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The Impact of Environmental Taxes on Greenhouse Gas Emissions in Selected BRICS Countries

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ABSTRACT

The study investigates the impact of environmental taxes on greenhouse gas emissions in selected BRICS nations. While existing literature investigates the impact of environmental taxes on greenhouse gas emissions, there is a gap in studies that focus on BRICS nations. This study utilized panel data from reputable secondary sources such as the World Bank, Global Economy, and OECD from 1995 to 2022. The study employed the PARDL model and found that in the short run, environmental taxes effectively reduce greenhouse gas emissions in Brazil and China, whereas for South Africa they are ineffective. The robust results of the FMOLS and DOLS models discovered that environmental taxes are associated with increasing greenhouse gas emissions both in the short and long-run periods. Based on empirical evidence, the study recommends a disaggregated approach to the implementation of environmental taxes to effectively address the issue of rising greenhouse gas emissions and climate change mitigation.

Keywords: Environmental Taxes, Greenhouse Gas Emissions, PARDL, FMOLS, DOLS, BRICS
JEL Classifications: H23, Q5, Q4, C7

1. INTRODUCTION

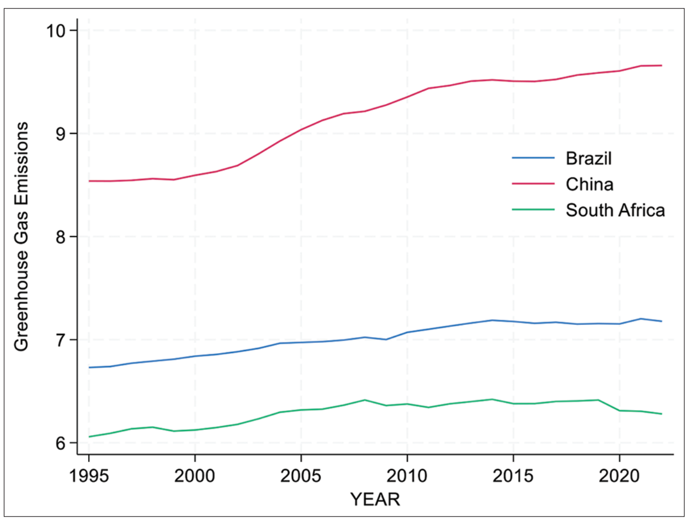
The urgent need to address climate change has led policymakers to explore innovative solutions to reduce greenhouse gas (GHG) emissions. Environmental taxes have emerged as a promising tool to mitigate climate change by providing a financial incentive for polluters to adopt cleaner technologies and practices such as renewable energy. The BRICS nations—Brazil, Russia, India, China, and South Africa—account for over 40% of the global greenhouse gas emissions and play a critical role in the global effort to combat climate change.

According to Pizarro et al. (2024), "the Paris Agreement outlines a direction for globally synchronized actions to reduce climate change and it comprises Nationally Determined Contributions (NDCs) which outline countries' strategies for cutting greenhouse gas emissions and coping with the effects of climate change." Nonetheless, the mitigation pledges outlined in the NDCs vary between countries regarding the kinds of targets, sectors included, and gases addressed. Assessing progress on national contributions from countries becomes challenging because of this. The Paris Agreement aims to restrict the increase in average global temperature to 2°C from pre-industrial levels and calls for additional actions to limit the rise to 1.5°C.

From Figure 1 above, the greenhouse gas emissions vary between these selected BRICS countries. China leads with the most emissions, followed by Brazil and South Africa as the last. The low emissions for South Africa may be associated with adhering to the Paris Agreement, Kyoto Protocol, and Sustainable Development Goals through the implementation of a carbon tax. According to Alton et al. (2014), Van Heerden et al. (2016), Garidzirai (2020), and Abel et al. (2023) the carbon tax has both economic and environmental implications in South Africa. According to Liu et al. (2019), Mohajan (2014), Wang et al. (2013), and Zou et al. (2015) China leads in greenhouse gas emissions as this may be linked to its recent growth rates and rapid industrialization. De Azevedo et al. (2018), Lima et al. (2020), De Oliveira Silva et al. (2016), and Fearnside (2019) contents that land use change in the Amazon and deforestation may be among the drivers of increased greenhouse gas emissions in Brazil witnessed in Figure 1 above.

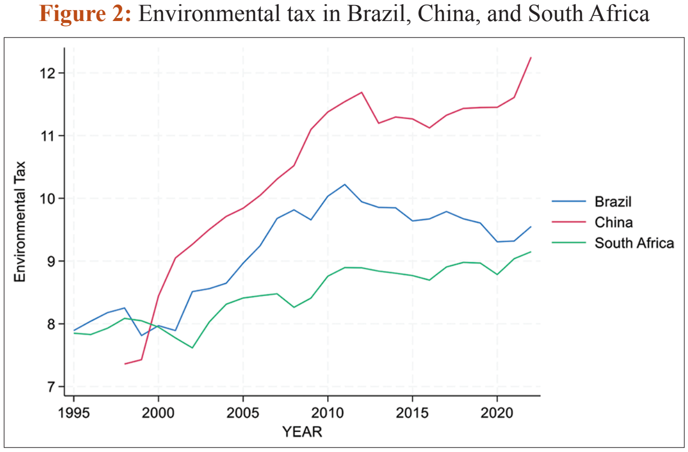
The studies of Silajdzic and Mehic (2018), Ulucak et al. (2020), Sarıgül and Topcu (2021), Karmaker et al. (2021), Wolde-Rufael and Mulat-Weldemeskel (2021), Doğan et al. (2022), Rafique et al. (2022), Yunzhao (2022), Wolde-Rufael and Mulat-Weldemeskel (2022), Xie and Jamaani (2022), Zhang and Zheng (2022), Telatar and Birinci (2022), Ya'u et al. (2023), Chen et al. (2023), Yunikewaty and Siswahyudi (2023), Zhu et al. (2023), Noubissi et al. (2023), Al Shammre et al. (2023), Saqib et al. (2023), Nsiah et al. (2024), Bala et al. (2024), Kirikkaleli (2023), Aydin (2024), Bashir et al. (2020), Ghazouani et al. (2021), Gafsi and Bakari (2025) have focused on the impact of environmental tax on greenhouse gas emissions in both developed and developing countries. Figure 2 below shows that China has collected the most in environmental tax revenue, followed by Brazil, and South Africa as the lowest. The trends show that greenhouse gas emissions tax revenue has been increasing for all three selected BRICS countries, however, the question of effectiveness in reducing these emissions remains unanswered since in Figure 1 we noticed that the emissions were rising throughout the period.

Figure 1: Greenhouse gas emissions in Brazil, China, and South Africa from 1995 to 2022



Source: Author's Stata computation using data from the World Bank

Figure 2: Environmental tax in Brazil, China, and South Africa



Source: Author's Stata computation using data from the OECD

Despite the growing importance of environmental taxation as a policy tool to mitigate climate change, the effectiveness of these policies in reducing greenhouse gas emissions remains unclear, particularly in the context of BRICS nations. The is a problem of environmental taxes being unable to effectively address the issue of rising greenhouse gas emissions in these selected BRICS countries as shown in Figures 1 and 2 above. The lack of empirical evidence on the impact of environmental taxes on greenhouse gas emissions in these countries hinders the development of evidence-based policies to address this critical issue. This study has identified specific research problems: What is the relationship between environmental taxes and greenhouse gas emissions in BRICS nations? To what extent do environmental taxes influence cleaner technologies and practices adoption in BRICS nations? How do environmental taxes interact with other climate policies to reduce greenhouse gas emissions in BRICS nations? What are the key factors influencing the effectiveness of environmental taxes in reducing greenhouse gas emissions in BRICS nations?

The study aims to investigate the impact of environmental taxes on greenhouse gas emissions in BRICS countries, exploring the potential for these taxes to drive emissions reductions and support sustainable development. Furthermore, the study has also formulated secondary objectives to support the primary objective, which is to analyze the factors influencing the effectiveness of environmental taxes in reducing greenhouse gas emissions and identify best practices for designing and implementing environmental tax policies in BRICS nations.

1.1. Significance of the Study

Furthermore, this study is significant to; policymakers by informing environmental tax policy design and implementation to reduce greenhouse gas emissions, academia contributing to the theoretical understanding of environmental taxation and its impact on greenhouse gas emissions, and practitioners by providing actionable recommendations for businesses and organisations to reduce their carbon footprint, and global community by addressing the global challenge of climate change through effective environmental taxation. This research aims to address the knowledge gap by:

1. Providing comprehensive comparative analysis of environmental taxation and greenhouse gas emissions reduction in BRICS nations.
2. Offering empirical evidence on the effectiveness of environmental taxes in reducing greenhouse gas emissions.
3. Developing policy-relevant insights to inform environmental tax policy design and implementation.

1.2. Research Questions

To achieve the study's objective of investigating the impact of environmental taxes on greenhouse gas emissions in BRICS nations, the study attempted to answer the following research questions:

1. What is the status of environmental taxation in BRICS nations?

2. How effectively are environmental taxes reducing greenhouse gas emissions in BRICS nations?
3. What are the challenges and opportunities for implementing environmental taxes in BRICS nations?
4. Are the impacts of environmental taxes on greenhouse gas emissions the same in BRICS nations?
5. Are there long-term relationships between environmental taxes and greenhouse gas emissions in BRICS nations?
6. What are the policy implications of the results of the study?

The rest of the study is structured as follows: Section 2 reviews the literature on environmental taxation and greenhouse gas emissions, and research gaps to be addressed by the study. Section 3 discusses the data collection and description of variables, followed by the methodology and data analysis. Section 4 presents the results, interpretations, and discussions, followed by Section 5 with a summary of the study, limitations, recommendations, and conclusion.

2. LITERATURE REVIEW

Purposed to investigate the impact of environmental taxes on CO_2 emissions in ten Central and Eastern European countries from 1995 to 2015, Silajdzic and Mehic (2018) employed the dynamic framework of the fully modified ordinary least squares model. They found that environmental taxes do not seem to be effective in modifying economic agents' behavior and protecting the environment. The authors further argue that though environmental taxes are perceived as a good way of reducing greenhouse gases, market-based instruments may still not be effective, let alone sufficient to achieve better environmental quality. Niu et al. (2018) investigate the relationship between ecological tax shocks and carbon emissions in China using a dynamic stochastic general equilibrium model. The results of the impulse response analysis and variance decomposition show that environmental tax shocks can drive the reduction of carbon emissions in China and recommend that environmental tax shocks can improve energy structure by promoting the introduction of clean energy which can reduce carbon emissions.

Ulacak et al. (2020) investigate the nonlinear effects of environmental taxation on CO_2 emissions in Brazil, China, India, and South Africa from 1994 to 2015. The results of the panel smooth transition regression approach show that environmental tax decreases CO_2 emissions at higher levels of globalization and recommend that further studies may contribute to related literature by employing alternative environmental indicators and control variables such as ecological footprint, environmental sustainability index, environmental performance index, energy consumption, renewable energy technologies, total factor productivity, and also using different panel samples or single country experiences. Sarıgül and Topcu (2021) analyzed the impact of environmental taxes on carbon dioxide emissions in Turkey from 1994 to 2015. Using the FMOLS, DOLS, and CCR models, the results revealed that there is evidence of long-run reduction of CO_2 emissions because of environmental taxes. The study recommends that the Turkish Tax System do not have the desired level of environmental impact, environmental taxes should be used effectively along with other financial or market instruments within the scope of combating environmental pollution.

Karmaker et al. (2021) investigate the effect of environmental taxes on economic growth and carbon emissions on a panel of 42 high and middle-income countries from 1995 to 2018. By employing CCEMG and AMG models, the results reveal that imposing environmental taxes can accelerate the advancement of environmental-related technologies for reducing carbon emissions and sustainable development in high and middle-income countries, with possible applications in a broad range of nations, particularly an evidence base for developing countries to shorten energy transition timelines. The study recommends that future research will need to focus on additional nations and economies over extended periods as data becomes available to enable the examination of the underlying effects of changes in environmental taxes toward environmental externalities. Wolde-Rufael and Mulat-Weldemeskel (2021) assess the effectiveness of environmental taxes and environmental stringency policies in reducing CO_2 emissions in a panel of 7 emerging economies from 1994 to 2015. The study employed AMG, FMOLS and Granger causality models and found that environmental taxes unidirectionally reduce CO_2 emissions alluding that environmental policy stringency and environmental taxes can be effective in mitigating CO= emissions.

Dogan et al. (2022) estimate the impact of green growth and environmental taxes on CO_2 emissions in 25 environmentally friendly countries from 1994 to 2018. By employing a novel quantile regression model, the study found that environmental taxes, renewable energy, and energy efficiency are key factors in decreasing CO_2 emissions. The study recommends that renewable energy should be given greater priority through research support, subsidies and government incentives while environmental taxes should be implemented to discourage activities that promote pollution. The study suggests that future research should investigate whether the relationship between green growth, environmental taxes and CO_2 emissions would be different if each type of environmental tax were considered in a multivariate framework. Zhang and Zheng (2022) employ the CS-ARDL model to determine the impact of environmental taxes on consumption-based carbon emissions for G-7 countries from 1990 to 2020. The results show that exports, energy efficiency and ecological taxes are negatively impacting the consumption-based CO_2 emission. The authors recommend that future studies may expand the range of this study to the organization of economic cooperation and development countries along with comparative studies for developing economies.

Doğan et al. (2022) explore the impact of an environmental tax on carbon emissions for the G7 nations from 1994 to 2014 and the importance of major drivers of emissions such as energy use, economic complexity, natural resources rent and economic growth. By employing the FMOLS and DOLS models, the findings indicate that strict environmental tax laws will allow businesses to shift production towards cleaner methods. The authors propose that redistributing tax revenues to the research and development of sustainable technology programs would empower the nations to achieve the United Nations SDG-7 and SDG-13 goals. Ryback et al. (2022) verify the effectiveness of environmental taxes in reducing greenhouse gas emissions using data from 2011 to 2019. By employing the ARMAX model, the findings show that environmental taxes fulfill mainly a fiscal function, while redistributive and incentive functions are insufficient. The authors recommend that future research extend explanatory variables such as primary energy consumption by product, electricity consumption, the share of renewable energy sources, energy efficiency, and gross domestic product.

Rafique et al. (2022) explore the role of environmental taxes and economic growth on the growing ecological footprint in 29 OECD countries from 1994 to 2016. The study employed the panel ARDL, FMOLS, and DOLS models and found that environmental taxes, economic growth, foreign direct investment, energy use, urbanization, renewable energy, and industrialization significantly influence the long-term ecological footprint across the OECD countries. The authors recommend that OECD countries need careful monitoring of environmental regulations for energy usage policies and cleaner production goals. Yunzhao (2022) models the role of eco-innovation, renewable energy, and environmental taxes in carbon emissions reduction in E-7 countries from 1995 to 2018. Employing the Continuous Updated Bias-Corrected, Continuously Updated Full Modified, and Dumitrescu-Hurlin Granger causality test reveals that renewable energy, eco-innovations, and environmental taxes positively reduce carbon emissions. The authors recommend implementing environmental taxes to help reduce carbon emissions and support the transition to renewable energy sources in the E-7 countries.

Wolde-Rufael and Mulat-weldemeskel (2022) investigated the effectiveness of environmental taxes and stringent policies in reducing CO_2 emissions in a panel of 20 European countries from 1995 to 2012. The results of the FMOLS, DOLS, and Quantile regression show that environmental taxes and environmental policy reduce CO_2 emissions in these countries and outline that the positive impact of environmental tax on improving environmental quality should encourage policymakers to increase ecological tax to achieve climate goals. Xie and Jamaani (2022) investigate the effect of environmental-related tax, energy productivity, green innovation, renewable energy, and gross domestic product on carbon emissions of G-7 countries from 1990 to 2020. The results of the method of moment quantile regression and quantile regression show that renewable energy consumption, green innovations, and environmental taxes significantly mitigate carbon emissions. At the same time, GDP causes a rise in CO_2 emissions in G-7 countries. The authors recommend that G-7 countries should focus on renewable energy consumption, encourage and support green innovations, and initiatives to boost productivity.

Tu et al. (2022) investigates the effect of carbon emission taxes on environmental and economic systems in China from 1978 to 2018. The findings of the departmental dynamic stochastic general equilibrium models show that introducing environmental taxes reduces carbon emissions and that a carbon emission tax shock has an instantaneous effect on most economic variables. The authors interpret that the results suggest that carbon emissions tax has a significant positive and robust impact on the environmental system, but a substantial negative effect on the economic system, and future research should try to explore the causality among these macroeconomic variables after the implementation of carbon tax to understand better the impact of a carbon emission tax on environmental and economic variables.

Teletar and Birinci (2022) investigate the effects of an environmental tax on ecological footprint and carbon dioxide emissions using a nonlinear cointegration approach from 1994 to 2019. The results show that environmental tax does not have long-run effects on ecological footprint and CO_2 emissions and conclude that environmental taxes do not affect preventing environmental degradation in Turkey. Chen et al. (2023) explored the influence of ecological taxes on CO_2 emissions in China by utilizing a spatial Durbin model. The results show that environmental taxes and fees reduce regional carbon emissions and suggest that efficiently promoting carbon emissions reduction requires effectively utilizing the spatial effects of environmental taxes and carbon emissions, establishing and improving the regional carbon emissions reduction linkages mechanism.

Zhu et al. (2023) examine the interactive effects of environmental taxes, renewable energy, and carbon emissions in 51 economically developed and developing countries using spatial econometric and panel threshold models from 2006 to 2020. The results suggest that environmental taxes and renewable energy consumption could mitigate carbon emissions as the share of renewable energy in the total energy mix increases. The authors recommend that future research could appropriately adjust the index system according to different regional conditions to make the constructed model more realistic. Noubissi et al. (2022) examine the impact of environmental policies on environmental quality for a panel of 36 OECD countries from 1994 to 2018. By employing the fixed effects techniques, Driscoll and Kraay, Lewbel 2SLS, and quantile regression, the researchers found that environmental tax contributes to reducing CO_2 emissions from transport and manufacturing sectors and recommend that taxes should be strengthened quantitatively and qualitatively to target better sectors known to be highly polluting.

Al Shammre et al. (2023) examine the effects of various environmental tax categories on CO_2 emissions in 34 OECD countries between 1995 and 2019. Employing a dynamic panel threshold regression, they reveal that the total environmental, energy, and pollution tax reduces CO_2 emissions in the upper regime once a given threshold has been reached. The authors recommend that implementing taxes on resource utilization may be effective but with limited environmental effects, therefore countries in the OECD must implement specific environmental taxes to reduce greenhouse gas emissions. Saqib et al. (2023) investigate the impact of environmental technological innovation, economic complexity, energy productivity, the use of renewable electricity generation, and environmental taxes on carbon dioxide emissions in the G-10 countries from 1995 to 2020. The results of the CS-ARDL, FMOLS, and DOLS models revealed that increased use of environmental-based technology, economic complexity, and renewable electricity generation positively impact carbon emissions reduction in both the short and long-run periods. The authors recommend updating modernized tax systems, improving tax collection, providing individuals with the means to finance Sustainable Development Goals through incentive regulations, and making grants from international organizations and the private sector available to fund investments toward sustainable development goals (SDGs) and carbon neutrality environment targets.

Ahmad et al. (2024) assess and compare the effectiveness of carbon taxes and emissions-trading systems in reducing carbon emissions through a meta-analysis based on 81 studies published between 2011 and 2022. The authors found that carbon-pricing policies are effective tools for reducing carbon emissions, but country and industry-specific factors can influence the effectiveness of these policies. Careful consideration of implementation strategies, economic structures, political commitment, technological advancements, and alternative energy sources is necessary to ensure carbon pricing policies' long-term effectiveness and sustainability. Furthermore, Aydin (2024) investigates the effects of national income, public expenditures, research and development investments, and environmental taxes on carbon emissions in selected EU member states from 1995 to 2020. The Dumitrescu and Hurlin Granger causality test results revealed a one-way causality from environmental, transport, and energy taxes to carbon emissions. The scholars emphasize that environmental taxes can effectively reduce carbon emissions within the Kyoto Protocol and the Paris Agreement framework. Considering these studies above, the identified research gaps are given below as follows:

2.1. Research Gaps

The studies of Silajdzic and Mehic (2018), Ulucak et al. (2020), Sarıgül and Topcu (2021), Karmaker et al. (2021), Wolde-Rufael and Mulat-Weldemeskel (2021), Doğan et al. (2022), Rafique et al. (2022), Yunzhao (2022), Wolde-Rufael and Mulat-Weldemeskel (2022), Xie and Jamaani (2022), Zhang and Zheng (2022), Telatar and Birinci (2022), Chen et al. (2023), Zhu et al. (2023), Noubissi et al. (2023), Al Shammre et al. (2023), Saqib et al. (2023), and Aydin (2024) but none of them focused on a panel of BRICS countries. Despite the growing importance of environmental taxation in reducing greenhouse gas emissions, a significant knowledge gap exists in understanding the effectiveness of environmental taxes in BRICS nations. Specifically:

1. Limited comparative analysis: Existing studies focus on individual BRICS countries or specific environmental tax policies, lacking a comprehensive comparative analysis.
2. Insufficient empirical evidence: There is a scarcity of empirical research on the impact of environmental taxes on greenhouse gas emissions in BRICS nations.
3. Lack of policy-relevant insights: Current research often fails to provide actionable recommendations for policymakers to design and implement effective environmental tax policies.

3. METHODOLOGY AND DATA COLLECTION

3.1. Research Approach, Data Collection, Variables, and Measures Methods

This study investigates the impact of environmental taxes on reducing greenhouse gas emissions in selected BRICS nations, that is, Brazil, China, and South Africa. This study follows a quantitative research approach. The data for the variables in Table 1 were collected from reputable online secondary statistical sources such as the Organization for Economic Cooperation and Development (OECD), World Bank, and Global Economy from 1995 to 2022. Brazil, China, and South Africa are the selected BRICS countries for this study. Russia and India were dropped from the study due to a lack of observation of environmental taxes. This study uses Stata 18 and EViews 10 for statistical analysis. The study takes logarithms for variables that are not in percentages to have the same unit of measurement and avoid spurious regressions.

3.2. Dependent Variable

- Greenhouse gas emissions refer to a measure of annual emissions of the six greenhouse gases (GHG) covered by the Kyoto Protocol (carbon dioxide [CO_2], methane [CH_4], nitrous oxide [N_2O], hydrofluorocarbons [HFCs], perfluorocarbons [PFCs], and sulphur hexafluoride [SF6]) from the energy, industry, waste, and agriculture sectors, standardized to carbon dioxide equivalent values. This measure excludes GHG fluxes caused by Land Use Change Land Use and Forestry (LULUCF), as these fluxes have larger uncertainties. The measure is standardized to carbon dioxide equivalent values using the Global Warming Potential (GWP) factors of IPCC's 5th Assessment Report (AR5). This variable was used in the studies of Silajdzic and Mehic (2018), Ulucak et al. (2020), Sarıgül and Topcu (2021), Wolde-Rufael and Mulat-Weldemeskel (2021), Doğan et al. (2022), Rybak et al. (2022), Yunzhao (2022), Wolde-Rufael and Mulat-Weldemeskel (2022), Xie and Jamaani (2022), Zhang and Zheng (2022), Telatar and Birinci (2022), Chen et al. (2023), Zhu et al. (2023), Noubissi et al. (2023), Al Shammre et al. (2023), Saqib et al. (2023), and Aydin (2024).

3.3. Independent Variables

- Environmental taxes refer to environmentally related taxes that are important for governments to shape relative prices of goods and services. The characteristics of such taxes included in the database (e.g. revenue, tax base, tax rates, exemptions, etc.) are used to construct the environmentally related tax revenues with a breakdown by environmental domain: energy products (including vehicle fuels); motor vehicles and transport services; measured or estimated emissions to air and water, ozone-depleting substances, certain non-point sources of water pollution, waste management and noise, as well as management of water, land, soil, forests, biodiversity, wildlife and fish stocks. The data have been cross-validated and complemented with Revenue statistics from the OECD Tax Statistics database and official national sources. This variable was used in the studies of Silajdzic and Mehic (2018), Ulucak et al. (2020), Sarıgül and Topcu (2021), Karmaker et al. (2021), Wolde-Rufael and Mulat-Weldemeskel (2021), Doğan et al. (2022), Rafique et al. (2022), Yunzhao (2022), Wolde-Rufael and Mulat-Weldemeskel (2022), Xie and Jamaani (2022), Zhang and Zheng (2022), Telatar and Birinci (2022), Chen et al. (2023), Zhu et al. (2023), Noubissi et al. (2023), Al Shammre et al. (2023), Saqib et al. (2023), and Aydin (2024).

- Renewable energy refers to the total renewable electricity net generation (net generation excludes the energy consumed by the generating units and excludes generation from hydroelectric pumped storage). This variable was used in the studies of Sarıgül and Topcu (2021), Doğan et al. (2022), Rafique et al. (2022), Yunzhao (2022), Wolde-Rufael and Mulat-Weldemeskel (2022), Xie and Jamaani (2022), and Saqib et al. (2023).
- Economic growth refers to the annual percentage growth rate of GDP at market prices based on constant local currency. Aggregates are based on constant 2015 prices, expressed in U.S. dollars. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for the depreciation of fabricated assets or for the depletion and degradation of natural resources. This variable was used in the studies of Ulucak et al. (2020), Sarıgül and Topcu (2021), Karmaker et al. (2021), Wolde-Rufael and Mulat-Weldemeskel (2021), Doğan et al. (2022), Rafique et al. (2022), Wolde-Rufael and Mulat-Weldemeskel (2022), Xie and Jamaani (2022), Noubissi et al. (2023), and Al Shammre et al. (2023).
- Population refers to the annual population growth rate for year t is the exponential rate of growth of the midyear population from year t-1 to t, expressed as a percentage. The population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship.
- Trade openness refers to the exports plus imports as a percent of GDP. Exports of goods and services represent the value of all goods and other market services provided to the rest of the world. They include the value of merchandise, freight, insurance, transport, travel, royalties, license fees, and other services, such as communication, construction, financial, information, business, personal, and government services. They exclude compensation of employees and investment income (formerly called factor services) and transfer payments. On the other hand, imports of goods and services represent the value of all goods and other market services from the rest of the world. They include the value of merchandise, freight, insurance, transport, travel, royalties, license fees, and other services, such as communication, construction, financial, information, business, personal, and government services. They exclude compensation of employees and investment income (formerly called factor services) and transfer payments. This variable was used in the study of Noubissi et al. (2023).

3.4. Data Analysis Techniques

3.4.1. Theory and model specification

The study adopts the Pigouvian taxation theory, a fundamental concept in environmental economics developed by Arthur Pigou in 1920 as highlighted by Pigou (2017), Walker (1920), and Robertson (1921). The Pigouvian taxation theory was developed because of the following key principles: Economic activities can impose external costs referred to as negative externalities on third parties, and unregulated markets may fail to account for these externalities, leading to inefficient resource allocation, and governments can internalize externalities through taxes, making polluters pay for environmental damage. The main aims of the Pigouvian taxation are to correct the market failure by aligning private costs with social costs, internalizing externalities by making polluters pay for environmental damage and efficient resource allocation through taxing natural resources extraction.

Different Pigouvian taxation types include pollution taxes on emissions, effluents, or waste, carbon taxes on CO_2 emissions, and resource extraction taxes. The Pigouvian taxation has the benefits of reducing pollution by making it more expensive, encouraging firms to adopt cleaner technologies, generating revenue for environmental projects, and reducing negative health impacts. On the other hand, Pigouvian taxation has limitations in its difficulties in calculating precise external costs, it requires effective monitoring and enforcement mechanisms, and taxes may disproportionately affect certain groups. Manta et al. (2023), Kurular (2020), Witkin (2019), Baiardi and Menegatti (2011), and Schmitt (2014) have investigated the application of the Pigouvian as a solution to climate change in their studies and concluded that it is effective in addressing the issue of greenhouse gas emissions and climate change.

The Pigouvian taxation is applicable in this study since its main objective is to investigate the impact of environmental tax on greenhouse gas emissions in selected BRICS countries. This theory provides a foundational framework for environmental policy, highlighting the importance of internalizing externalities and correcting market failures. Based on this theory and incorporating explanatory variables, this study specifies the model as follows:

$$LGHG_{it} = f(LETX_{it}, LEG_{it}, LRE_{it}, LPOP_{it}, LTO_{it}) \quad (1)$$

LGHG is the logged greenhouse gas emissions, LETX is the logged environmental tax, LRE is the logged renewable energy generation, LPOP is the natural logarithm of population, LEG is the natural logarithm of economic growth, and LTO is the natural logarithm of trade openness. The study assumes natural logarithm for variables in percentages and it applies logarithms to variables not in percentages to smooth the data helping in reducing autocorrelation, and heteroskedasticity, and providing results that are more accurate and consistent than a simple linear form (Karmaker et al., 2021). The study forms a multivariate linear econometric model by modifying the models used in the studies of Saqib et al. (2023), Zhang and Zheng (2022), Doğan et al. (2022), Wolde-Rufael and Mulat-Weldemeskel (2021), Karmaker et al. (2021), Sarıgül and Topcu (2021), and Silajdzic and Mehic (2018) to achieve the study's objectives. The multivariate econometric model is specified as follows:

$$LGHG_t = \alpha_1 + \alpha_{LETX}LETX_t + \alpha_{LPOP}LPOP_t + \alpha_{LTO}LTO_t + \alpha_{LRE}LRE_t + \alpha_{LEG}LEG_t + \varepsilon_t \quad (2)$$

Whereby α_1 is the slope coefficient, α_1–α_6 refers to the slope coefficients of the regressors, and ε_t is the error term. The study continues to perform the unit root test presented in Section 3.2.2 below.

3.4.2. Panel unit root test

The research will additionally conduct the Levin-Lin-Chu (2003) and Im-Pesaran-Shin (2003) unit root tests to confirm that the variables lack a unit root. The unit root test for LLC was created by Levin and Lin (1992; 1993) and by Levin et al. (2002). The examination involves a variable tracked across N countries and T timeframes and a model that features individual effects and lacks a temporal trend. The LLC examines a model where the coefficient of the lagged dependent variable is constrained to be uniform across all units of the panel as indicated:

$$\Delta y_{i,t} = \alpha_i + \rho y_{i,t-1} + \sum_{z=1}^{p_i} \beta_{iz} \Delta y_{i,t-z} + \varepsilon_{i,t} \quad (3)$$

For $i = 1,\ldots, N$ and $t = 1,\ldots T$. The errors are independent and identically distributed random variables with finite variance on a normal distribution. The null hypothesis of unit root is given as follows: $H_{0:}\, p = 0$ against the alternate hypothesis $H_1{:}\rho = \rho_1 < 0 < 0$ for all $i = 1,\ldots,$N, with auxiliary assumptions about the individual effects ($\alpha_I = 0$ for all $i = 1$, under H_0). The IPS unit root test of Im et al. (2003) relaxes the assumption of first-order AR coefficients and allows for heterogeneity in the alternate hypothesis. It involves the Fisher-ADF and Fisher-PP test with two combined ρ_i test statistics. The null hypothesis is that there is a unit root. The ADF-Fisher and ADF-Choi equations are specified as follows:

$$ADF - Fisher\ x^2 = -2\sum_{i=1}^{N} log\left(\rho_i\right) \rightarrow x^2\left(2N\right) \quad (4)$$

$$ADF - Choi\ Z = \frac{1}{\sqrt{N}} \sum_{i=1}^{N} \varnothing^{-1}\left(\rho_i\right) \rightarrow N\left(0,1\right) \quad (5)$$

Where, $\varnothing^{-1}$ represents the reciprocal of the cumulative function of standard normal distribution. If the probability value of the computed statistic is less than the probability value at any level of significance (1%, 5%, and 10%) the null hypothesis is rejected in favor of the alternate hypothesis implying that there is no unit in the variable.

3.4.3. Panel cointegration test

The study will perform Cointegration tests to check for the presence of long-run relationships among the variables. Considering the following panel regression model:

$$y_{it} = x_{it}' \beta + z_{it}' \gamma + e_{it} \quad (6)$$

Where y_{it} and x_{it} are I(1) and non-cointegrated. For $z_{it} = \{\mu_{it}\}$, Kao (1999) proposed Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) type unit root tests for e_{it} as a test for the null of no cointegration. The DF and ADF types can be calculated from the fixed residuals as follows:

$$\hat{e}_{it} = \rho \hat{e}_{it-1} + v_{it} \quad (7)$$

$$\hat{e}_{it} = \rho \hat{e}_{it-1} + \sum_{j=1}^{p} \vartheta_j \Delta \hat{e}_{it-j} + v_{itp} \quad (8)$$

Where $\hat{e}_{it} = \tilde{y}_{it} - \tilde{x}_{it} \hat{\beta}$ and $\tilde{y}_{it} = y_{it} - \overline{y}_i$. To test for the null hypothesis of no cointegration, the null hypothesis can be specified as follows:

$$H_0{:}\ \rho = 1 \quad (9)$$

If the probability value of the computed statistic is less than the probability value at any level of significance (1%, 5%, and 10%) the null hypothesis is rejected in favor of the alternate hypothesis implying that there is co-integration among the variables. The study will also perform the Pedroni (2000; 2004) test for the null hypothesis of no cointegration in a panel data model that allows for considerable heterogeneity. The first test of Pedroni (2000) involves averaging test statistics for cointegration in the time series across cross-sections. The second involves averaging in pieces so that the limiting distributions are based on limits of pairwise numerator and denominator terms. The first set of statistics includes a form of the average of Phillips and Ouliaris (1990) statistic as follows:

$$\tilde{Z}_\rho = \sum_{i=1}^{N} \frac{\sum_{t=1}^{T} (\hat{e}_{it-1} \Delta \hat{e}_{it} - \grave{\lambda}_i)}{(\sum_{t=1}^{T} \hat{e}_{it-1}^2)} \quad (10)$$

If the probability value of the computed statistic is less than the probability value at any level of significance (1%, 5%, and 10%) the null hypothesis is rejected in favor of the alternate hypothesis implying that there is co-integration among the variables.

3.4.4. Panel regression methods

3.4.4.1. Panel autoregressive distributed lags (PARDL) model

The study adopts the panel autoregressive distributed lags (PARDL) model developed by Pesaran and Smith (1995) and later modified by Pesaran et al. (1999). This model was used in the studies of Karmaker et al. (2021), Wolde-Rufael and Mulat-Weldemeskel (2021), Zhang and Zheng (2022), Rafique et al. (2022), and Saqib et al. (2023). The PARDL model can be specified as follows:

$$y_{it} = \phi_i y_{i,t-1} + \beta_i' x_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^* \Delta \gamma_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}^* \Delta \chi_{i,t-j} + \mu_i + \varepsilon_{it} \quad (11)$$

$i = 1,2,\ldots,$N and $t = 1,2,\ldots T$. The panel ARDL model has the advantage of making it possible to estimate the short-run and long-run effects of environmental taxes on greenhouse gas emissions reduction allowing heterogeneous short-run relationships and homogenous long-run relationships.

3.4.4.2. Robustness check

The study will estimate the Fully modified ordinary least squares (FMOLS) developed by Phillips and Hansen (1990) and Dynamic Ordinary Least Squares (DOLS) developed by Stock and Watson (1993) for robustness checks. The FMOLS is designed to offer "more accurate estimates of cointegrating regressions by adjusting for serial correlation, heteroskedasticity, and endogeneity in the regressors." Conversely, the DOLS allows for "the estimation of cointegration vectors while accounting for dynamics, endogeneity, and serial correlation." These tests are robust to other models such as 2-stage least squares and instrumental variable regression in dealing with autocorrelation and non-stationary variables. The DOLS is specified as follows:

$$Y_t = \alpha + \beta X_t + \sum_{j=-q}^{j=r} \delta \Delta X_{t-j} + \varepsilon_t \quad (12)$$

For all $i = 1, \ldots, N$ and $t = 1, 2, 3, \ldots, T$. The DOLS assumes that adding q lags and r leads of the differenced regressors soaks up all the long-run correlation between error terms. Considering the FMOLS estimator for the coefficient of β of the model:

$$\beta^*_{NT} - \beta = \left(\sum_{i=1}^{N} L_{22i}^{-2} \sum_{i=1}^{T} (x_{it} - \bar{x}_{it})^2) \right) \sum_{i=1}^{N} L_{11i}^{-1} L_{22i}^{-1}$$

$$\left(\sum_{i=1}^{T} \left(x_{it} - \bar{x}_{it} \right) \mu^*_{it} - T \hat{\gamma}_i \right) \quad (13)$$

Where, $\mu^*_{it} = \mu_{it} - \frac{\hat{L}_{21i}}{\hat{L}_{22i}} \Delta x_{it}, \hat{y}_i = \hat{\Gamma}_{21i} \hat{\Omega}^0_{21i} - \frac{\hat{L}_{21i}}{\hat{L}_{22i}} \left(\hat{\Gamma}_{22i} - \hat{\Omega}^0_{22i} \right)$

and $\hat{\Gamma}_i$ is a lower triangulation of $\hat{\Omega}_i$. The FMOLS will be utilized for static relationships, while the DOLS for dynamic relationships between environmental taxes and greenhouse gas emissions.

3.4.5. Cross-section dependence test

The cross-sectional test of residuals from the study will be conducted on the Breusch and Pagan (1980) proposed using the Lagrange multiplier (LM) statistic, which is valid for fixed N as T is infinity specified as follows:

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}^2_{ij} \quad (14)$$

Pesaran (2004) proposed a cross-section dependence (CD) test which is commonly used to test whether the residuals for cross-section i at period t are correlated or not. Pesaran (2006) proposes that when N is large which could be homogeneous or heterogeneous, the following equation must be employed:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{p}_{ij} \right) \quad (15)$$

Furthermore, under the null hypothesis of no cross-section independence, the CD test is normally distributed with zero mean and variance of one where N and T approach infinity.

4. RESULTS, INTERPRETATIONS, AND DISCUSSIONS

4.1. Descriptive Statistical Analysis

The study conducted the descriptive statistical test as shown in Table 2 above, trade openness and renewable energy are negatively skewed whereas greenhouse gas emissions, environmental taxes, population, and economic growth are positively skewed. The kurtosis values for environmental taxes, population, and economic growth are >2 indicating that the data is leptokurtic and may not be normally distributed. However, the Jarque-Bera statistics for population, environmental taxes, trade openness, and economic growth have a probability value of >0.05 indicating that the data is normally distributed, except for greenhouse gas emissions and renewable energy. This does not pose a risk for the study since we assume the normality of the estimated models. The study continues to perform correlation analysis as presented in Section 4.2 below.

4.2. Correlation Analysis

The results of the correlation analysis show that population and greenhouse gas emissions are negatively correlated, while environmental taxes, trade openness, renewable energy, and economic growth are positively correlated with greenhouse gas emissions as presented in Table 3 above. The statistics of environmental taxes, renewable energy, and economic growth are less than 0.8 suggesting that there might be a weaker linear relationship among the explanatory variables and the dependent

Table 1: Data sources and variable description

Variable	Description	Unit	Source
Environmental Tax (LETX)	Environmentally related tax revenue	US$ Millions	OECD
Greenhouse Gas Emissions (LGHG)	Total greenhouse gas emissions excluding LULUCF (Mt CO2e)	Million tonnes	World Bank
Economic growth (LEG)	The rate of change of real GDP	Percentage	Global Economy
Renewable energy (LRE)	Renewable power generation	Billion kilowatts	Global Economy
Population (LPOP)	Population growth as a percentage	Percentage	Global Economy
Trade openness (LTO)	Exports plus imports as a percentage of GDP	Percentage	Global Economy

Source: Author's compilation

Table 2: Descriptive statistics

Variable	LGHG	LETX	LPOP	LTO	LRE	LEG
Mean	7.442913	9.309507	0.931235	40.65000	4.459857	4.196914
Median	6.996012	9.037122	0.930000	39.48000	5.698569	3.390000
Maximum	9.659001	12.25040	2.070000	65.97000	7.907306	14.23000
Minimum	6.058564	7.359141	−0.010000	15.64000	−0.634878	−5.960000
Std. Dev.	1.255060	1.220767	0.381472	13.59714	2.615065	3.784468
Skewness	0.705841	0.578017	0.171396	−0.020319	−0.640561	0.143183
Kurtosis	1.867112	2.386160	3.075442	1.903191	1.797371	3.158250
JB-Stat	11.05746	5.782099	0.415793	4.065662	10.42061	0.361290
Probability	0.003971	0.055518	0.812291	0.130964	0.005460	0.834732
Observation	81	81	81	81	81	81

Source: Author's computation

Table 3: Correlation analysis

Correlation	LGHG	LETX	LPOP	LTO	LRE	LEG
LGHG	1.000000					
LETX	0.788788	1.000000				
LPOP	−0.736526	−0.728847	1.000000			
LTO	0.035777	0.042299	−0.133558	1.000000		
LRE	0.749280	0.673205	−0.553933	−0.491350	1.000000	
LEG	0.668565	0.373837	−0.448380	0.288102	0.321348	1.000000

Source: Author's computation

Table 4: Panel Unit Root Test

Variables	Im et al. (2003)				Levin et al. (2002)			
	Without trend		Trend		Without trend		Trend	
	Level	Δ	Level		Level	Δ	Level	Δ
LGHG	−0.3292	−3.3194***	2.1976	−3.8356***	−1.2382	−1.7933**	1.2547	−1.6542**
LETX	−0.2673	−3.6866***	−0.6538	−3.9286***	0.8327	−1.9670**	0.2356	−5.5978***
LPOP	1.7877	−2.7456***	0.1282	−2.7921***	0.4795	−4.4913***	0.2396	−3.6594***
LTO	0.5896	−4.3305***	−0.6285	−4.3943***	0.0050	−2.3127**	−0.1184	−4.7960***
LRE	2.7207	−5.1395***	−2.2502**	−5.1406***	1.1702	−3.8114***	−0.4963	−2.8694***
LEG	−2.9192***	−6.2519***	−3.6643***	−6.2304***	−0.9138	−4.2160***	−0.6231	−2.4978***

Source: Author's computation (***), (**), (*) significance at 1%, 5% and 10% respectively

Table 5: Optimal lag selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−629.8015	N/A	23.49828	20.18417	20.38828	20.26445
1	−136.1553	877.5932	1.160005	5.655723	7.084480*	6.217660*
2	−96.86767	62.36128	1.080005	5.551355	8.204759	6.594952
3	−53.12640	61.09892	9.120006	5.305600	9.183653	6.830857
4	−1.869252	61.83402*	6.590006*	4.821246	9.923948	6.828164
5	38.17031	40.67511	7.700006	4.693006	11.02036	7.181584
6	86.62493	39.99429	8.340006	4.297621*	11.84962	7.267859

Source: Author's computation (*) indicates lag order selected by the criterion

variable. The study continues to estimate unit root tests for panel data to avoid spurious regressions and identify the order of integration of variables as presented in Section 4.3 below.

4.3. Unit Root Test

The research conducted the second-generation panel unit root tests of Levin-Lin-Chu (2002) and Im-Pesaran-Shin (2003) to avoid spurious regression and ascertain the order of integration of variables to evaluate the appropriateness of the selected model for the analysis. The findings in Table 4 indicate that the variables are integrated of I(1) making it suitable to use the panel ARDL model proposed by Pesaran et al. (1999). The research persists in examining the best lags to apply in the model as detailed in Section 4.4 below.

4.4. Optimal Lag Length Selection Criteria

The research performed the VAR optimal lags selection criterion presented in Table 5 above to identify the best lags to employ in the model. The outcomes from the AIC criterion indicate that 6 lags may be employed, whereas the SIC indicates that 1 lag may be utilized in the model. This study relies on the SIC criterion of 1 lag since it is more robust than the AIC criterion (Vrieze, 2012). The research proceeds with the cointegration tests to examine long-run relationships within the model, as detailed in Section 4.5 below.

4.5. Cointegration Test

The research performed cointegration tests of Kao (1999) and Pedroni (2001) as presented in Table 6 above. Based on the results,

Table 6: Panel cointegration test

Test	Statistic	Probability
Kao (1999)		
Modified Dickey-Fuller t	−2.3934	0.0083**
Dickey-Fuller t	−1.0424	0.1486
Augmented Dickey-Fuller t	−1.4047	0.0801*
Unadjusted modified Dickey-Fuller t	−1.3034	0.0962*
Unadjusted Dickey-Fuller t	−0.6944	0.2437
Pedroni (2001)		
Modified Phillips-Perron t	1.8585	0.0316**
Phillips-Perron t	1.6029	0.0545*
Augmented Dickey-Fuller t	2.2266	0.0130**

Source: Author's computation (***), (**), (*) significance at 1%, 5% and 10% respectively

we reject the notion that there is no cointegration among panels, thus supporting the alternative hypothesis of cointegration. The findings indicate the existence of long-run relationships between the variables in the model. Thus, determine that the research will assess both short-term and long-term connections between the variables in the model.

4.6. The Impact of Environmental Tax on Reducing Greenhouse Gas Emissions in Selected BRICS Nations

4.6.1. Comparative short-run analysis of the impact of an environmental tax on greenhouse gas emissions in Brazil, China, and South Africa

The study has performed the short-run country-by-country analysis since the PARDL model assumes heterogeneity short-run relationships as presented in Table 7 above. The error correction terms for Brazil (−0.2781) and China (−0.3038) are negative and significant indications that 27.81% and 30.38% of the error in greenhouse gas emissions are corrected annually towards long-run equilibrium. South Africa has a positive error or correction term of 0.0629 indicating a positive adjustment of 6.29% towards long-run equilibrium. Furthermore, there is a negative significant relationship between environmental taxes and greenhouse gas emissions in Brazil and China. A 1% increase in environmental taxes significantly results in greenhouse gas emissions declining by 0.005% and 0.003% in Brazil and China respectively, ceteris paribus. However, for South Africa, their results show that environmental taxes are failing to reduce greenhouse gas emissions since a 1% increase in environmental taxes significantly results in greenhouse gas emissions rising by 0.07%, ceteris paribus. These results are consistent with the studies of Saqib et al. (2023), Doğan et al. (2022), Zhang and Zheng (2022), and Sarıgül and Topcu (2021) that found environmental taxes to be effective in reducing greenhouse gas emissions. These results imply that environmental taxes are beneficial for reducing greenhouse gas emissions in Brazil and China, however, for South Africa, there is a need to revise environmental taxes to reduce greenhouse gas emissions.

Moreso, renewable energy found to be effective in reducing greenhouse gas emissions in Brazil and China. A 1% increase in renewable energy significantly reduces greenhouse gas emissions by 0.21% and 0.13% in Brazil and China, ceteris paribus. However, for South Africa, renewable energy seems not to be effective in reducing greenhouse gas emissions since a 1% increase in environmental taxes significantly results in greenhouse gas emissions rising by 0.008%, ceteris paribus. These results are consistent with the studies of Sarıgül and Topcu (2021), Doğan et al. (2022), and Saqib et al. (2023) that found renewable energy to be effective in reducing greenhouse gas emissions. These results imply that renewable energy is good for reducing greenhouse gas emissions in China and Brazil, however, for South Africa, there's a need to revise policies on renewable energy to reduce greenhouse gas emissions.

Economic growth is associated with increases in greenhouse gas emissions in Brazil and China since a 1% increase in economic growth significantly results in greenhouse gas emissions rising by 0.005% and 0.005% respectively, ceteris paribus. On the other hand, economic growth reduces greenhouse gas emissions in South Africa. These results imply that economic growth for Brazil and China must be revised to align with the goals of reducing greenhouse gas emissions. These results are consistent with the studies of Doğan et al. (2022), Zhang and Zheng (2022), Silajdzic and Mehic (2018), and Sarıgül and Topcu (2021) that found economic growth rising greenhouse gas emissions.

Population growth is associated with rising greenhouse gas emissions in Brazil and South Africa since a 1% rise in population growth raises greenhouse gas emissions by 0.04% and 0.002% respectively, ceteris paribus. On the other hand, in China, a 1% rise in population growth is associated with declining greenhouse gas emissions by 0.10%, ceteris paribus. These results imply that population growth is not good for reducing greenhouse gas emissions in Brazil and South Africa, however, for China it is effective. Trade openness reduces greenhouse gas emissions in Brazil while raising greenhouse gas emissions in China and South Africa. The study provides the long-run relationships as shown in Section 4.6.2 below.

4.6.2. Long-run analysis of the impact of an environmental tax on greenhouse gas emissions in Brazil, China, and South Africa

The model assumes long-run homogeneous relationships among the variables as presented in Table 8 above. The results indicate that a 1% increase in environmental taxes is associated with a 0.15% rise in greenhouse gas emissions at a 1% significance level, ceteris paribus. These results imply that in the long run, increasing environmental taxes is not an effective measure of addressing greenhouse gas emissions. These results call for policymakers, and governments of these selected BRICS nations to find other alternative ways of addressing the issue of rising greenhouse gas emissions. These results are inconsistent with the studies of Chen et al. (2023), Sarıgül and Topcu (2021), Zhang and Zheng (2022), Doğan et al. (2022), and Saqib et al. (2023) who found that environmental tax to reduce greenhouse gas emissions. On the other hand, the results are consistent with the results of Karmaker et al. (2021) who found environmental tax to increase greenhouse gas emissions in G-7 and OECD countries.

The data uncovered contradictory findings, such as renewable energy significantly increasing greenhouse gas emissions in the long run as opposed to the short-term results. A 1% rise in renewable energy in the long run is associated with greenhouse gas emissions rising by 0.29% in selected BRICS nations, ceteris paribus. These results imply that renewable energy has not yet been able to effectively address the issue of rising greenhouse gas emissions in the long run in BRICS nations which may be due to the differentiated approach to adopting renewable energy by BRICS countries. These results are inconsistent with the studies of Saqib et al. (2023), Doğan et al. (2022), and Sarıgül and Topcu (2021) that found renewable energy to reduce greenhouse gas emissions in the long run.

Table 7: Comparative short-run analysis

PNARDL (1,1,1,1,1,1) short run equation			
Variables	**Brazil**	**China**	**South Africa**
ECT	−0.278066***	−0.303820***	0.062892***
ΔLETX	−0.004939***	−0.002624***	0.069993***
ΔLPOP	0.037466*	−0.099867***	0.001572**
ΔLTO	−0.000319***	0.000440***	0.003551***
ΔLRE	−0.210735***	−0.129913***	0.008197***
ΔLEG	0.004602***	0.004755***	−0.000115***

Source: Author's computation (***), (**), (*) significance at 1%, 5% and 10% respectively

Table 8: Homogeneous long-run analysis

PNARDL (1,1,1,1,1,1) long run equation				
Variables	**Coefficient**	**Standard error**	**t-statistic**	**Probability**
LETX	0.152669	0.031021	4.921454	0.0000***
LPOP	0.287538	0.080411	3.575850	0.0007***
LTO	0.013437	0.002450	5.485207	0.0000***
LRE	0.286101	0.042563	6.721887	0.0000***
LEG	−0.009459	0.006241	−1.515569	0.1354

Source: Author's computation (***), (**), (*) significance at 1%, 5% and 10% respectively

Furthermore, population growth and trade openness are associated with increased greenhouse gas emissions in selected BRICS nations in the long run. A 1% increase in population growth and trade openness is associated with greenhouse gas emissions rising by 0.29% and 0.01% respectively, ceteris paribus. These results imply that population growth and trade openness are not good for reducing the issues of increasing greenhouse gas emissions in the long run in selected BRICS nations. This calls for policymakers, governments, and investors in the selected BRICS nations to revise policies on trade openness to reduce greenhouse gas emissions. The study continues to perform residual diagnostics tests as presented in Section 4.6.3 below.

4.6.3. Residual diagnostics test

The study conducted the cross-sectional dependence test from the estimated model as presented in Table 9 above. The results of the Breusch-Pagan LM, Pesaran scaled LM, and Pesaran CD test all show that we fail to reject the null hypothesis of no cross-sectional dependence in residuals from the estimated model at a 5% significance level. These results imply that there are no correlations among the residuals from the estimated model and we can conclude that the results are reliable for policy recommendations and formulation in selected BRICS nations. The study continues to perform robustness checks as presented in Section 4.7 below.

4.7. Robustness Check of the Impact of an Environmental Tax on Reducing Greenhouse Gas Emissions in Selected BRICS Nations

4.7.1. Panel fully modified ordinary least squares and dynamic ordinary least squares models robustness check

The study has performed the robustness checks using the FMOLS for static relationships and the DOLS for dynamic relationships as presented in Table 10 above. The DOLS model shows that environmental tax is associated with increases in greenhouse gas emissions in selected BRICS countries. A 1% increase in environmental taxes in the short run is associated with a 0.69% increase in greenhouse gas emissions, ceteris paribus. The FMOLS shows that a 1% increase in environmental tax is associated with a 0.56% increase in greenhouse gas emissions in the long run in selected BRICS nations. These results imply that both in the short and long run environmental taxes have not been able to reduce greenhouse gas emissions. These findings align with the outcomes of the PARDL model in Tables 6 and 7, which indicate that environmental taxes have led to a rise in greenhouse gas emissions in certain BRICS countries. These results are inconsistent with the studies of Chen et al. (2023), Sarıgül and Topcu (2021), Zhang and Zheng (2022), Doğan et al. (2022), and Saqib et al. (2023) who found that environmental tax to reduce greenhouse gas emissions. On the other hand, the results are consistent with the results of Karmaker et al. (2021) who found environmental tax to increase greenhouse gas emissions in G-7 and OECD countries.

Furthermore, the DOLS results show that renewable energy insignificantly reduces greenhouse gas emissions in the short run, however, these results cannot be taken seriously since they are insignificant. The FMOLS results indicate that a 1% rise in renewable energy generation is associated with a 0.14% rise in greenhouse gas emissions in the long run in the selected BRICS nations. These results imply that renewable energy has not yet been able to effectively address the issue of rising greenhouse gas emissions in the long run in BRICS nations which may be due to the differentiated approach to adopting renewable energy by BRICS countries. These results are inconsistent with the studies of Saqib et al. (2023), Doğan et al. (2022), and Sarıgül and Topcu (2021) that found renewable energy to reduce greenhouse gas emissions in the long run. These results align with the long run from the PARDL model in Table 7 above. Policymakers, investors, and governments of these nations need to revise policies on renewable energy so it can reduce greenhouse gas emissions and mitigate the impacts of climate change.

Long-term economic growth correlates with higher greenhouse gas emissions, as a 1% rise in economic growth leads to a 0.13% increase in greenhouse gas emissions, ceteris paribus. These findings suggest that the economic expansion of chosen BRICS countries needs to be adjusted to meet the targets for lowering greenhouse gas emissions. These findings align with the research of Doğan et al. (2022), Zhang and Zheng (2022), Silajdzic and Mehic (2018), and Sarıgül and Topcu (2021), which discovered that economic growth increases greenhouse gas emissions. The R-squared value for the FMOLS stands at 0.85, indicating that 85% of the changes in greenhouse gas emissions are accounted

Table 9: Cross-sectional dependence test

Residual cross-sectional dependence test Null hypothesis: No cross-sectional dependence (correlation) in residuals			
Test	**Statistic**	**d.f.**	**Probability**
Breusch-Pagan LM	4.374380	3	0.2238
Pesaran scaled LM	0.561088		0.5747
Pesaran CD	1.782981		0.0746*

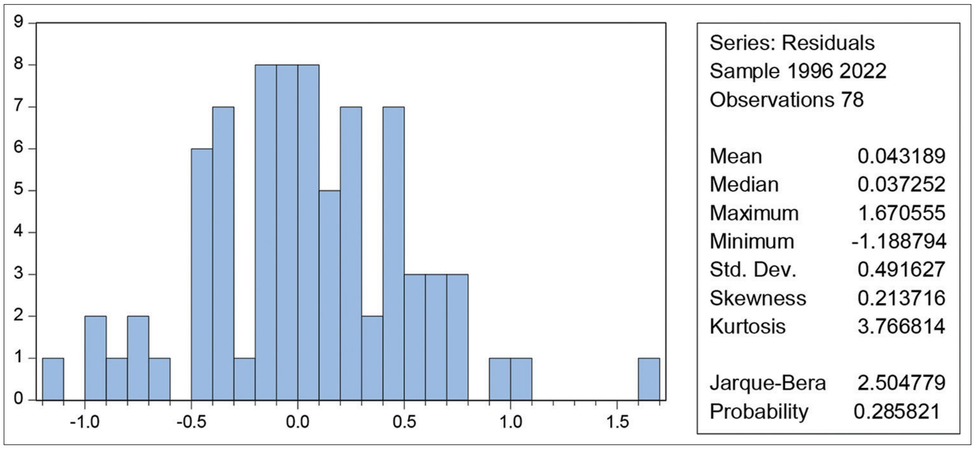
Source: Author's computation (***), (**), (*) significance at 1%, 5% and 10% respectively

Table 10: FMOLS and DOLS robustness check

Variables	Panel FMOLS		Panel DOLS	
	Coefficient	Probability	Coefficient	Probability
LETX	0.537581	0.0000***	0.686725	0.0000***
LPOP	0.340963	0.0968*	0.828363	0.0138**
LTO	0.015357	0.1087	−0.008248	0.4582
LRE	0.191428	0.0049***	−0.045140	0.6782
LEG	0.137049	0.0000***	0.037613	0.4591
R^2	0.846670		0.983427	
Adjusted-R^2	0.838268		0.946516	

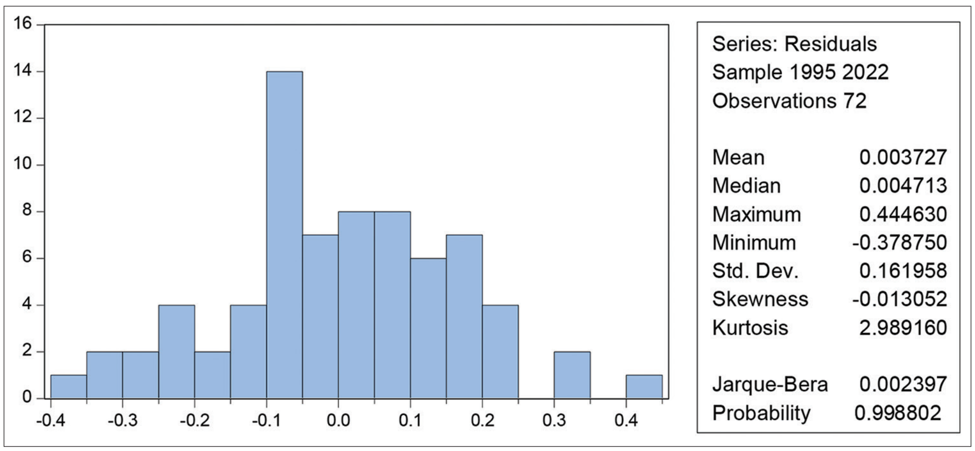
Source: Author's computation (***), (**), (*) significance at 1%, 5% and 10% respectively

Figure 3: FMOLS histogram normality test



Source: Author's computation

Figure 4: DOLS histogram normality test



Source: Author's computation

for by the model over the long term. The R-squared value of the DOLS models is 0.98, indicating that 98% of the fluctuations in greenhouse gas emissions in the short term are accounted for by the model. The research proceeds to carry out the diagnostics for both models as detailed in Section 4.7.2 below.

4.7.2. Diagnostics check

The study performed a residual normality test for the FMOLS and DOLS model to check the normality of the residuals from the estimated models as shown in Figures 3 and 4 above. The results of the histogram normality test have a Jarque-Bera statistic of 2.50 and 0.002 with probability values greater than 0.05. This entails that we fail to reject the null hypothesis that the residuals from the FMOLS and DOLS models are normally distributed and reliable for policy formulation. The study continues to offer conclusion and policy recommendations as given in Section 5 below.

5. CONCLUSION, RECOMMENDATIONS AND LIMITATIONS

This study utilized panel data From Brazil, China, and South Africa, to investigate the impact of environmental tax on reducing greenhouse gas emissions in selected BRICS nations utilizing data from 1995 to 2022 utilizing panel estimation techniques such as PARDL, FMOLS, and DOLS models. The findings indicate that environmental taxes can be an effective tool in reducing greenhouse gas emissions, but their effectiveness varies across countries due to differences in policy design, economic structure, and institutional capacity. The main takeaways from the findings are that environmental taxes are effective in reducing greenhouse gas emissions in the short run in Brazil and China, however, for South Africa, they are not. Furthermore, renewable energy is also effective in reducing greenhouse gas emissions in the short run in Brazil and China, however, for South Africa it is ineffective.

This study has raised interest and debate among scholars, researchers, policymakers, and governments. This study performed a comparative analysis of country-by-country for Brazil, China, and South Africa. Contrary to the existing literature, the findings revealed unexpected insights, provoking a reassessment of the current theories on the impact of environmental taxes on reducing greenhouse gas emissions. Contradictory patterns emerged within the data, challenging the initial assumption from the literature that environmental taxes are effective in reducing greenhouse gas emissions.

Based on empirical evidence, the study makes the following recommendations. Firstly, the contradicting results between the short-run heterogeneous impact of environmental tax and that of the long run imply that there is a need for a differentiated approach when it comes to structuring and implementation of environmental taxes in these selected BRICS nations. There's a need for Brazil to align the fossil fuels tax rate with international standards and expand the scope of environmental taxes to include other pollutants. China needs to implement a national carbon tax to replace existing regional schemes and increase public awareness and engagement on environmental taxation. South Africa needs to develop a green finance framework to support low-carbon investments, introduce a carbon tax on fossil fuel combustion, and enhance public education and participation in environmental taxation.

Secondly, the impact of renewable energy that is heterogeneous among these selected BRICS nations needs to be harmonized. China needs to allocate revenue to support renewable energy investments and green infrastructure though it leads globally in renewable energy capacity, with solar and wind power. South Africa should increase investment in renewables to meet its goal of 20% of total electricity generation by 2030 though solar and wind power are the primary drivers of renewable energy growth. Brazil leads in hydropower dominating its energy mix, it should also allocate finance to solar and wind to diversify its renewable energy mix.

Thirdly, economic growth has indicated that it does not necessarily lead to increased greenhouse gas emissions. Brazil, China, and South Africa demonstrate a decoupling of economic growth from emissions from the results of the PARDL long run, FMOLS, and the DOLS results being insignificant. Though this is the case, these countries need to encourage international cooperation and knowledge sharing in sustainable economic growth practices. This will help integration with other climate policies such as Sustainable Development Goals, the Kyoto Protocol, the Paris Agreement, and net zero by 2050.

The study acknowledges its limitation in that it does not include India and Russia in its analysis due to the lack of observation of environmental taxes and carbon emissions data. The challenges are that it is difficult to isolate the impact of environmental taxation from other climate policies where there is limited generalizability to other emerging economies and the availability of data varies across countries. The study has achieved its objective by deploying the panel ARDL, FMOLS, and DOLS model and found that the impact varies in the short run while it's the same in the long run of environmental taxes on reducing greenhouse gas emissions in these selected BRICS nations. The study therefore recommends that in the future, researchers must consider other models and develop a comparative analysis of environmental taxation across emerging economies.

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