

Research article

Green industrial transition: Leveraging environmental innovation and environmental tax to achieve carbon neutrality. Expanding on STRIPAT model

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ABSTRACT

Anthropogenic global warming strategies on carbon mitigation are driven by encouraging green innovation and using carbon taxes, yet an empirical model to validate this is non-existing. Moreover, the existing stochastic effects by regression on population, wealth, and technology (STRIPAT) model has been found to lack policy tools on taxes and institutions that cut carbon emissions. This study amends the STRIPAT model with environmental technology, environmental taxes, and strong institutional frameworks to create a new model STIRPART (stochastic impacts by regression on population, affluence, regulation, and technology) to understand the factors impacting carbon pollution using the emerging 7 economies. Using data from 2000 to 2020, the Driscoll-Kraay fixed effects are employed in this analysis to conduct evidential tests of the impacts of environmental policies, eco-friendly innovations, and strong institutions. The outcomes indicate that environmental technology, environmental taxation, and institution quality decrease E7's carbon emissions by 0.170%, 0.080%, and 0.016%, respectively. It is recommended that E7 policymakers should adopt the STIRPART postulate as the theoretical basis for policies favoring environmental sustainability. The key contribution is the amendment of the STRIPAT model and the enhancement of the market-based mechanisms, such as patents, strong institutions, and carbon taxes, to enable environmental policy to be carried out sustainably and cost-effectively.

1. Introduction

A necessary need for the near future is industrial transition endorsing eco-friendly production and consumption patterns (Ofori et al., 2023a, 2023b, 2023c). Although organizational and technological improvements may have a huge positive impact, complementary strategies are crucial given the delayed worldwide transmission of new ideas (Chen and Lee, 2020; Churchill et al., 2019). According to theory, the most cost-effective methods to support technological breakthroughs may be found in environmental taxes. This is not a brand-new realization, and several governments in emerging economies claimed they would

introduce comprehensive adjustments to the green tax system. Based on such premise, this essay examines the little advancements in environmental technology usage, taxation, and institutional quality that create a favorable atmosphere for all such attempts to succeed. As an alternative to the traditional model of environmental pollution abatement, this study expands on the prior STRIPAT model.

1.1. Background

Many countries, even emerging ones, see industry as one of the most crucial factors in bolstering their economies. However, without the necessary environmental measures and laws, industrial operations

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Nomenclature

STRIPAT	stochastic impacts by regression on population, affluence, and technology
SDG	Sustainable Development Goals
INDCs	Intended Nationally Determined Contributions
CO ₂	Carbon emissions
OECD	Organisation for Economic Co-operation and Development
STIRPART	stochastic effects by regression on population, affluence, regulation, and technology
IPAT	Impact, Population, Affluence, and Technology

might result in massive waste production, resource exploitation, and excessive energy use (Pedota and Piscitello, 2022). Those environmental concerns have led to several treaties seeking the best approach to tackle such a dilemma (SDG, 2019) as governments are being pressured to incentivize the industry to adopt sustainable manufacturing techniques and procedures quickly (Cheng et al., 2021). Again salient questions about whether sustainable development strategies burden or benefit a nation have been raised in the recent literature. This led this study to ask what novel approaches are best to lead emerging countries unto the path of carbon Neutrality.

Literature indicates the main drivers for reducing global warming trends and redefining carbon abatement techniques are the effective execution of environmental rules and acceptance of green technology (Chen et al., 2021; Ofori et al., 2023a, 2023b, 2023c). However, these variables differ across nations; therefore, their evaluation of carbon reduction is restricted. Intended Nationally Determined Contributions (INDCs), national plans that detail mitigation measures for tackling the difficulties of climate change concerns in the Paris Agreement, have been filed by governments worldwide. Even if they still lack information, these INDCs are the greatest means to comprehend a country's climate action beyond 2020 (Pradhan et al., 2017). The current study intends to quantify the impact of environmental legislation and green innovation on emerging economies that are the spur for economic growth but have already started seeing evidence of environmental Kuznets curve (Ansari, 2022; Anwar et al., 2022).

The ambitious target for the emerging economy and industrial sector would generate more industrial waste and pollution (Wan et al., 2022). Without constraint and novel environmental regulation of resources, the industry may be reluctant to transition to low-carbon production patterns and adopt abatement reduction technology unless there is a compliance requirement (Abbas et al., 2022; Jin et al., 2019; Ofori et al., 2023a, 2023b, 2023c). However, Prospective sectors may have trouble with the unavoidably strict environmental regulatory policies since rising levels of environmental policy stringency result in increased costs for compliance operations (Wang et al., 2019). As such, there is a need to properly augment such policies into emerging economies which literature seem to have neglected. Environmental preservation and industrial growth are hot topics among academics and professionals. Many solutions for sustainable development, including technological advancement, market-based instrument structure change, energy transition, and others, are developing while keeping the traditional core objective of industrialization in mind. Due of the initial investment required by these tactics, businesses are less willing to adopt them, particularly in developing nations.

A model that best incorporates several factors into the carbon neutrality and environmental debate is the stochastic impacts by regression on population, affluence, and technology (STIRPAT) model (Li et al., 2023a; York et al., 2003). It provides a multivariate approach to ascertaining the drivers of carbon emissions; however, it still offers some shortcomings as technology was not the main focus (Yang et al.,

2023; York et al., 2003). Also, it fails to show which type of technology is best to tackle the environmental risk associated with the production pattern.

Due to the growth of human civilisations and the development of new technologies, there is a tremendous strain on the environment's resources (Gyamfi et al., 2022; Ofori et al., 2023a, 2023b, 2023c; Raman et al., 2022). The environmental effect of industrial processes is decreased by technological advancement (Hassan et al., 2023; Wang et al., 2023a). Technology makes inexpensive renewable energy possible (Li et al., 2023b). However, despite significant green technologies (Li et al., 2021b) and worldwide technological advancement, the global temperature has exceeded the 1 °C threshold relative to pre-industrial levels in 2017 (Nikzad and Sedigh, 2017). This is because traditional technologies are still in play, and literature has failed to expressly show which form of technology (either traditional technology or green technology) is efficient within the current dispersion.

In recent years, the importance of technological innovation in addressing long-term environmental issues such as climate change has increased (Chen et al., 2023; Dong et al., 2022; Ofori et al., 2023a, 2023b, 2023c). However, simulations from sources such as Stern (2006) and IPCC (2018) Report indicate that significant emissions reductions are necessary, and the international targets being discussed may be unworkable without sacrificing future economic growth. In this context, environmental innovation is anticipated to become crucial in finding a solution to this challenging problem (Zhongming et al., 2018). One example of environmental innovation is the creation of catalytic converters (Cerruti et al., 2023), which are installed in automobiles to reduce the pollutants they produce. However, such innovations are often the result of a complex process, and adopting current methods and technologies can also benefit the environment. While technological innovations such as 3D printing have led to less waste in production, they are not always intended to improve the environment but to maximize profits. Despite the many advantages of environmental innovation, implementing such improvements can be challenging. Nevertheless, a combination of technological and environmental innovations will be essential in achieving the necessary emissions reductions and creating a sustainable future for the planet.

Therefore, it is no longer desirable to rely exclusively on technology (traditional or environmental) to help the environment; instead, it is imperative to explore other alternatives that can reduce environmental risk. As a result, another complementary market base instrument is the environmental tax which offers a double dividend benefit within the socio-economic debate (Andersen, 1994; Bosquet, 2000; Dogan et al., 2022). Compared to other pollution abate policies, environmental taxes offer compelling benefits. First, taxes provide a framework to induce good "environmental practice (Liu and Ge, 2023); second, they provide an incentive to incorporate modern technological processes that increase efficiency and energy conservation (Dogan et al., 2023; Nchofoung et al., 2023); third, they offer substantial opportunities to managers (producers) to choose where pollution abatement must be implemented (Abbas et al., 2023), thereby contributing to reducing environmental damage at the lowest economic cost; and finally, taxes provide new revenue that can be used to subsidize environmental, technological innovation (Li et al., 2021a). Environmental taxation is an indirect instrument that authorities employ to encourage businesses to choose the "correct" technologies, as opposed to, say, banning the utilization of specific technologies (Alola et al., 2023; Sharif et al., 2023). The present research aims to investigate the capabilities and constraints of this instrument, as well as connected tools like subsidies and rebates. The study wants to know: Under what circumstances might a certain technology decision be induced? What are the environmental repercussions of these instruments?

The history and extensive expertise with environmental taxes normally found in industrial economies are not present in emerging countries (Cheng et al., 2022; Yunzhao, 2022). However, interest in problems connected to the application of environmental taxation in E7 has

intensified since the government proclaimed its intention to utilise environment taxes to supplement existing pollution abatement initiatives. As such, an effective government has established a tax review committee in these nations first to evaluate the merits of environmental taxes and the degree to which the taxes can contribute “to wider economic and social goals” and second, suggest potential changes to the current tax structure as they see fit. It is on this merit that this study finds novelty as it offers new strategies emerging economies can access to navigate toward the carbon neutrality objectives,

Though the aforementioned shows evidence of copious work to reduce carbon emissions. Some pertinent gaps can still be pointed to. In particular, earlier research did not take the impact of environmental innovation into account independently. Furthermore, to the best of the authors' knowledge, no study has included any kind of policy tools in the STIRPAT framework, neither market-based nor command-and-control. Regulation, however, is one of the most significant variables that may affect carbon emissions, and rules and policy changes may impact the level of technology and its results (Kemp, 2000). Therefore, it is anticipated that regulation and CO₂ emissions have a negative connection comparable to that of environmental innovation. The authors suggest using the stochastic effects by regression on population, affluence, regulation, and technology (STIRPART) framework instead of the conventional STIRPAT model to analyse the variables impacting carbon emissions in light of this research gap.

The following important research topics are addressed by this study:

1. What effects do climate change legislation and technological advancements have on carbon emissions in the context of emerging nations? Do green technologies, as opposed to conventional ones, considerably affect the decrease of carbon emissions? If so, how much more so?
2. Do environmental measures like environmental tax work to reduce carbon emissions? If so, how much, if at all?
3. As to how these policy augmentations be implemented, as a whole or in partial?
4. Does Governance play any role within the policy implementation, and to what extent? More specifically, which governance indices (either institutional quality, political Governance, or economic Governance are essential within the carbon neutrality agenda?
5. What role do transitions such as structural change and clean energy offer in improving the STIRPAT Model

This research offers a numerical measurement to address these questions.

The primary contributions of this work are listed below. 1). First, the results may help emerging country policymakers determine if the decreasing impacts of environmental tax and green technology innovation are “smaller” than the rising effects of population growth and economic prosperity on pollution emissions. For the effects to be responsive to carbon reductions, governments must create policies encouraging efficient green technology and complementary carbon price schemes. 2). Second, this analysis separates the impact of conventional innovation from that of eco-friendly innovation on decarbonisation in the STIRPAT model using patent data (i.e., innovations that produced with the intended goal of reducing environmental risk; henceforth termed non-environmental innovation or traditional technology in this paper). Previous research has not used the STIRPAT model to evaluate the hypothesis of the differing effects of environmentally friendly innovation versus non-environmental or conventional innovation (Acemoglu et al., 2016; Ahmad and Zheng, 2021). The research also investigates how regulation affects emission reductions. In addition to population, wealth, and conventional technology, the authors think that regulation is an essential factor that influences carbon emissions. Thus, a substantial methodological advance is made to calculate carbon reductions by extending the current STIRPAT model to the STIRPART model. The numerical measurements may inform the relevant

policymaking circles of emerging countries from the STIRPART model.

2. Theoretical underpinnings and empirical review

The STIRPAT model (York et al., 2003), initially built on the IPAT model (Impact, Population, Affluence, and Technology) is employed as the theoretical Framework. The IPAT model provides an advanced premise to determine the driver of environmental grounds (Dietz et al., 2007; York et al., 2003). The key strength of the IPAT lies in its grounding in ecological principles coupled with its ability to illustrate how changes in driving forces are likely to alter impacts. A drawback of the IPAT model is its assumption that only fixed proportionality variation occurs between effects and factors. Also, the IPAT model escapes the possibility of non-proportional and non-monotonic effects. To overcome these limitations, the IPAT was reformulated into a stochastic model called STIRPAT to capture the stochastic impacts by regression on affluence, population, and technology. Several scholars expanded the STIRPAT model by incorporating other proxy variables to explore how many factors affect the environment. For instance, Jin et al. (2019) use the STIRPAT model to examine the effect of innovation on green total factor efficiency. The STIRPAT model was used by Tian and Zhou (2019) to investigate the factors influencing China's eco-efficiency at the prefectural city size. The STIRPAT model was also used by (Ahmad et al., 2021) to examine the relationship between environment, wealth, population, and technology across 27 Chinese provinces. As a result, the study uses the STIRPAT model to examine how technological innovation in China has affected eco-efficiency.

But as with every model, there are susceptible to shortcoming, especially when new variations are identified and missing within earlier concepts. The main drawback of the current STIRPAT model or its variations is the absence of policy tools that cut carbon emissions within the model specification, as was mentioned in the introduction's gaps. In addition, there is a lack of institutions with high standards that provide an atmosphere conducive to the synthesis and synergy of all the elements. Additionally, the STIRPAT model does not discriminate between new and old technologies. Understanding the efficacy of mitigation techniques is equally important to comprehend the effects of carbon emissions on climate change and the ecosystem. The current STIRPAT paradigm is unable to do this. Therefore, the study suggests the STIRPART model, which takes into account both tax policy and institutional quality, as well as the different impacts of environmental technology.

2.1. Premise for environmental innovation as against non-environmental technological (traditional innovation)

The advancement of developing industries, as well as the creation of innovations for environmental protection in industrial businesses, are all facilitated by technological innovation (Kaletnik and Lutkovska, 2020), which is a key aspect in the development of a nation that values innovation. This will have an impact on how well natural resources are used. Achieving sustainable development depends critically on the deployment of environmental technologies and environmental control (Capasso et al., 2019; Sahoo et al., 2022). As such most emerging economies' governments have also prioritised green development; in the case of China, a classical emerging country, policymakers offered many policy strategies to achieve green growth. One such policy plan is the “13th Five-Year Plan,” which intends to foster innovation, co-operation, green opening, and sharing (Fan et al., 2019; Hong, 2017).

The theme of “innovation” is seen as critical in resolving environmental problems at the source of production, reducing energy consumption, and realising green economic development (Ofori et al., 2023a, 2023b, 2023c; Perez, 2016). However, innovation has some shortfalls as they are not intended to tackle environmental risk but to aid in productivity –which sometimes leads to abatement of waste and reduction of by-products like carbon emissions. However, to cure this shortfall, new and improved innovations have been introduced termed

environmental technology (Huo et al., 2023), which are targeted at attending to the bane of the environment. as such, this study will try to express the dichotomy between the two and access it relation on environmental sustainability (Yasmeen et al., 2023).

2.1. Environmental innovation and non –environmental innovation (Technological innovation on environmental sustainability)

The relationship between environmental and technological innovation has been the subject of much research, yet academics still see it as a mystery (aforementioned explanation). Production innovation and green innovation are the two primary categories of technological innovation (Jiang et al., 2023; Long et al., 2018). Green technology often reduces environmental pollutants and increases environmental efficiency (Ren et al., 2022). Patents that are connected to energy or the environment are recognized as green technical innovations, according to the definition of the “green patent” provided by (OECD, 2016) and adopted by (Bannerman, 2012). Numerous studies supported this green technology’s beneficial impact on eco-efficiency or energy intensity (Chen et al., 2022; Ye et al., 2022). The use of fossil fuels and environmental degradation, on the other hand, may rise when technology is energy-biased, which will reduce eco-efficiency. According to (Godil et al., 2021), technological innovation in Chinese industrial sectors was skewed towards reducing carbon emissions and energy utilization.

Additionally, technological advancement may have positive feedback on energy efficiency (Ganda, 2019). When technological advancement increases the effectiveness of energy use, it may encourage economic expansion and raise the demand for energy (Zhang et al., 2022). It eventually worsens the quality of the environment and has a detrimental impact on the advancement of eco-efficiency. carbon emission but often has been used for such endeavors. Therefore its efficiency has been called to order, especially with emerging states.

2.2. Environmental regulation supports traditional policies to promote environmental sustainability

A variety of sectors have created alternate pollution-abatement technologies (Anderson, 2001; Golinelli, 2022; Ofori et al., 2023a, 2023b, 2023c), the majority of which need substantial upfront capital expenditures and usually raise volatile production costs as well (Sadiq et al., 2022; Zakari and Khan, 2022). As a consequence, given the current pricing, the investment in such technologies is sometimes not justifiable on economic grounds alone (Zhang et al., 2022). Therefore, it is necessary for regulators to make use of the resources at their disposal to encourage the use of green technology. These instruments include cap-and-trade systems, environmental taxes, penalties, subsidies, and consumer refunds, among many more. However, the study dictates the payment of an exclusive concentration on environmental tax (Bashir et al., 2021, 2022; Bosquet, 2000).

Environmental taxation is an indirect instrument that authorities employ to attempt to encourage businesses to use the “right” technologies (Abbas et al., 2022), as opposed to, say, banning the use of particular technologies. Environmental taxes undoubtedly have certain disadvantages. The most crucial aspect is how they affect distribution: this seeks to discover a strategy to lessen the possible regressivity of such taxes (Cheng et al., 2022; Ciaschini et al., 2012). Additionally, since each country only contributes a minor amount to global emissions, the issue of CO₂ buildup has to be addressed globally. However, it now does not seem easy to obtain a global consensus over the administration, implementation, and source of usage of tax revenue.

2.3. Gap in literature

A Plethora of work has been done showing commitment to achieve Carbon neutrality, but recent Cops 17 still showed the world is far from reaching the goal ending 2023 (Ofori et al., 2023a, 2023b, 2023c). A quick assessment of the literature shows the effects of several policy

tools on carbon neutrality. Yet, the magnitude and direction of these repercussions are uncertain. Lacking in developing existing hypotheses and jumping on the latest trend There is space for policy incoherence because the STRIPAT model’s technology metric is never completely developed as either traditional innovation or environmental technology. This raises the following important issue for decision-makers: What exactly are the carbon neutrality targets measuring, and why do the policy tools behave differently depending on the situation? Two research gaps were found in the current study as a result of these two questions: The current study aims to build a framework for policy that will allow the STRIPAT MODEL to be expanded.

3. Methodology

3.1. Conceptual framework

This study extends the STIRPAT model to include policy tools that account for environmental technologies, environmental taxes, and institutional quality to create the STIRPART model to investigate how these mechanisms contribute to cutting carbon emissions. Environmental technologies have been included to account for how new technologies could be used to address and manage environmental risk concerns. Environmental tax, a market-based tool with the potential to enhance the policies for reducing pollution, provide an additional role of encouraging compliance (Bosquet, 2000), and provide the funding required to launch green initiatives (Doğan et al., 2022) has been considered. Another advantage of environmental taxes is their ability to provide opportunities to bring about structural change as businesses will switch to environmentally friendly manufacturing methods and low-carbon industrial areas to lower their tax burden (Adebayo et al., 2022). For all the above considerations to be efficient, an enabling environment is needed, and this is created by Governance. As such, the role of government cannot be overlooked within the policy augmentation on achieving carbon neutrality targets. Based on the aforementioned premise, Fig. 1 presents the STIRPART model

3.2. Model

The model employed in this section has been modified from prior studies (Hashmi and Alam, 2019; Lin and Zhai, 2023; Opoku-Mensah et al., 2021; Wang et al., 2023b).

The expanded STIRPART (Hashmi and Alam, 2019) model’s multiplicative functional form is stated as follows:

$$I_{it} = \varphi P_{it}^\alpha A_{it}^\beta T_{it}^\gamma E_{it}^\delta R_{it}^\epsilon Q_{it}^\zeta G_{it}^\eta \quad (1)$$

Where I refer to environmental risk, P is a population measure using urbanization, A represents income, and T stands for conventional technology. Environmentally technology is represented by E, environmental regulation in the form of environmental levies is represented by R. G represents institutional quality and structural change is represented by S. Each variable’s subscript *i* or *t* stands for the cross-sectional unit or time period, respectively. are the parameters that need to be estimated. The constant term is φ , and the residual term is $\varphi \delta \sigma \cup \infty \cap \exists$.

3.2.1. Specific model simulation

Equations (2)–(7) becomes as follows when both sides are subjected to the natural logarithm (ln): except for institutional quality.

$$\text{Model 1} - \ln I_{it} = \beta_0 + \beta_1 \ln P_{it} + \beta_2 \ln UR_{it} + \beta_3 \ln GDP_{it} + \beta_4 \ln TI_{it} + \beta_5 \ln REN_{it} + \beta_6 \ln SER_{it} + \beta_7 \ln Q_{it} + \varepsilon_{it} \quad (2)$$

Model 1 takes the form of the traditional STRIPAT model with control variables. ie. Urbanization (ur) is used to express population, GDP represents affluence, and Ti represents traditional technology which the study argue is Non-environmental technology. This is controlled for by renewable energy(ren), structural change(ser), and institutional quality

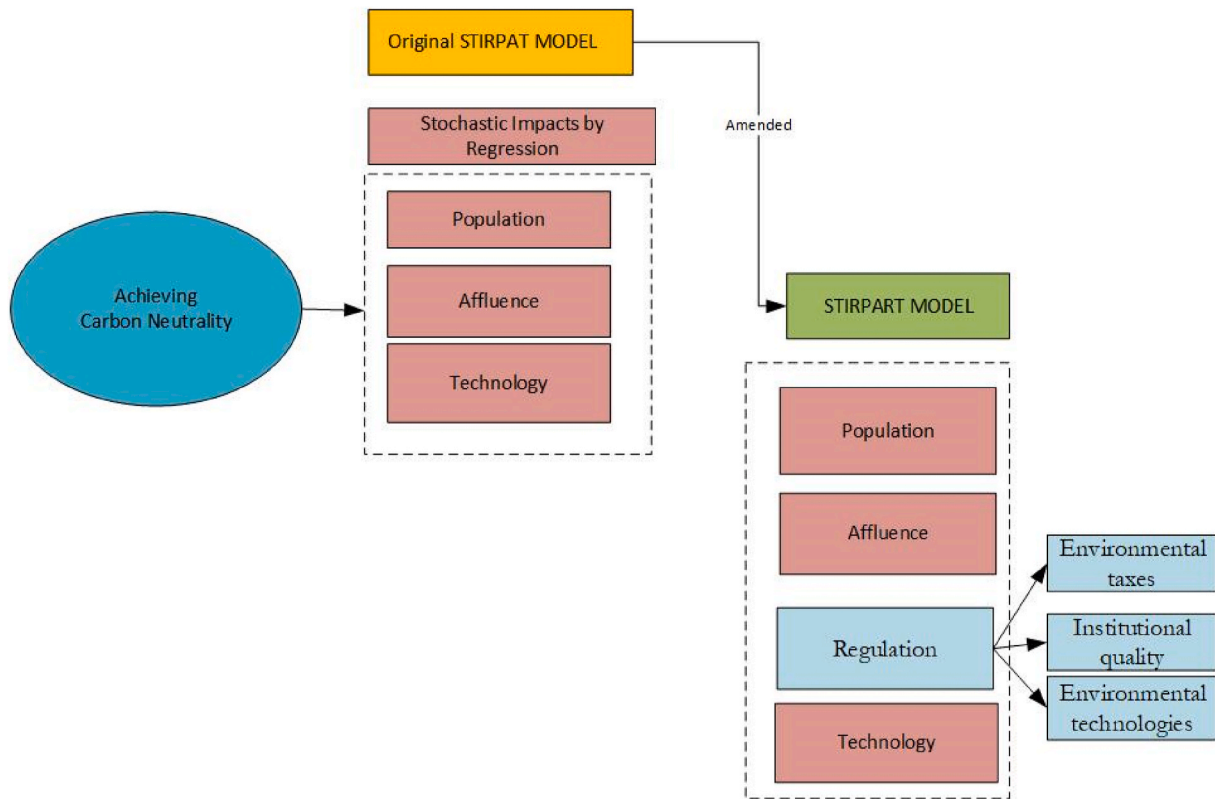


Fig. 1. Research framework.

(IQ).

$$\text{Model 2} - Ep_{it} = \beta_0 + \beta_2 UR_{it} + \beta_3 GDP_{it} + \beta_4 TI_{it} + \beta_5 ENTECH_{it} + REN_{it} + \beta_8 SER_{it} + \beta_9 IQ_{it} + \varepsilon_{it} \quad (3)$$

Model 2 assumes that traditional innovation has shortcomings as it is a direct duty to seek productivity and not directly promote environmental sustainability. To cure these mishaps, the study introduced environmental technology.

Assumption 1. Environmental technology is complementary to traditional innovation and induces environmental sustainability

$$\text{Model 3} - Ep_{it} = \beta_0 + \beta_2 UR_{it} + \beta_3 GDP_{it} + \beta_4 TI_{it} + \beta_6 ENVTAX_{it} + \beta_7 REN_{it} + \beta_8 SER_{it} + \beta_9 IQ_{it} + \varepsilon_{it} \quad (4)$$

Model 3 takes on the assumption that environmental regulation can augment the STRIPAT model to promote environmental sustainability. As such environmental tax is used to represent regulation towards curbing excess carbon production from firms.

Assumption 2. Environmental regulation in the form of environmental tax augment the traditional route to reduce environmental pollution

$$\text{Model 4} - Ep_{it} = \beta_0 + \beta_2 UR_{it} + \beta_3 GDP_{it} + \beta_4 TI_{it} + \beta_5 ENTECH_{it} + \beta_6 ENVTAX_{it} + \beta_7 REN_{it} + \beta_8 SER_{it} + \beta_9 IQ_{it} + \varepsilon_{it} \quad (5)$$

Model 4 Takes on the combined assumption that environmental technology and environmental regulations provide the best route to promote environmental sustainability.

Assumption 3. Environmental technology provides additional support for traditional technology and environmental regulation as tax provides a compelling basis for firms to take up a sustainable practice.

3.2.2. Introduction of interaction terms

The interaction terms take the position of the presence of green Governance that takes particular interest in promoting environmental technology and environmental tax with the prospect of reducing environmental pollution.

$$\text{Model 5} - Ep_{it} = \beta_0 + \beta_2 UR_{it} + \beta_3 GDP_{it} + \beta_4 TI_{it} + \beta_5 IQ * ENTECH_{it} + \beta_7 REN_{it} + \beta_8 SER_{it} + \beta_9 IQ_{it} + \varepsilon_{it} \quad (6)$$

Model 5. Governance takes particular interest in environmental technology

$$\text{Model 6} - Ep_{it} = \beta_0 + \beta_2 UR_{it} + \beta_3 GDP_{it} + \beta_4 TI_{it} + \beta_6 IQ * ENVTAX_{it} + \beta_7 REN_{it} + \beta_8 SER_{it} + \beta_9 IQ_{it} + \varepsilon_{it} \quad (7)$$

Model 5. Governance takes particular interest in environmental tax

$$\text{Model 7} - Ep_{it} = \beta_0 + \beta_2 UR_{it} + \beta_3 GDP_{it} + \beta_4 TI_{it} + \beta_5 IQ * ENTECH_{it} + \beta_6 IQ * ENVTAX_{it} + \beta_7 REN_{it} + \beta_8 SER_{it} + \beta_9 IQ_{it} + \varepsilon_{it} \quad (8)$$

Model 5. Governance takes particular interest in environmental technology and environmental tax

3.3. Data acquisitions and source

For the years 200–2020, a balanced panel dataset is built for emerging nations. The study concentrated on emerging economies since they are at the beginning of the environmental Kuznets curve and need the development of tools to either avoid or benefit from the early start of environmental restoration. Table 1 shows the variable definition and the sources of the variables. Except for the data for environmental tax and technology gathered from the OECD statistics (OECD, 2023), all other data are taken from World Development Indicators and world governance indicator for institutional quality (The World Bank, 2023) (see Table 2). The six indicators for institutional quality was transformed into an index

Table 1
Detailed variables –indices – sources.

Variable	Indices	Source
CO2 emissions (kg per 2015 US\$ of GDP)	EP	WDI
Urbanization growth (annual %)(	UR	WDI
GDP per capita per 2015 US\$	GDP	WDI
Technological innovation (sum of patent residents and nonresidents)	TI	OECD
Environmental Technology(all environmental patents)	ENTECH	OECD
Environmentally related tax per capita	ENVTAX	WDI
Renewable energy consumption (% of final consumption)	REN	WDI
Services, value added (constant 2015 US\$)	SER	WDI
Institutional quality Index	IQ	WDI

Table 2
Principal components/correlation.

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	2.966	1.780	0.494	0.494
Comp2	1.186	0.308	0.198	0.692
Comp3	0.877	0.276	0.146	0.838
Comp4	0.601	0.360	0.100	0.938
Comp5	0.241	0.111	0.040	0.978
Comp6	0.130		0.022	1.000

using Principal component analysis (pca) as seen in Table 3 and Table 4. Also a test was done to ascertain if the index expressed sufficient attribute from the six indicators as seen in Fig. 3.

3.4. Estimation procedure

In order to properly fit the model, a number of diagnostic tests are carried out. Prior to the deadline, we forecast new variables for the governance indicators using the principle component technique. Then displayed, a scree plot to demonstrate the reliability of the findings. The dataset was then subjected to the primary preliminary test,

1. Which looked for serial correlation, heteroscedasticity, time-fixed effects, and panel effects.

A)The CD test(Breusch and Pagan, 1980; Pesaran, 2004; Pesaran et al., 2008) was run to look into the influence of the variables' cross-sectional dependency. In other terms, the CD test investigates the country spillover effect. (b) The two second-generation unit root tests (Pesaran, 2007) were used. This is due to the possibility that using the first-generation panel unit root would result in false estimations; hence, (c) the Westerlund cointegration(Persyn and Westerlund, 2008) was utilised. The latter sought to determine if the long-run estimate was tenable. The cointegration analysis looks at the potential for long-term relationships between variables. High correlation coefficients between independent and dependent variables might indicate that the model has problems with multicollinearity. The study created a correlation matrix as a consequence to look for such a defect. Following the thorough first testing, we carried out the long-run parameter estimates. Then, the central hypothesis was tested using the Driscoll Kray standard error estimation fixed model(Driscoll and Kraay, 1998), and the comparative

Table 3
Principal components (eigenvectors).

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6	Unexplained
controlofc~e	0.530	−0.029	−0.113	0.178	−0.665	0.481	0.000
government~e	0.429	−0.397	−0.413	−0.182	0.601	0.306	0.000
politicals~i	0.258	−0.449	0.706	0.446	0.175	−0.068	0.000
regulatory~e	0.436	−0.037	0.295	−0.746	−0.169	−0.370	0.000
ruleoflaw~e	0.466	0.279	−0.340	0.424	0.070	−0.636	0.000
voiceandac~e	0.249	0.749	0.341	−0.016	0.363	0.358	0.000

Table 4
Scoring coefficients-sum of squares(column-loading) = 1.

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6
controlofc~e	0.530	−0.029	−0.113	0.178	−0.665	0.481
government~e	0.429	−0.397	−0.413	−0.182	0.601	0.306
politicals~i	0.258	−0.449	0.706	0.446	0.175	−0.068
regulatory~e	0.436	−0.037	0.295	−0.746	−0.169	−0.370
ruleoflaw~e	0.466	0.279	−0.340	0.424	0.070	−0.636
voiceandac~e	0.249	0.749	0.341	−0.016	0.363	0.358

analysis was performed using variance decomposition. This was done with the knowledge that Panel Data needs to be modified for heteroskedasticity and autocorrelation.

4. Discussion of findings

Table 5 shows the descriptive statistics we obtained (Fig. 2). To quantify multicollinearity, we next conducted a pairwise correlation study. From the analysis, there is a negatively significant relationship between all of the variables that were analyzed. All significant correlations between independent variables and CO₂ emissions are also demonstrated by the results (see Table 6).

4.1. Stationarity and cross-sectional analysis

The CD test was carried out during the estimate to check for a possible spillover impact among the key variables of concern. Changing one factor in one nation may have an effect on other factors in other countries, as suggested by indications of cross-sectional dependence between the research variables. The study concludes that cross-sectional dependence exists in the dataset since the CD test's anticipated factors are statistically significant (Table 7).

Additionally, an investigation into the dataset's integration order using the unit root test is shown (Table 8). All variables are shown to be stationary at the first difference, indicating that they are all of order I (1), as shown by the findings.

Next, the results of the slope confidence and the cointegration between factors are analyzed. The findings are shown in Tables 9 and 10 below.

4.2. Empirical analysis of the study

4.2.1. Bivariate result

The statistical correlations between various variables are often the main focus of traditional statistical analysis techniques. However, a single factor can cause industrial pollution. It can often be overlooked. To address this issue, a preliminary bivariate analysis is carried out to pinpoint each variable's unique impact on environmental degradation. As seen in Fig. 4. Environmental tax, Renewable energy, structural change, and institutional quality help reduce environmental pollution as against Urbanization, economic growth, and traditional innovation, which seem to have a positive relation with carbon emission. This is in tangent with earlier works like (Ofori et al., 2023a, 2023b, 2023c; Radmehr et al., 2022). However, environmental technology exhibiting a positive relationship was at variance with the literature, which either

Table 5
Descriptive statistics.

Variables	Obs	Mean	Std. Dev.	Min	Max	Skew.	Kurt.
LnEP	140	−0.433	0.582	−1.51	0.695	−0.174	1.934
LnUR	138	0.569	0.83	−4.062	1.459	−2.753	11.933
LnGDP	147	27.94	0.812	26.689	30.339	1.209	4.298
INTI	146	10.033	1.533	6.73	14.253	0.773	3.998
LnENVTECH	140	4.278	1.822	−0.693	8.684	0.088	3.136
LnENVTAX	91	0.238	0.63	−2.303	1.386	−0.449	5.051
LnREN	140	2.839	0.867	1.157	3.89	−0.556	2.247
LnSER	147	27.275	0.846	25.665	29.685	0.881	3.932
IQ	140	0	1.722	−4.215	2.815	−0.452	2.388

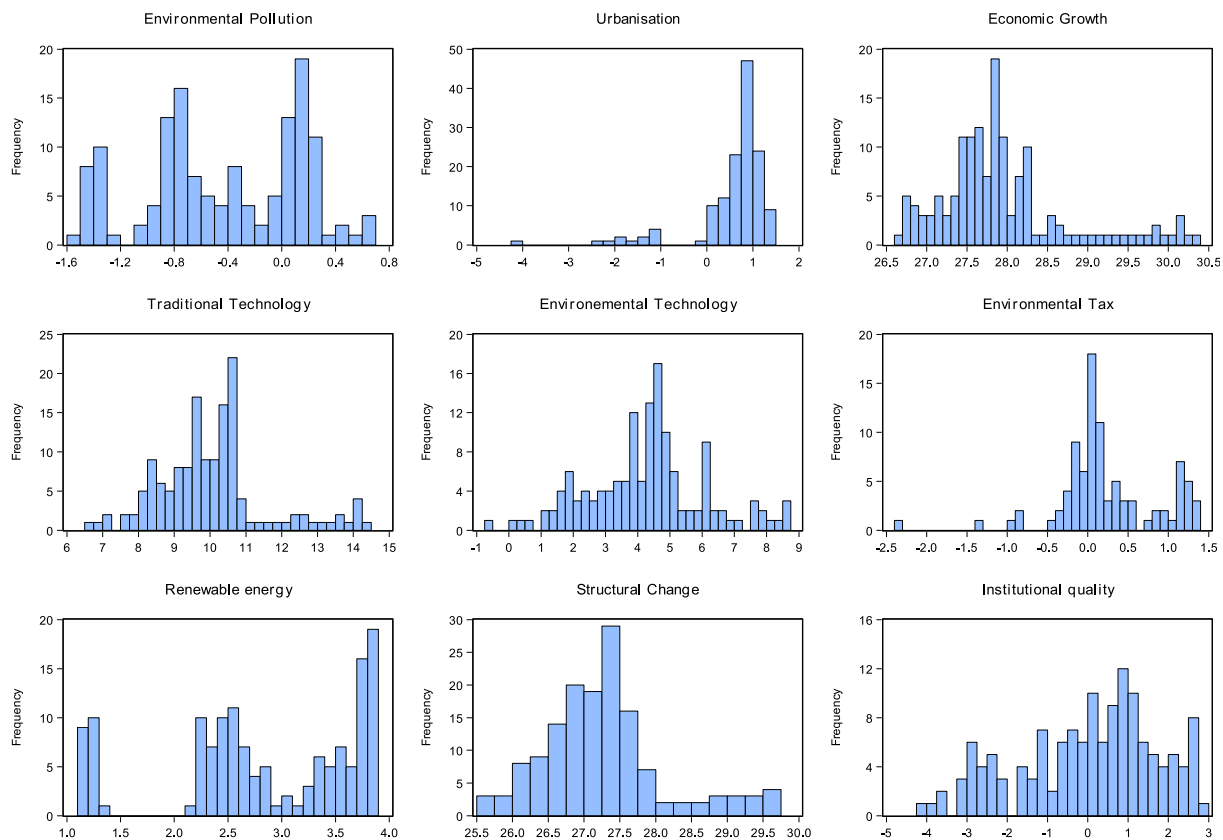


Fig. 2. The variable of interest normality graph.

dictates a biased result using the bivariate analysis or poor policy implementation of environmental technology. Leading to the use of a more robust analyzing for the hypothesis testing. However, this analysis gives credence to the sufficient ground to improve environmental regulation to help protect the environment as stipulated by (Gyamfi et al., 2022).

4.2.2. Multivariate analysis for the main hypothesis.

Table 11 show the baseline regression that analyzes the effects of urbanization, economic growth, conventional technological innovation, renewable energy, structural change, institutional quality, green environmental technology, and environmental tax on E7's carbon dioxide (CO₂) emissions using the Driscoll-Kraay's fixed-effect OLS technique. The analysis presented in Table 11 displays some intriguing results. Urbanization is seen to have a negative, significant connection with emissions for the E7 economies for all the models employed. Thus, as urbanization increases, pollution decreases by 0.097%, 0.036%, 0.416%, 0.456%, 0.077%, 0.455%, and 0.456%, respectively. The significantly negative long-run coefficients of the urbanization rate show that urbanization slows down carbon emissions and confirms the assertions made by (Danish et al., 2019) that urbanization increases

access to health care, pipeline water, efficient garbage disposal, and sustainable environments are supported by this evidence. Likewise, Sun and Huang (2020) confirmed an increase in urbanization to decrease carbon emissions by 0.637%. This result is also supported by both the urbanization's "agglomeration effect" and the urbanization's "scale effect" literature, Wang et al. (2021).

Furthermore, economic growth has been found to enhance pollution within the E7 economies and confirms the findings of previous studies such as Gyamfi et al. (2022), Salman et al. (2019), and Narayan et al. (2016). According to Opoku-Mensah et al. (2021), an increase in GDP raises pollution of AfCFTA countries due to the unchecked growth of the businesses that pollute the environment the most as they grow. The findings suggest that the E7 countries' faster economic growth is to blame for the economic pollution in the region.

Also, conventional technological innovation positively connects with pollution for the E7 economies. This finding contradicts the position of Churchill et al. (2019), who contend that technological progress can significantly cut CO₂ emissions. One possible justification is that if a country is to rapidly industrialize as a result of cutting-edge technological advancement, it would greatly increase the quantity of

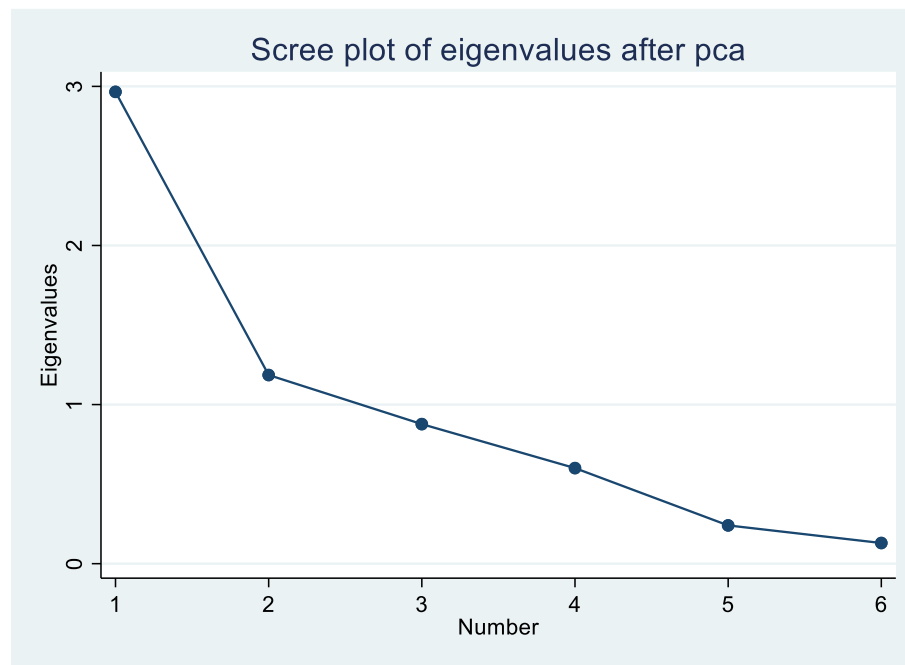


Fig. 3. Scree plot.

Table 6
Correlation analysis.

	lnep	lnur	lngdp	lniti	lnenvtech	lnenvtax	lnren	lnser	iq
LnEP	1								
LnUR	0.876***	1							
LnGDP	0.492***	0.385***	1						
INTI	0.518***	0.371***	0.979***	1					
LnENVTECH	0.649***	0.490***	0.892***	0.878***	1				
LnENVTAX	0.0237*	0.164	-0.394***	-0.469***	-0.183	1			
LnREN	0.216*	-0.349**	-0.0286	0.00251	-0.0194	-0.268*	1		
LnSER	0.391***	0.295**	0.992***	0.965***	0.849***	-0.419***	-0.0309	1	
IQ	0.520***	-0.369***	-0.522***	-0.539***	-0.496***	0.332**	0.0882	-0.496***	1

Table 7
Cross-sectional dependence test results.

Variables	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
LnEP	170.5146	23.0706	22.88639	9.997218
LnUR	189.2343	25.95911	25.78411	8.136714
LnGDP	397.7401	58.13227	57.95727	19.92443
INTI	246.1146	34.73594	34.56094	15.44244
LnENVTECH	261.5091	37.11135	36.92714	15.91998
LnENVTAX	28.28806	4.089333	3.964333	1.50071
LnREN	146.7841	19.40891	19.2247	8.213397
LnSER	408.2143	59.74846	59.57346	20.19285
IQ	184.893	25.28923	25.10502	-2.91833

manufactured goods available on the global market and thereby lessen the ecological damage caused by manufacturing in other countries. The current finding is supported by some existing studies of Chen and Lee (2020) for cross-national evidence and those of [Mughal et al. \(2022\)](#) for South Asia.

The study has found a statistically significant negative link between carbon emissions and the share of renewable energy in the total energy mix. This evidence is consistent with the findings of [Gyamfi et al. \(2022\)](#) for the E7 economies, and [Bekun et al. \(2019\)](#) for the EU countries and show emissions for the E7 economies are reduced for every percentage point increase in renewable energy. The finding confirms how switching from polluting energy sources (fossil fuels) to cleaner ones could reduce

Table 8
Panel Unit root test.

	CIPS		CADF	
	Level	1st Diff.	Level	1st Diff.
LnEP	-1.449	-2.716***	2.39	-2.816***
LnUR	-1.562	-3.558***	-2.279	-5.824***
LnGDP	-1.875	-3.683***	-0.315	-5.016***
LnTI	-1.944	-3.723***	-0.503	-5.120***
LnENVTECH	0.53	-5.456***	0.580	-2.92***
LnENVTAX	0.53	-5.456***	0.580	-2.92***
LnREN	-1.237	-3.599***	1.427	-4.801***
LnSER	-1.841	-3.934***	-0.221	-5.662***
IQ	-0.455	-3.330***	3.560	-4.109***

Table 9
Slope heterogeneity (SH) technique.

Test	Value	P-value
$\hat{\Delta}$	2.873**	0.004
$\hat{\Delta}_{adjusted}$	4.557***	0.000

environmental damage.

Carbon emissions are significantly and inversely related to structural change across all models and demonstrate that modifying E7's structure can lessen the region's environmental impact. Similar results were

Table 10
Conintegration test.

Kao cointegration	t-Statistic	Prob.
ADF	-1.442	0.014**
Residual variance		0.000
HAC variance		0.000
Westerlund cointegration		
Variance ratio	-4.486***	0.000

discovered in the research undertaken by Villanthenkodath et al. (2021) and Adebayo et al. (2022). The evidence suggests that structural change permits E7 economies to move from less polluting agriculture to more polluting secondary sectors and ultimately to the less polluting tertiary sector, a structural transition has major economic importance. The evidence shows that the E7's economy is primarily service-based and has substantially impacted the environmental impact.

This study has found that better institutions also lead to better environmental conditions. The findings corroborate with studies that have argued that enhanced ecological sustainability is a direct result of the positive feedback loop between greater IQ and the spread of economic freedom and market economies Bekun et al. (2021) and Appiah et al. (2023). By taking reducing corruption, enhancing laws, and strengthening the rule of law in E7's, CO₂ emissions could be dramatically reduced. The findings also give empirical evidence in favor of the argument that affective components promote the stringency of ecological standards and, thus, decrease pollution.

In addition, both environmental tax and green environmental technology have a significant negative connection with the E7's carbon emissions. The implication is that higher carbon taxes substantially reduce their intended effect on emissions. Scrimgeour et al. (2005) came to similar conclusions in their analysis that shifting carbon prices and

environmental levies could reduce CO₂ emissions. Likewise, Hsu et al. (2021) and Li et al. (2021)) have confirmed similar findings. Again, as environmental technology increases in the E7 economies, emission levels within the countries reduce, which confirms the findings of Sharif et al. (2023), Dong et al. (2022), and Hussain et al. (2022). This evidence translates to the continued appeal of highly efficient green technology investments.

Lastly, the interaction between IQ and environmental tax and IQ and green environmental technology show a negatively significant relationship with carbon emission for the E7 economies. This strongly suggests that improved government anti-corruption efforts can be supported by higher levels of institutional quality. The results show that high-quality institutions help fight corruption, which in turn helps stop tax evasion and improve environmental technologies, all of which are good for the environment.

4.3. Sensitivity analysis (using all governance components and categorising governance)

Because determining the precise relationship between governance indicators and pollution in the environment is critical, the government index in Table 12 is divided into economic, institutional, and political components to strengthen the based line technique. All of the findings are similar to those of the baseline technique. Urbanization, renewable energy, environmental tax structural changes, and green environmental technology all decrease carbon emissions for the E7 economies, while economic growth and conventional technological innovation also increase carbon emissions for the E7 economies.

The next outcome also indicates that institutional Governance enhances carbon emissions for the E7 economies. Thus, as observed in Tables 12, 1% enhancement of rule of law and corruption (institutional

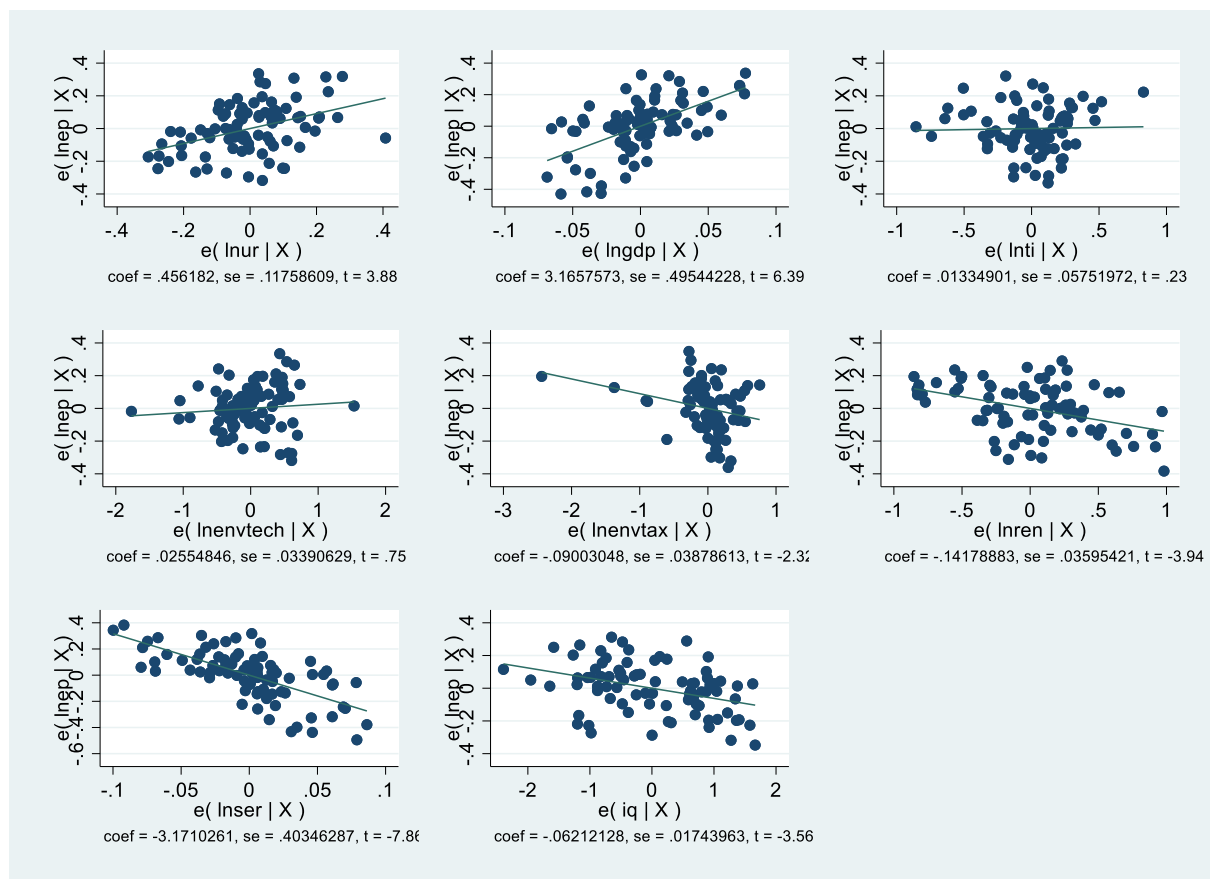


Fig. 4. Bivariate result of the interested variable on environmental pollution.

Table 11

Baseline regression using Driscoll and Kraay fixed effects.

	Interaction terms						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
LnUR	−0.097** (−2.18)	−0.036** (−0.96)	−0.416*** (−3.98)	−0.456*** (−3.88)	−0.077* (−1.95)	−0.455*** (−4.28)	−0.456*** (−4.22)
LnGDP	3.264*** (10.01)	2.655*** (9.46)	3.413*** (9.21)	3.166*** (6.39)	3.158*** (10.87)	3.334*** (9.33)	3.335*** (9.27)
LnTI	0.206** (1.41)	0.207** (1.73)	0.209* (0.16)	0.213* (0.23)	0.0296* (1.34)	0.217* (0.31)	0.214* (0.29)
LnREN	−0.326*** (−8.70)	−0.287*** (−9.18)	−0.146*** (−4.15)	−0.142*** (−3.94)	−0.315*** (−8.79)	−0.153*** (−4.63)	−0.153*** (−4.58)
LnSER	−3.191*** (−12.73)	−2.925*** (−13.96)	−3.367*** (−10.93)	−3.171*** (−7.86)	−3.048*** (−15.80)	−3.296*** (−10.88)	−3.297*** (−10.82)
IQ	−0.016* (−0.74)	−0.023* (−1.28)	−0.063*** (−3.63)	−0.062*** (−3.56)			
LnENVTECH		−0.170*** (−7.55)		−0.026* (−0.75)			
LnENVTAX				−0.090** (−2.32)			
IQ * LnENVTECH					−0.546*** (−2.61)		−0.657** (−0.04)
IQ * LnENVTAX						−0.128*** (−3.53)	−0.228*** (−3.23)
Constant	−4.713 (−1.40)	4.159 (1.38)	−3.886 (−1.55)	−2.528 (−0.82)	−5.571* (−1.71)	−3.723 (−1.57)	−3.727 (−1.56)
No. of Observations	125	125	83	83	125	90	90

Table 12

Driscoll-kraay fixed effects analysis showing the dynamism of green Governance toward Carbon neutrality.

	Institutional Governance		Political Governance		Economic Governance	
	Rullaw	cc	ps	voa	regq	goveff
Lnur	−0.288*** (−4.80)	−0.184** (−2.41)	−0.240*** (−3.53)	−0.256*** (−4.08)	−0.167** (−2.45)	−0.186*** (−3.90)
Lngdp	0.022** (0.14)	0.179** (0.95)	0.086*** (0.49)	0.077** (0.41)	0.043** (0.25)	0.003** (0.02)
Lnti	0.113** (0.93)	0.116* (1.06)	0.124** (1.20)	0.125** (1.31)	0.116** (0.68)	0.115** (0.32)
Lnenvtech	−0.025 (−1.69)	−0.033* (−2.09)	−0.046** (−2.11)	−0.018 (−1.26)	−0.018 (−1.38)	−0.029** (−2.13)
Lnenvtax	−0.037** (−2.65)	−0.036** (−2.36)	−0.030** (−2.11)	−0.032** (−2.32)	−0.034** (−2.79)	−0.037** (−2.53)
Lnren	−0.498*** (−8.34)	−0.498*** (−8.64)	−0.517*** (−8.89)	−0.505*** (−7.95)	−0.516*** (−10.33)	−0.515*** (−9.34)
Lnsr	−0.415** (−2.67)	−0.558*** (−2.94)	−0.308** (−1.54)	−0.377* (−1.97)	−0.464** (−2.53)	−0.395** (−2.36)
Rulelaw	−0.124** (−2.68)					
Cc		−0.098*** (−2.89)				
Ps			−0.075** (−2.53)			
Voa				−0.088** (−2.43)		
Regq					−0.119*** (−2.94)	
Goveff						−0.120** (−2.83)
Constant	13.405*** (16.34)	11.697*** (9.54)	12.481*** (8.3)	13.990*** (8.3)	12.907*** (8.3)	12.262*** (8.3)
No. of Observations	83	83	83	83	83	83
F Statistic	252.281	211.194	875.276	694.506	1716.2	255.382

Governance) raises 0.124% and 0.098% pollution levels for the E7 countries. Secondly, political Governance also mitigates E7's pollution level. When authority is given in these countries' governance systems, both political stability and the voice of accountability decrease pollution. Next, economic Governance also mitigates the carbon emissions of the E7 countries. This implies that economic Governance decreases carbon emissions by degrading ecological degradation via the rule of law and corruption.

4.4. Results of robust analysis using method of moment quantile

For the goal of examining the interactions at various quantiles of Pollutant emissions of the E7 nations, MMQR is also employed in supplementary to the panel estimates. The use of MMQR produced several intriguing findings outlined in Table 13. The moment-by-moment quantile regression is advantageous because it enables the evaluation of the covariance effects between Emission factors and their various interim heterogeneity (Sarpong et al., 2023), which proscribes the

Table 13
Robustness Test with the Method of moment quantile.

VARIABLES	location	scale	qtile_1	qtile_2	qtile_3	qtile_4	qtile_5	qtile_6	qtile_7	qtile_8	qtile_9
Lnur	-0.211*** (-3.081)	-0.0345 (-0.965)	-0.161** (-2.024)	-0.176** (-2.429)	-0.185*** (-2.640)	-0.196*** (-2.865)	-0.206*** (-3.015)	-0.222*** (-3.105)	-0.240*** (-3.042)	-0.248*** (-2.969)	-0.269*** (-2.754)
lngdp	0.0826 (0.384)	0.166 (1.482)	-0.159 (-0.380)	-0.0865 (-0.380)	-0.0454 (-0.206)	0.00731 (0.0339)	0.0565 (0.262)	0.136 (0.601)	0.219 (0.884)	0.260 (0.991)	0.359 (1.175)
lnit	-0.0135 (-0.658)	-0.00930 (-0.871)	5.82e-05 (0.00245)	-0.00402 (-0.185)	-0.00633 (-0.303)	-0.00928 (-0.455)	-0.0120 (-0.591)	-0.0165 (-0.771)	-0.0211 (-0.898)	-0.0234 (-0.938)	-0.0290 (-0.994)
lnenvtech	-0.0351* (-1.853)	-0.00643 (-0.651)	-0.0257 (-1.173)	-0.0286 (-1.426)	-0.0302 (-1.562)	-0.0322* (-1.711)	-0.0341* (-1.813)	-0.0372* (-1.884)	-0.0404* (-1.857)	-0.0420* (-1.819)	-0.0458* (-1.700)
lnenvtax	-0.0348** (-2.500)	-0.00103 (-0.142)	-0.0333** (-2.067)	-0.0337* (-2.295)	-0.0340** (-2.400)	-0.0343** (-2.488)	-0.0346** (-2.512)	-0.0351** (-2.428)	-0.0356** (-2.232)	-0.0359** (-2.118)	-0.0365* (-1.843)
lnren	-0.519*** (-9.146)	0.0137 (0.463)	-0.539*** (-8.202)	-0.533*** (-8.888)	-0.529*** (-9.163)	-0.525*** (-9.329)	-0.521*** (-9.260)	-0.514*** (-8.717)	-0.507*** (-7.800)	-0.504*** (-7.300)	-0.496*** (-6.143)
lnser	-0.477** (-2.553)	-0.138 (-1.422)	-0.276 (-1.267)	-0.336* (-1.700)	-0.371* (-1.938)	-0.415** (-2.214)	-0.456** (-2.433)	-0.522*** (-2.657)	-0.591*** (-2.748)	-0.625*** (-2.743)	-0.708*** (-2.663)
iq	-0.0230*** (-3.798)	0.00303 (0.963)	-0.0274*** (-3.904)	-0.0261*** (-4.076)	-0.0253*** (-4.103)	-0.0243*** (-4.045)	-0.0234*** (-3.896)	-0.0220*** (-3.485)	-0.0205*** (-2.950)	-0.0197*** (-2.678)	-0.0179** (-2.080)
Constant	12.30*** (6.840)	-0.710 (-0.759)	13.33*** (6.398)	13.02*** (6.852)	12.84*** (7.009)	12.62*** (7.061)	12.41*** (6.945)	12.07*** (6.440)	11.71*** (5.677)	11.54*** (5.269)	11.11*** (4.343)
Observations	83	83	83	83	83	83	83	83	83	83	83
deunmethod	fitted	fitted	fitted	fitted	fitted	fitted	fitted	fitted	fitted	fitted	fitted

precise relationship and relates to the general outlook of the data, as stated in (Koenker, 2004)-whereas, in conventional methods, this is accomplished solely by adjusting the averages). Also, this test provides accurate findings when endogeneity exists in the response variable and when a particular influence tries to balance out the general variance in the dataset. As a result of the quantiles being produced in the overlapping assessment scenarios, this approach yields more revealing results. Urbanization expresses the propensity to promote environmental sustainability in all quantiles. Contrary to what is often believed (Dong et al., 2021; Wang et al., 2016), urbanization may have good ecological effects, but only if managed appropriately. Urbanization fosters innovation, green initiatives (such as recycling bins), and new green technologies, resulting in ecologically friendly cities. Finally, urbanised people have a better quality of life and are more likely to participate in green initiatives such as utilising electric vehicles and trains, which have grown fairly popular in China (Zhao and Wang, 2022). Because of urban clustering, less resources may be used to provide the same output (Liu et al., 2022).

- However, economic growth and traditional innovation didn't significantly affect pollution, which aligns with the works of (Acheampong et al., 2022; Garrone and Grilli, 2010). This can be associated with the panel being emerging economies, and the growth trajectory is yet to be situated within the context of the environment. This leads credence that most firms have not employed much innovation in production and hence yet to reap benefits or otherwise of such components in the production
- The statistical validity of the hypothesis on environmental technology facilitating environmental sustainability is confirmed in the 4th to 9th quantile (upper quantile), with just one quantile in the lower quantile (1st quantile). This means that the environmental technology lowering pollution hypothesis is likely true for the relatively high-income E7 countries that can now afford such innovation confirming works of (Du et al., 2019; Paramati et al., 2021). Furthermore, it can be argued that the E7 countries with relatively high incomes can relatively decouple economic growth from CO2 emissions by pursuing more environmentally friendly technological innovations (Hussain et al., 2022).
- Lastly, relatively the environmental taxes, structural change, renewable energy, and institutional quality all serve as pathways toward achieving SDG 13 within the E7. Environmental taxes are crucial in promoting the use of alternative (clean) energy sources leading to reducing carbon emissions -which meet the tenets of SDG -13. Also, Hazardous waste generation may be deterred by environmental levies (Hao et al., 2021). This result implies that altering the economic structure of E7 will lower CO2 emissions. A structural transition is important economically because it allows a nation to migrate to a low-carbon economy that is not too dependent on energy. This is hardly surprising given the E7 countries' rising service sector tendency. The E7 is a service-driven economy with a recent major influence on global GDP. Surpassing G7 The service sector includes telecommunication, retailing, new transport systems, health, and banking. Given that it consumes less energy than other sectors, the service industry's environmental effect in the E7 is in line with expectations. (Adebayo et al., 2022; Ofori et al., 2023a, 2023b, 2023c; Sarpomg et al., 2023). Also, renewable energy exerting a negative correlation with carbon emission provides further evidence of the need to fulfill SDG -7. The Paris Agreements, Sustainable Development Goals (SDGs), and international development sustainability framework are all compelling reasons to strive towards this objective as a result of the synergy it creates between SDGs (SDG, 2019; UN, 2019)

4.5. Decomposition results

Fig. 5 shows the decomposition to ascertain which variable has the

most influence attributes on carbon emission within the next 10-year forecast. These enable policymakers to identify loopholes within current policies and attend to them quickly. The results provide decomposition for all variables of interest. However, the primary focus will be Environmental pollution. A glance at Fig. 5 and Table 14 show that although they may not be accountable for changes in the short run, the dependent variable and control variable shocks may result in longer-term fluctuations. As the findings demonstrate, they have gradually and consistently impacted carbon emissions. An additional graph that provides further evidence of the results is in Appendix 1.

- The 1st year showed a 100% threshold which dictates Carbon emission on their own score has a high propensity for rising if not tackled properly. Thus About 100% of the volatility in the carbon emission rate during the early period may be attributed to shocks to the pollutant emission rate itself.
- Over the first five periods, the per-capita output's contribution to the fluctuation in the rate of carbon emissions varies quite quickly.

Finally, it looks to converge at around 10%, lending support to the environmental Kuznets curve.

- Although structural change followed a similar pattern to economic growth, economic growth continued to have the greatest impact on carbon emissions after ten years.
- Environmental technology, environmental taxes, and institutional quality all revealed delayed shock characteristics in the contribution of factors expected to assist in controlling carbon emission increase.

This finding exerts worrying trend for emerging economies; the forecast shows more policy streamlining is needed if the fight against carbon emission will yield any favorable result.

In summary, the proposed STIRPART model demonstrates how effective environmental management can be achieved. The results of this study highlight how environmental policies, such as green environmental technology, environmental tax, structural change, renewable energy, and urbanization, effectively reduce carbon emissions. Given the reducing effects of environmental taxes and green environmental technology on emissions, governments could consider implementing or

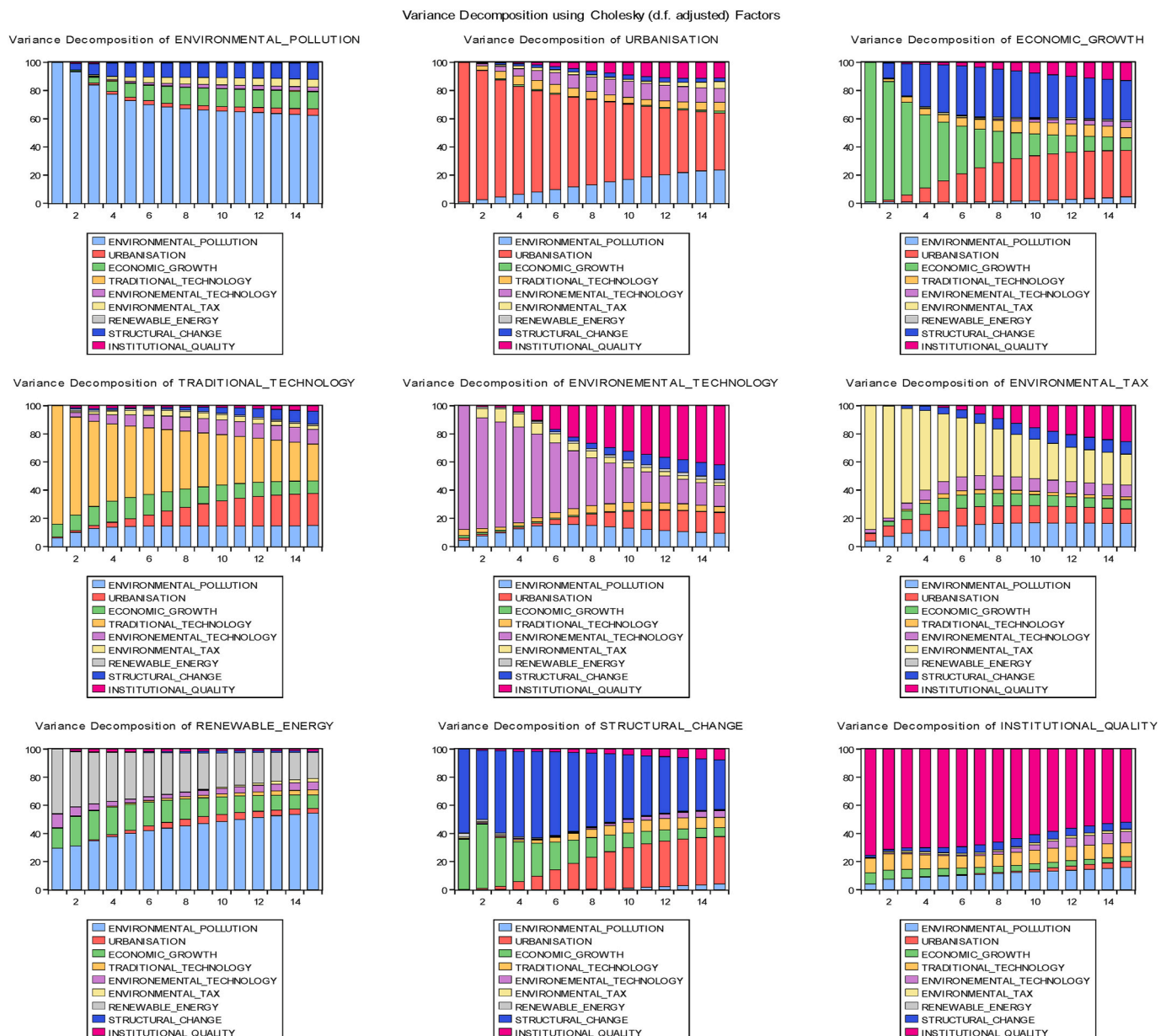


Fig. 5. Decomposition results of the variables of interest.

Table 14
Variance decomposition analysis (10-year forecast).

Period	S.E.	lnep	lnur	lngdp	Lnti	lnenvtech	lnenvtax	lnren	lnser	iq
1	0.036	100	0	0	0	0	0	0	0	0
2	0.052	93.155	0.408	0.875	0.168	0.007	0.121	0	4.45	0.815
3	0.068	84.09	1.281	3.998	0.625	0.262	0.918	0.006	7.939	0.882
4	0.082	77.339	1.986	7.313	0.66	0.562	2.182	0.038	9.312	0.609
5	0.093	72.937	2.412	9.598	0.565	0.939	3.227	0.044	9.745	0.533
6	0.104	70.11	2.646	10.993	0.476	1.333	3.942	0.04	9.883	0.579
7	0.113	68.273	2.782	11.803	0.412	1.705	4.401	0.034	9.96	0.631
8	0.121	67.049	2.886	12.248	0.37	2.029	4.696	0.03	10.045	0.647
9	0.129	66.188	3.002	12.461	0.351	2.29	4.897	0.028	10.155	0.628
10	0.136	65.518	3.154	12.528	0.353	2.485	5.047	0.028	10.298	0.59

expanding such policies. Additionally, governments should strive to enhance the quality of institutions to ensure that environmental policies are implemented and enforced efficiently. By incorporating the results of this study into their environmental management strategies, governments can effectively reduce carbon emissions and protect the environment.

5. Conclusion and policy recommendations

5.1. Conclusion

A key strategy for reconciling industrial development with environmental performance objectives is to enhance the STRIPART MODEL. There is a void in the literature about how businesses affect environmental performance since most current research focuses on the causality between economic growth, population growth, or traditional technology on environmental performance (environmental sustainability). As a result, we also included additional environmental indicators in our analysis, such as environmental taxes and environmental technology, which are directly related to innovative business models that help enterprises achieve their environmental goals, resulting in the filling of gaps and expanding the body of knowledge on environmental management.

Thus this research incorporates environmental tax, environmental technology, and regulatory influences into the STIRPAT model to develop a novel STIRPART framework for evaluating environmental issues. In addition, the study has considered how structural change, renewable energy, urbanization, and economic growth influences environmental quality using the Driscoll-Kraay's fixed-effect OLS technique and data from 2000 to 2020. The key results show that: while green environmental technology, environmental tax, structural change, renewable energy, urbanization, and institutional quality have a significant negative connection with carbon emission, economic growth, urbanization, and technological innovation have a positively connection with carbon emission. Finally, the interaction between institution quality and environmental tax, as well as the interaction between institutional quality and green environmental technology, reduces carbon emissions.

➤ The positive effect of technological innovation on emissions suggests that such innovation does not always help countries cut their CO₂ emissions, and countries that are more open to making sacrifices that have negative effects on the environment to boost their economies upsurge their emissions with increased technological innovation. In this regard, technological innovation and environmental quality policies should be strengthened. When improving the level of technological innovation, nations should be mindful of their effects on the environment and steer the advancement of technologies that are helpful to ecological sustainability. At the same time, economic, political, and social globalization require more in-depth discussions of environmental safety challenges, and they should use their unique

technological strengths to support the evolution of technological innovation.

- It is suggested that governments implement effective energy regulations as soon as possible to help solve environmental issues by using renewable, low-carbon energy. For this reason, renewable sources of energy should be emphasized more.
- Environmental taxes deter activities that increase carbon dioxide emissions hence should be strengthened. Carbon pricing should be enhanced to motivate people to make more low-carbon choices in both production and consumption.
- The preservation of the natural world relies on a stable system of government. The effectiveness of government initiatives to deal with ecological issues is a reflection of the state of institutions. Clear institutional frameworks facilitate ecological responsibility by mediating conflicts and creating mutually beneficial outcomes. To effectively control emissions and determine how their practical integrity may be improved, authorities must focus on many aspects of Governance and their interconnections.

5.2. Limitations of the study

The major theoretical contribution of the study is the amendment of the traditional STIRPAT model. Although a plethora of [Tian and Zhou \(2019\)](#) ([Ahmad et al., 2021](#)), exist on STIRPART model, studies that have modeled policy tools on environmental taxes, differentiated old and new environmental technologies, and institutional qualities together are non-existing. The inclusion of environmental tax, environmental technology, and institutional technology in the model is significant as all variables are interrelated, providing a clearer picture in the quest to reduce emissions. While environmental taxes provide incentives for businesses to invest in environmental technology, environmental technology reduces the emissions and waste that can cause environmental degradation and institutional quality ensures that environmental taxes and technology are implemented in a way that is effective and efficient and that environmental standards are being met.

The study establishes that institutional quality provides necessary regulations to ensure that firms comply with environmental laws. It is suggested that laws protecting the environment be made stricter, efforts should be made to raise awareness on environmental practices. Strong regulatory enforcement and institutional backing for the widespread use of green energy technologies go hand in hand. The reducing effect of both environmental technologies and environmental tax on emissions shows how carbon efficacy in businesses will improved by the proliferation of environmentally friendly green technologies and fiscal policies. Thus, when developed effectively, environmental technologies will improve the efficiency of energy production, the amount of energy needed to produce a given output and decrease carbon emissions. Also, effective fiscal policies on the environment targeted on activities that contribute to carbon emissions, such as the production and consumption of fossil fuels will increase the cost of these activities and make business switch to more efficient and cleaner technologies. The proposed model could be adopted in whole or modified in future studies on

environmental quality.

5.2. Future studies

The E7 nations were the study's exclusive focus, and the impact of environmental tax, environmental technology, technological advancement, and institutional qualities on CO₂ was only partially evaluated. Future studies may include factors like financial development, economic complexity, and human capital in the model. Also, evaluations at the state and municipal levels will be helpful to have more focused policy implications.

Finally, as conventional non-environmental technologies have a greater impact on CO₂ emissions than regulated and green technologies, switching from "non-environmental technology" to "green technology" can substantially reduce greenhouse gas production. In order to reduce carbon dioxide emissions, it is advised that further studies be conducted on the regulatory impact of technology migration from conventional to green technologies.

Authorship statement

Elvis Kwame Ofori: Conceptualization Data curation, - Original draft preparations, Methodology, Software Writing- Reviewing and Editing, **Prof Jinkai Li:** supervisor- Reviewing and Editing, corresponding, **Dr. Bright Akwasi Gyamfi:** Reviewing. Discussion and Editing, **Dr. Evans Opoku Mensah** - Reviewing and editing, **Dr. Jin Zhang:** Assitant supervisor- Reviewing and Editing.

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.

Data availability

Data will be made available on request.

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