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Insights of resources productivity and green technologies impact on renewable energy consumption: Novel MMQR approach

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This study investigates the dynamic effect of resource productivity and green technologies on renewable energy (RE) use in 28 middle-income countries from 2006 to 2022 using MMQR, QR and causality techniques. Results suggested that green technology innovation substantially influences RE use. Second, the significant positive coefficients show that resource productivity leads to higher RE consumption at the upper quantile due to decoupling Gross Domestic Product (GDP) growth from extracting natural resources, indicating a transition towards more sustainable and efficient practices. Based on the empirical findings, several policy implications are suggested for middle-income economies.

KEYWORDS
green technologies, middle-income economies, MMQR, resource productivity

1 | INTRODUCTION

At the COP28 Summit, the dialogue focused on the current patterns of conventional energy consumption, emphasizing how these trends pose a risk to economies, particularly to middle and poorer economies. The conversation also promoted analysis of natural resource utilization, stressing the necessity for a deliberate transition towards more environmentally friendly energy sources and more integration of green technologies and resource productivity (United Nations Climate Change, 2023).

Several policy outcomes have been recommended to promote renewable energy (RE) use. For instance, (Dar & Asif, 2023; Garzón

Baquero & Bellon Monsalve, 2024; Si Mohammed & Pata, 2023) urge emerging countries to transform their economies from fossil fuel (FF) to clean energy to address climatic extremes. Similarly, (Dradra, 2024; Hu et al., 2023; Wang et al., 2023) urge environmental taxation to enhance environmental sustainability in advanced countries while urging middle and emerging countries to use green technology (Behera et al., 2023; Li, 2023).

Furthermore, a strong connection exists between economic well-being, resource productivity and green technology, as emphasized in the sustainable development goal (SDGs). This goal mandates countries to progressively enhance the effectiveness of their production and consumption of RE sources (Abbas et al., 2024; Sun et al., 2023).

According to Wu et al. (2019), source control and end-of-pipe control are two methods to control environmental pollution and enhance RE use. The resource productivity proxies source control, while the environmental policy is an End-of-pipe control regulator. Resource productivity can be calculated by dividing the economic growth (GDP) by total resource consumption. Following empirical literature, such as Ansari (2022) and Lenzen et al. (2022), energy consumption is modelled by using total Domestic Material Consumption (DMC) that includes all forms of energy such as biomass (Bio), FFs, metal ores (MT), and non-metal ores (NM), earth material (EM), mixed product (MP) and product from non-metallic and minerals (PNMM). Improving energy productivity indicates efficient and less energy use in the production process.

This research analyses resource productivity and green innovation in RE among the 28 middle-income countries in Figure 1. It identifies certain countries that have excelled in effectively converting natural resources into economic growth, namely, Algeria, Belarus, Brazil, Colombia, Ecuador, Egypt, Georgia, India, Indonesia, Jordan, Kazakhstan, Kenya, Lebanon, Malaysia, Mexico, Moldova, Morocco, Nicaragua, Nigeria, Pakistan, Peru, Philippines, Russia, South Africa, Thailand, Tunisia, Turkey and Vietnam. Turkey stands out as the leader in resource productivity among the group, with an average of 2.34 USD/kg. The Russian Federation closely follows with 2.17 USD/kg, followed by Lebanon with 1.93 USD/kg, Mexico with 1.89 USD/kg and India with 1.84 USD/kg. These countries demonstrate the utmost efficiency in utilizing their resources to produce economic output, suggesting a more sustainable approach to resource utilization and economic expansion.

In contrast, several countries demonstrate lower productivity in this aspect. Kenya, Moldova, Brazil, Vietnam and Peru have relatively low resource productivity, with prices per kilogram of their resources being 1.02 USD, 0.93 USD, 0.78 USD, 0.74 USD and 0.58 USD, respectively. The lower values indicate that these countries possess less effective means of converting natural resources into economic growth.

High resource productivity signifies the efficient utilization of resources to produce economic output and significant RE consumption. This highlights their dedication to sustainable growth, as RE reduces dependence on non-renewable resources and mitigates environmental impacts (Alola & Adebayo, 2023). In contrast, countries with lower resource productivity can improve their sustainability by increasing their utilization of RE. This shift would diminish their reliance on non-renewable resources and potentially enhance their resource efficiency by decreasing resource consumption for energy requirements.

Examining green patents (GRP) across the 28 middle-income countries uncovers valuable observations regarding the emphasis on environmentally sustainable technologies and advancements within these nations. The countries that demonstrate the highest average percentages of GRP are Morocco, Kazakhstan, Algeria, Peru and the Philippines, with rates of 19.47%, 18.68%, 17.31%, 16.91% and 15.09%, respectively. The significant amount of green patent activity

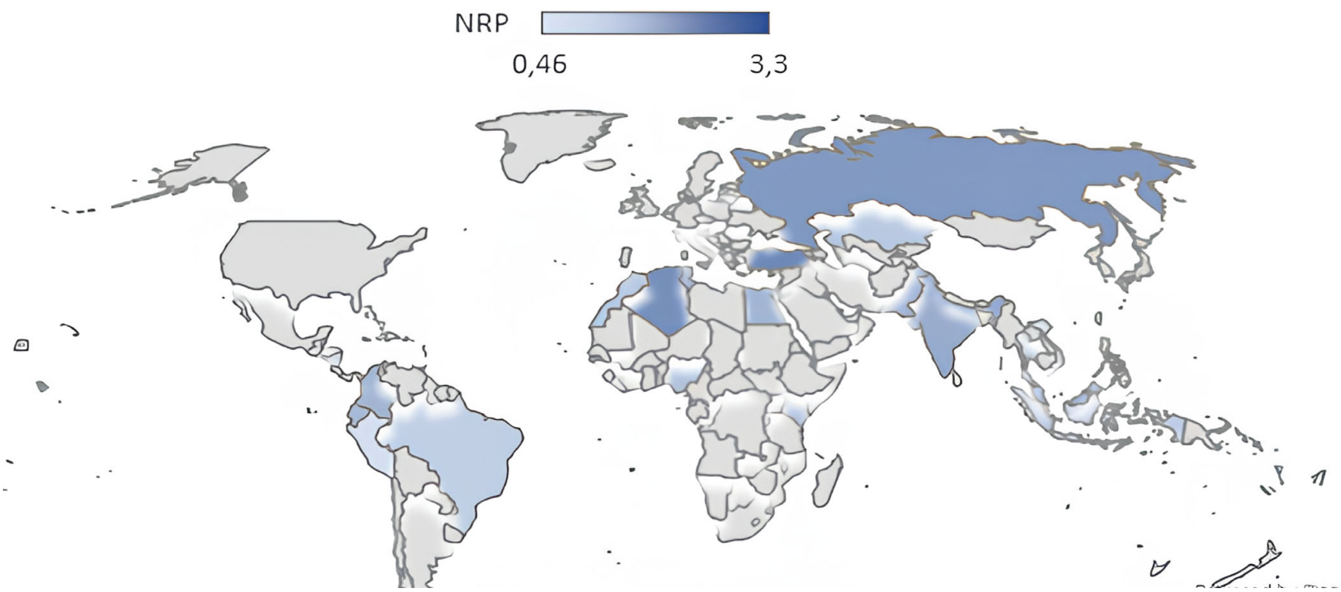

FIGURE 1 Resource productivity in the 28 middle-income countries from 2006 to 2022. *Source*: Elaborated by authors based on data from OECD database (2024).

demonstrates a firm dedication to advancing sustainable technologies, specifically those that reduce environmental harm. Conversely, Lebanon, Egypt, Indonesia, Malaysia and Turkey exhibit the lowest mean proportions of GRP, which range from 10.25% to 7.88%. The lower values indicate that these countries may prioritize green technology innovation less.

The frequency of GRP, particularly those about RE technologies, can substantially impact a nation's utilization of RE. An elevated quantity of GRP generally indicates extensive research and development in RE sources, resulting in heightened acceptance and utilization of these sustainable energy alternatives. Countries with higher green patent percentages are more inclined to incorporate RE actively, diminishing reliance on non-renewable resources and promoting environmental sustainability (Anwar et al., 2024).

When Figure 2 is analysed between 2006 and 2010, there is a consistent increase in the average proportion of GRP. These findings indicate a growing emphasis on developing green technology innovation in the 28 countries during this period. During 2014 and 2018, there is a clear and consistent upward trend, with the highest point occurring in approximately 2016. The current period is characterized by a high level of activity in green technology innovation, possibly indicating a global shift towards sustainability and the implementation of international agreements to mitigate climate change under the Paris Agreement (Bataille et al., 2018; Fabrizi et al., 2018). Following 2018, there has been a conspicuous decrease in the average proportion of GRP. The trend experienced a significant decline in 2020, potentially due to the worldwide economic repercussions of the COVID-19 pandemic. The pandemic likely impacted research and development budgets, priorities and the overall rate of innovation (Guderian et al., 2021; Zhao et al., 2023). The marginal uptick in 2021, followed by a subsequent decline in 2022, indicates that although there may have been a partial rebound from the pandemic's impact, the level of green patent activity has not yet reached its previous zenith.

This research makes several contributions. This is the first study investigating resource productivity and GRP's role in RE consumption using data from 28 middle economies between 2006 and 2022. This research addresses a gap in the international scientific literature by highlighting the absence of studies that specifically examine the viewpoint of green energy next with resource productivity and GRP in middle economies. Discontinue the examination in the developed and developing countries, as the top emitter has already conducted a sufficient analysis of the effect on environmental sustainability (Alola & Adebayo, 2023; Awosusi et al., 2023; Pei et al., 2021; Razzaq et al., 2021; Wahab et al., 2021; Zhu & Gao, 2019). Choosing this sample offers several advantages. It provides a thorough understanding of resource productivity and the impact of GRP in various geographic and economic contexts, highlighting long-term trends and the evolution of their influence to promote RE. The research also reveals distinct obstacles and prospects specific to middle-income countries, providing vital knowledge to the scholarly literature on energy, technology and sustainability.

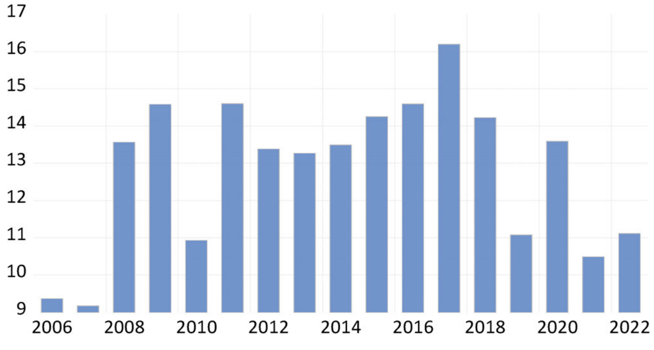

FIGURE 2 Green patents (GRP) in the 28 middle-income countries from 2006 to 2022. *Source*: Elaborated by the authors.

Moreover, within middle and poor economies, the dependence on abundant natural resources, despite low incomes and restricted availability of RE, poses both a difficulty and a prospect. These nations frequently encounter a paradox: despite their abundant natural resources, they grapple with economic challenges and a lack of access to energy (Kammen & Kirubi, 2008). Second, no studies have examined the nexus between resource productivity, greener energy and environmental technology for middle-income economies. Third, our study contributes simultaneously to policy discussions regarding attaining the SDGs. Green investments can facilitate resilient infrastructure development, accelerating progress towards SDG 9. Clean energy focuses on SDG 7, which can combat climate adversities. Such steps address SDG 13 on climate concerns.

In conclusion, this research significantly enhances the literature by focusing on middle-income economies and elucidating the interrelationships between resource productivity, GRP and the adoption of RE. Its findings are pivotal for advancing both academic understanding and policy initiatives aimed at achieving sustainable development on a global scale.

In addition, the econometric methods used in the study are up-to-date and powerful techniques, increasing the findings' reliability. Among these methods, the Method of Moment Quantile Regression (MMQR) technique, which is the econometric method used in the study, provides advantages in terms of flexibility, resilience to external outliers, obtaining the best estimates, statistical inference, simple calculation process and interpretability of coefficients. Another analysis method, the Dumitrescu-Hurlin (D-H) Panel Causality Test, is flexibly applicable for $N > T$ and $N < T$ cases. It performs particularly well in the presence of slope heterogeneity and cross-sectional dependence across countries and is effective in analysing unbalanced panel data. Monte Carlo simulations show that the test statistics produce strong results, especially for small data sets and spatial dependence.

The study begins with the introductory section and continues with the literature review section, where the essential studies on resource productivity and green patterns on RE identified in the international literature are presented to recognize the research gap that justifies completing this work. The authors present the data and the method used in the third section. The paper ends with the discussion and conclusions section, in which the authors give the implications of the study as well as the limits and future research directions.

2 | LITERATURE REVIEW

Within the traditional economic model, labor and capital are accepted as the elements of productivity. However, resource productivity has been generally neglected. Nevertheless, the increasing population and economic developments have made resource productivity important for the future (Gan et al., 2013). On the other hand, both excessive and inefficient use of resources leads to environmental degradation (Behrens et al., 2007). In this context, resource productivity is essential for a sustainable world and economy, because resource productivity enables the creation of more benefits with limited resources.

On the other hand, we have not found a study that directly investigates the effect of resource productivity on RE. For example, Li et al. (2020) documented that energy productivity encourages RE in their survey of OECD economies. Lucas et al. (2016) explored that energy security, a part of resource productivity, affects RE. Makieła et al. (2022) discovered that RE increases total factor productivity in their study for 133 countries. In addition, many studies (Alola & Adebayo, 2023; Awosusi et al., 2023; Pei et al., 2021; Razzaq et al., 2021; Wahab et al., 2021; Zhu & Gao, 2019) show that resource productivity has a positive impact on sustainability. In light of these findings, it is possible to say that resource efficiency positively affects RE. In this context, Oyebanji and Kirikkaleli (2022) examined the influence of energy productivity on Greece's environmental sustainability, considering the effect of non-RE consumption from 1990 to 2019. This indicates that an increase in energy productivity substantially affects Greece's environmental sustainability by controlling NRE consumption.

GRP include important innovations focusing on environmentally friendly and sustainable energy sources (Saunila et al., 2018; Solangi et al., 2024). These patents include inventions such as developing solar energy technologies, increasing the efficiency of solar panels, or making them more effective with new materials (Fusillo, 2023; Jianing et al., 2024). The main purpose of GRP is to reverse the linear relationship between economic growth and environmental degradation within the scope of a sustainable economy. In other words, it eliminates or minimizes the damages of economic growth. GRP reduce emissions that cause environmental degradation by encouraging energy conservation, increasing firms' competitiveness, and increasing their social responsibility (Xie et al., 2019). When the literature on the impact of GRP on RE is examined, it is generally found that green or environmental patents encourage RE (Jafri & Liu, 2023). According to Li et al. (2020), advances in GRP direct countries towards RE. Ji et al. (2021) found in their study that GRP increased the share of RE in OECD countries.

Similarly, Rehman Khan et al. (2023) found that GRP are the most important determinant of increasing RE consumption in OECD countries. Jafri and Liu (2023) discovered that environmental technologies and patents increase RE in their study for China. Bamati and Raoofi (2020) found that technological developments encouraged RE in their study, which covered 25 countries. Solarin et al. (2022) noted that green innovations positively affect RE in their research covering BRICS countries.

The literature has four common views on the relationship between economic growth and RE. The first of these views is that an increase in RE will increase economic growth. The other view is the opposite of the first view, and according to this view, economic growth increases energy consumption. The third view emphasizes a reciprocal relationship between RE and economic growth. In other words, both economic growth and RE affect economic growth. The last view is based on the fact that there is no relationship between RE and economic growth (Wang et al., 2022). Inglesi-Lotz (2016) found that RE positively affects economic growth.

Similarly, Gozgor et al. (2018) found that RE positively affects economic growth. Magazzino et al. (2021) have demonstrated for Brazil that an increased use of RE may accelerate economic growth and may offset the negative impact of Covid crisis on the economy. Wang et al. (2022) found that RE has a positive effect on economic growth. In their study for Turkey, Ocal and Aslan (2013) concluded that RE is a determinant of economic growth. Rafindadi and Ozturk (2017) explored how economic growth and RE variables affect each other. Acheampong et al. (2021) found a reciprocal relationship between economic growth and RE consumption in a study covering 45 sub-Saharan African countries. Apergis and Payne (2009) argued that there is no relationship between renewable and non-RE consumption and economic growth. Sadorsky (2009) for G7 countries and Sadorsky (2009) for 18 developing countries find that GDDPER positively affects RE. Similarly, Aguirre and Ibikunle (2014) for 38 countries, Omri and Nguyen (2014) for 64 countries, Salim and Rafiq (2012) for Brazil, India, China, Indonesia, Philippines and Turkey found that GDPER increased RE. Kang et al. (2021), in their study of South Asian countries, found that GDP increases RE.

Another factor affecting RE is urbanization. Urbanization causes both an increase in economic activities and a relative increase in population density. Increases in economic activity especially lead to increased energy consumption (Jones, 2004). Since this increase in energy consumption mainly depends on FF, policymakers have considered different alternatives. One of these alternatives is RE sources such as solar energy and wind energy (Salim & Shafiei, 2014). Jones (1991) found that a 10% increase in urbanization leads to a 5% increase in energy consumption.

Similarly, Parikh and Shukla (1995) found that a 10% increase in urbanization in developing countries leads to about a 5% increase in energy consumption. Poumanyvong et al. (2012), in their study of low-income and high-income country groups, found that urbanization decreases energy demand in low-income countries and increases it in middle- and high-income countries. Zhang and Lin (2012), Zhao and Zhang (2018), and Wang and Yang (2019) found that urbanization increases energy consumption in China. Shahbaz et al. (2016) discovered that urbanization increases energy consumption in India. On the other hand, Fang et al. (2022) found that urbanization decreases RE for BRICS economies.

In energy production, fossil energy sources and RE sources are sources that can be alternatives to each other. However, there is a trend towards RE due to the negative effects of FF. Of course, although countries give up FF due to their negative environmental impact, the price is one factor affecting FF abandonment. According to Knopf et al., increasing FF prices will reduce investments in fossil energy resources and direct investments in RE resources. Similarly, Li and Leung, in their study covering European countries between 1985 and 2018, found that the increase in fossil energy prices positively affected RE.

On the other hand, Sadorsky (2009) found that the increase in oil prices in G7 countries had a small but negative effect on RE. Similarly, in their study for Azerbaijan, Mukhtrov et al. found that the increase in oil prices has a negative impact on RE. They argue that this is because this country, rich in FF, sees this situation as an advantage.

A literature review reveals that studies on the impact of foreign direct investment (FDI) on RE are limited. Akpanke et al. (2023) found that FDI positively affected RE in their research, which covered 15 West African countries from 1990 to 2021. Kutan et al. (2018) reported that FDI encouraged RE in their study of South Africa, China, India and Brazil from 1990 to 2012. Kang et al. (2021) found that FDI decreased RE in their study of South Asian countries between 1990 and 2019. Kumaran et al. demonstrated that FDI positively affected RE in their study covering ASEAN (Association of South East Asian Nations) countries.

3 | DATA AND METHODOLOGY

3.1 | Data

This study examines the effect of GRP, natural resources productivity (NRP), economic growth, FDI, urban population and energy prices on greener energy consumption using annual data from 2006 to 2022 from 28 middle economies, namely, Algeria, Belarus, Brazil, Colombia, Ecuador, Egypt, Georgia, India, Indonesia, Jordan, Kazakhstan, Kenya, Lebanon, Malaysia, Mexico, Moldova, Morocco, Nicaragua, Nigeria, Pakistan, Peru, Philippines, Russia, South Africa, Thailand, Tunisia, Turkey and Vietnam. The base model for this study can be written as follows:

$$REC_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 GRT_{it} + \beta_3 NRP_{it} + \beta_4 FDI_{it} + + \beta_5 URB_{it} + \beta_6 BRT_{it} \varepsilon_{it} \quad (1)$$

where ε_{it} represents β_0 is constant, and β_1 to β_5 are the coefficients.

Based on the streaming literature (Abbas et al., 2024; Athari, 2024; Guo et al., 2024; Li et al., 2020; Liu & Liang, 2024; Pata et al., 2023; Yasmeen et al., 2023), we can hypothesize the signs of the respective coefficients of the parameters mentioned in Equation (1), of which the signs $\beta_2, \beta_3, \beta_4 = > 0$ and $\beta_{5,} \beta_{1,} < 0$. Table 1 provides a brief account, abbreviations and summary statistics for the variables of interest. Figure 3 presents the trend data from 28 middle economies during the period between 2006 and 2022. The logarithm of each variable was employed.

Energy is one of the important dynamos of economic growth and the impact of economic growth on energy consumption is inevitable (Fotourehchi, 2017; Magazzino, 2018). Therefore, GDP is expected to affect RE. Another variable in the model is URB. Since countries will need more energy to meet the growing population's needs, population changes are expected to affect both renewable and non-RE consumption (Cui et al., 2022). Natural resources of productivity variable is expected to impact both renewable and non-RE consumption (Aziz et al., 2021). Foreign investments are expected to increase or decrease energy consumption depending on the technology produced in the country, especially in the industrial sector (Doytch & Narayan, 2016). Finally, GRP are expected to reduce energy consumption (Oyebanji et al., 2022), while fossil energy prices are expected to affect RE consumption in different ways (Popp, 2015).

3.2 | Methodology

Traditional techniques such as ordinary least squares (OLS) and ARDL are mostly applied to assess the effect of natural resources and green technology on RE. However, the normality condition used in analysing dependence between the variables is a drawback of such an association (Ye et al., 2023). Accordingly, the estimate coefficients based on the OLS technique are not the best suited for investigating the nexus between variables at specific points of the joint distribution (Hayashi, 2000; Wooldridge, 2010). Therefore, the specification introduced by Koenker and Bassett Jr. (1978), the quantile regression (QR) method, is employed. Recent research has focused significantly on joining quantile-based estimation techniques with panel data (Mohammed & Mellit, 2023; Radulescu et al., 2022; Rehman et al., 2021; Si-Mohammed et al., 2022). In order to detect

TABLE 1 Variables description.

Data	Abbreviation	Measures	Source
Renewable energy	RE	RE consumption as % of total energy	EIA
Economic growth	GDP	US $ GDP per capita/1000	WDI
Urbanization	URB	Urban population (% of total population)	WDI
Natural resources productivity	NRP	GDP (Million US$)/Domestic Resources Consumption (Million tons)	OECD (2024)
FDI	FDI	Net flow as % of GDP	WDI
Green patents	GRP	% of total patents	OECD (2024)
Energy prices	BRT	Oil brint prices US $	EIA

Source: Authors' elaboration.

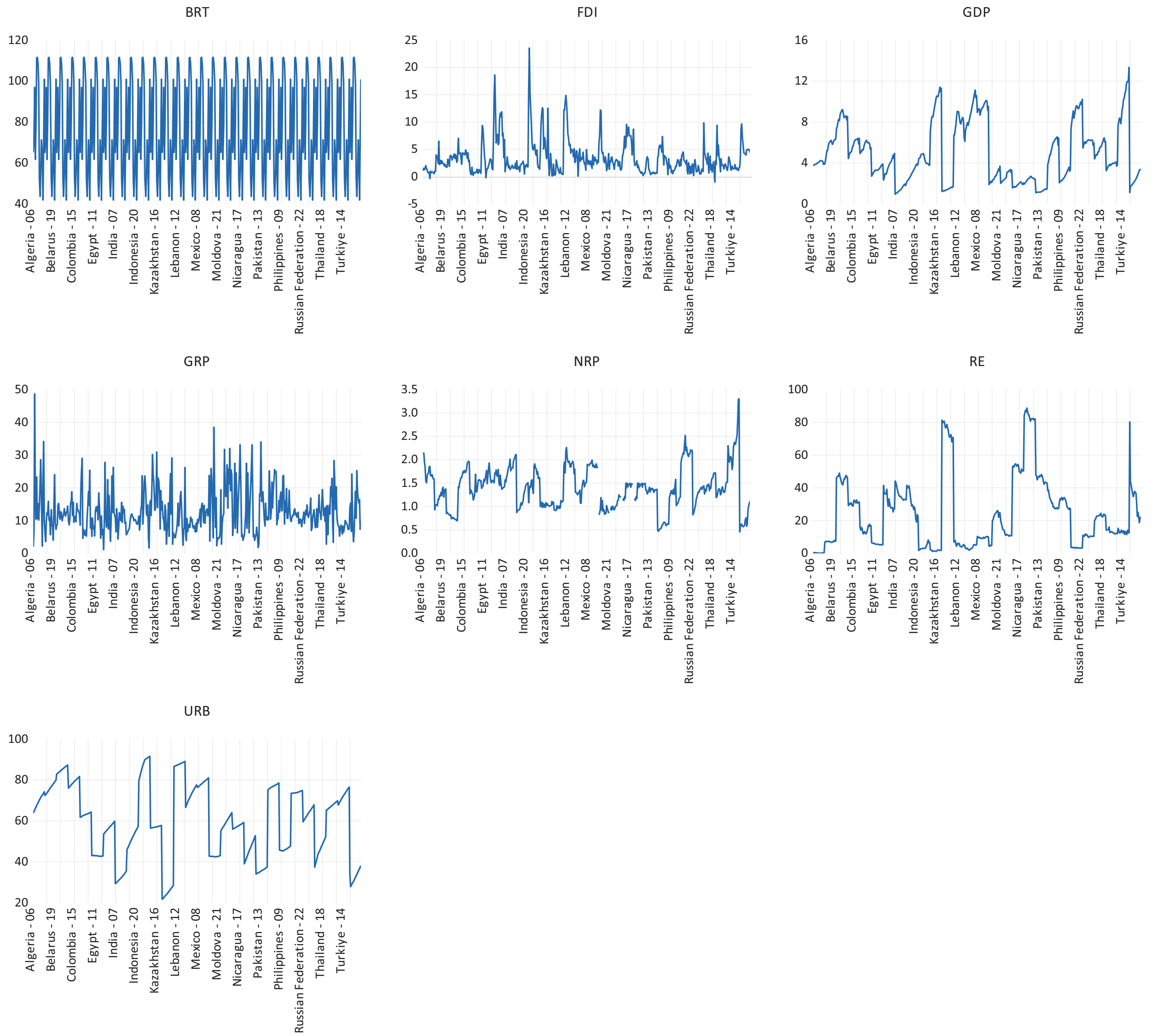

FIGURE 3 Trend data. BRT, energy prices; FDI, foreign direct investment; GDP, economic growth; GRP, green patents; NRP, natural resources productivity; RE, renewable energy; URB, urbanization. *Source*: Elaborated by the authors.

heterogeneity over classes, the fixed effects processes are used in a traditional panel data specification. A similar method is used in several quantile panel data regressions incorporating additive fixed effects. Previous research on fixed effects using quantile regression has focused on the problems associated with estimating fixed effects in a quantile framework and parameter issues when *T* is small (Powell, 2016). Machado and Santos Silva (2019) developed a new QR methodology for panel data (QRPD) to address this issue. The main benefit of Machado and Santos Silva's (2019) regression over current quantile approaches is based on additive fixed effects (αi) that supply distribution estimates of the dependent variable αi given *Dit*. In addition, it permits the use of methods only applicable for estimating conditional means, such as the differentiation of individual effects in panel data models, while presenting evidence on how the regressors affect the entire conditional distribution. The MMQR is more applicable when the model's explanatory variables are endogenous (Tiwari et al., 2023). Finally, the MMQR yields estimates of the regression quantiles that do not cross, an important requirement that empirical applications frequently disregard (Machado & Santos Silva, 2019; Ojekemi et al., 2023). Therefore, we use the MMQR methodology. The conditional quantiles estimate $Qy(\tau|X)$ of the location-scale variant model is written in equation (2):

$$y_{it} = a_i + X'_{it} b + \left(\vartheta_i + Z'_{it} d \right) U_{it}, \tag{2}$$

where $P(ci + Zit'\gamma > 0) = 1$ determine the probability (a, b', c, d') are denote the coefficient to be estimated. (*ai*, *ci*), $i = 1, 2, 3, \ldots, n$, corresponds to the fixed effect *i* of each individual in the panel. *Z* defines a *k*-vector of operators in *X*, this signifies conversions differentiable by factor l, given in equation (3):

$$Z_i = Z_i(X), i = 1, \ldots, k \tag{3}$$

Xit and *Uit* are i.i.d and also do not vary over time (*t*). *Uit* is orthogonal to *Xit* to follow the switching circumstance introduced by Machado and Santos Silva (2019). In this regard, after some changes in equation (2), we obtain

$$Q_y(\tau|X_{it}) = (a_i + c_i q(\tau)) + X'_{it} b + Z'_{it} d q(\tau) \tag{4}$$

In equation (4), *Qy*(τ|*Xit*) refers to the quantile distribution *Yit* depending on the position of the independent factors observed in *Xit*. *Xit*' corresponds to the vector of independent factors; thus, *Xit*' = capital formation, labour force, renewable energy, natural resources, technological innovation, fossil energy′. The expression *Xit*' − ai(τ) ≡ ai + ciq(τ) refers to the scalar estimate for individual effects (*i*) at quantile (τ). The parameter *q*(τ) is the (τ−th) quantile snippet, which reflects the solution to the subsequent optimization problem:

$$min \sum i \sum t \rho_{it}\left(R_{it} - \left(\delta_i + Z'_{it} + \gamma\right)\right) \tag{5}$$

In equation (1), the term ρτ(*Rit* − (δ*i* + *Zit*'γ)*q*) represents the verification function.

For this purpose, we employ the Granger causality (Dumitrescu & Hurlin, 2012). This methodology has several advantages, which consider heterogeneous slopes in both null and alternate hypotheses. This method may be susceptible to substantial size distortions. It overcomes the challenge of employing too many moment conditions, which often reduces the usual MMQR (Singh et al., 2023; Wang et al., 2023).

3.3 | Cross-sectional dependence test

A tool to look at possible interdependence between several components in panel data is the Cross-sectional Dependency Test (or CD). Panel data are the study of observations from various sources, including people, nations, and businesses, where these entities may impact one another. The basic tenets of conventional linear regression models are broken if observations from various entities impact one another. This suggests that the observations are not independent and equally distributed. The CD test aids in identifying the presence of this kind of problem. The conventional OLS regression may produce skewed and unhelpful inferences if panel data exhibit cross-sectional dependence. The CD test results can help researchers choose techniques more suited for panel data. Missing CD might cause inaccurate model approximations. It is possible to increase the accuracy and robustness of the model by running the CD. Below is the equation for this test.

$$CD_{test} = \frac{\sqrt{2T}}{[N(N-1)]^{\frac{1}{2}}} \sum_{i=1}^{N-1} \sum_{k=1+i}^{N} T_{ik} \tag{6}$$

According to (Hashem Pesaran & Yamagata, 2008), Slope homogeneity (SH) is the degree to which the coefficient of slope in a regression model is constant or comparable among various subsamples or groups. Researchers can ascertain whether data heterogeneity exists by using SH analysis. One can use SH analysis to see whether the slopes of several subgroups differ significantly. We can also determine whether two variables interact under various circumstances with SH analysis. The existence of SH indicates that to capture the differences between distinct entities adequately, the investigation must use more sophisticated models. Thus, carrying out this test aids in directing the choice of model.

$$\tilde{\Delta}_{ASH} = (N)^{\frac{1}{2}}(2k)^{\frac{1}{2}}\left(\frac{1}{N}\tilde{\mathcal{S}} - k\right) \tag{7}$$

$$\tilde{\Delta}_{ASH} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{\mathcal{S}} - 2k\right) \tag{8}$$

It is assumed that slope coefficients are steady for this test. The equations (7) and (8) above reflect the corrected delta and delta tilde.

4 | EMPIRICAL FINDINGS

4.1 | Descriptive statistics

Before examining the model estimation results, performing a statistical analysis of the variables specified in Table 2 is crucial. The findings, presented in Table 2, reveal crucial insights. The total observations in each series is 472, indicating that this is a balanced panel model. The average value of the RE variable is 24%, with a standard deviation of 21%. This discrepancy highlights the substantial variation observed during the study period between the relatively low utilization of RE, exemplified by Algeria at approximately 0.06% of total energy, and the higher utilization of RE, represented by Brazil.

Similarly, the GDP variable in India had a relatively low value of approximately 941 US$ per year in 2006, while Turkey documented a high income of about 13,342 US$ in 2002. These figures indicate significant disparities among the countries being analysed. The data points remain fase to their mean values across all reports, according to the standard deviation values (SD). All selected series are positively skewed, except for URB. The variables are not symmetric, as seen by the fact that the skewness coefficients are negative and different from zero. The series' kurtosis coefficients show excess kurtosis as the number exceeds three, stipulating the deviation of these series from the normal distribution. All the series pass the Jarque-Bera test and fail the normality test, as evident from the probability values, which are significant at a 99% confidence interval, indicating that the

TABLE 2 Descriptive statistics.

	RE	GDP	GRP	NRP	FDI	BRT	URB
Mean	24,061	4967	12,824	1393	3390	76,607	60,199
Median	16,679	4171	11,450	1380	2579	71,340	61,699
Maximum	88,680	13,342	48,690	3300	23,537	111,630	91,626
Minimum	0.060	0.948	1150	0.460	−0.990	41,960	21,675
SD	21,630	2850	6624	0.446	3081	22,927	17,840
Skewness	1181	0.594	1239	0.443	2276	0.193	−0.226
Kurtosis	3868	2320	5359	3747	10,094	1731	2022
Jarque-Bera	124,616	36,856	230,291	26,446	1397,267	34,604	22,812
Probability	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	472	472	472	472	472	472	472

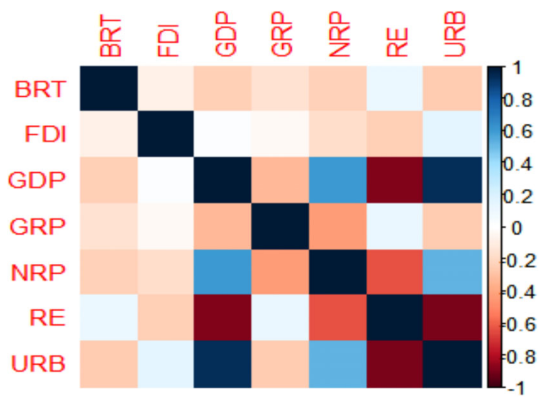

FIGURE 4 Correlation matrix. BRT, energy prices; FDI, foreign direct investment; GDP, economic growth; GRP, green patents; NRP, natural resources productivity; RE, renewable energy; URB, urbanization.

TABLE 3 Multicollinearity results.

	VIF	1/VIF
URB	2.73	0.366756
GDP	2.61	0.383266
NRP	1.10	0.905743
FDI	1.09	0.915999
GRP	1.02	0.980523
BRT	1.01	0.991167
Mean		1.59

series periods do not follow a normal distribution. The Jarque–Bera test statistics also reveal that the quantile-based framework is the most suitable approach for tackling the non-linearity in the data series.

The correlation coefficients presented in Figure 4 indicate statistically the associations between the explanatory variables GDP, GDP, GRP, NRP, FDI, BRT, URB and the dependent variable RE. ORE with green patent and energy price consistently show the highest positive correlation among all other selected series, as evidenced by 0.12 and 0.11, respectively. The RE appears to have a negative association with GDP, URB, NRP, and FDI, where the correlation coefficients are 0.89, 0.88, 0.63 and 0.24, respectively.

TABLE 4 Results of the CSD.

Test	Test statistics	*p*-value
BP LM	1389.642	.0000
PS LM	36.79305	.0000
P CD	2.047689	.0406

Note: 0.000 indicates statistical significance at 1% levels.

TABLE 5 Slope homogeneity.

	Statistics	*p*-value
Δ	7.295	.000
Δ adj	10.026	.000

The VIF test findings, as shown in Table 3, confirm no multicollinearity among the explanatory variables. The VIF coefficients for all variables are below 5, with an average of 1.48. The correlation among the explanatory variables is moderate and acceptable since it falls within the range of 1 to 5. This highlights the strong and reliable nature of the model about concerns about multicollinearity.

4.2 | CSD test results

Table 3 shows that in CSD test, the *p*-values suggest the existence of CD and predict a strong rejection of the null hypothesis among the RE, economic growth, urbanization (URB), natural resources productivity, FDI, green patents (GRP) and energy prices (BRT).

4.3 | Homogeneity slope test

The Table 4 displays the SH test findings that were carried out utilizing Yamagata and Pearsan's methodology. The data in Table 5 can be examined to see that the *p*-values for delta are remarkably small both before and after adjustment. As a result, the slope coefficient

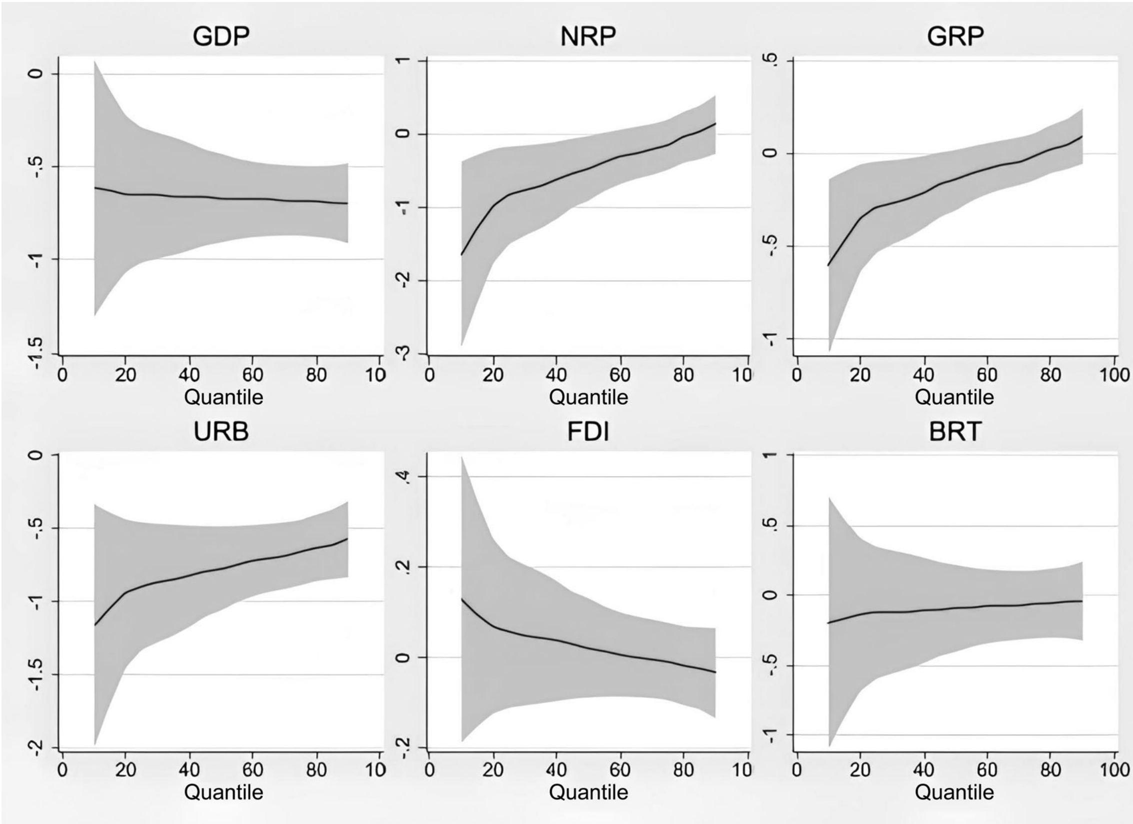

FIGURE 5 MMQ regression results.

hypothesis of uniformity can be rejected, indicating significant variability in slope coefficients above 1%.

4.4 | MMQR findings

Figure 5 shows the findings of the MMQR technique. The result shows the effect across the six quantiles, which are, in order, 01%, 20%, 40%, 60%, 80% and 10% quantiles. The final product exhibits a negative effect of GDP on RE in middle economies across different quantiles, as evidenced by about −0.6%. In middle economies, there may frequently be a better reliance on conventional energy sources such as FF, primarily because of their cost-effectiveness and convenient availability, decreasing the RE use. Further, the middle economies' GDP depends on manufacturing and agriculture. The transition to a service-based or high-tech economy, which tends to support RE, typically occurs at a later phase. This outcome aligns with the findings (Wang et al., 2022).

Notably, the resource productivity effect is negative during the lower and medium quantiles but positive at the upper quantile. In the upper quantile, an increase in total natural resource productivity substantially impacts RE consumption due to a decoupling of GDP growth from extracting environmental resources, indicating a transition towards more sustainable and efficient practices. These findings are consistent with the previous study of Oyebanji and Kirikkaleli (2022), as they noted that increasing resource productivity entails creating greater economic value while reducing dependence on natural resource extraction, a crucial element of sustainable development.

Similarly, GRP can be reported for the green patent's effects on RE, where the influence experiences a notable enhancement in the higher quantiles, particularly between the 85th and 95th percentiles, culminating in a significant increase to approximately 1.5. This result, particularly in the upper quantile, highlights the critical role. In the higher upper quantiles, where there are more resources for innovation, there is a greater tendency to invest in technologies that contribute to economic growth and support environmental sustainability, such as the increased utilization of RE sources, by safeguarding and promoting innovative technologies that facilitate its use. This is a greater tendency to invest in technologies that contribute to economic growth and support environmental sustainability, which explains how the FDI contributes positively to RE. This finding is consistent with the existing scholarship of Kang et al. (2021). Urbanization has a detrimental impact across all quantiles, regardless of the increasing effect from the lower to upper quantiles.

Similarly, energy prices continue to benefit, particularly in enhancing RE consumption. This finding can explain how rapid urbanizing in the middle economies often prioritizes the swift expansion of urban infrastructure by relying on easily accessible non-RE sources. The findings suggest that energy prices have a negligible impact, close to zero, on RE.

TABLE 6 Quantile regression results.

	Quantile	Coefficient	SE	*t*-statistic	*p*
GDP	0.100	−1.271429	0.140424	−9.054197	.0000
	0.200	−1.069560	0.141256	−7.571808	.0000
	0.300	−0.823271	0.141427	−5.821171	.0000
	0.400	−0.727270	0.171487	−4.240972	.0000
	0.500	−0.594840	0.187366	−3.174751	.0016
	0.600	−0.567136	0.166588	−3.404416	.0007
	0.700	−0.688929	0.125750	−5.478562	.0000
	0.800	−0.729857	0.134617	−5.421710	.0000
	0.900	−0.857220	0.128014	−6.696300	.0000
NRP	0.100	−0.161323	0.061744	−2.612775	.0093
	0.200	−0.583214	0.327979	−1.778206	.0761
	0.300	−0.599430	0.251658	−2.381921	.0176
	0.400	−0.614026	0.302906	−2.027120	.0432
	0.500	−0.711883	0.340801	−2.088855	.0373
	0.600	−0.215553	0.065405	−3.295669	.0011
	0.700	−0.131433	0.060533	−2.171255	.0304
	0.800	0.263292	0.116381	2.262334	.0242
	0.900	0.781534	0.246420	3.171552	.0016
GRP	0.100	−0.266621	0.121644	−2.191804	.0289
	0.200	−0.173544	0.082230	−2.110472	.0353
	0.300	−0.075913	0.070534	−1.076259	.2824
	0.400	−0.047400	0.075736	−0.625862	.5317
	0.500	0.004851	0.086058	0.056373	.9551
	0.600	0.064502	0.101119	0.637884	.5239
	0.700	0.126183	0.072064	1.750989	.0806
	0.800	0.129913	0.060537	2.146016	.0324
	0.900	0.160716	0.061959	2.593925	.0098
URB	0.100	−0.942136	0.280724	−3.356096	.0009
	0.200	−0.690317	0.252334	−2.735726	.0065
	0.300	−0.551632	0.162501	−3.394642	.0007
	0.400	−0.507037	0.183503	−2.763095	.0060
	0.500	−0.448762	0.224953	−1.994911	.0466
	0.600	−0.673814	0.131432	−5.126714	.0000
	0.700	−0.525786	0.119942	−4.383665	.0000
	0.800	−0.333941	0.111248	−3.001765	.0028
	0.900	−0.716102	0.126178	−5.675337	.0000
FDI	0.100	−0.132127	0.073528	−1.796957	.0730
	0.200	−0.242492	0.066650	−3.638281	.0003
	0.300	−0.146320	0.061892	−2.364139	.0185
	0.400	−0.115747	0.057505	−2.012818	.0447
	0.500	−0.062785	0.058252	−1.077820	.2817
	0.600	−0.015189	0.068355	−0.222211	.8242
	0.700	0.068826	0.057018	1.207108	.2280
	0.800	−0.006593	0.067592	−0.097547	.9223
	0.900	−0.164844	0.061833	−2.665949	.0079

TABLE 6 (Continued)

	Quantile	Coefficient	SE	*t*-statistic	*p*
BRT	0.100	−0.244785	0.285019	−0.858836	.3909
	0.200	−0.266325	0.197776	−1.346596	.1788
	0.300	−0.075721	0.133198	−0.568484	.5700
	0.400	−0.081007	0.133093	−0.608652	.5430
	0.500	−0.026274	0.136476	−0.192516	.8474
	0.600	−0.042909	0.143944	−0.298094	.7658
	0.700	−0.075961	0.128778	−0.589864	.5556
	0.800	−0.065646	0.135816	−0.483345	.6291
	0.900	−0.003847	0.137023	−0.028076	.9776
C	0.100	7.154415	1.603000	4.463142	.0000
	0.200	6.921474	1.129722	6.126704	.0000
	0.300	6.748285	0.988744	6.825107	.0000
	0.400	6.760176	1.137400	5.943532	.0000
	0.500	6.741336	1.274354	5.290002	.0000
	0.600	5.693890	1.234807	4.611156	.0000
	0.700	5.647740	1.090360	5.179703	.0000
	0.800	4.854496	1.124025	4.318850	.0000
	0.900	2.109284	1.098684	1.919828	.0555

TABLE 7 Results of Dumitrescu-Hurlin causality test.

H_0	W-stat.	Zbar-stat.	*p*-value	Decision (H_0)	Causality direction
NRP ⇏ RE	1.93911	2.05998	.0394	Yes	Uni-directional
RE ⇏ NRP	1.11615	−0.18633	.8522	No	
GRP ⇏RE	0.74648	−1.19365	.2326	No	No causality
RE ⇏ GRP	1.41070	0.62755	.5303	No	
GDP ⇏ RE	3.60625	6.64743	3.E-11	Yes	Bidirectional
RE ⇏GDP	2.32672	3.13915	.0017	Yes	
FDI ⇏RE	2.01075	2.27282	.0230	Yes	Bidirectional
RE ⇏FDI	2.19005	2.76443	.0057	Yes	
BRT ⇏RE	2.95948	4.87408	1.E-06	Yes	Uni-directional
RE ⇏BRT	1.29285	0.30443	.7608	No	
URB ⇏RE	3.80266	7.18597	7.E-13	Yes	
RE ⇏ URB	16.8418	42.9373	.0000	Yes	Bidirectional

4.5 | Robustness test

Table 6 presents the estimated coefficients of QR approaches, serving as a robustness test to the MMQR approach. This outcome confirmed the above findings across different percentiles (20th, 40th, 60th, 80th and 99th), namely a negative effect of GDP on RE in middle-income economies. The findings indicate a −1.27% decrease to −0.85% in RE consumption from lower to upper quantiles. Resource productivity decreases RE consumption in the lower and medium quantiles but increases it in the upper quantiles, as evidenced by the numbers −0.3 and 0.8, respectively.

Moreover, GRP lead to increased medium and higher quantiles of RE consumption. This suggests that GRP, technology development and application boost RE consumption at all market conditions except the lower quantiles. All quantiles of urbanization seem to reduce RE consumption. Meanwhile, oil price and FDI (in middle and upper quantiles) have a negligible effect on RE consumption.

4.6 | Causality test

Moreover, a causal analysis is necessary to understand better the relationship between RE use and the other variables in the model. Dumitrescu and Hurlin (2012) Granger non-causality test is applied under the null hypothesis of no causality (xi,t does not represent Granger cause for yi,t). Table 7 shows that the null hypothesis is accepted in all cases of association of RE and its determinants except for the causality between green technology. Further, bidirectional causation exists in the RE/GDP, RE/FDI, RE/BRT and RE/URB. This reciprocal causality suggests a mutual relationship in which alterations in these factors can impact RE consumption, and changes in RE consumption can, in turn, affect these factors. The lack of causality between green technology and RE consumption implies that green technology does not substantially impact the consumption of RE, nor is it significantly affected by changes in RE consumption. These insights are essential for comprehending the interplay between RE and diverse economic and social factors, guiding policymakers in formulating efficacious energy and environmental strategies.

5 | CONCLUSIONS AND POLICY IMPLICATIONS

This research contributes to the literature on green innovation, resource productivity and renewable sources by investigating the effect of green technology on green energy consumption. We analysed panel data for the major provinces in 28 middle-income economies from 2006 to 2022. The novel quantiles via moments method recently introduced by Machado and Santos Silva (2019) discusses the effect of the explanatory variables, particularly green technology and resource productivity, on green energy at several quantile levels. We find that green technology innovation plays a substantial role in RE. Second, the significant positive coefficients show that resource productivity leads to higher RE consumption at the upper quantile. Therefore, accelerating resilient and green infrastructure (SDG 9) and taking climate action (SDG 13) can help promote affordable and clean energy (SDG 7) in middle-income countries. The estimated findings indicate that improving the productivity of resources can serve as a significant policy tool for promoting environmental sustainability in middle-income economies. The enhancement of energy productivity hinges on the advancement and implementation of novel energy-efficient technologies. Thus, these countries should increase their research and development investment to promote advancing energy-efficient and environmentally friendly technologies.

Consequently, this study recommends that countries in the sample adopt more stringent environmental taxation policies to reduce carbon emissions. The findings strongly recommend that the sampled countries transition from FF to clean RE to effectively address the rapidly deteriorating ecological conditions. Moreover, industrialization and innovation have been identified as significant factors contributing to carbon dioxide emissions in the countries surveyed. Hence, it is imperative to broaden the scope of industrialization by incorporating renewable sources while simultaneously prioritizing the development of environmentally friendly and energy-efficient technologies to mitigate carbon dioxide emissions. According to the achieved results, it is necessary to prioritize the private and public partnerships for enhancing research and development to obtain GRP that can support transition to clean energy sources. Also, attracting FDI inflows is crucial for knowledge transfer and for adopting clean technologies. For attracting FDI, not only tax incentives and budgetary subsidies are necessary, but also some institutional measures are necessary to reduce competition barriers and for promoting an easy entrance on the foreign markets. Reducing waste and increasing recycling can improve natural resources efficiency so that the economic growth can be decoupled of the extensive use of natural resources that can cause resources depletion. This will also support energy transition process and reduce FF usage.

Thoroughly analysing the various limitations of the investigation is of utmost importance. It is crucial to acknowledge the significance of considering various economic and political contexts when analysing the interrelationships among the investigated variables. However, the thorough examination of potential supplementary variables has not been sufficiently investigated, posing a possible risk of unintentionally excluding vital variables and compromising the reliability of the findings, such as green productivity and research and development (R&D). Recognizing these limitations and analysing the findings within their particular contextual limitations is crucial. Investigating potential research questions that effectively address these challenges may result in a more comprehensive understanding of the complex mechanisms that govern the interconnections.

AUTHOR CONTRIBUTIONS

All the authors have contributed equally to scheming the research, studying concepts or design, processing data collection, calculating, and writing the manuscript. All authors read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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