadeh, A., Ashraf, R. U., Khan, I., & Zaidi, S. A. H. (2023). Digital financial inclusion, environmental quality, and economic development: The contributions of financial development and investments in OECD countries. *Environmental Science and Pollution Research*, 30(54), 116336–116347.
- Heine, D., & Black, S. (2019). Benefits beyond climate: Environmental tax reform. *Fiscal Policies for Development and Climate Action*, 1.
- Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, 115(1), 53–74.
- Jenkins, J. D. (2014). Political economy constraints on carbon pricing policies: What are the implications for economic efficiency, environmental efficacy, and climate policy design? *Energy Policy*, 69, 467–477.
- Koçak, E., & Şarkgüneşi, A. (2017). The renewable energy and economic growth nexus in Black Sea and Balkan countries. *Energy Policy*, 100, 51–57.
- Levin, A., Lin, C. F., & Chu, C. S. J. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics*, 108(1), 1–24.
- Li, R., Wang, Q., & Li, L. (2023). Does renewable energy reduce per capita carbon emissions and per capita ecological footprint? New evidence from 130 countries. *Energy Strategy Reviews*, 49, Article 101121.
- Lu, W. C. (2017). Renewable energy, carbon emissions, and economic growth in 24 Asian countries: Evidence from panel cointegration analysis. *Environmental Science and Pollution Research*, 24, 26006–26015.
- Mahmood, N., Wang, Z., & Hassan, S. T. (2019). Renewable energy, economic growth, human capital, and CO₂ emission: An empirical analysis. *Environmental Science and Pollution Research*, 26, 20619–20630.
- Miceikienė, A., Čiulevičienė, V., Rauluskeviciene, J., & Štreimikienė, D. (2018). Assessment of the effect of environmental taxes on environmental protection. *Ekonomický časopis*, 66(3), 286–308.
- Montzka, S. A., Dlugokencky, E. J., & Butler, J. H. (2011). Non-CO₂ greenhouse gases and climate change. *Nature*, 476(7358), 43–50.
- Morley, B. (2012). Empirical evidence on the effectiveness of environmental taxes. *Applied Economics Letters*, 19(18), 1817–1820.
- OECD database (2020). <https://data-explorer.oecd.org/>.
- Onofrei, M., Vintilă, G., Dascalu, E. D., Roman, A., & Firtescu, B. N. (2017). The impact of environmental tax reform on greenhouse gas emissions: Empirical evidence from European countries. *Environmental Engineering And Management Journal (EEMJ)*, 16(12).
- Pesaran, M. H. (2004). General diagnostic tests for cross section dependence in panels. Cambridge Working Papers. *Economics*, 1240(1), 1.
- Pesaran, M. H. (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica*, 74(4), 967–1012.
- Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, 22(2), 265–312.
- Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews*, 34(6–10), 1089–1117.
- Pesaran, M. H. (2021). General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, 60(1), 13–50.
- Piciu, G. C., & Trică, C. L. (2012). Trends in the evolution of environmental taxes. *Procedia Economics and Finance*, 3, 716–721.
- Pretis, F. (2022). Does a carbon tax reduce CO₂ emissions? Evidence from British Columbia. *Environmental and Resource Economics*, 83(1), 115–144.
- Rafique, M. Z., Fareed, Z., Ferraz, D., Ikram, M., & Huang, S. (2022). Exploring the heterogenous impacts of environmental taxes on environmental footprints: An empirical assessment from developed economies. *Energy*, 238, Article 121753.
- Ripple, W. J., Smith, P., Haberl, H., Montzka, S. A., McAlpine, C., & Boucher, D. H. (2014). Ruminants, climate change and climate policy. *Nature Climate Change*, 4(1), 2–5.
- Sadiq, M., Hassan, S. T., Khan, I., & Rahman, M. M. (2023). Policy uncertainty, renewable energy, corruption and CO₂ emissions nexus in BRICS-1 countries: A panel CS-ARDL approach. *Environment, Development and Sustainability*, 1–27.
- Sarafidis, V., Yamagata, T., & Robertson, D. (2009). A test of cross section dependence for a linear dynamic panel model with regressors. *Journal of Econometrics*, 148(2), 149–161.
- Sarkar, A., & Singh, J. (2010). Financing energy efficiency in developing countries—lessons learned and remaining challenges. *Energy Policy*, 38(10), 5560–5571.
- Shahzad, U. (2020). Environmental taxes, energy consumption, and environmental quality: Theoretical survey with policy implications. *Environmental Science and Pollution Research*, 27(20), 24848–24862.
- Shikwambana, L., Mhangara, P., & Kganyago, M. (2021). Assessing the relationship between economic growth and emissions levels in South Africa between 1994 and 2019. *Sustainability*, 13(5), 2645.
- Sundar, S., Mishra, A. K., & Naresh, R. (2016). Effect of environmental tax on carbon dioxide emission: A mathematical model. *American Journal of Applied Mathematics and Statistics*, 4(1), 16–23.
- Tvinnereim, E., & Mehling, M. (2018). Carbon pricing and deep decarbonisation. *Energy Policy*, 121, 185–189.
- Uluçak, R., Danish, & Kassouri, Y. (2020). An assessment of the environmental sustainability corridor: Investigating the non-linear effects of environmental taxation on CO₂ emissions. *Sustainable Development*, 28(4), 1010–1018.
- Usman, A., Ozturk, I., Naqvi, S. M. M. A., Ullah, S., & Javed, M. I. (2022). Revealing the nexus between nuclear energy and ecological footprint in STIRPAT model of advanced economies: Fresh evidence from novel CS-ARDL model. *Progress in Nuclear Energy*, 148, Article 104220.
- Zakari, A., Khan, I., & Alvarado, R. (2023). The impact of environmental technology innovation and energy credit rebate on carbon emissions: A comparative analysis. *Journal of International Development*, 35(8), 2609–2625.
- Zhang, Y., Khan, I., & Zafar, M. W. (2022). Assessing environmental quality through natural resources, energy resources, and tax revenues. *Environmental Science and Pollution Research*, 29(59), 89029–89044.
- Zhang, J., & Khan, I. (2024). Energy use, energy access, and oil price fluctuations as new determinants of environmental quality in APEC countries. *Gondwana Research*.
- Zhu, S., Zafar, M. W., Usman, M., Kalugina, O. A., & Khan, I. (2024). Internalizing negative environmental externalities through environmental technologies: The contribution of renewable energy in OECD countries. *Sustainable Energy Technologies and Assessments*, 64, Article 103726.
- Wei, D., Ahmad, F., Abid, N., & Khan, I. (2023). The impact of digital inclusive finance on the Growth of the renewable energy industry: Theoretical and logical Chinese experience. *Journal of Cleaner Production*, 428, 139357.
- Wolde-Rufael, Y., & Mulat-Weldemeskel, E. (2021). Do environmental taxes and environmental stringency policies reduce CO₂ emissions? Evidence from 7 emerging economies. *Environmental Science and Pollution Research*, 28(18), 22392–22408.
- Wolde-Rufael, Y., & Mulat-Weldemeskel, E. (2022). The moderating role of environmental tax and renewable energy in CO₂ emissions in Latin America and Caribbean countries: Evidence from method of moments quantile regression. *Environmental Challenges*, 6, Article 100412.