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Green Technology Adoption and Industrial Competitiveness in Emerging Economies: The Moderating Effect of Institutional Quality

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Article

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GREEN TECHNOLOGY ADOPTION AND INDUSTRIAL COMPETITIVENESS IN EMERGING ECONOMIES: THE MODERATING EFFECT OF INSTITUTIONAL QUALITY.

Abstract

As the world faces environmental challenges and the urgent need for sustainable development, the adoption of green technology stands at the forefront in shaping the future of various industries in the world. This study contributes to the literature by investigating the impact of GTA measured through the Environmental Performance Index (EPI) and Renewable Energy Consumption (REC), and Industrial Competitiveness (IC), while examining the moderating role of Institutional Quality (IQ). Using the Balance of Panel data from 24 emerging economies covering 2002 to 2021. The study employed the System Generalized Method of Moments (SYS-GMM) estimator to address endogeneity concerns and Panel Quantile Regression to capture heterogeneous effects across the competitiveness distribution. The results indicate a nuanced relationship. EPI positively and significantly enhances Industrial Competitiveness, supporting the Porter Hypothesis that stringent yet well-designed environmental policies stimulate innovation and competitiveness. Conversely, REC exhibits a negative effect on Industrial Competitiveness, reflecting structural bottlenecks, transitional costs and energy system constraints within emerging economies. Further, Institutional Quality demonstrated mixed effects. Rule of law and political stability enhance competitiveness, whereas Control of corruption negatively affects it, implying that governance weakness undermines the gains associated with green technology adoption. The study underscores the need for emerging economies to strengthen the institutional framework, prioritize innovation-driven environmental policies, and address renewable energy system inefficiency. These measures are essential for leveraging green technologies to enhance industrial competitiveness and support sustainable development.

Keywords: Green technology adoption (GTA); institutional quality; industrial; competitiveness; environmental; innovation.

1. Introduction

In an era where environmental sustainability is no longer a choice but a necessity, the adoption of green technology (GT) has become a strategic priority for individuals, government, and business development. This is particularly salient in emerging economies, which face the dual challenge of promoting economic growth while minimizing environmental degradation (Verra, 2025). As the global community intensifies efforts to combat climate changes and meet the United Nations Sustainable Development Goals (SDGs), green technologies such as renewable energy system, energy-efficient manufacturing and clean production techniques have emerged as essential tools for reducing greenhouse gas emissions, resource depletion, and advancing sustainability (Sun & Wu, 2024; Guo et al., 2020; Hauxin, 2019; UNCTAD, 2018). For firms, adoption of GT not only generates environmental benefits but also enhances industrial competitiveness. Specifically, green technology facilitates higher product quality, increase value creation, reduced development time, greater operational efficiency, all of which contribute to long-term industrial competitiveness (Forcadell et al., 2021; Han & Chan, 2021). In addition, GT enables firms to access environmentally conscious market, comply with international standards, reduce cost and improve productivity (Santra 2017; Hasanbeigi 2012; Mathai & Goulder 2000). Consequently, Industries are increasingly encouraged to embed environmentally friendly practices into their operations.

Despite its potential, the diffusion of green technology in emerging economies remains uneven. Key barriers include institutional and financial constraints (Wakeford et al., 2017; Ji & Zhang, 2019; Bhandari et al., 2019), and policy-related barriers (Yoshino et al., 2019; Darko et al., 2018; He et al., 2019). Prior research highlights the role of green technologies in improving firm-level competiveness and environmental performance (Van Holt et al., 2020; Xia et al., 2022). Yet, critical gap remains, particularly regarding the mechanism that facilitate GTA in institutional context. Market failures (Campiglio, 2016; Agyemang et al., 2018), regulatory weakness (Murillo-Luna et al., 2015; Xia et al., 2019; Luthra et al., 2015), and technical knowledge (Darko et al., 2017; Liao and Shi, 2018) continue to constrain adoption. The quality of institutional environment encompassing regulatory quality, government effectiveness, rule of law, and control of corruption play a pivotal role in enabling or obstructing green transitions. Strong institutions enforce environmental standards, incentivize innovation, and reduce investment risks, thereby facilitating the GT adoption and diffusion (Ansari et al., 2019; Shahbaz et al., 2013).

However, while both green technology adoption and institutional quality have been independently linked to industrial performance, limited empirical research examines how institutional quality moderates the relationship between green technology adoption and industrial competitiveness, particularly in emerging economies characterized by heterogeneous institutional capacity. Previous studies frequently treat institutional quality as a control variable rather than a key mechanism influencing the effectiveness of green technology adoption and industrial outcomes. Such treatment obscures the critical role governance structures in determining how efficiently green technologies implemented and, in turn to industrial competiveness. In recent years, emerging economies have exhibited substantial variation in industrial competitiveness, as seen figure 1, highlighting difference in industrial performance that may partly reflect variations in governance and institutional capacity. The disparities in CIPI underscore the importance of government structure in enabling or constraining green technology transitions, emphasizing the need to institutional quality such as a potential moderator of the relationship between GTA an IC.

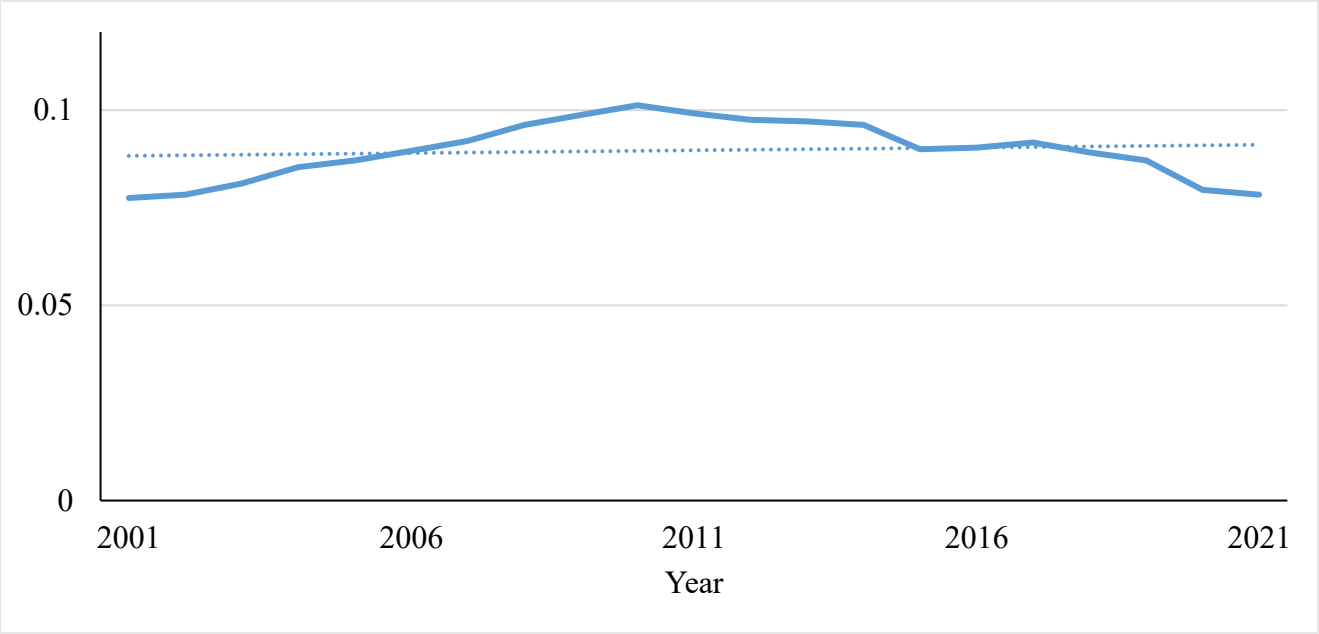


Figure 1: Average Competitive Industrial Performance Index of 24 emerging economies
Source: Author's construct based on data from UNIDO

Building on these observation, the study makes four key contributions. First, it examines the effect of green technology adoption on industrial competitiveness across emerging countries. Second, it integrates the influence of institutional quality on green technology adoption and industrial competitiveness. Third, it examines the moderating role of institutional quality on GTA and IC. Fourth, the study employs the most recent and complete data (2001 to 2021) and robust results from equipped econometric techniques such as SYS-GMM, quantile regression, and Fisher's stationary type root. By linking green technology with institutional structure, the study provides a nuanced understanding of how green transition interacts with governance quality to shape industrial outcomes.

The findings will contribute to the theoretical discourse on sustainable development and industrialization. It may also offer practical insights for policymakers aiming to align green technology policies with industrial reforms. For academia, the study contributes to the growing literature on GTA and industrial competitiveness in emerging economies

The structure of this paper is as follows: the next section provides a comprehensive review of relevant literature, laying the foundation for the study. The third section presents a detailed explanation of the data and methodology utilized to analyze the empirical relationship. Additionally, the fourth section discusses the empirical studies' results, and finally, the last section summarizes the key findings and offers practical recommendations and insights.

2. Literature review

2.1 Green technology

Green technology adoption (GTA) refers to the integration of environmentally sustainable innovations into firms' operations to reduce environmental impacts and improve efficiency across production and service delivery (Xia et al., 2022; Khan et al., 2024). GTA encompasses the application of clean and sustainable technologies during product development, manufacturing processes, workforce training and the promotion of green consumption to end users (Xia et al., 2022). According to Braun and Wield

(1994), Green Technology (GT) focuses on minimizing material wastage and energy consumption through the development of environmentally sound processes. It serves as a foundational element for green innovation, enabling firms to reduce input and energy waste, while maintaining or improving productivity and output quality (Rossini et al, 2019). Huynh (2020) mentions that GTA is complemented as a crucial resource and support for green innovation. Similarly, Afum et al (2021) emphasize that firms engaging in GTA often benefit from reduced variable costs in product design and enhance product quality, which contribute to the competitive advantage of the firm.

2.2 Industrial competitiveness

Industrial competitiveness (IC) refers to a country's or firm's capacity to produce and export manufactured goods competitively, especially in the international market, while maintaining or increasing value addition and technological advancement in production. According to UNIDO (2013), industrial competitiveness is assessed using the Competitive Industrial Performance (CIP) index, which emphasizes value added, industrial export and technological intensity of manufacturing sectors. Countries with higher IC often demonstrate strong technological capacity, productive capacity, and infrastructural development, enabling them to sustain economic transformation and export-led growth (UNIDO, 2022). Therefore, for emerging economies, enhancing competitiveness is vital for industrial transformation, poverty alleviation and economic diversity.

2.3 Institutional Quality

In development economies, Institutional Quality (IQ) refers to the effectiveness and efficiency of institutions such as governance structure, legal system and regulatory frameworks, in promoting economic growth and sustainable development. According to North (1990), institutions are "rules of the game" in society or human-devised constraints that shape human interaction, while Grief (2006) and Aoki (2000) emphasize the IQ role in structuring behavior. High institutional quality is marked by transparent regulations, rule of laws, and corruption control that minimizes uncertainty and transaction costs, fostering a predictable environment crucial for investment and innovation (Chhabra et al., 2023; Kaufmann et al., 1999). Linked to SDGs 16, strong institutions are essential for innovation by reducing uncertainty and encouraging knowledge transfer (Uddin et al. 2023). Weak institutions, on the other hand, reduce environmental regulations and increase pollution (Khurshid et al., 2023) and increase carbon emissions (Khan and Rana, 2021; Salman et al., 2019).

2.4 Green technology, Industrial competitiveness and institutional quality

The relationship between GTA and IC is increasingly gaining attention in the context of sustainable industrialization. GTA enables firms and countries to reduce environmental degradation while enhancing production efficiency (Xia et al., 2022; Khan et al., 2024). Such improvement can lead to cost savings, enhance brand value, improve product quality, and provide greater access to the international market. As noted by Afum et al. (2021) and Huynh (2020), GTA helps reduce waste and improve energy efficiency, resulting in lower production costs and higher product quality. These improvement makes firms not only competitive in the domestic market but also able to meet international environmental standards.

Beyond immediate efficiency gain, GTA also serves as a catalyst for long term technological upgrading and innovation. This is particularly crucial in the manufacturing sector, where sustained competitiveness depends on the ability to evolve with market and environmental standards (Xia et al., 2022). Firms that adopt green technology tend to develop dynamic capacity and are more likely to engage in innovation

both in product and production processes. This aligns with UNIDO's conceptualization of industrial competitiveness, which emphasizes technological learning and value addition (UNIDO, 2020; UNIDO, 2013). Therefore, GTA and IC are not merely correlated but mutually reinforcing: the more firms invest in green technologies, the more they gain a competitive advantage in both cost efficiency and reputation, which in turn promotes further industrial performance.

However, the relationship between GTA and IC is contingent upon the quality of institutions. IQ, defined as the "rule of the game" that structures human interactions, North (1990), plays a moderating role in how green technology translates into competitiveness. According to the Porter Hypothesis (1995), stringent but well-designed regulations spur green innovation, which ultimately boosts competitiveness. Yet this hypothesis fundamentally depends on the nature of the institutional environment that enforces rules, reduces costs and offers stability.

Empirical findings underscore the importance of institutional context. Khan et al (2022) find that the GTA has a positive effect on productivity and international market positioning when institutions provide adequate regulatory policy and support. Conversely, Zhao et al (2021) caution that in the absence of institutional capacity and transparency, green innovation may become costly and ineffective. This implies that without robust institutions, firms may lack the incentive capability to implement GT effectively, failing to translate into real competitiveness gain and being ineffective.

Further, IQ shapes firm's environmental behavior by enforcing strict regulations that curb environmental pollution and foster technology investment in green technologies. Strong institutions set binding rules that deter environmental degradation and promote technology adoption, while weak institutions do otherwise. Thus, institutional quality not only facilitates the adoption of green technology but also determines whether such adoption translates into actual competitiveness gains. Several empirical studies have focused on the effect of green technology innovation, institutional quality, FDI, research and development on CO_2, environmental sustainability and economic and sustainable growth. These studies span in firm-level and cross-country analyses.

Table 1 contains the selected literature on green technology adoption, industrial competitiveness and institutional quality. Despite the growing emphasis on green innovation for sustainable industrial growth, the relationship between GTA and IC in emerging economies context has received limited empirical attention. This gap underscores the need for the study to examine the nexus between green technology adoption and industrial competitiveness

Table 1: Summary of selected literature on green technology adoption, industrial competitiveness and institutional quality.

Author	**Methodology/scope**	**Results**
Song and Wang (2018)	Multi-index multi-factor constitutive model. Scope: 468 Chinese industries.	U-shape relationship between green technology progress and comparative advantages
Dunyo et al (2024)	GLSPCE, GMM and SEDLP Period: 2000 to 2020 Scope: 58 countries	Availability of technology reduce CO2 emission. R&D activities increase CO2 emission in the uncertainty.
Elgin et al (2020)	Principal component analysis Period: 1990 to 2016 Scope: 89 countries	Positive correlation between green technology adoption and economic development.
Wenlong et al (2023)	ARDL, AMG and CCEMG Period: 1995-2018 Scope: 10 Asian countries	Institutional quality and trade openness damages environmental quality.
Warsame et el (2022)	ARDL Period: 1990 to 2017	Quality institutions enhances the share of renewables in the energy mix

	Scope Somalia	
Chhabra et al (2023)	Dynamic Common Correlated Effect Period: 1991 to 2019 Scope: BRICS countries	Trade openness (TO) causes environmental degradation in BRICS countries. Institutional quality improves environmental sustainability
Behera et al (2022)	Pooled mean group, random effects and GMM	FDI and Green Technology Innovation are negatively related. Environment regulations significantly relates to GTI which pushes economy to adopt green technology.
Khurshid et al 2024	Feasible generalized least square (FGLS), panel correlated structure error (PCSE) Period: 2001 to 2021 Scope:26 Africa nation	Green Innovation and Institutional Quality negatively affect Clean Fuel Technologies (CFT). Positive relationship between CFT and R&D expenditure
Narayan et al (2023)	Driscoll-Kray and two-step SGMM model. Period: 1998 to 2019. Scope: 25 developing countries	Green finance, green technology innovation, and institutional quality induce CO_2 emissions. Renewable energy have detrimental effect on CO2 emission.
Buitrago et al. (2024)	Partial Least Squares – Structural Equation Modeling (PLS-SEM). Period 2007–2017. Scope: emerging economies	Political and lack of systemic conditions have a significant and negative effect on international competitiveness.
Noja et al 2022	Structural Equation Modelling (SEM), Gaussian Graphical Models (GGM). Period: 2018 Scope: EU-27 Member States	Energy innovations increased environmental performance. Digital transformation significantly affects sustainable development of EU countries

in emerging economies, to better understand how institutional quality shapes the effectiveness of green technology in driving industrial performance across different policy and regulatory contexts.

The present paper contributes to the literature in the following important ways. First, the study argues that to understand the role of institutional quality on the adoption of green technology and the industrial competitiveness nexus, one has to thoroughly examine the interactive effect of IQ on the GTA-IC nexus rather than measuring its direct effect only. This oversight limits the understanding of how IQ shapes the effectiveness of the green technology investment. By analyzing IQ as a moderator, this study aims to provide a more nuanced understanding of the conditions under which green technology contributes to competitiveness. Second, the study focuses specifically on two dimensions of GTA (i.e., Environmental Performance index and Renewable Energy consumption) and investigates how these indicators influence IC in the emerging economies under varying levels of IQ. This approach allows for a more context-sensitive analysis that reflects the realities of governance and regulatory diversity across emerging economies. Such analysis would provide meaningful insight into policymaking. For instance, policymakers would be interested in knowing how the GTA affects industrial competitiveness in the presence or absence of IQ.

Notably, the existing literature failed to provide answers for these questions, especially within the context of emerging economies; hence, the need for this study to fill in this research gap to contribute to the broader discourse on sustainable industrial development**. Figure 2** below presents the conceptual framework illustrating the moderating effects of IQ in the relationship between GTA and IC. Based on

the gaps identified in the literature and the conceptual framework proposed, the study advances the following hypotheses:

H1. Green technology adoption (i.e. EPI and REC) significantly influences industrial competitiveness

H2. IQ moderates the relationship between EPI and industrial competitiveness

H3. IQ moderates the relationship between REC and industrial competitiveness

H4. IQ moderates jointly the effect of EPI and REC on industrial competitiveness

2.5 Conceptual framework

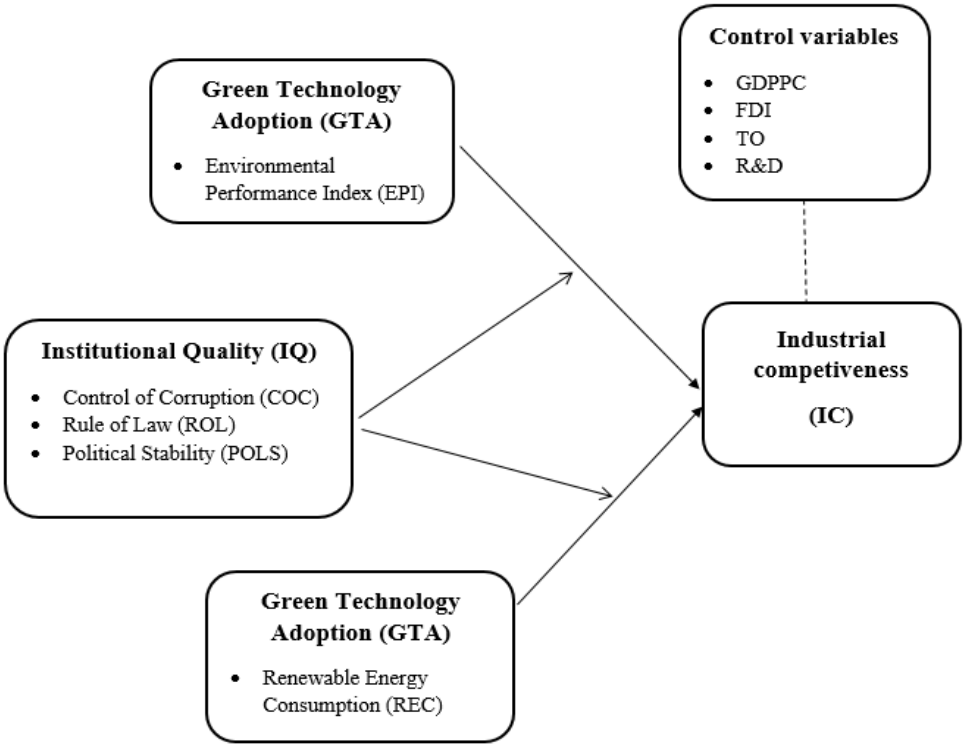


Figure 2. Conceptual framework

3. Data and empirical model

The main objective of the study is to assess how green technology adoption impacts the industrial competitiveness of emerging economies.

3.1 Data

For the data analysis, the study assembled annual data from 2001 to 2021 for 24 countries in emerging economies, and the study sample choice is guided by data availability especially for industrial competitiveness. The study's sample consists of Argentina, Brazil, Bulgaria, China, Colombia, Costa Rica, Egypt, India, Israel, Kazakhstan, Macedonia, Mexico, Moldova, Mongolia, Panama, Poland, Romania, Russian, Serbia, Singapore, South Africa, Thailand, Ukraine, and Uruguay. Competitive Industrial Performance (CIP) index was used as a proxy for industrial competitiveness (IC), while Environmental Performance Index (EPI) and renewable energy consumption (REC) for green technology adoption. Institutional quality (including control of corruption, political stability and rule of law) was employed as a moderating variable. Figure 3 shows the plot of the Institutional Quality (IQ)

by countries. It was observed from the graph that the level of IQ varies across countries. Following closely the literature, GDP per capita, Trade Openness, Foreign Direct Investment (inflows) and Research and Development were used as the control variables. All the time series variables collected for the study have been described with their data source in Table 3.

The summary statistics for the variable are reported in Table 2. The IC serves as the dependent variable proxy as CIP and GTA as the independent variable: EPI and REC. The study observes that the Competitive Industrial Performance (CIP) Index, on average, is 0.0903 with a level of dispersion of 0.0840. CIP also depicted an increase from 0.01 to 0.4 across the study period. Additionally, the EPI of emerging economies showed an increase during the study period, with their mean of 18.1538 and a standard deviation value of 13.4054.



Figure 3 : Plot of Institutional Quality index (IQ) of the sample countries

REC demonstrates significant progress in emerging economies with an average of 17.3029 (Table 2 refers). China was found to have, on average, the highest CIP (0.336) while Moldova and Panama had the least (0.01). Singapore and Uruguay have been confirmed to be the emerging economies with the highest EPI (50.9165) and REC (50.4432), respectively. Conversely, Serbia was the lowest in EPI (0.963) and Singapore lowest in REC (0.6063)

Control variables of the study include TO, FDI, GDPPC, and R&D. The study found the GDPPC of emerging economies on average to be $10057.99 with a standard deviation of $10862.39. Further, TO, FDI, and R&D of emerging economies on average were $86.0518, $4.9609 and 81.82% respectively. The institutional quality: COC, ROL and POLS shows a fluctuating trend ranging from -1.1767, -1.2024, and -2.3760 to 2.3011, 1.8381 and 1.5991, respectively, during the study period (see Table 2).

Table 2. Descriptive statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
CIP	480	0.0903	0.0840	0.01	0.4
EPI	480	18.1538	13.4054	0.89	51.7
REC	456	17.3029	14.2153	0.47	61.09
R&D	464	0.8182	0.9011	0.0621	5.7056
GDPPC	480	10057.99	10862.39	793.101	67638.65
FDI	475	4.9609	5.8044	-37.1727	43.9121
TO	480	86.0518	66.4721	22.1060	437.3267
COC	480	-0.1449	0.7349	-1.1767	2.3011
ROL	480	-0.0868	0.6030	-1.2024	1.8381
POLS	480	-0.2018	0.7688	-2.3760	1.5991

Further, the pairwise correlation matrix for sample data is presented in Table 4, give a preliminary insight into the co-movement among the time series variables (see **Table 4**). Importantly, none of the correlation coefficients is sufficiently high to raise concern about multicollinearity. The study found EPI to be positively correlated with CIP, while REC shows a negative correlation with CIP. Further, the study estimated a positive correlation between all classes of IQ and EPI, REC and CIP, supporting the preliminary evidence that stronger institutions support industrial performance. Taken together, these mixed patterns underscore the importance of IQ in moderating the tradeoff between the GTA and IC nexus in emerging economies.

3.2 Theoretical framework and hypothesis

The study is grounded in Porter's Hypothesis theory, which posits that well-designed environmental regulations can drive innovation in firms, particularly in green technology, leading to improvements in both environmental outcomes and industrial competitiveness. Originally proposed by Porter and Van der Linde (1995), the hypothesis challenges the conventional view that environmental regulations impose unnecessary costs on firms and reduce competitiveness. Instead, the Porter hypothesis posits that well-designed environmental regulations can stimulate innovation within firms, which can offset the cost of compliance, improve operational efficiency, and ultimately enhance competitiveness. In this regard, environmental regulation can serve as a catalyst for green technology adoption, which contributes to industrial competitiveness.

In the context of emerging economies, green technology adoption is not a response to environmental concerns but also a strategic move toward industrial modernization and competitive positioning. Firms that adopt cleaner technologies can reduce production costs, meet international standards, and improve their long-term resilience. However, the extent to which gains are realized depends on the quality of institutions. Strong institutions facilitate innovation, ensure fair competition, and reduce uncertainty. In contrast, weak institutions create inefficiencies and erode the gains from technological improvement. Thus, this study views green technology adoption as a potential driver of industrial competitiveness, but the strength and direction of this effect are moderated by institutional quality. Where institutional quality is effective, the Porter hypothesis is more likely to hold and may fail when institutions is weak.

Table 3: Data Description.

Variables	Description and measurement	Source

CIP	Competitive Industrial Performance Index, representing country's productivity, structural change and competitiveness, measures the capacity of countries to increase their presence in international and domestic markets whilst developing industrial sectors and activities with higher value added and technological content (UNIDO, 2013).	United Nations Industrial Development Organization (UNIDO)
EPI	Environmental Performance Index (EPI), which was determined in 2006 being measured in every 2 years. At the level of 2022, EPI captures 40 performance indicators target, environmental health and ecosystem covering 10 groups of fields; "air quality, water and sanitation, heavy metals, biodiversity and habitat, forests, fisheries, climate and energy, air pollution, water resources and agriculture" for vitality and mitigate climate change, for 180 countries, measuring progress towards environmental sustainability.	Wendling et al, (2020); Yale Center for Environmental law and Policy-Yale University
REC	Renewable Energy Consumption, indicating the progress towards renewable energy transition, measured as percentage of renewable energy in total energy consumption.	World Bank (WDI), and International Energy Agency (IEA).
GDPPCs	GDP per capita, indicating economic growth, measured as constant US dollar of 2015.	World bank, national account data and OECD national account data files
FDI	Foreign Direct Investment, representing the long-term investment by foreign entity in another country, measured through equity capital, reinvestment earnings, other long term capital and short term capital.	World Bank (WDI), OECD GDP estimates.
TO	Trade Openness, representing the sum of export and imports of goods and services, measured as a share of gross domestic product.	World bank (WDI), national account data and OECD national account data files
R&G	Research and Development, express as percent of GDP represents innovative activities undertaken by firms or government, measure expenditure and patent outputs.	World Bank (WDI), UNESCO institute for statistics (UIS)
COC	Control of Corruption, captures perception of the extent to which public power is exercised for private gains and state.	World bank, World Governance Indicators(WGI)
ROL	Rule of Law captures perception of the extent to which agent have confidence in and abide by the rule of the society and in particular the quality of contract enforcement.	World bank, World Governance Indicators(WGI)
POLS	Political stability measures perception of the likelihood of political instability and politically motivated violence.	World bank, World Governance Indicators(WGI)
S_enrol	School enrollment, tertiary (% gross) measures the % of population in the 5-year age group immediately following upper secondary education	World Bank, UN Educational, Scientific and Cultural Organization (UNESCO)

Eploy_industry	Employment in industry measures the % of total employment	World Bank, UN Educational, Scientific and Cultural Organization (UNESCO)

3.3 Theoretical and Empirical modeling

The theory underpinning the study is Porter's Hypothesis Theory, which focuses on how well-designed environmental regulations can stimulate innovation within firms. Based on these foundations of the Porter Hypothesis Theory, this study employs the general equation for the relationship between green technology adoption and industrial competitiveness, which is specified as

$$CIP_{it} = f(EPI_{it}, REC_{it}, RD_{it}, GDPPC_{it}, FDI_{it}, TO_{it}, IQ_{it}) \quad (1)$$

Following the study by Adnan et al. (2024), The econometric specification is written as

$$CIP_{it} = \rho_0 + \varphi_i' x_{it} + \mu_{it} \quad (2)$$

Modeling the effect of green technology adoption on industrial competitiveness

The empirical models utilized to address the three main objectives of the study are in equations (3), (4), (5), and (6). These equations are derived from the discussion of the introduction section concerning the significance attributed to each variable in the analysis of the industrial competitiveness of the emerging economies.

$$CIP_{it} = \rho_0 + \varphi_1 CPI_{it-1} + \varphi_2 EPI_{it} + \varphi_3 REC_{it} + \varphi_4 RD_{it} + \varphi_5 GDPPC_{it} + \varphi_6 FDI_{it} + \varphi_7 TO_{it} + \mu_{it} \quad (3)$$

$$CIP_{it} = \rho_0 + \varphi_1 CPI_{it-1} + \varphi_2 EPI_{it} + \varphi_3 RD_{it} + \varphi_4 GDPPC_{it} + \varphi_5 FDI_{it} + \varphi_6 TO_{it} + \varphi_6 CCOV_{it} + \varphi_7 ROL_{it} + \varphi_8 POLS_{it} + \varphi_9 (EPI_{it} * CCOV_{it}) + \varphi_{10} (EPI_{it} * ROL_{it}) + \varphi_{11} (EPI_{it} * POLS_{it}) + \mu_{it} \quad (4)$$

$$CIP_{it} = \rho_0 + \varphi_1 CPI_{it-1} + \varphi_2 REC_{it} + \varphi_3 RD_{it} + \varphi_4 GDPPC_{it} + \varphi_5 FDI_{it} + \varphi_6 TO_{it} + \varphi_6 CCOV_{it} + \varphi_7 ROL_{it} + \varphi_8 POLS_{it} + \varphi_9 R(EC_{it} * CCOV_{it}) + \varphi_{10} (REC_{it} * ROL_{it}) + \varphi_{11} (REC_{it} * POLS_{it}) + \mu_{it} \quad (5)$$

$$CIP_{it} = \rho_0 + \varphi_1 CPI_{it-1} + \varphi_2 EPI_{it} + \varphi_3 REC_{it} + \varphi_4 RD_{it} + \varphi_5 GDPPC_{it} + \varphi_6 FDI_{it} + \varphi_7 TO_{it} + \varphi_8 CCOV_{it} + \varphi_9 ROL_{it} + \varphi_{10} POLS_{it} + \varphi_{11} (EPI_{it} * CCOV_{it}) + \varphi_{12} (EPI_{it} * ROL_{it}) + \varphi_{12} (EPI_{it} * POLS_{it}) + \varphi_{13} (EPI_{it} * CCOV_{it}) + \varphi_{14} (EPI_{it} * ROL_{it}) + \varphi_{15} (EPI_{it} * POLS_{it}) + \mu_{it} \quad (6)$$

In the above equations, CIP represents the dependent variable. $i = 1, \dots, N$ captures the cross sectional dimension of the regression and $t = 1. \dots, T$ captures the time dimension, ρ_0 is regression coefficient, $(\varphi_1, \varphi_2, \varphi_3, \varphi_4, \varphi_5, \varphi_6, \varphi_7, \varphi_8, \varphi_9, \varphi_{10}, \varphi_{11})$ represent the coefficient of the predictor variables under $\mu_{it} = i + t + \varepsilon_{it}$ where μ_{it} represents error term, $_i$ resents individual country effects and $_t$ represents time specific effect and ε_{it} represent disturbance term. The choice of the independent variable is based on its potential to impact dependent the variable.

3.5 GMM Estimation technique

In order to test the effect of green technology adoption (i.e. EPI recycling and renewable energy consumption) on industrial competitiveness, the study employed a balanced panel data set of 24

countries in emerging economies. All missing data point was omitted from the study period for the period of 2002 to 2021, using Generalized Method of Moments (GMM). The sensitivity of the study estimates is carried out using fixed effects panel quantile regression. GMM estimator is employed for several reasons: (1) endogenous relationship between GTA and IC; and (2) inclusion of the lagged dependent variable in model 1 will cause endogeneity in the model. Additionally, in estimating the distributional effects in the model 1, will give rise to problem of endogeneity bias due to measurement errors, omitted variable bias, and causality effects. (Doku et al., 2024; Lee Vu, 2022). Putting together these reasons raises cause the OLS estimator to yield biased and consistent results.

To address this problem, one needs to employ an external instrument that will satisfy the exclusion restrictions: that is, an exogenous instrument that correlates with the endogenous variables, and at the same time is uncorrelated with the stochastic error term (Doku et al., 2024; Doku et al., 2021c). However, it is a daunting task to obtain external instruments that meet these conditions. As a result, model 1 is estimated using internal instruments, that is, lags of the endogenous variables.

Table 4. Pairwise correlations

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) CIP	1.0000									
(2) EPI	0.4215	1.0000								
(3) REC	-0.2283	-0.1243	1.0000							
(4) R&D	0.5427	0.3510	-0.2224	1.0000						
(5) GDPPC	0.5010	0.4876	-0.2048	0.6613	1.0000					
(6) FDI	0.1187	0.2205	-0.2069	0.0596	0.4448	1.0000				
(7) TO	0.3249	0.4901	-0.3233	0.1617	0.6194	0.6109	1.0000			
(8) COC	0.3678	0.5686	0.1678	0.4570	0.7818	0.3475	0.5177	1.0000		
(9) ROL	0.3407	0.6173	0.1354	0. 4941	0.7574	0.3474	0.5450	0.9184	1.0000	
(10) POLS	0.0404	0.1453	0.0285	-0.1391	0.3465	0.4072	0.4568	0.5048	0.4906	1.0000

To remove the bias associated with the unobserved country heterogeneity, Nguyen (2021) and Arellano and Bond (1991) proposed the use of the first difference of the variable for estimation to eliminate the country fixed effects, known as difference GMM. A situation where the variables are highly persistent, past values of the variables show little information about their future challenges; this makes lag variables a weak instrument for difference series (Nguyen, 2021; Doku et al., 2021a). Against that backdrop, Arellano and Bover (1995) suggested combining the difference equation instrumented by lagged levels and the level equation instrumented by lagged differences to yield a system (SYS-GMM). Based on the foregoing, the study employs SYS-GMM by Arelleno and Bover (1995) and Blundell and Bond (1998) as the main estimator of the study, for its ability to promote efficiency: this is done by dealing with the problem of weak instruments in the difference GMM estimator and reducing biases in its estimates (Roodman, 2009). In summary, SYS-GMM is used in this study due to its ability to overcome the problem of endogeneity using lagged values of explanatory variables as instruments, to eliminate problem the of information loss in cross-sectoral regressions and to give consistent estimates in the face of small time periods. The study employed the Arellano-Bond (AR [2]) and the Sargan test to determine the validity of the instruments. To find out whether the second-order autocorrelation exists in the model, we employed the Arellano and Bond test (AR [2]). The post estimation test will be climaxed by the Sargan test of over-identifying restrictions.

4. Results and Discussions

4.1 Stationarity tests

Most time series variables have been found to exhibit non-stationary characteristics, which, when not differentiated, pose challenges to estimation. This paper applies the Fisher-type panel unit root test developed by Maddala and Wu to determine whether the variables used in this study are stationary at level I (0) or at first difference I (1). The test was performed with both intercept and trend specifications. The results reported in Table A1 indicate that all the time series variable CIP, ERI, REC, FDI, GDPPC, R&D, TO, IQ proxies, and the interaction terms are stationary at the level, as all p-values from the inverse chi-square, inverse normal and inverse logit statistics are statistically significant at the 1% level (see Table A1). This implies that the variables are integrated of order zero I (0), and no differencing is required for further estimation.

4.2 Main regression results

In this section of the paper, Table 5 presents the result of the System Generalized Method of Moments (SYS-GMM) estimation used to examine the impact of green technology adoption proxies by Environmental Performance Index (EPI) and Renewable Energy Consumption (REC) on industrial competitiveness in emerging economies. Diagnostic test supports the validity of the model: Arellano-Bond test for second order autocorrelation AR (2), fails to reject the null hypothesis of no serial correlation, indicating no evidence of autocorrelation in the differenced error terms. Moreover, the Sargan test failed to reject the null hypothesis of instrument validity, indicating that the instruments employed are appropriate and the model specification is valid.

Specifically, four models were estimated to test the four interrelated hypotheses above. Table 5 presents SYS-GMM regression estimates, and the results are displayed in four columns of Table 5. (i) Model 1 is the regression inclusive of EPI, REC, RD, GDPPC, FDI, and TO. (ii) Model 2 is the regression inclusive of EPI, control variables (RD, GDPPC, FDI, TO) and institutional qualities (COC, ROL, POLS). (iii) Model 3 is the regression inclusive of REC, control variables (RD, GDPPC, FDI, TO) and institutional qualities (COC, ROL, POLS). (iv) Model 4 is the regression that includes all variables.

In Model 1, the coefficient of EPI is positive and statistically significant (0.0025), suggesting that better environmental performance enhances industrial competitiveness. This finding supports Porter's Hypothesis (Porter & Van der Linde, 1995), which argues that strict but well-designed environmental regulations can stimulate innovation and competitiveness. Additionally, the findings aligned with existing literature (Ghisetti and Rennings, 2014; Olasehinde et al., 2016; Noja et al., 2022; Xialing et al., 2024). Conversely, REC, in Model 1, has a negative and statistically significant coefficient (-0.0065), indicating that an increase in REC may, at least in the short run, undermine industrial competitiveness. This may reflect high transition costs, technological constraints, and reliability issues in renewable energy infrastructure in the emerging economies. Noja et al. (2022) highlighted a similar conclusion. Hence, hypothesis H1, which posits that EPI and REC significantly affect industrial competitiveness is supported.

Further, in Model 2, the interaction terms between EPI and IQ indicators are introduced to test Hypothesis H2, which posits that IQ moderates the relationship between Environmental Performance Index (EPI) and Industrial Competitiveness (IC). These findings reveal that the interaction term EPI*COC and EPI*ROL have a significant positive coefficient, implying that stronger legal institutions amplify the positive effects of environmental performance on competitiveness. However, the interaction terms of EPI*POLS is negative, implying that in contexts with political instability, the benefit of improved environmental performance may not fully translate into enhanced industrial competitiveness (see Table 5 column 2). Additionally, the direct effect of ROL and POL also indicated positive and significant, reinforcing the view that effective governance structures enhance the capacity of firms to

comply with environmental policies in a way that boosts performance. These findings confirm those of Ghisetti and Rennings (2014), Olasehinde et al. (2016), Noja et al. (2022), and Xialing et al. (2024), who underscore the importance of institutional strength in realizing the gains from environmental investments. Overall, Model 2 confirms Hypothesis H2, highlighting the crucial role of IQ as a moderator factor.

Model 3, which focuses on REC and its interaction with institutional variables, reveals a negative and significant relationship between REC and IC, after controlling for IQ. However, the interaction between REC and IQ indicators is not statistically significant, suggesting that IQ does not significantly moderate the relationship between IC and GTA. Further, Model 4, which includes all variables, reveals that both EPI and REC retain their respective signs and significance levels, confirming the robustness of the initial findings. The IQ variables (ROL and POLS) remain positively significant, while COC continues to show a negative relationship. The interaction terms involving EPI remain significant and positive for ROL and POLS, again reinforcing the moderating effect of the institutions on environmental policy outcomes.

Among the control variables, GDPPC generally has a weak but positive effect on industrial competitiveness across models, while FDI shows mixed results; positive and significant in model 2 and negative in models 1, 3 and 4. This indicates that FDI increases may crowd out domestic industries, create market asymmetry and lead to technology dependence, particularly where institutional quality is weak. The findings align with Magbonde et al. (2025) and Konings (2001) studies.

Table 5. System GMM results for emerging economies

Dependent variable: Industrial competitiveness (CIPs)				
Variables	(1)	(2)	(3)	(4)
Cons	0.48753***	0.21086***	0.22202***	0.01114
	(0.12883)	(0.05125)	(0.05195)	(0.06003)
$\mathbf{CPI_{t-1}}$	-1.10754***	-0.12351	-0.50208***	0.08465
	(0.28452)	(0.09441)	(0.135569)	(0.17763)
EPI	0.00248***	0.00260**		0.02543
	(0.00044)	(0.00102)		(0.00185)
REC	-0.00647***		-0.00285**	0.00299***
	(0.00181)		(0.00127)	(0.00105)
RD	-0.05394*	-0.05850***	-0.01011	0.03211
	(0.03244)	(0.02002)	(0.01533)	(0.03936)
GDPPC	6.77e-06**	-5.47e-06***	3.89e-06 *	-3.37e-06
	(3.07e-06)	(1.16e-06)	(2.09e-06)	(3.17e-06)
FDI	-0.03380***	0.00772*	-0.01703***	-0.013092
	(0.01028)	(0.00414)	(0.00501)	(0.0119422)
TO	-0.00109**	-0.00262***	0.000299	-0.0003207
	(0.00043)	(0.00049)	(0.00021)	(0.0010877)
COC		-0.41186***	-0.06918	-0.31058**
		(0.04317)	(0.06569)	(0.1456175)
ROL		0.19253***	0.14280*	0.1601552
		(0.04690)	(0.0847804)	(0.161474)
POL		0.07697***	0.04156	0.0538376*
		(0.02824)	(0.02639)	(0.0321014)
EPI*COC		0.01345***		0.01307***
		(0.00222)		(0.00258)
EPI*ROL		0.008395**		-0.001353
		(0.00385)		(0.0051255)
EPI*POLS		-0.01092***		-0.0037354*

		(0.00231)		(0.00255)
Renew*COC			0.00435	-0.000304
			(0.00514)	(0.00627)
Renew*ROL			-0.00752	0.01475**
			(0.00653)	(0.00413)
Renew*POL			-0.00229	-0.00306
			(0.00238)	(0.00561)
Arellano-Bond test for AR(1) in first differences	0.083	0.002	0.002	0.015
Arellano-Bond test for AR(2) in first differences	0.249	0.289	0.176	0.961
Sargan test	0.984	0.992	0.882	0.326
Observations	355	371	421	355

Robust standard errors in parentheses. Notes: $^{***}{}^{***} p < 0.01,^{**} p < 0.05,^{*} p < 0.1$

The empirical results from the SYS-GMM estimation offer several important insights. First, green technology measured through EPI positively affects industrial competitiveness, in line with the innovation-induced Porter hypothesis. These findings are in line with previous studies; for example, Ghisetti and Rennings (2014) found that high EPI leads to industrial competitiveness and Xialing et al. (2024) found that stronger institutions amplify the competitiveness benefit of environmental performance. Second, while REC appears to have a negative effect, IQ does not significantly moderate this relationship, due to systematic inefficiencies in the energy transition process in emerging economies. Third, IQ, particularly the rule of law and political stability, plays a significant moderating role in enhancing the competitiveness benefits of environmental performance. The result confirms H1, H2 and H4 but does not offer strong evidence for H3.

4.3 Sensitivity analysis

In this section of the study, a sensitivity analysis of the estimate is carried out using panel quantile regression (PQR) following the study by Powell (2020), Doku et al. (2024) and Khan et al. (2024) to complement the GMM estimates. Most prior studies, including the GMM estimator, compute the panel model at their conditional means and ignore the heterogeneous impacts of green technology adoption on industrial competitiveness. Neglecting heterogeneity would result in biased estimations of the panel data models, leading to over or under-estimation of relevant coefficients (Doku et al., 2024; Zhu et al., 2016). To address this issue, the study utilizes PQR with fixed effects to estimate the study model, as this estimator offers a systematic strategy for examining how green technology affects industrial competitiveness. Moreover, the PQR allows for the estimation of conditional mean function on a full range of the conditional quantile "points," hence providing a more complete picture relationship between the dependent and the independent variables. Consider the following conditional quantile function

$$Q_{(Y|X)}(\tau) = X\beta_\tau$$

Where Y is the dependent variable with dimension matrix $N \times 1$, X is a set of k independent variables with dimension matrix $N \times K$, and β_τ is the distribution function of Y with a dimensional matrix $K \times 1$ vector.

Table 6. Panel quantile regression for emerging economies.

Variables	25^{th}	50^{th}	75^{th}	90^{th}
EPI	-0.0001215	0.0011083***	0.0028665***	0.0020386***
	(0.0002142)	(0.0003858)	(0.0005097)	(0.0006352)

REC	-0.000478**	0.0000219	0.0008239 *	-.0009987*
	(0.0001953)	(0.0003517)	(0.000464)	(0.0005791)
R&D	0.0271353 ***	0.0537123***	0.0705944***	.1232253***
	(0.0039055)	(0.007033)	(0.0092923)	(0.011581)
GDPPC	9.18e-07**	2.91e-06***	2.26e-06**	1.89e-06
	(4.42e-07)	(7.95e-07)	(1.05e-06)	(1.31e-06)
FDI	-0.0004139	-0.0009965	-0.0020125*	-.0023656*
	(0.0004354)	(0.0007841)	(0.0010359)	(0.0012911)
TO	-.0001424 ***	0.0000315	0.0001959	-2.03e-06
	(0.0000508)	(0.0000915)	(0.0001208)	(0.0001506)
COC	0.0166257**	-0.0063026	-0.0252286	-0.0103926
	(0.0080429)	(0.0144838)	(0.0191361)	(0.0238493)
ROL	-.0146482	-0.0112004	-0.0414304*	-.0524629*
	(0.0094877)	(0.0170857)	(0.022573)	(0.0281336)
POLS	-0.0040042	0.0009655	0.0256146***	-0.015615
	(0.0037627)	(0.00677)	(0.0089525)	(0.0111575)
constant	0.0377511 ***	-0.0090624	-0.0355985	0.0547832*
	(.0100421)	(0.0180841)	(0.0238929)	(0.0297776)
observations	440	440	440	440

Standard errors in parenthesis
***P<0.01, **p <0.005, *p < 0.1

The conditional distribution function β_τ can be obtained as

$$\beta_\tau = arg\min_{\beta}[\theta_\tau(y - X\beta)]$$

And therefore, solving the sample analogue defines the estimator of β as

$$\widehat{\beta_\tau} = arg\min_{\beta}\sum_{i=1}^{N}[\theta_\tau(y_i - X_i\beta)]$$

Where y_i and x_i are ith element of Y and X, respectively, $\theta_\tau(u) = u\big(\tau - I(u < 0)\big), I$ is an indicator function, and $0 < \tau < 1$. This study focuses on four values of $\tau = 0.25, 0.50, 0.75\ and\ 0.90$, which represent 25th, 50th, 75th and 90th distributional quantiles, respectively.

From the regression results reported in Table 6, two key proxies used for green technology adoption are the environmental performance index and renewable energy consumption. Clearly, the findings showed a heterogeneous effect of EPI and REC on industrial competitiveness. The results reveal that the EPI coefficient exhibits a significant positive relationship with industrial competitiveness at the 50th, 75th and 90th percentiles. This indicates that as countries become industrially competitive, environmental regulation may begin to impose higher short-term compliance costs, consistent with earlier critique of the Porter hypothesis (Porter & Van der Linde, 1995). In contrast, REC shows a negative significant effect at the 25th and 90th percentile but positive significant at the 75th percentile. This depicts that countries at a lower level of competitiveness may struggle with the disruptive impacts of transitioning towards renewable energy. These results harmonies with the GMM results estimates. The results from ROL, COC and POL also indicate that institutional quality significantly moderates the impact of the GTA variables. The negative estimate of ROL, COC and POL suggests that in an environment with poor institutional quality, the positive impact of EPI and REC might have diminished. Further, the result indicates that Green Technology Adoption increases industrial competitiveness. The moderating role of IQ is crucial, indicating that robust governance frameworks amplify the positive impact of GT. The control variable also shows similar results to the GMM estimates. This shows that the GMM estimates are robust, since the findings are consistent with the PQR.

5. Conclusion and policy recommendation

Promoting green technology adoption as a pathway to sustainable industrial competitiveness has become central in global policy and academic discourse, especially in the era of climate change and the Sustainable Development Goals (SDGs). This study investigates the dynamic between green technology, institutional quality and industrial competitiveness across 24 emerging economies from 2001 to 2021. The findings reveal a nuanced relationship. Specifically, the environmental performance index (EPI), which captures environmental innovation and regulatory outcomes, significantly enhances industrial competitiveness. This outcome aligns with the Porter hypothesis, which posits that well-design environmental regulation can drive innovation, efficiency, and ultimately strengthen industrial competitiveness. In contrast, Renewable energy consumption (REC) hurts competitiveness, reflecting transitional inefficiencies, financing gaps, and infrastructural weakness in many emerging economies. These suggest that while environmental innovation generates competitive advantage, renewable transitions may impose short-term economic trade-offs unless supported by robust institutional and economic frameworks. Institutional quality plays a critical role in shaping this dynamic. Strong rule of law and political stability amplify the competitiveness benefits of environmental performance. However, IQ does not significantly moderate the REC-IC relationship, implying that renewable adoption requires more than government reforms. It also demands large-scale investment, financing and industrial restructuring. Emerging economies must therefore strengthen institutional capacity to transform GTA into a genuine driver of competitiveness. In light of the findings, the study recommends strengthening institutions through transparent, anti-corruption measures, and political stability will reduce investment risk and the incentives for eco-innovation. This should focus on fiscal reforms, including subsidy realignments, green bonds, and concessional credit schemes needed to ease renewable transitions costs. Further, industrial policies must integrate eco-innovation into value chains while ensuring compliance with global standards. Finally, trade and FDI strategies should align with sustainability goals: trade agreements should embed green standards to expand market access, and foreign investment should promote technology transfer. Future research should move beyond country-level aggregates to explore sector-specific competitiveness effects and cross-sectional comparisons, offering deeper insight into how governance diversity shapes green transition.

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Declaration of interest

The author declares that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in the manuscript.

Data availability

The dataset and replication materials supporting the findings of this study are available in the google drive repository at https://drive.google.com/file/d/1eQkPBjec2CkqnfAWJ0XCzvqG_xnOw2cq/view?usp=sharing. the repository includes raw data, proceed/cleaned datasets, variable definition, and statistical code used for analysis.

Ethical statement

The study uses publicly available secondary datasets and does not involve human participation, clinical procedure, or patients' trial; therefore, clinical trial registration or ethical is not applicable.

Clinical trial number

Clinical trial number not applicable

Appendix

Table A1: Fisher Type Stationary Test

	Inverse chi squared		Inverse normal		Inverse logit		Modified inverse chi squared	
	Statistics	p-value	Statistics	p-value	Statistics	p-value	Statistics	p-value
CIPI	577.4073	0.0000	-21.8056	0.0000	-35.7657	0.0000	60.0840	0.0000
EPI	473.5756	0.0000	-19.3965	0.0000	-29.3341	0.0000	48.4752	0.0000
Renew	534.6770	0.0000	-20.9132	0.0000	-33.9878	0.0000	56.9728	0.0000
R&G	464.7695	0.0000	-18.9243	0.0000	-28.7885	0.0000	47.4907	0.0000
GDPPC	495.2332	0.0000	-19.9220	0.0000	-30.6757	0.0000	50.8966	0.0000
FDI	477.2446	0.0000	-18.9100	0.0000	-29.5607	0.0000	48.8854	0.0000
Trade	388.2252	0.0000	-17.1549	0.0000	-24.0472	0.0000	38.9328	0.0000
COC	398.8587	0.0000	-17.4261	0.0000	-24.7058	0.0000	40.1216	0.0000
ROL	446.6836	0.0000	-18.7000	0.0000	-27.6684	0.0000	45.4686	0.0000
POL	339.5416	0.0000	-15.7185	0.0000	-21.0304	0.0000	33.4898	0.0000
EPI*COC	334.0065	0.0000	-15.6244	0.0000	-20.6883	0.0000	32.8709	0.0000
EPI*ROL	366.3348	0.0000	-16.5582	0.0000	-22.6911	0.0000	36.4853	0.0000
EPI*POLS	282.8309	0.0000	-14.0166	0.0000	-17.5166	0.0000	27.1493	0.0000
Renew*COC	118.4959	0.0000	-7.3020	0.0000	-7.3910	0.0000	9.2335	0.0000
Renew*ROL	196.6394	0.0000	-10.9050	0.0000	-12.4726	0.0000	18.1972	0.0000
Renew*POL	312.6976	0.0000	-14.9100	0.0000	-19.8745	0.0000	31.5100	0.0000

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