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Role of Corruption and Governance Quality on Green Electricity Transition: Learning Through the Lens of Economic Complexity and Sustainability

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Abstract

The transition towards green and clean energy sources is the need of the day and a key target for several economies across the globe. Besides, emerging economies also aim to minimize fossil fuel dependence, promoting the adoption of green electricity. However, several obstacles, including governance, corruption and economic-related issues, are forthcoming in attaining sustainability in the context of green energy. This research examines seven emerging economies from 1990 to 2020. The study uses novel panel diagnostic assessment approaches, which validate the slope heterogeneity and cross-sectional dependence and confirm the cointegration between the study variables. Employing the method of moments quantile regression, this research concludes that corruption and governance quality adversely influence the transition to green electricity. On the other hand, the influence of economic complexity, research and development expenditures and per capita GDP is positive and significant. These results are robust as validated by estimators such as mean group and fully modified ordinary least squares. Furthermore, a two-way Granger causality exists between regressors and green energy transition, which allows this research to offer appropriate policy implications. This study recommends improving institutions, strengthening bureaucracy, enhancing accountability and investing in research and development, green technologies and human capital to encourage green energy transition.

Keywords: Green energy transition, governance quality, corruption, economic complexity, green electricity, Emerging Seven

JEL Classification: P48, Q47, Q28

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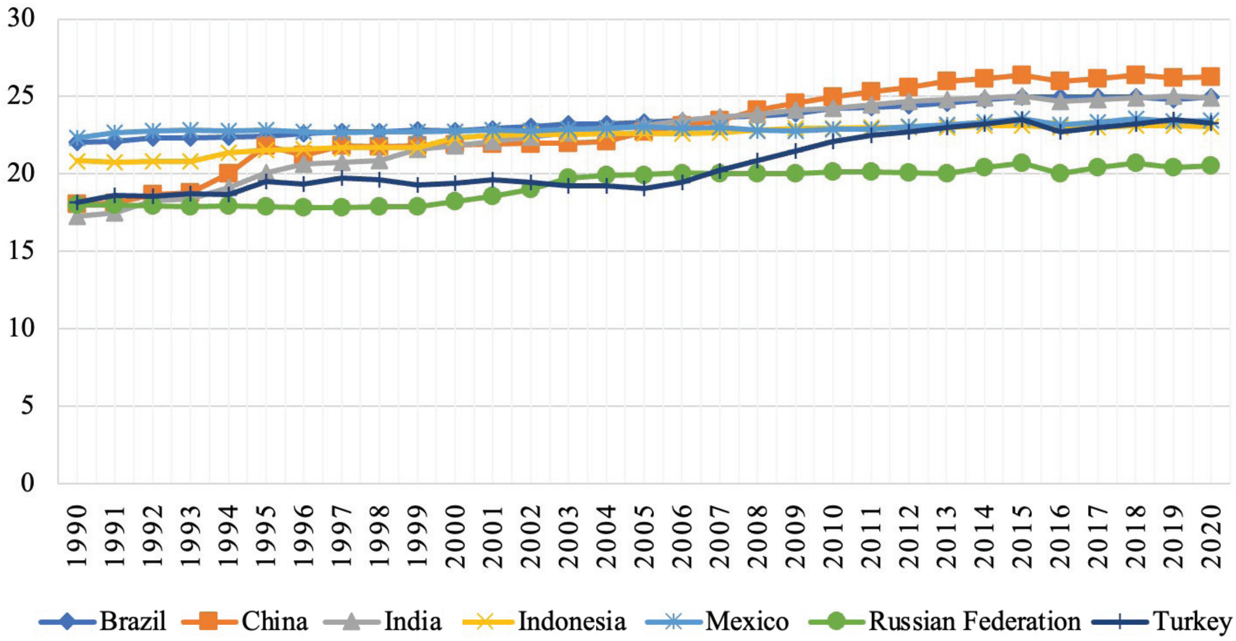
1. Introduction

Green electricity has become a tool for revolutionary change in the global energy landscape as we slowly but steadily move towards green transition (Dai *et al*., 2023). The pressing need of countries across the globe is to mitigate emissions and swiftly transition towards green energy sources. The rise in natural disasters increases the international community's concerns about limiting climate abnormalities. To expedite the transition to green electricity and achieve climatic goals, it is necessary to understand the possible factors that significantly contribute to the slowdown of sustainable objectives (Chan *et al*., 2023). This transformation requires technological advancements, efficient environmental policies or economic prosperity and is closely related to controlling corruption and alleviating poor governance quality. Corruption and poor governance are believed to become obstacles in implementing climate policies and initiating green projects, potentially delaying climate action (Mahmood *et al*., 2021). The difficulties of the green transition are now usually party-political, societal or administrative. Thus, it is necessary to explore the role of governance quality and corruption in the growth of green electricity for efficient policymaking, which the present study aims to observe empirically in E7 economies.

Governance covers a bureaucratic framework of an economy as well as effectively controlling law and order. The main objective is to examine how governance quality affects the green transition and whether corruption acts as a counterforce in the process, because economies around the world are shifting towards renewable change along with creating and adopting sustainable practices. Consequently, understanding the governance dynamics, institutions' effectiveness and corruption control is necessary to accelerate the transition process. It is important because an effective law and order system attracts international businesses, builds trust and authority among investors and ensures the overall success of the transition process (Haffoudhi, 2019; Degbedji *et al*., 2024). However, corruption disrupts the equilibrium and comes in the way of green projects, becoming a formidable challenge for the economy (Mahmood *et al*., 2021). The existence of corrupt practices unfavourably influences energy sectors, making green investments unattractive. Gennaioli and Tavoni (2016) and Wysocki and Dec (2022) indicated that corruption and criminal activities in the renewables sector significantly disrupted the green transition process (Ren *et al*., 2021). Hence, the study dissects the interaction between corruption, governance and green transition in the Emerging Seven.

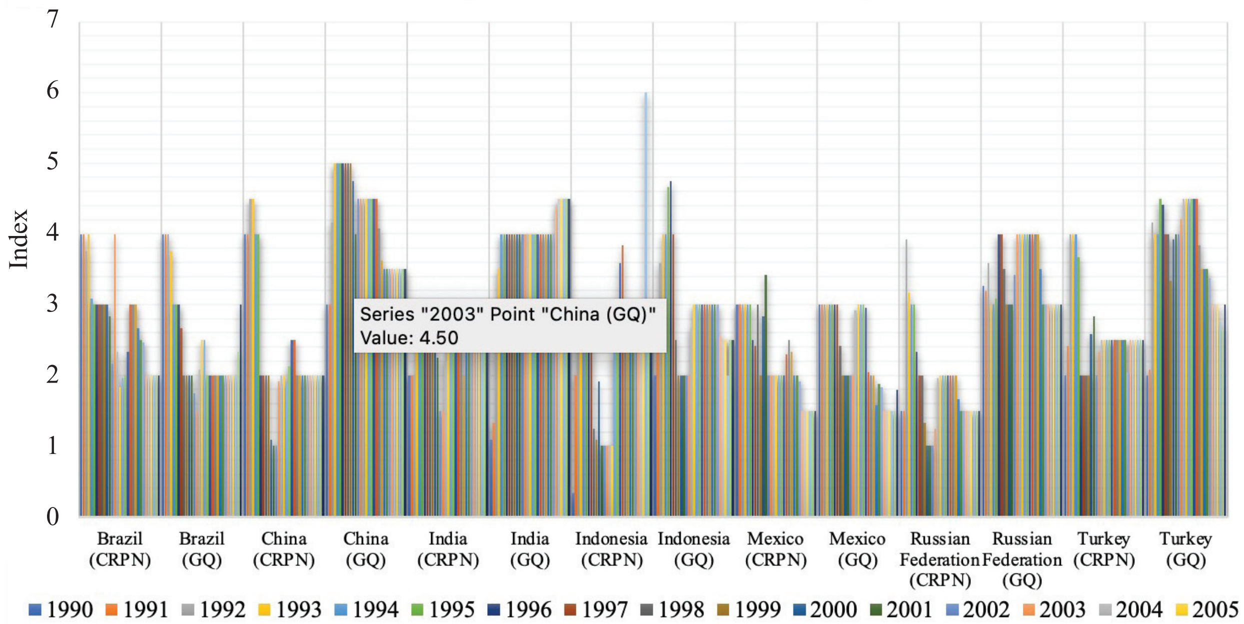
Figure 1: Green energy in emerging economies



Source: Authors´ estimations

The Emerging Seven are characterized by potential growth economies having diverse governance structures and a global impact on sustainable practices. Analysing their green transition strategies would be a resourceful contribution to the international community as it provides significant insights for policy implications that will contribute to global efforts towards sustainable energy. Figures 1 and 2 show a graphical presentation of green energy, levels of corruption and governance quality in the Emerging Seven. As represented by the diversity of law and order, the rise of green energy signifies the importance of eco-friendly transition. The challenges faced during the transition to green energy must be addressed with an inclusive approach. Hence, considering the research objectives, inspecting their effect on green change will be beneficial for policy enthusiasts and researchers to address whether these drivers contribute to equitable and sustainable growth in future.

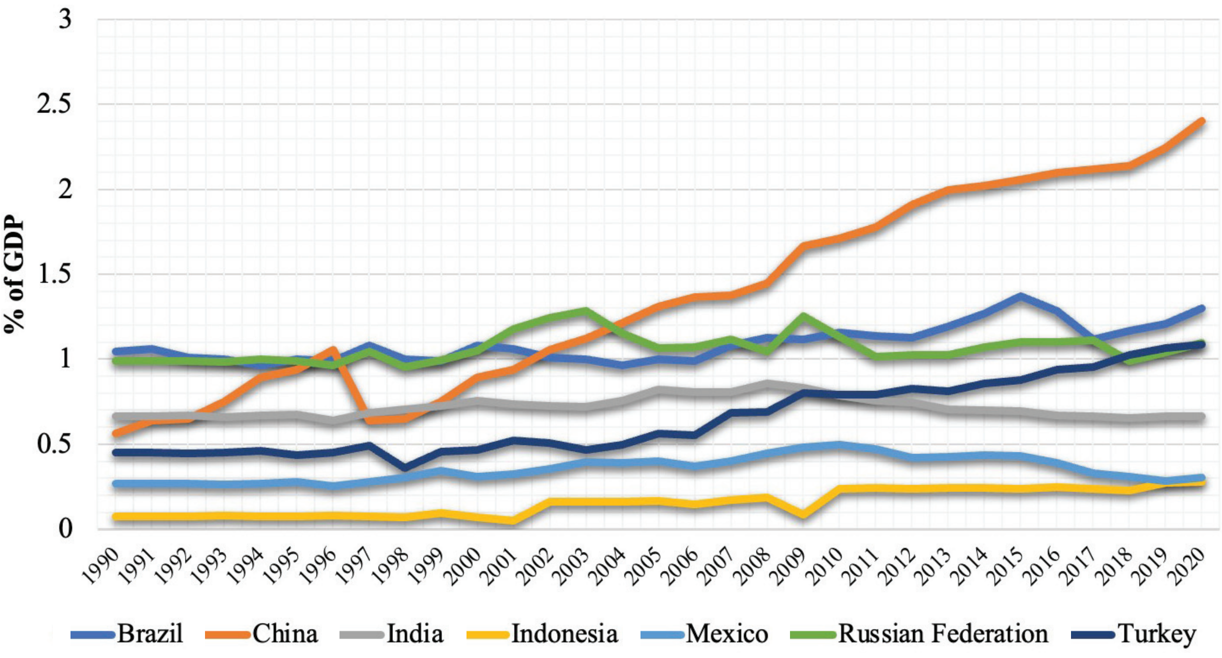
Figure 2: Corruption and governance quality in emerging economies



Source: Authors´ estimations

The economies need to increase economic complexity and implement welfare strategies for curtailing environmental degradation and achieving green transition (Murshed *et al*., 2022; Wan *et al*., 2022). However, the role of R&D in the transition to green electricity is another linchpin in expediting the process. This ensures a more sustainable environment through green energy; businesses profit from spending on research and development (R&D) on green energy (Li *et al*., 2023). The visual R&D presentation in Figure 3 shows that, over the years, China has made significant progress in R&D compared to other emerging nations and it is now believed that China is spending on R&D to accelerate its green transition (Li *et al*., 2023). Nowadays, every emerging nation aims to support sustainable measures for green transition to fulfil the 26th COP targets. Since R&D is an essential factor for nurturing innovation and transparent governance effectively facilitates growth, empirically exploring the determinants of green electricity, *i.e.*, governance and corruption, alongside examining the role of R&D in the transition, will be an innovative contribution to the academic and empirical literature.

Figure 3: R&D expenditures in emerging economies



Source: Authors´ estimations

The transition to green electricity has captured our attention since the scarcity of academic literature in this area motivated us to investigate its determinants in E7 from 1990 to 2020. Hence, a comprehensive methodological approach considering governance, corruption, economic complexity, R&D and human capital will be a significant contribution to the academic literature as no prior study has examined these collectively, providing valuable insights for policy implications that will identify the challenges or opportunities in the way of green electricity transition. This underlines the study's significance because it will further expedite thought-provoking research and theoretical discussion. Besides, the study outcomes can be used as a reference by governments to enhance law and order alongside strengthening institutions to support the sustainable energy transition.

The rest of the paper is organized as follows. Section 2 presents a review of the available literature. Section 3 deals with the methodology and data. Section 4 summarizes and discusses the results. Finally, Section 5 presents the conclusion and suggests policy implications.

2. Literature Review

The recent literature has investigated the determinants of renewable energy. The academic literature on renewables is split into two portions. The first strand is concerned with the renewable consumption determinants. The overall literature on this is inconclusive as some have demonstrated that renewable energy consumption accelerates with increasing economic growth or vice versa, and some have failed to find any casual association (Saba and Biyase, 2022; Saadaoui and Chtourou, 2022). The other strand is focused on renewable development. Employing various approaches and datasets, scholars believe that energy demand, trade, technological innovation, renewable electricity output and nonrenewable sources substantially influence the production and development of renewable energy (Saba and Biyase, 2022; Gu *et al*., 2024). Besides, improvement in the green energy use substantially improves environmental quality (Xu *et al*., 2024) and reduces carbon footprints (Yu *et al*., 2024). There is limited literature on determinants of green electricity transition, but considering the following set of studies, its relationship with the present study factors is expounded for effective research.

Governance plays an influential part in steering the sustainability wheel. The quality of management and institutions helps increase economic development. The more an economy moves towards a sustainable development path, the more efficient institutions are required (Kwilinski *et al*., 2023). Studies suggest that good governance promotes renewable energy development (Saba and Biyase, 2022). It is commonly argued that having strong management and institutional quality, a country is bound to attract green investments. Besides having a better trade regime, the negative influence of a weak government tends to diminish significantly in the country (Bellakhal *et al*., 2019; Degbedji *et al*., 2024). Hao (2023) investigated the influence of good governance and technological innovation using a panel data approach on a BRICS dataset. The empirically estimated outcomes demonstrated that governance and technological innovation support significantly accelerate green transition. In a similar study, Sinha *et al*. (2023) inspected the influence of governance quality on the transition of green electricity in OECD countries during the period 2000-2019. The study described that governance helps enforce laws and regulations crucial for tackling climate shifts and shaping a green energy future. The empirical results provided a positive governance role in the transition to green electricity, signifying its importance for a sustainable future. Moreover, the literature emphasizes that solid governmental institutions and governance mitigate environmental deterioration and smooth the transition to green energy (Du *et al*., 2023; Zhang, 2023).

It has been specified that solid governance in a country positively interacts with its green transition. However, certain regulatory limitations often challenge green economic integration (Mahmood *et al*., 2021). Ozturk *et al*. (2019) described that corruption control is essential for an efficient green transition as increased corruption slackens the sustainable initiatives and transition path towards green electricity. Rampant corruption practices adversely affect energy sectors, making green investments unattractive. Previously, studies such as Gennaioli and Tavoni (2016) and Wysocki and Dec (2022) indicated that corruption and criminal activities in the renewables sector, probably due to poor institutions, have an adverse influence on energy markets, which in turn affects the green technological innovation leading to disruption of the transition process (Ren *et al*., 2021).

Nonetheless, on the other hand, having high economic complexity in the country often translates into the economy having a significant set of industrialized sectors that attract many potential investors due to increasing interconnectedness among countries. Thus, it becomes easier to adopt new technologies, indicating that economic complexity is positively associated with green energy (Can and Ahmed, 2023). Likewise, Wang *et al*. (2023) also examined the positive interaction between economic complexity and green transition using panel data analysis. However, few studies in the literature have observed heterogeneous responses between economic complexity and green change (Chu, 2023; Chu *et al*., 2023). Then again, the majority favour economic complexity for promoting green growth. Economic complexity is imperative for a sustainable environment because it encourages environmental welfare. Economies are required to increase economic complexity indices and implement welfare policies to accomplish green growth plans and minimize ecological degradation (Murshed *et al*., 2022; Wan *et al*., 2022). Likewise, in a renowned study by Sun *et al*. (2022), the authors demonstrated that economic complexity substantially leads to a renewable transition that grounds a reduction in environmental degradation. In addition, a complex economy demands research and development initiatives for prompt green energy solutions. In a recent study on drivers of green transition, Li *et al*. (2023) declared that research and development budgets and financial development are essential in promoting green electricity transition. The study suggested that promoting renewable R&D and economic expansion encourage green transition as R&D significantly increases green electricity transition (Caglar and Ulug, 2022; Qi *et al*., 2022). Most of the research conclusions have asserted the importance of R&D in green energy transition; in addition, Kılıç Depren *et al*. (2024) demonstrated in their panel data assessment that improvements in R&D investment strengthen environmental sustainability.

In a recent study, Hao (2023) empirically examined the association between economic growth and green transition in BRICS. The panel estimates depicted a positive and significant relationship between the study variables. Furthermore, the study findings suggested that strong institutions and regulative quality significantly contribute to promoting green transition and attaining sustainable goals. Similarly, Mahmood *et al*. (2021) empirically explored the interaction between economic growth and green energy. Their empirical estimates depicted a positive relationship between them in South Asia. However, some governance issues come in the way of the transition to green electricity.

In contrast, Ergun and Rivas (2023) observed a U-shaped interaction between economic growth and renewable energy, depicting a lower initial with an increase in GDP; the renewable transition decreases, but after a certain level, the economy moves towards a green change. In another study, Feng and Zhao (2022) demonstrated that initially, during the transition phase, economic growth interacts with green electricity negatively, whereas later, the association becomes positive. Besides, an additional study investigated a similar association in the Chinese economy and found electricity's direct and indirect influence on economic growth. Thus, the study suggested reliable policies for a smooth transition.

The transition to green electricity and energy is the ultimate solution for lessening global warming, and human capital is a significant tool. Recently, Huang *et al*. (2022) examined the role of human capital in green transition in OECD economies during the period 1990-2017. The results showed that human capital and eco-innovation are essential for a sustainable future in green growth. In a recent study conducted in China, Li *et al*. (2023) inspected and declared that human capital resources contribute to stimulating green transition by enhancing work efficiency. Achuo *et al*. (2023) also examined that human capital significantly and positively affects the growth of green electricity, but the effect is non-significant. Another study found a one-way positive causal link between human capital and short-term and long-term production of green electricity and the overall amount of energy used (Fatima *et al*., 2019). Besides, Zhang *et al*. (2022) described that human capital is an essential tool for reducing fossil energy use and promoting green electricity. Correspondingly, adopting green energy is imperative for enhancing the well-being of humans (Liao *et al*., 2021). On the contrary, Khan *et al*. (2020) observed the negative interaction between green energy and human capital in the case of G7 economies.

2.1 Research gap

The above section describes the possible relationships between green electricity transition and study factors. The present literature is occupied with studies on the determinants of renewable or green energy consumption and development (Saba and Biyase, 2022). Since renewable consumption and development are the talk of the town, and based on the increasing demand for achieving sustainable goals, the transition to green electricity has captured the authors' attention. Due to the scarcity of academic literature in this area, the study investigates the determinants of the growth of green electricity in E7 from 1990 to 2020. A comprehensive approach considering governance, corruption, economic complexity, R&D and human capital will be essential to the academic literature as no prior study has deemed it necessary to examine these collectively. According to the reviewed literature, it can be assumed that having good governance, significant R&D budgets, rising economic progression and an abundance of skilled human capital significantly escalates the green electricity transition process (Sinha *et al*., 2023; Qi *et al*., 2022; Wang *et al*., 2023; Hao, 2023; Huang *et al*., 2022). However, corrupted policies or ineffective regulatory laws take their toll on the process and may slow it down (Wysocki and Dec, 2022; Ren *et al*., 2021). Therefore, the thorough literature review demonstrates that all study factors are essential, and careful consideration is necessary for a successful transition. The outcomes will provide valuable insights for policy enthusiasts to identify the challenges or opportunities in the transition to green electricity.

3. Methodology

Following the objectives of this research, the study aims to identify the pertinent factors affecting the transition to green electricity (GRE) in emerging economies. In this respect, the present study considers two governance or institutional indicators, including corruption (CRPN: estimate) and governance quality (GQ: estimate), which are considered in two separate models. Besides, this research uses the economic complexity index (ECI), R&D expenditures (% of GDP), GDP per capita and human capital index (HCI) as explanatory factors of GRE (electricity production from renewable sources, excluding hydroelectric (kWh)) in both models, given as:

Model 1

$$GRE_{it} = \alpha_0 + \beta_1 CRPN_{it} + \beta_2 ECI_{it} + \beta_3 R\&D_{it} + \beta_4 GDP_{it} + \beta_5 HCI_{it} + \varepsilon_{it} \tag{1}$$

Model 2

$$GRE_{it} = \alpha_0 + \beta_1 GQ_{it} + \beta_2 ECI_{it} + \beta_3 R\&D_{it} + \beta_4 GDP_{it} + \beta_5 HCI_{it} + \varepsilon_{it} \tag{2}$$

In the models above, it must be noted that the intercept and slope terms are indicated as α's and β's. respectively. In addition, the symbol for error correction is presented as ε, while the cross sections (E7 economies: India, Brazil, Turkey, China, Russia, Mexico and Indonesia) and period (1990–2020) are represented by i and t, respectively. Regarding the data collection, this research uses the World Bank (2023): R&D, GDP and HCI; ICRG (CRPN and GQ) and OEC (ECI) as authentic data sources.

These variables have essential implications for emerging economies, where each of the variables included in the regression model is critical for understanding the dynamics of green electricity adoption and sustainability. Corruption is particularly problematic, as numerous studies indicate, for the adoption and effectiveness of green energy policies and projects in emerging economies. It undermines regulatory enforcement, distorts market mechanisms and diverts resources away from sustainable development projects (Ross, 2006). Taking on corruption will be critical to securing an attractive environment for clean energy investors in emerging economies and promoting transparency and accountability in the development of the energy sector (Lambsdorff, 2007). The variable corruption index ranks countries by the perception levels of public sector corruption, as determined by expert valuations and opinion surveys. Besides, good governance is essential for establishing an environment that enables the transition to clean energy. Higher governance quality is associated with more robust, more stable political institutions, a more solidly entrenched rule of law and better regulatory institutions, the latter of which are especially critical for the carbon trading programmes required to meet carbon reduction targets, as they entail a large number of emission sources that must be accurately measured and strictly regulated (Knack and Keefer, 1995). The index for governance quality is formed by five indicators, including riots, crime rates, the Gini index, industrial disputes and strikes, and the debt-income ratio.

As noted, reflecting a country's economic complexity, which is essential for diversification and innovation, is critical as economies seek to integrate and build green energy technologies. High economic complexity can allow a country with a comparative advantage to diversify and, therefore, create a more resilient energy system that is dynamic and able to integrate new renewable energy sources (Hidalgo and Hausmann, 2009). Investment in R&D is also essential for the innovation and technically advanced systems that green energy requires. Emerging economies that channel funds into R&D could advance legacy-embedded technologies in the long run and develop domestically cleaner energy technologies as they reduce their dependence on fossil fuels and enhance energy security (Dauda *et al*., 2019).

GDP proxies the overall economic health and development level of a country. Traditionally, it is seen that the greater the GDP, the more resources the government has and the more of them it invests in infrastructure in particular. Both are helpful to the adoption and deployment of green energy solutions in emerging economies (Inglesi-Lotz, 2016). Lastly, the HCI, defined by factors including the level of education and skills of individuals, plays an instrumental role in driving innovation and adopting green energy technologies. A highly skilled workforce can support R&D activities, enforce the implementation of clean energy policies and drive the transition to a knowledge-based economy (Halilbegović *et al*., 2023).

3.1 Analytical approach

The early stages of this investigation include doing a descriptive evaluation and performing normality tests for all factors. This study calculates the panel data series median, mean and range. The calculated standard deviation demonstrates the level of variability in the time series due to variations in observations and mean values. Moreover, the application of kurtosis and skewness is employed in this study to evaluate the normality of the data. Similarly, the normality evaluation proposed by Jarque and Bera (1987) is utilized, which considers both the former measures while maintaining zero values. The statistical methodology to assess the normality of the data is expressed as:

$$JB = \frac{N}{6}\left(S^2 + \frac{(K-3)^2}{4}\right) \tag{3}$$

Since this research delves into the analysis of panel data, it must employ diagnostic tests, including slope homogeneity and panel cross-sectional dependence (PCD). In this regard, the present research uses the slope coefficient heterogeneity test proposed by Pesaran and Yamagata (2008), expressed as:

$$\hat{\Delta}_{SCH} = \sqrt{N\left(2k\right)^{-1}}\,(N^{-1}\acute{S} - \mathrm{K}) \tag{4}$$

$$\hat{\Delta}_{SCH} = \sqrt{N}\sqrt{\frac{T+1}{2K.\left(T-K-1\right)}}\,(N^{-1}\acute{S} - 2\mathrm{K}) \tag{5}$$

This test offers both the SCH and adjusted SCH results while opting for homogeneity of slopes as H_0. To test for the issue of PCD, this research employs the Pesaran (2004) test, which is formulated below with independent cross-sections as H_0:

$$\mathrm{CD}_{Test} = \frac{\sqrt{2T}}{\left[N\left(N-1\right)\right]^{1/2}}\sum_{i=1}^{N-1}\sum_{k=1+i}^{N}T_{ik} \tag{6}$$

The diagnostic test involves doing a stationarity evaluation for each specified variable. The present study utilizes several unit root approaches, including Levin, Lin and Chu (2002), Breitung (2001), Im, Pesaran and Shin (1995), ADF–Fisher (Maddala and Wu, 1999) and Phillips and Perron (1988). These tests are conducted on both level [I(0)] and first-difference [I(1)] datasets. Based on H_0, all of these assessments are predicated on the existence of a unit root.

Following the stationarity, evaluating the potential existence of a long-term relationship among the components is important. There are a multitude of methodologies for panel data analysis. In this study, the investigation of cointegration was conducted using the evaluation methodology proposed by Maddala and Wu (1999), including the Johansen–Fisher cointegration test. One of the advantages of this method is its inherent adjustability. Furthermore, the stated approach has characteristics that make it accessible to users and intellectually attractive in terms of its conceptual framework. Furthermore, Hanck (2009) demonstrated that this test has superior performance compared to the studies conducted by Pedroni *et al*. (2004) and Larsson *et al*. (2001). Furthermore, the present research additionally uses the residual cointegration test proposed by Kao (1999) to provide further confirmation of the cointegration.

Sophisticated methodologies may be used to develop enduring projections for precise predictions. Consequently, the present study utilizes the method of moments quantile regression (MMQR) estimation technique proposed by Sarkodie and Strezov (2019). The superiority of this technique over simple regression methods stems from its ability to analyse coefficients at a specific scale and location. This methodology exhibits a higher level of precision compared to other methods since it considers the impacts of individual quantiles instead of relying just on average effects. Moreover, given its ability to address the issue of endogeneity, this methodology is suitable for conducting long-term correlation analysis. The formula representing the location-scale variance $Q_y(\tau|R)$ is provided along with the accompanying ramifications:

$$Y_{it} = \alpha_i + \beta R_{it} + \left(\gamma_i + \rho \acute{Z}_{it}\right)\mu_{it} \tag{7}$$

The preceding equation incorporates a probability formula, where $p(\gamma_i + \rho \acute{Z}_{it} > 0) = 1$. In the present inquiry, the variables α, β, γ, ρ are used to determine the expected values. The subscript i denotes a fixed effect in this particular instance, as seen by the constrained α_i and γ_i (where $i = 1, 2, \ldots, n$). The k-vector, denoted by the symbol $\boldsymbol{Z}$ and the vector $\boldsymbol{\iota}$, on the contrary, illustrate the variances of R.

$$\boldsymbol{Z}_{\mathbb{I}} = \boldsymbol{Z}_{\iota}(R),\ \iota = 1, 2, ..., k \tag{8}$$

In the equation above, the variable R_{it} is allocated in a symmetrical and impartial manner across t and i. This allocation is done in a linear and orthogonal order to both i and t while also maintaining the integrity of the external reserves and observations (Machado and Silva, 2018). Based on the aforementioned rationale, the research models may be generalized and reformulated as follows:

$$Q_y\left(\tau|R_{it}\right) = \left(\alpha_i + \gamma_i q\left(\tau\right)\right) + \beta R_{it} + \rho \acute{Z}_{it}\, q\left(\tau\right) \tag{9}$$

In this study, the variable R_{it} represents the regressors, namely CRPN, GQ, ECI, R&D, GDP and HCI. All the components are expressed as percentages once transformed into the natural logarithm. In addition to this, R_{it} provides insights into the distribution of regression coefficients, as shown by R_{it}, which displays GRE and is also influenced by quantiles. Furthermore, the formula $-\alpha_i(\tau) \equiv \alpha_i + \gamma_i q(\tau)$ represents the vector component that consistently affects i but does not have any effect on the intercepts. Finally, $q(\tau)$ denotes the τ-th quantile sample (here, Q0.20, Q0.40, Q0.60, Q80 and Q0.90). The quantile description for this research is as follows:

$$min_q \sum_i \sum_t \theta_\tau \left(R_{it} - \left(\gamma_i + \rho \acute{Z}_{it} \right) q \right) \tag{10}$$

The measurement method, denoted as $\theta_\tau(A)$ may be expressed as follows: $(\tau - 1)\ AI\{A \leq 0\} + TAI\{A > 0\}$.

Apart from the analysis of the coefficients via MMQR, this research uses two parametric approaches, *i.e.*, the mean group (MG) and fully modified ordinary least squares (FMOLS) approach, to test the robustness of the models under consideration. In addition to the empirical estimations of each coefficient, this research also utilizes the paired Dumitrescu and Hurlin (2012) panel causality test. The test is designed to examine the causal relationship between variables, a shortcoming that was not addressed in previous non-parametric methods.

4. Results and Discussions

4.1 Diagnostic tests

The panel data analysis approximation starts with the descriptive statistics for the available data. Table 1 shows the results from descriptive statistics and normality distribution. The overall statistical values indicate that the study variables are not normally distributed. This is because each variable shows the presence of non-identical mean and median values, distinct skewness values and values non-equal to average kurtosis. The minimum and maximum values describe the range of the data for each variable, while the standard deviation represents the volatility of each variable. Besides, it explains how much the variable deviates from its respective mean value. The results in the table show that GQ is highly volatile after GRE, with 0.95 and 2.16, respectively. The two conventional measures of the normality test, *i.e.*, skewness and kurtosis, report statistics that vary from their critical values, such as 1 and 3, respectively, depicting non-normal distribution. The unequal data distribution leads this study to consider an appropriate long-run estimator. The identification of descriptive values leads to the application of diagnostic tests, as shown below.

Table 1: Descriptive statistics and normality

	GRE	*CRPN*	*GQ*	*ECI*	*R&D*	*GDP*	*HCI*
Mean	22.05664	2.396498	3.255760	0.353141	0.772704	2.131224	2.364931
Median	22.66860	2.420000	3.000000	0.297075	0.749630	2.186225	2.316139
Maximum	26.37172	6.000000	5.000000	1.163790	2.400930	2.262507	3.434408
Minimum	17.28125	0.330000	1.080000	−0.592783	0.047560	1.849280	1.486921
Std. dev.	2.161530	0.787827	0.947810	0.394046	0.467917	0.112161	0.453083
Skewness	−0.333060	0.685363	−0.158722	0.093486	0.802540	−0.942915	0.579735
Kurtosis	2.414548	4.660571	2.036320	2.454187	3.972230	2.646531	2.809059
Jarque–Bera	7.110994	41.92064	9.307946	3.009705	31.84035	33.28505	12.48501
Probability	0.028567	0.000000	0.009524	0.222050	0.000000	0.000000	0.001945
Obs.	217	217	217	217	217	217	217

Source: Authors' own calculations

Table 2 presents the results of slope homogeneity. The slope homogeneity test for both Model 1 and Model 2 shows a probability value equal to 0. This signifies that the null prediction of both models could be rejected at the 1% significance level with the conclusion that the slopes are non-homogenous. This means that relationships among the variables might differ across regions, or it describes that one variable might depend on another variable. In all, the study factors are heterogeneous in nature, which leads to another diagnostic analysis of cross-sectional dependence. Followed by a cross-sectional dependence test, each variable outcome is presented in Table 3.

Table 2: Slope homogeneity

	Model 1	
	Coef.	**Prob.**
Delta	9.436***	0.000
Adj. delta	10.724***	0.000
	Model 2	
Delta	9.690***	0.000
Adj. delta	11.013***	0.000

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own calculations

We perform a CD test for cross-sectional dependence for GRE, CRPN, GQ, ECI, R&D, GDP and HCI with their probability values at the 1% significance level. The null prediction of these variables is rejected, indicating that cross-sectional dependence prevails among these study factors in the long run. In simple terms, all the variables are cross-sectionally dependent and are significantly connected in the long run.

Table 3: Cross-sectional dependence

Variable	CD test	Prob.
GRE	22.294***	0.000
CRPN	7.573***	0.000
GQ	5.971***	0.000
ECI	5.13***	0.000
R&D	11.199***	0.000
GDP	22.872***	0.000
HCI	24.108***	0.000

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own calculations

4.2 Stationarity and cointegration tests

The prevalence of heterogeneity and cross-sectional dependence is predicted in emerging economies. Therefore, applying an appropriate unit root test is crucial, which handles both the stated panel problems. The study employs a comprehensive set of tests mentioned in the table for detailed analysis. At this level, the test depicts mixed outcomes and on the other hand, all the variables represent stationary outcomes for each study variable. The asterisks at the probability statistics show the level of significance at which they become stationary. Once the stationarity of the variables is obtained, the research is inclined to inspect the long-run equilibrium association between study variables, the outcomes of which are displayed in Table 4 below.

The study employs the Johansen–Fisher panel cointegration test and the Kao residual cointegration test to scrutinize the long-run interconnectedness. The general assessment of these tests shows that all the variables are statistically significant, where $p < 0.01$ or $p < 0.05$. This rejects the null hypothesis, signifying the presence of long-run equilibrium or interconnectedness among GRE, CRPN, GQ, ECI, R&D, GDP and HCI for the E7.

Table 4: Stationarity testing

Panel unit root summary [I(0)]							
Test	***GRE***	***CRPN***	***GQ***	***ECI***	***R&D***	***GDP***	***HCI***
LLC	−0.171	−0.471	−10.636***	0.701	−0.930	1.207	−1.257
Br	2.336	−3.669***	0.3185	−0.441	0.427	3.213	5.777
IPS	1.374	−2.531***	−8.377***	0.946	−0.173	0.795	1.155
ADF	5.482	28.872**	212.966***	9.571	15.948	13.033	8.207
PP	8.055	34.069***	35.074***	10.884	17.435	10.906	4.520
I(1)							
LLC	−3.969***	−5.886***	−8.853***	−5.039***	−4.506***	−4.113***	4.871
Br	−4.640***	−3.167***	−1.922**	−7.344***	−5.101***	−2.514***	6.467
IPS	−5.501***	−9.270***	−8.224***	−5.646***	−6.374***	−2.717***	3.754***
ADF	55.954***	95.465***	84.387***	55.618***	63.004***	30.472***	17.549***
PP	269.202***	145.615***	77.052***	126.961***	204.927***	221.346***	27.558***

Notes: LLC is Levin, Lin and Chu t*, Br is Breitung *t*-stat, IPS is Im, Pesaran and Shin *W*-stat, ADF is ADF–Fisher Chi-square and PP is PP–Fisher Chi-square. Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).

Source: Authors' own calculations

Table 5: Testing cointegration

Johansen–Fisher panel cointegration test				
Unrestricted coins. rank test (trace and maximum eigenvalue)				
	Model 1		**Model 2**	
Hypothesized no. of CEs	**Fisher stat.* (from trace test)**	**Fisher stat.* (from max-eigen test)**	**Fisher stat.* (from trace test)**	**Fisher stat.* (from max-eigen test)**
None	217.5***	115.5***	219.3***	113.5***
At most 1	112.0***	57.47***	117.1***	58.01***
At most 2	66.11***	32.07***	70.13***	29.12**
At most 3	43.49***	21.30*	50.24***	27.30**
At most 4	34.18***	28.07**	35.33***	26.45**
At most 5	27.38**	27.38**	31.42***	31.42***
Kao residual cointegration test				
	***t*-statistics**	**Prob.**	***t*-statistics**	**Prob.**
ADF	–3.486***	0.000	–2.993***	0.001
Resid. var.	0.072	–	0.073	–
HAC var.	0.085	–	0.085	–

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own calculations

4.3 Regression investigation

Considering these diagnostics and non-normality distribution tests, the study employs the MMQR approach because it provides efficient estimates compared to the traditional linear regression approach. Table 6 shows the analysed results from MMQR Model 1. Firstly, corruption heterogeneously affects the transition to green electricity in emerging nations. This indicates that the increasing level of corruption initially disrupts the transition process. Later, however, with efficient management of resources and transparency with corruption control, the interaction becomes positively related to green transition. Such empirical outcomes are somehow in line with the studies of (Ozturk *et al.*, 2019; Wysocki and Dec, 2022) for corruption control and green transition. Secondly, economic complexity and green transition interaction depict an overall positive association, denoting that the more complex the economy is, the more interconnected it is with other economies and will swiftly transition to green energy (electricity).

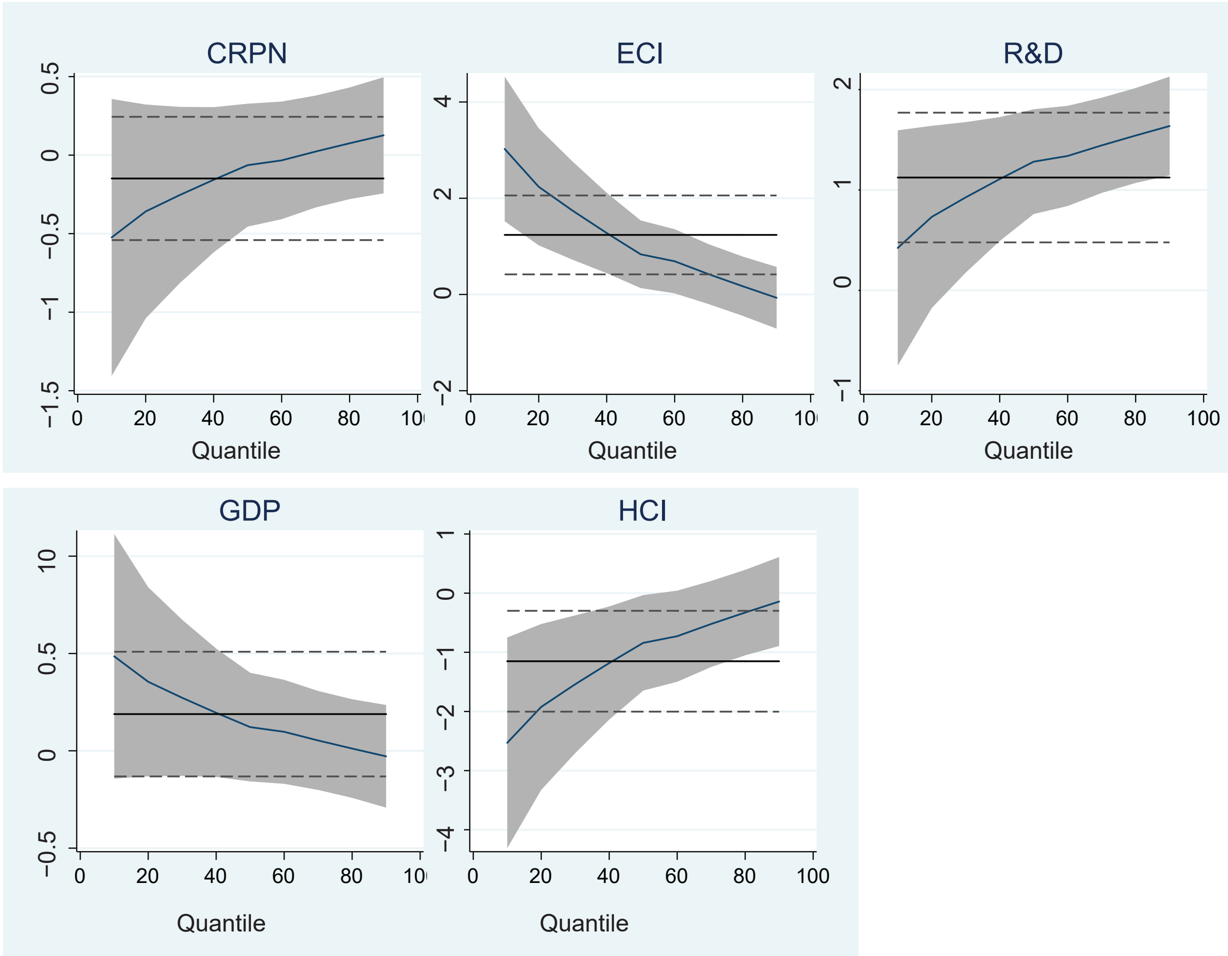
However, the statistical values signify that initially, the impact is positive and later, the influence of economic complexity becomes insignificantly negative, denoting a heterogeneous association. Similar heterogeneous results were obtained by Chu (2023) and Chu *et al*. (2023). Besides, the location and scale results also symbolize the significance of the estimated results of these variables. Thirdly, the role of R&D and GDP on green electricity transition is positive in emerging nations. These outcomes are comparable with the studies of Li *et al*. (2023), Hao (2023) and Mahmood *et al*. (2021). The empirical results of GDP are positively insignificant, while for R&D, they are entirely significant at the 1% significance level and consistent with the studies mentioned above. This shows that economic progression and rising R&D budgets are fruitful for promoting the transition to green electricity in emerging nations. Lastly, the role of human capital in green electricity is statistically significant but negatively related to the transition to green electricity. Generally, the positive impact is that human capital effectively encourages economic development by innovating green and efficient technologies (Paramati *et al*., 2022; Liu *et al*., 2023; Zhou *et al*., 2024). However, the estimated results indicate that certain factors or reasons could negatively influence green transition. Some possible reasons could be a lack of skills, resistance to change to green development, or underdeveloped economies that are dependent on traditional industrial structures. The nexus between human capital and green transition is comparable to the study by Khan *et al*. (2020). These variables are graphically represented in Figure 4 below. The interaction of all the independent variables in the analysis with the dependent variable is depicted in Table 6.

Table 6: MMQR [Model 1]

Variable	Location	Scale	Quantiles				
			$Q_{0.20}$	$Q_{0.40}$	$Q_{0.60}$	$Q_{0.80}$	$Q_{0.90}$
CRPN	−0.149 [0.230]	0.206 [0.148]	−0.359 [0.347]	−0.157 [0.236]	−0.033 [0.191]	0.075 [0.181]	0.126 [0.189]
ECI	1.238*** [0.400]	−0.979*** [0.257]	2.238*** [0.621]	1.278*** [0.426]	0.690** [0.340]	0.173 [0.314]	−0.069 [0.327]
R&D	1.124*** [0.306]	0.384* [0.197]	0.731 [0.463]	1.108*** [0.315]	1.339*** [0.255]	1.542*** [0.241]	1.637*** [0.251]
GDP	1.887 [1.642]	−1.626 [1.057]	3.549 [2.479]	1.954 [1.684]	0.978 [1.364]	0.117 [1.293]	−0.284 [1.346]
HCI	−1.151** [0.469]	0.756** [0.302]	−1.924*** [0.715]	−1.182** [0.488]	−0.728* [0.393]	−0.328 [0.369]	−0.142 [0.384]
CONS.	19.807*** [3.085]	2.884 [1.986]	16.859*** [4.646]	19.689*** [3.154]	21.420*** [2.557]	22.946*** [2.431]	23.657*** [2.530]

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own calculations

Figure 4: Quantile estimates (Model 1)



Source: Authors' own elaboration

Table 7 displays the estimated outcomes from the MMQR for Model 2. Firstly, the impact of governance on the transition to green electricity is negative in all the quantiles, depicting weak governments in the countries and leading to inconsistent policies and ineffective strategies. It also indicates political instability and the presence of corruption that may or may not be an obstacle in the way of the transition to green electricity. This signifies that due to weak governance, higher environmental consequences will become an obstacle to green growth. Besides, the lack of transparency leads to lesser investment in green initiatives. This nexus outcome is somehow in line with the findings of Mahmood *et al*. (2021), who argued that weak governance and the presence of regulatory issues have become a challenge in green integration. Secondly, economic complexity under the existence of a weak government is positively associated. This signifies that businesses have the freedom to explore diverse sectors and approaches. The positive interaction between ECI and GRE demonstrates that weak governance can be desirable for economic progression, indicating that increasing economic complexity promotes the transition to green electricity. This significantly positive outcome is in line with the studies of Wang *et al*. (2023) and Sun *et al*. (2022), implying that economic complexity speeds up the renewable transition because a complex economy drives initiatives for prompt green energy technology. Thirdly, R&D also positively affects the growth of green electricity in the Emerging Seven. The result is similar to the empirical outcomes of Li *et al*. (2023) and Qi *et al*. (2022). This implies that R&D stimulates innovation and enables the development of more efficient solutions that pave the way for the transition to green electricity. Fourthly, GDP and HCI harm the growth of green electricity, indicating that under weak governance quality, both factors are negatively associated with the transition to green electricity. Countries usually depend on and are vested in investing in nonrenewable resources and may perceive green resources as risky. Besides, a lack of skilled people and an absence of awareness among people about the green transition can cause resistance to change. This outcome is in line with the studies of Khan *et al*. (2020) and Feng and Zhao (2022). The graphical presentation of these estimated outcomes is shown in Figure 5 below.

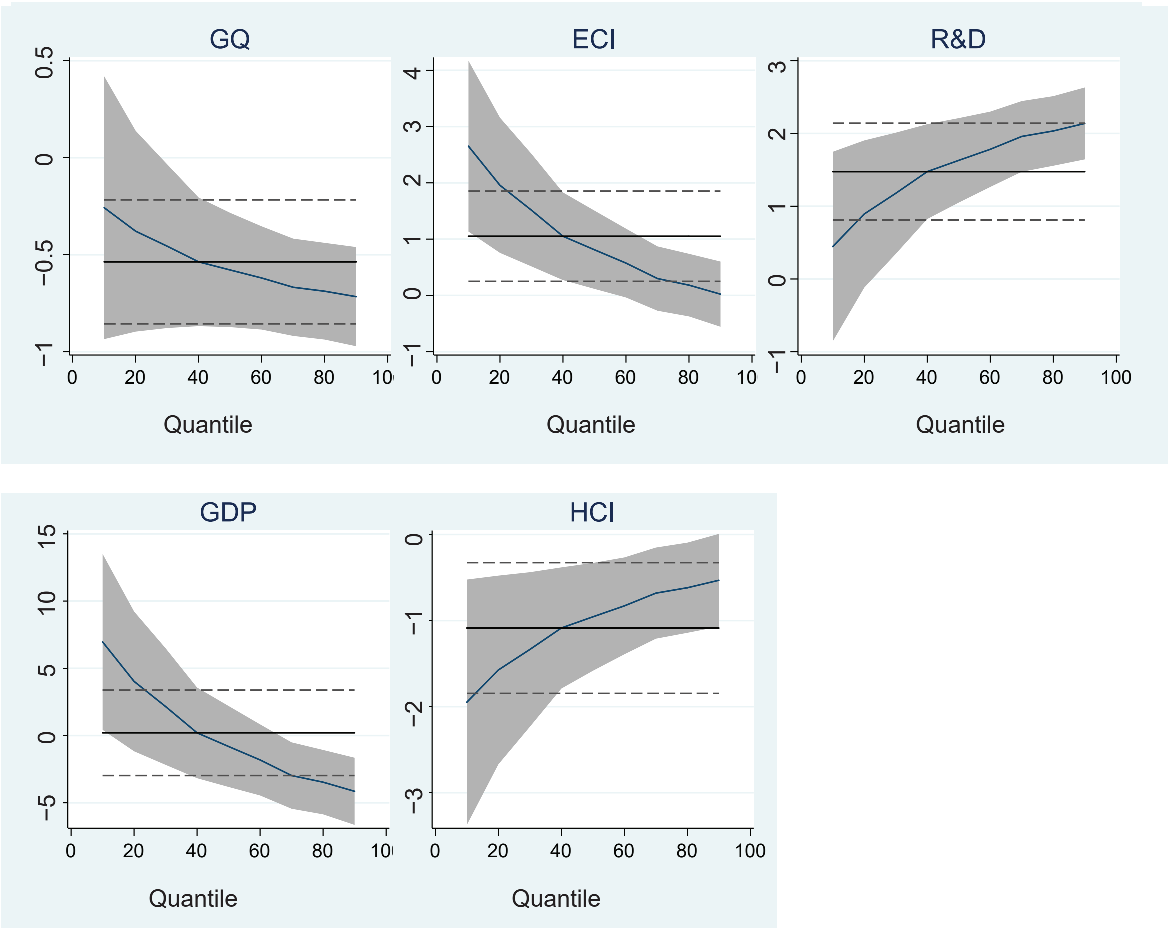
Table 7: MMQR [Model 2]

Variable	Location	Scale	Quantiles				
			$Q_{0.20}$	$Q_{0.40}$	$Q_{0.60}$	$Q_{0.80}$	$Q_{0.90}$
GQ	−0.537*** [0.168]	−0.146 [0.111]	−0.379 [0.264]	−0.537*** [0.169]	−0.620*** [0.136]	−0.688*** [0.127]	−0.716*** [0.130]
ECI	1.052*** [0.380]	−0.836*** [0.2 52]	1.957*** [0.612]	1.051*** [0.397]	0.575* [0.312]	0.184 [0.284]	0.023 [0.295]
R&D	1.475*** [0.324]	0.538** [0.215]	0.893* [0.516]	1.476*** [0.332]	1.783*** [0.264]	2.034*** [0.244]	2.138*** [0.252]
GDP	0.204 [1.645]	−3.532*** [1.092]	4.029 [2.653]	0.200 [1.721]	−1.813 [1.349]	−3.467*** [1.222]	−4.146*** [1.275]
HCI	−1.086*** [0.354]	0.450* [0.235]	−1.574*** [0.559]	−1.086*** [0.359]	−0.829*** [0.287]	−0.618** [0.267]	−0.532* [0.275]
CONS.	24.427*** [3.615]	8.376*** [2.399]	15.356*** [5.849]	24.435*** [3.801]	29.211*** [2.972]	33.132*** [2.681]	34.743*** [2.803]

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).

Source: Authors' own calculations

Figure 5: Quantile estimates (Model 2)



Source: Authors' own elaboration

4.4 Tests for robustness and causality

Table 8 shows the robustness tests for each variable. Although the MMQR results are reliable estimates, the study uses a parametric robustness test and its outcomes have demonstrated similar results, indicating the reliability of the model outcomes. Hence, this shows that corruption and governance quality play a huge role in the green transition. Besides the impact of economic complexity, R&D, HCI and GDP are also influenced by weak economic law and order conditions.

Table 8: Parametric robustness tests

Var.	AMG	FMOLS	AMG	FMOLS
CRPN	0.026	−0.041	–	–
GQ	–	–	−0.011	0.206
ECI	−0.134	−0.041	−0.021	0.027
R&D	2.035	0.196	1.729	0.550
GDP	12.537**	24.920***	13.466***	21.594***
HCI	1.447	1.827***	0.851	2.201***
CONS.	−11.406	–	−11.602	–

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own calculations

Lastly, the causal relationship is determined for the direction of causation. This provides a more comprehensive validation of the regression model. Table 9 displays the panel causality test, signifying that all the study factors have a causal association with the transition to green electricity. ECI and GDP show one-way causality, while the rest of the pairs have two causal associations with the green transition.

Table 9: Panel causality test

Pairwise Dumitrescu–Hurlin panel causality tests			
H_0:	*W*-stat.	Z bar stat.	Prob.
ECI → GRE	7.973***	4.001	6.E-05
GRE → ECI	3.050	−0.227	0.8197
RD → GRE	6.456***	2.698	0.0070
GRE → RD	8.101***	4.110	4.E-05
GDP → GRE	9.631***	5.425	6.E-08
GRE → GDP	3.476	0.137	0.8904
HCI → GRE	10.268***	5.972	2.E-09
GRE → HCI	9.674***	5.462	5.E-08
GQ → GRE	6.784***	2.979	0.0029
GRE → GQ	6.578***	2.802	0.0051
CRPN → GRE	5.319*	1.721	0.0852
GRE → CRPN	5.566*	1.933	0.0532

Note: Asterisks indicate a statistical significance level of 1% (***), 5% (**) and 10% (*).
Source: Authors' own calculations

5. Conclusion and Policy Implications

For decades, the green transition has been a topic of debate among scholars and policymakers for achieving net zero by 2050. Several attempts have been made to inspect the renewable energy determinants. Nevertheless, the academic literature has ignored the nexus between governance, corruption and the transition to green electricity in the Emerging Seven. To scrutinize the true interaction between these, the study employed the MMQR estimation approach and causality analysis from 1990 to 2020. The influence of governance, corruption, economic complexity, R&D and human capital is a unique contribution to the academic literature, as no prior study has considered inspecting this collectively. The findings are an innovative contribution to the educational and empirical literature since the empirical results indicated that governance and corruption may or may not become significant barriers to the transition to green electricity, giving ultimate insights on policy making. Besides, the role of economic growth, research and development and human capital gives an understanding of reviving the strategies to speed up the green transition process. However, strong law and order are necessary to escalate the transition process, showing that green drivers contribute to equitable and sustainable future growth.

Based on the empirical findings, following are a few suggestions for policymakers and scholars. Firstly, evaluating and updating regulations to remove barriers to using green electricity is necessary. Reducing administrative obstacles and simplifying regulatory procedures are required to accelerate the implementation of green technology. Secondly, public awareness and skill training programmes for green energy must be promoted to inform citizens because these will help them adopt green practices and technologies. Thirdly, a corruption uncertainty assessment for energy projects is needed to identify vulnerabilities in green transition. Lastly, we recommend developing a comprehensive policy framework that combines human capital development, governance, anti-corruption measures and R&D incentives. Policies ought to complement each other to ease the transition to green electricity.

The study has a few limitations and recommendations. Firstly, the study employs data from 1990 to 2020 due to the unavailability of data for the Emerging Seven. Therefore, to formulate comprehensive policies for the green transition, the study recommends considering fresh data to capture the present economic situation. It is suggested that E7 be examined with other economies for more thorough policymaking. Secondly, for in-depth analysis, the study suggests exploring the scrutiny between institutional quality and governance over sustainability considering environmental policies.

The findings reported in this paper on the influence of corruption, governance quality and human capital on green electricity uptake in the context of E7 economies may be of broader relevance to other emerging or developing economies. These factors are primarily interconnected and indicate the broader institutional, social and economic structures that condition sustainable energy policy implementation. However, the strength with which they operate may differ across countries and contexts. The positive impacts of the economic complexity index, research and development expenditures and GDP indicate the central importance of technological innovation, economic diversification and financial resources in underpinning the shift to cleaner energy sources. Further research is required to test these findings more rigorously in other countries and contexts with varying geological, economic and socio–political security.

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