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Research

Drivers of trade market behavior effect on renewable energy consumption: a study of MINT (Mexico, Indonesia, Nigeria, and Turkey) economies

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Abstract
This study provides an in-depth analysis of how key macro trade determinants affect renewable energy consumption in MINT economies (Mexico, Indonesia, Nigeria, and Turkey) over the period from 1995 to 2022. By applying the energy bundle theory as a guiding framework, we investigate the influence of factors such as trade balance, trade reserves, exchange rate, population, and labor force participation rate on trade openness (TOPEN) and its connection to renewable energy consumption (REC). Advanced econometric techniques, including Step-wise regression, fully modified least squares, pooled ordinary least squares and fix effect methods, are used to assess the dynamics of these relationships. Granger causality and Pedroni co-integration tests reveal both short- and long-term interactions between trade factors and renewable energy consumption. The results indicate that trade balance, trade reserves, and labor force participation have a significant positive effect on renewable energy consumption, while exchange rates and population growth show a negative impact. Although no reciprocal relationship between trade reserves and renewable energy consumption is found, unidirectional influences are identified between renewable energy consumption and other trade determinants, specifically trade balance, exchange rate, population, and labor force participation, underscoring the distinctive economic interactions within MINT economies.This study emphasizes that trade balance, trade reserves, and labor force participation significantly enhance renewable energy consumption in MINT economies. It advises policymakers to stabilize exchange rates and address population growth due to their adverse effects.

Keywords Trade openness · Panel data · Trade openness drivers · Trade reserves

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1 Introduction

The MINT countries—Mexico, Indonesia, Nigeria, and Turkey—are a dynamic group of emerging economies with substantial growth potential [1]. These nations leverage distinct geographic, demographic, and economic strengths, positioning themselves as influential players in global trade [2]. However, as they advance, ensuring the sustainability of their growth trajectories becomes critical. Transitioning from conventional to renewable energy sources is essential to achieving sustainable development [3, 4]. This analysis examines the relationship between trade and renewable energy consumption in the MINT countries, shedding light on the opportunities and challenges within this transition [5, 6]. Trade forms a backbone of economic activity in these nations, driving growth through exports and imports [7]. Mexico, for instance, capitalizes on its proximity to the United States through the United States-Mexico-Canada Agreement (USMCA), while Indonesia's wealth in natural resources fuels its exports of commodities like palm oil and coal. Nigeria, Africa's largest economy, remains reliant on oil exports, and Turkey's strategic position enables it to serve as a trade bridge between Europe and Asia [8]. Yet, these trade activities are predominantly linked to fossil fuel consumption, presenting significant sustainability challenges [9, 10].

REC is emerging as an important component for long-term growth in MINT countries [11, 12]. Concerns about climate change, energy security, and the need for sustainable economic practices all contribute to the global transition toward greener energy sources. Mexico has made strides in adopting renewable energy, particularly wind and solar power, driven by supportive government policies and international investments [13]. Indonesia, despite its reliance on coal, has significant potential for geothermal and hydro-power development. Nigeria's vast solar potential remains largely untapped [14] while Turkey has made considerable progress in wind and solar energy installations [15]. Despite these advancements, the MINT countries face several barriers in aligning trade with renewable energy consumption [16]. High tariffs and non-tariff barriers on renewable energy technologies and components can increase costs and hinder the adoption of cleaner energy solutions [17]. Additionally, political instability, regulatory uncertainty, and underdeveloped financial markets deter FDI in renewable energy projects. Effective renewable energy adoption also requires stable and supportive regulatory frameworks, which are often inconsistent or unclear in these countries.

Participation in international trade agreements and cooperation with global renewable energy initiatives can encourage the use of technology for renewable energy but MINT countries often face difficulties in negotiating favorable terms and ensuring compliance with international standards [18, 19]. MINT countries hold significant potential for leveraging trade to enhance renewable energy consumption, they face substantial challenges that need to be addressed through coordinated policy reforms, international cooperation, increased investment in infrastructure and technology, and improved public education and support for renewable energy [20]. By overcoming these barriers, the MINT countries can better position themselves for sustainable economic growth and contribute to the global transition towards renewable energy. The motivation for this study stems from the urgent need to address the complex interplay between trade openness and renewable energy consumption in MINT countries (Mexico, Indonesia, Nigeria, and Turkey). As these nations integrate into the global economy, understanding the macroeconomic determinants influencing renewable energy use is critical for achieving sustainable development goals.

This study explores the increasingly important relationship between renewable energy consumption and macro trade drivers in emerging MINT economies—Mexico, Indonesia, Nigeria, and Turkey [21–24]. Given these countries' expanding roles in global trade, it is essential to understand how trade policies, foreign direct investment, exchange rates, trade reserves, and trade balance influence REC for sustainable growth [25, 26]. REC is vital for sustainable development, as it offers reduced greenhouse gas emissions and enhances energy security [27, 28]. To address gaps in existing literature, this study examines three research questions: (1) To what extent do trade policies, FDI, ER, TR, and TB impact REC in MINT economies? (2) Do unique short- and long-term interactions exist between these macroeconomic factors and REC? (3) What actionable insights from these dynamics can inform policy to support REC in MINT economies? This research contributes to economic and environmental sustainability by enhancing the understanding of the trade-REC relationship in emerging markets.

Although previous studies [29–33] have examined renewable energy usage and trade, none have specifically investigated how macro trade determinants influence renewable energy consumption (REC) within the MINT economies (Mexico, Indonesia, Nigeria, and Turkey). This study addresses this gap by focusing on the unique macroeconomic conditions of the MINT nations and linking these to REC through an energy bundle theoretical framework. By examining the direct impacts of trade balance, trade reserves, exchange rate, population, and labor force on REC, this

research uniquely explores the underlying mechanisms that foster or inhibit renewable energy adoption in emerging markets with rapidly evolving trade dynamics. Through its insights, this study aims to provide policy-makers and industry stakeholders with targeted recommendations that can support sustainable energy development in MINT economies, contributing meaningfully to the global transition towards a resilient and sustainable energy landscape.

This study makes a substantial contribution to the international trade and renewable energy consumption literature by providing a nuanced analysis of how specific trade drivers affect trade openness in MINT nations. By uncovering the distinct impacts of these trade drivers on renewable energy consumption, this research advances understanding in the field, offering new insights into the interplay between trade dynamics and renewable energy utilization in emerging economies. These findings not only enrich existing literature but also provide a framework for policy-makers to align trade policies with sustainable energy goals. Trade drivers encompass the key elements shaping a country's trade patterns [34, 35]. While much of the existing research has been empirical, it often overlooks the implications of various theoretical frameworks. This study addresses this gap by exploring the theoretical foundations of trade drivers that promote trade openness in MINT countries and examining how these macro trade drivers influence renewable energy consumption in these economies. However, the findings are constrained by limitations such as the data sets, variable selection, time span, and econometric methods applied.

In this study, we make a substantial contribution to the body of literature by using 28-year data from MINT countries to investigate whether a long-term causal relationship exists rather than just an association. Using model-fitness tests (using stepwise AIC) and the most recent panel regression methodology involving pooled and fixed effects panel regressions, we first identified five macro trade drivers influencing trade openness of MINT economies and these macro trade drivers' impact on REC of specifically MINT countries. The findings show that TOPEN has associations with the five trade drivers—trade balance, trade reserves, exchange rate, labour force participation rate, and population—which in turn affect the Renewable energy consumption of MINT nations in particular. Both short- and long-term co-integration relationships are found by further cointegration tests (using Pedroni), indicating a more complex relationship between trade and the five trade drivers. Finally, Granger causality tests show a causal relationship between the five theory-driven components and TOPEN and REC. As far as current research is concerned, no study has looked at the macro trade factors—which are theoretically based—that affect TOPEN and the use of renewable energy in the setting of MINT countries.

There are four additional sections throughout the remainder of the paper. The pertinent literature is compiled in the section that follows. The research design and technique for (i) assessing the estimated parameters of the relationship between trade openness and its drivers and the theory-suggested drivers are described in Sect. 3. Section 4 discusses the outcomes, and Sect. 5 wraps up the report.

2 Literature review

2.1 Theory

The Energy Bundle Theory is a conceptual framework that examines how various energy sources are consumed and integrated within an economy, influenced by macroeconomic and trade-related factors. It posits that the overall energy consumption of a country is not solely dependent on individual energy sources but rather on a combination or "bundle" of different energy types, including fossil fuels, renewable, and other energy forms. This theory highlights that economic dynamics, such as trade balances, investment flows, labor market participation, demographic changes, and exchange rate fluctuations, play a critical role in shaping energy consumption patterns. In practical terms, the theory suggests that as economies evolve, the interplay between these macroeconomic factors can either promote or hinder the adoption of renewable energy. For instance, a favorable trade balance might lead to increased investment in renewable energy technologies, while unfavorable exchange rates could make importing renewable energy infrastructure more costly, thus slowing down the transition.

In the context of emerging economies, particularly in MINT countries—Mexico, Indonesia, Nigeria, and Turkey—the Energy Bundle Theory can be particularly illuminating. These countries face unique energy challenges and opportunities, and the theory helps in analysing how their specific macroeconomic conditions affect the consumption of renewable energy. By applying this framework, researchers can better understand the complex relationships between trade openness, energy policies, and economic growth, ultimately guiding strategies that facilitate a more sustainable energy future.

Trade reserves, including foreign exchange reserves, are vital for economic stability and international trade facilitation. In MINT countries, robust reserves enhance the ability to import renewable energy technologies by mitigating

currency risks and securing funds for critical imports. These reserves serve as a buffer, supporting a smoother transition to renewable energy sources. Similarly, a positive trade balance strengthens a country's financial position, allowing for investments in renewable energy projects. In contrast, a trade deficit may constrain such initiatives, limiting resources. For MINT countries, a favorable trade balance enables resource allocation toward renewable energy projects, encouraging diversification and sustainability. Surpluses can further support research, development, and technology deployment in this sector.

Labor force participation also impacts economic productivity, which in turn affects energy demand. In MINT countries, a youthful and expanding labor force offers a valuable asset for renewable energy sector growth, facilitating job creation and economic resilience. Investment in education and training in renewable energy technologies could further enhance this sector's workforce readiness.

Population growth directly influences energy demand, as larger populations require increased energy supplies. In MINT nations, rapid growth underscores the need for renewable energy solutions. This expanding population also creates a substantial domestic market for renewable energy products, driving investment and innovation within the sector. Meeting these demands sustainably could result in significant economic and environmental benefits. Exchange rates also play a key role by affecting the costs of importing renewable energy technologies. Favorable exchange rates make renewable projects more cost-effective, while unfavorable rates may impede technology adoption. For MINT countries, exchange rate stability is essential to facilitate renewable energy technology trade and attract foreign investment.

Trade openness enables MINT countries to access advanced technologies, attract foreign investments, and participate in global renewable energy networks. By expanding trade openness, these countries gain access to the latest renewable innovations, position themselves within international supply chains, and can leverage global partnerships to accelerate renewable energy adoption. In summary, macroeconomic factors like trade reserves, trade balance, labor force, population growth, exchange rates, and trade openness shape the renewable energy landscape in MINT countries. Mexico's favorable trade balance and reserves position it to attract renewable investments. Indonesia's reliance on fossil fuel exports presents a challenge, but its large labor force and population offer potential if aligned with supportive policies. Nigeria's abundant solar potential could be unlocked with better trade balance and exchange rate stability, while Turkey's strategic trade relationships and active workforce create promising conditions for renewable growth. By optimizing these macroeconomic drivers, the MINT countries can integrate renewable energy effectively, enhancing sustainable growth and energy security.

2.2 Review of empirical studies

This study aligns with and expands upon recent research that highlights factors such as financial development, economic globalization, ICT, and clean energy as pivotal in progressing toward carbon neutrality (aligned with SDGs 7 and 13). In the broader literature, financial development has been observed to promote sustainable energy investments, which directly supports de-carbonization efforts [36, 37]. Similarly, the digital economy, driven by ICT and digital trade, has stimulated innovation in environmental sustainability, particularly by enabling advancements in de-carbonization technologies [38].

This research distinguishes itself by targeting the macro trade drivers that affect both trade openness and renewable energy consumption, specifically within the context of MINT countries (Mexico, Indonesia, Nigeria, and Turkey). While previous studies generally explore the effects of these factors across different economies, there is a notable gap in the literature concerning how trade dynamics within MINT countries uniquely impact the transition toward carbon neutrality [39, 40]. These countries present a distinct profile with rapidly growing economies, diverse energy demands, and varying levels of dependence on fossil fuels, which offers a unique opportunity to analyze the specific trade and policy factors influencing renewable energy adoption. By filling this gap, this study contributes to the literature by providing critical insights into how trade policies, in conjunction with other macroeconomic factors, can be optimized to promote sustainable energy use and support the carbon–neutral goals in MINT economies. This specificity not only enhances the understanding of how emerging markets navigate the challenges of carbon neutrality but also offers policy implications that could guide similar economies toward sustainable energy transitions.

A critical analysis of these studies reveals both insights and limitations in the literature on renewable energy dynamics within emerging economies, with a focus on Latin America. Koengkan suggest that short-run economic growth encourages renewable energy capacity, particularly when coupled with financial openness and governmental support [41]. However, a critical perspective might question the sustainability of this impact in the absence of long-term policy frameworks that consistently prioritize renewables, especially given the volatility in government investment and financial markets.

Similarly, Silva et al. observed that financial flows, globalization, and CO_2 emissions collectively drive non-hydro renewable capacity, hinting that as CO_2 levels rise, a shift toward renewable energy sources may become more urgent. This finding, while insightful, raises questions about causality: Are renewable investments primarily reactive to environmental pressures, or do they also reflect proactive government or private sector initiatives? The study assumes a strong, linear relationship, but further research could investigate if these dynamics vary under different regulatory environments or economic structures, such as those seen in MINT countries [41]. highlight a critical issue by finding that trade openness can increase fossil fuel consumption, potentially complicating sustainable transitions. This association implies that liberalized trade might prioritize immediate economic gains, often tied to fossil fuels, over long-term sustainability. However, it's worth examining whether this relationship holds universally, as trade openness could theoretically foster renewable energy by lowering costs of green technology imports or encouraging international environmental standards.

Despite extensive research on the economic and environmental impacts of trade, a critical gap persists in understanding how macro drivers of trade openness influence renewable energy consumption. Current literature has made strides in related areas but remains limited in capturing the intersection of trade dynamics and energy transitions. For instance, [42] examined Latin American economies, revealing that financial incentives for renewable energy spur economic growth and increase green energy consumption. However, their study did not address the direct relationship between trade openness and renewable energy, leaving unexplored whether trade liberalization policies could similarly foster renewable energy use [43]. Used an NCA model to identify economic complexity and fossil fuel consumption as essential drivers of high-carbon emissions, with economic growth, urbanization, and institutional quality among key factors exacerbating carbon intensity. This research highlights how macroeconomic conditions shape emissions but does not consider the potential mitigating role of renewable energy consumption within open trade frameworks. Similarly, [41] found that co-innovation, economic growth, and renewable energy reduce premature mortality, yet their study overlooked trade openness as a factor influencing energy choices and environmental health. This gap in the literature points to an urgent need for studies that analyze how macroeconomic drivers of trade openness—such as trade balance, exchange rates, and reserves—affect renewable energy consumption. Such research could provide critical insights for policymakers in balancing trade growth with sustainable energy transitions, addressing both environmental and economic objectives.

This study seeks to bridge these gaps by focusing on MINT countries, where trade openness and renewable energy adoption may interact uniquely due to diverse economic structures and policy environments. By exploring these specific dynamics, this study contributes to a more nuanced understanding of how trade policies impact renewable transitions, offering insights that could support tailored sustainable energy strategies in these emerging economies. This approach not only fills a critical gap in the literature but also emphasizes the importance of context-specific policies in achieving effective, long-term carbon neutrality.

3 Method

3.1 Data and variables

First, this research study investigates the impact of macro trade drivers on trade openness, as well as the consequent impact on MINT nations' renewable energy use. The macro variables under consideration in this inquiry are TB, TR, ER, POP, and LFP. These specific parameters were chosen because of their theoretical potential as predictors of TOPEN and the resultant impact on renewable energy use. To achieve this goal, the study uses a panel data methodology, with data collected from 1995 to 2022. The study uses a panel data approach to analyse both time-series and cross-sectional variations, providing a thorough understanding of the complex relationship between macro trade determinants' impact on TOPEN and REC.

This research study focuses solely on MINT countries for three primary reasons. For starters, these countries have various trade driver factors when compared to other regions, owing to fundamental differences in their economic and political systems. Second, confining the sample to this particular group of economies helps to reduce sample heterogeneity. Thirdly, the availability of data on the variables of interest from readily available sources limited the number of nations that could be included in the sample. The availability of information regarding the factors that influence trade openness forms the basis of this study. When the pertinent variables were examined in its initial phase, it was discovered that data had been available since 1995. As such, the research project started in 1995. The sample consists of four countries, for which panel data were obtained from a variety of sources, such as the International Monetary Fund (IMF) and the World Development Indicators (WDI).

3.2 Procedure

This study assessed the significance of the findings and validated the conceptual framework using a range of verification approaches to improve the investigation's credibility. Initially, the Akaike Information Criterion (AIC) was employed to ascertain whether the model, which included nine explanatory factors, was at risk of over-fitting or under-fitting. Subsequently, stepwise regression was applied to pinpoint the key explanatory variables that influence trade liberalization effectively. This process identified five variables with statistical significance: TB, TR, ER, LFP, and POP size. To further solidify the model's stability, different estimation methods were implemented, comprised of pooled ordinary least squares, fully modified ordinary least squares, and the fixed effects model. The FEM and FMOLS was specifically chosen to address potential endogeneity issues within the model, echoing the recommendations of prior research [44]. Furthermore, F-tests were employed to examine the statistical dependability of the model's appropriateness, On the other hand, differences in particular impacts were investigated using the Breusch-Pagan and Lagrange Multiplier tests. Additionally, contrasting the estimates from two distinct models (fixed effects and random effects approaches), the Chow and Housman tests were applied. These validation techniques ensured the credibility, accuracy, and statistical relevance of the study outcomes, offering a detailed insight into the association between macro factors and trade openness within the framework of the MINT nations.

This research explores causality and co-integration among five factors pinpointed through stepwise regression and endorsed by a theoretical framework. Granger causality analysis, a broadly utilized technique in previous research [45], was utilized to examine causation. Additionally, the Padroni co-integration test (1981) was employed for cointegration testing. Further To test for cross-sectional dependence in the current dataset, this study employed the [46] CD test, as shown in Table 8. The null hypothesis for this test posits that residuals across entities are uncorrelated. The test results indicate a non-significant probability, suggesting the absence of cross-sectional dependence in the macro panel dataset used in this study.

In the realm of panel data analysis, especially when dealing with datasets spanning more than a decade and featuring over fifteen observations, conducting a stationarity test, also known as a panel Progress in the Granger causation research has driven the creation of approaches that integrate time-series analysis attributes of the data, including tests for stationarity and incorporation of panel data. By identifying the direction and nature of this causality, we gain insights into whether changes in trade-related factors—such as trade balance, exchange rate, and trade reserves—can predict shifts in renewable energy consumption patterns. This approach helps clarify the interdependence between trade dynamics and energy transitions, informing policy decisions aimed at enhancing sustainable energy use within these economies. Unit root test, is imperative. Detecting non-stationarity, indicative of the presence of a unit root, is essential to prevent potentially misleading estimations. This research adopts the ADF-Fisher chi-square and PP-Fisher chi-square tests, renowned for their applicability to datasets comprising numerous panels and extended time frames.

Greene et al, [46] cointegration examination analyzes the leftover errors from a misleading regression carried out with I(1) to ascertain the co-integration status of the variables. Co-integration is confirmed if the residuals are I (0); otherwise, they are considered I(1). The Pedroni cointegration test is advantageous as it can examine the null hypothesis of non-cointegration when there are diverse slope coefficients. These statistical methods can adapt to various fixed effects, anticipated trends, and both usual and extraordinary disruptions to the fundamental cause. This study utilized a range of econometric approaches to perform empirical investigations aimed at addressing the non-stationarity issue. Assorted panel unit root examinations were carried out, considering both individual and common unit roots. Before investigating the long-term, to explore the connection between two or more time series datasets, a unit root examination is necessary. Consequently, it becomes imperative to convert a nonstationary dataset into a stationary version by employing the most suitable technique. The panel unit root analysis determines the degree of integration required for the panel variable to reach stationarity.

3.3 Models

Section 3.3 outlines a model designed to evaluate the impact of macro trade drivers on trade openness and the marginal impacts of the macro trade factors that influence trade openness and energy consumption of MINT economies. In this context, the dependent variable is denoted as TOPEN and REC, and Eq. 1's left-hand side encompasses

various elements influencing trade openness. Trade openness is defined as the ratio of a country's trade to its gross domestic product, represented as TOPENjt, where j ranges from nation 1 to N, and t spans from 1995 to 2022. The independent variables, identified as Xjt, represent the key drivers, including the XX factor, as described in Table 1.

Consequently, the formulated model for examination can be expressed as:

$$\mathrm{TOPEN}_{jt} = \theta_{jt} + \theta_{jt1}(GNS_{jt}) + \theta_{jt2}(\mathrm{FDI}_{jt}) + \theta_{jt3}(\mathrm{TR}_{jt}) + \theta_{jt4}(\mathrm{ER}_{jt}) + \theta_{jt5}(\mathrm{PCI}_{jt}) + \theta_{jt6}(TIN) + \theta_{jt7}(POP) + \theta_{jt8}(LEP) + \eta_{jt} \quad (1)$$

In Eq. 2 left-hand side encompasses macro trade drivers influencing renewable energy consumption of MINT countries. Renewable energy is defined as Renewable energy consumption (% total energy consumption) represented as RECjt, where j ranges from nation 1 to N. The independent variables, Xjt, are identified as the drivers of renewable energy consumption, encompassing the X factor as outlined in Table 1.

.. Consequently, the formulated model for examination can be expressed as:

$$\mathrm{REC}_{jt} = \theta_{jt} + \theta_{jt1}(\mathrm{GNS}_{jt}) + \theta_{jt2}(\mathrm{FDI}_{jt}) + \theta_{jt3}(\mathrm{TR}_{jt}) + \theta_{jt4}(\mathrm{ER}_{jt}) + \theta_{jt5}(\mathrm{PCI}_{jt}) + \theta_{jt6}(TiN) + \theta_{jt7}(POP) + \theta_{jt8}(\mathrm{LFP}) + \eta_{jt} \quad (2)$$

The factors that drive macro trade in Eqs. 2 include per capita income, trade reserves, gross national savings, foreign direct net flow investment, exchange rate, gross capital formation, total investment, population, and the labour force actively participating in the economy.

An overview of the dependent and independent variables' descriptive statistics for each of the MINT countries is shown in Table 2. With a range of 96.18 to 20.72, the mean trade openness for the dataset, which spans 1995 to 2022, is 50.29. The descriptive statistics highlight the greater average trade proportion displayed by the MINT trading nations. Further MINT economy's average renewable energy consumption is 36.92, ranging from 21.72 to 88.68. The trade balance ranges from 23.05 to −7.74, with an average value of 1.25. Trade reserves show a range between 23.79% and 3.27%, with an average trade reserve of 10.48. Additionally, the average exchange rate is 2498.37, ranging from 14,481.10 to 0.05. The average labor force participation rate in MINT countries is 60.95, with a range from 70.74 to 48.49. The mean population value in MINT countries is 61.77, with a range of 67.80 to 52.88. The fact that these means are within the range typically found in other research indicates that these factors can accurately depict the dynamics of trade openness in MINT nations.

Figure 1 illustrates the trends in Mexico's trade openness and renewable energy consumption over the period from 1995 to 2022. The graph tracks how trade openness, reflecting Mexico's engagement in global markets, and the use of renewable energy have evolved concurrently. Observing these two variables over time helps highlight any correlations between Mexico's trade policies and its commitment to sustainable energy practices.

Figure 2 presents the trends in Indonesia's trade openness and renewable energy consumption from 1995 to 2022. This figure highlights Indonesia's level of integration in global trade markets alongside its renewable energy usage over the same period.

Figure 3 displays the trends in Turkey's trade openness and renewable energy consumption from 1995 to 2022. This figure provides a comparative view of Turkey's integration into global trade and its renewable energy usage over nearly three decades.

Figure 4 illustrates the trends in Nigeria's trade openness and renewable energy consumption over the period from 1995 to 2022. This figure provides insights into the relationship between Nigeria's global trade engagement and its renewable energy usage. By examining these trends together, we can explore how shifts in Nigeria's trade openness may correspond with changes in renewable energy consumption.

4 Findings

4.1 Data diagnostic test

Section 4.1 delves into a thorough exploration of diagnostic assessments performed to validate the sample's adequacy for subsequent analysis. The Jarque–Bera (J-B) assessment for normal distribution, the primary examination, was employed to gauge the presence of a normal distribution within the variables. Subsequently, the Variance Inflation Factor (VIF) assessment was utilized to identify potential intercorrelation across the explanatory variables. The outcomes of the VIF assessment for multicollinearity are presented in Table 3, which was employed to evaluate the existence of multicollinearity using the average VIF ratio. Multicollinearity can complicate the isolation of specific impacts of explanatory variables

Table 1 Data description

Variables	Description	Symbol	Source	DV/IV
Trade openness	Trade/GDP	TO	WDI	Dependent variable
Renewable energy consumption	Renewable energy consumption (% total energy consumption)	REC	WDI	Dependent variable
Saving	Gross National Savings)/GDP	GNS	IMF/WDI	X1 factor effect '+'
Foreign direct net flow investment	FDI net inflow/ GDP		WDI	X2 factor effect '+'
Trade reserve	Total reserve minus gold/GDP	TR	WDI	X3 factor effect '+'
Exchange rate	Exchange rate (Domestic Currency per U.S. Dollar, End of Period)	ER	IMF/WDI	X4 factor effect '+'
GDP per capita incomes	Total GDP/Total Population	PCI	WDI	X5 factor effect '+'
Labour force participation	Economically active labour (Labour force participation rate, %of total population	LFP	WDI	X6 factor effect '+'
Gross capital formation	Gross capital/GDP	GCF	IMF/WDI	X7 factor effect '+'
Population	Total Population (Age 15 -64) % of total population	ADR	WDI	X8 factor effect '+'
Total Investment	Total Investment/GDP	TIN	IMF/WDI	X9 factor effect '+'

Table 2 Statistical overview of MINT countries n

Variables	Mean	Median	Max	Min	Std. dev	J-B
TOPEN	50.29	49.63	96.18	20.72	12.85	9.93***
REC	36.92	21.72	88.68	8.97	29.86	15.11***
TB	1.250	−0.26	23.05	−7.74	5.282	64.07***
TR	10.84	10.76	23.79	3.27	3.57	8.98 ***
ER	2498.37	21.30	14,481.0	0.05	4545.5	40.26***
LF	60.95	60.98	70.74	48.49	6.06	4.99***
POP	61.77	63.92	67.80	52.88	5.27	14.87***

Table 1 also contains information on and no missing values (balance panel). **Significance: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$ denotes significance level respectively

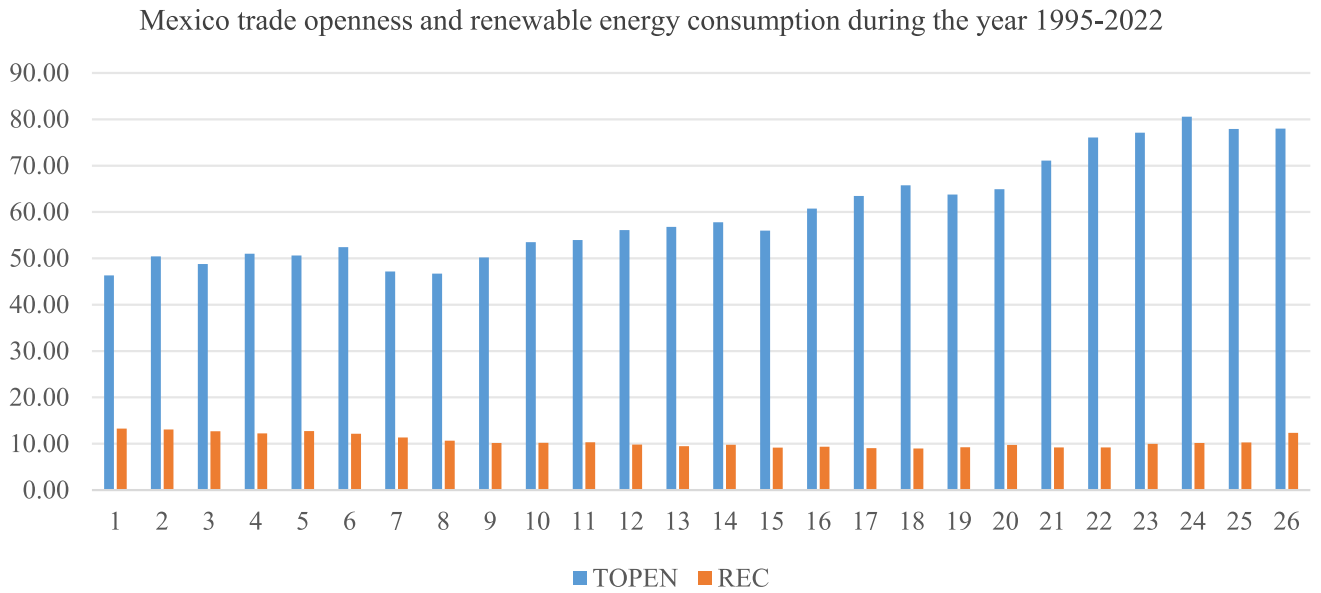

Fig. 1 Mexico trade openness and renewable energy consumption during the year 1995–2022

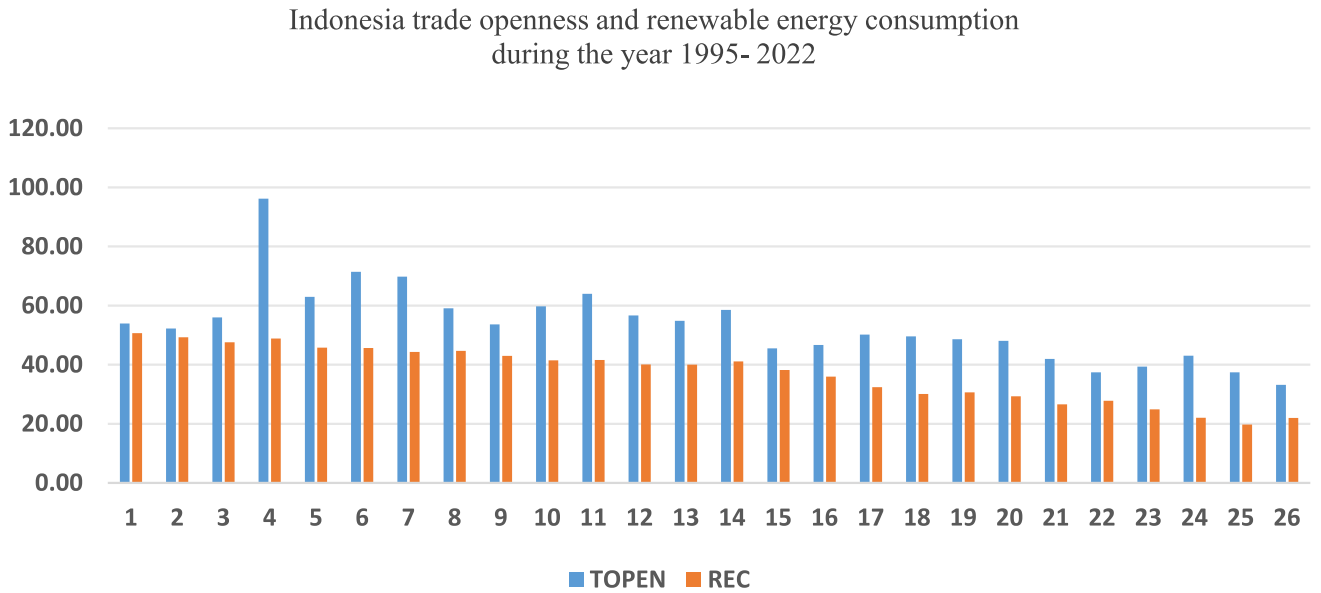

Fig. 2 Indonesia trade openness and renewable energy consumption during the year 1995–2022

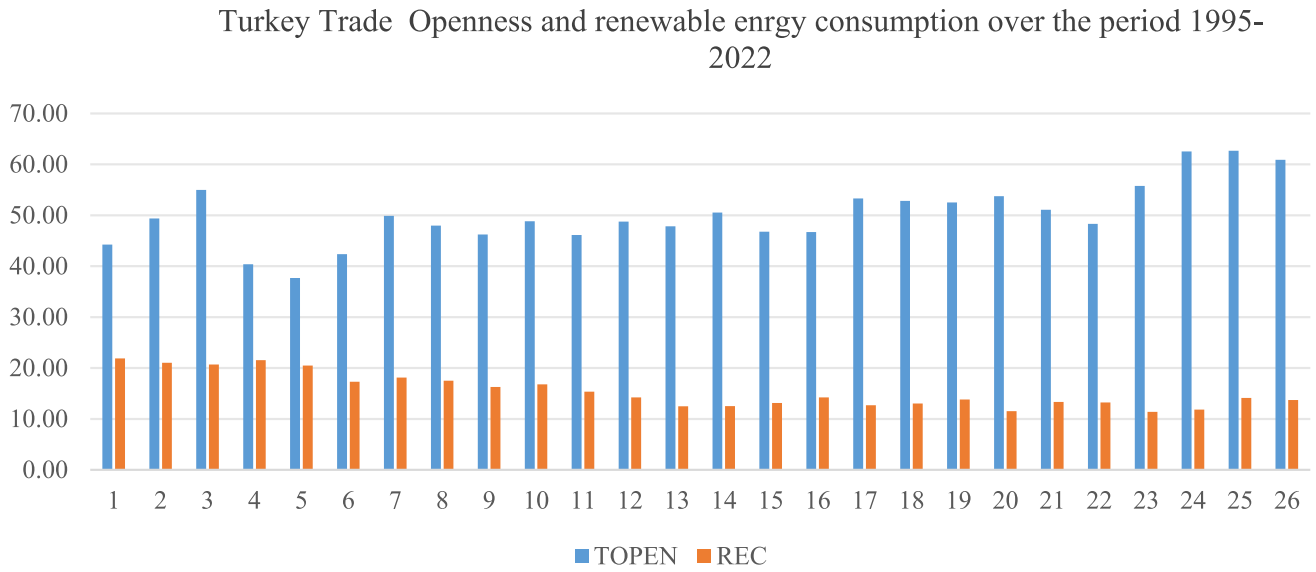

Fig. 3 Turkey trade openness and renewable energy consumption during the year 1995–2022

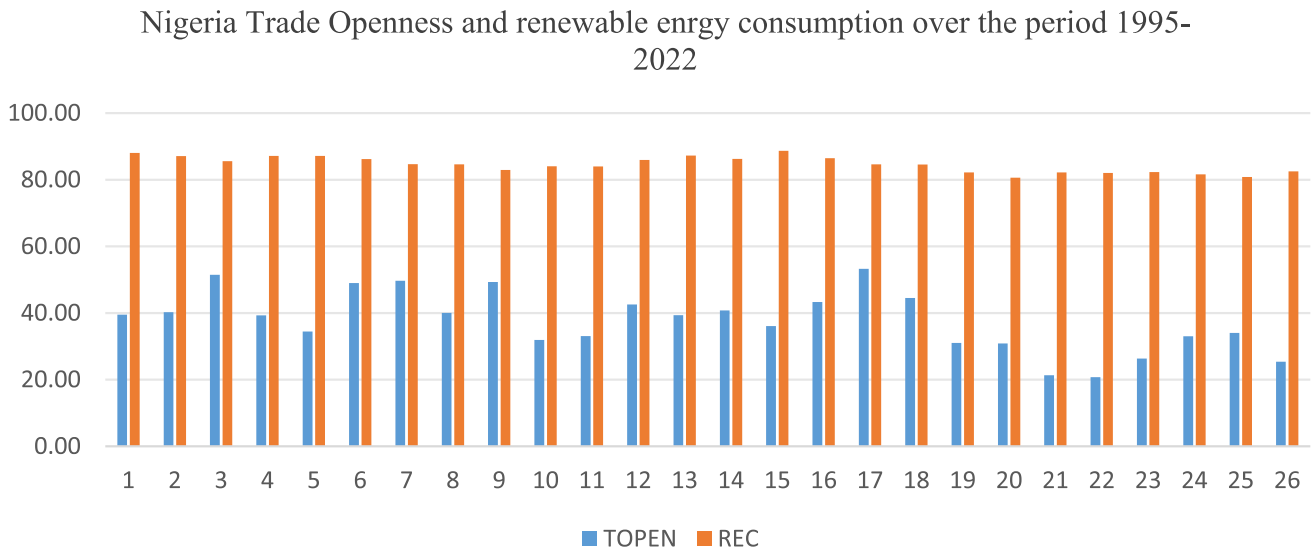

Fig. 4 Nigeria trade openness and renewable energy consumption during the year 1995–2022

on outcome factors in regression studies. A VIF value exceeding 10 suggests multicollinearity. The table incorporates all pertinent variables for mean–variance analysis to detect potential multicollinearity. The VIF ratings for all variables were at or under 10, indicating a lack of multicollinearity within the framework.

Table 4 showcases the outcomes of stationarity tests performed on both the initial and differenced chronological sequence of the factors within the singular intercept group. The test outcomes reveal that while all variables exhibit non-stationarity at their initial levels, they demonstrate stationarity when first differenced. This indicates that the variables follow a first-order integration, denoted as I(1). This signifies the null hypothesis being disproved that a unit root does not exist within the underlying mechanism of the variables. After achieving stationarity through the first differencing of the variables has been verified, the subsequent stage involves determining the optimal lag length for each economy, utilizing criteria for ideal lag choice elucidated in Table 5: The correct lag time is critical for using sophisticated econometric procedures like Pedroni cointegration and Granger causality tests.

Table 5 presents the findings of the lag order determination tests carried out on the MINT countries. Five different standards were used for choosing the lag sequence: the likelihood ratio, Final Prediction Error, Akaike's Information Criterion, Schwarz's Bayesian Criterion, and Hannan-Quinn Information Criterion. These criteria were applied to identify

Table 3 Summary of multicollinearity test (VIF)

Variables	T	VIF
Model II TOPEN		
TB	0.53	1.86
TR	0.72	1.37
ER	0.43	2.31
LF	0.51	1.94
POP	0.50	1.93
Model II REC		
TB	0.51	1.94
TR	0.50	1.99
ER	0.72	1.37
LF	0.43	2.31
POP	0.53	1.86

This table presents the results of the cross-dependency VIF test. VIF ≤ 10; no multicollinearity: VIF > 10; multicollinearity

Table 4 Panel unit root results

	ADF-Fisher- chi-square		Im, Pesaran, Shin		Fisher-PP		Levin, Lin, and Chu	
	Intercept		Intercept		Intercept		Intercept	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
TOPEN	6.17	6993***	0.51	−8.53***	8.20	99.10***	−1.02	−9.22***
REC	5.07	34.56***	0.742	−4.26***	10.15	56.71***	−1.05	3.341***
TB	13.86*	51.84***	0.003***	−6.40***	16.88***	78.29***	0.19	−5.73***
TR	20.68***	67.24***	−1.85***	−8.29. ***	20.25**	73.19***	−0.32	−6.19
ER	2.98	40.13***	4.72	−4.51***	3.08***	43.84***	4.00	−4.99***
LFP	6.84	24.50.***	0.36	−2.90***	2.45	24.63***	−0.34	−3.55
POP	27.28***	26.68***	−3.12***	−4.80***	62.03***	24.66***	−3.78***	−3.68***

Table 5 Lag order selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
Model I						
0	−1735.41	NA	4.10e + 13	48.37	48.56	48.44
1	−1043.18	1249.86	499,082.3	30.144	31.47	30.67
2	−962.61	132.04	147,668.4	28.90	31.37*	29.88*
Model II						
0	−1743.13	NA	5.08e + 13	48.58	48.77	48.66
1	−949.30	1433.29	36,783.68	27.53	28.86443*	28.06
2	−881.62	110.92	15,569.73	26.65	29.12	27.63

the best lag duration. The best lag was recognized as the one having the lowest value by each standard. The analysis determined that the most appropriate lag order for the MINT countries is 2.

Using Engle's two-phase approach for testing co-integration based on residuals, the research conducted the Pedroni panel co-integration analysis to explore a long-term association among the chosen factors within the MINT economies. While discussing the results, a deeper interpretation of the outcomes from the Pedroni co-integration analysis, succinctly summarized in Table 6, reveals significant long-term relationships among the variables in Model 1, which includes trade drivers such as trade balance, trade reserves, exchange rate, labor force participation, population, and trade openness. These relationships indicate that changes in trade dynamics have persistent effects on the economic landscape of the MINT countries. In Model 2, the analysis further illustrates the interactions between trade drivers and renewable energy

Table 6 Pedroni co integration results

Within dimension measure	Statistics	P-value	Weighted statistics	P-value
Panel- v statistic	−0.32	0.62	−1.25	0.89
Panel- rho statistic	0.58	0.72	1.09	0.86
Panel- PP statistic	−2.28	0.01	−3.20	0.00
Panel- ADF statistic	−2.96	0.00	−5.44	0.00
Between-Dimension				
Group- rho statistic	1.69	0.95	–	–
Group- PP statistic	−4.60	0.00	–	–
Group-ADF statistic	−4.47	0.00	–	–
Model II				
Panel- v statistic	−1.00	0.84	−1.39	0.91
Panel- rho statistic	1.05	0.85	1.39	0.91
Panel- PP statistic	−1.70	0.04	−2.60	0.00
Panel- ADF statistic	−1.60	0.04	−1.84	0.03
Between-Dimension				
Group- rho statistic	1.86	0.96	–	–
Group- PP statistic	−3.24	0.00	–	–
Group-ADF statistic	−2.64	0.00	–	–

**Significance: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$ denotes significance level respectively

consumption. The significant co-integration suggests that as trade drivers evolve, they are likely to influence renewable energy consumption patterns over the long term. This interconnection highlights the importance of trade policies and economic conditions in shaping sustainable energy practices within these economies. Overall, the findings underscore the critical role that trade drivers play in not only facilitating economic growth but also in promoting the transition towards renewable energy, emphasizing the need for policy-makers to consider these long-term relationships when formulating strategies for economic and environmental sustainability.

Granger causality is employed to predict the association between the factors, in contrast to co-integration analysis, which overlooks the influence of a variable's previous value in relation to the present value of another. Applying the Granger causality test is crucial for investigating possible cases of these effects.

Table 7 presents the results of the Granger causality study for the MINT countries, which offer interesting new information. TOPEN and TB have a unidirectional causal relationship, according to this analysis, with TOPEN Granger driving TB at a 1% significant level. This finding suggests that growth in TOPEN leads to a boost in the trade surplus; similarly, a boost in the trade balance contributes to an increase in TOPEN within MINT economies. In a study by [47], The findings suggest a unidirectional relationship between increasing exports to economic expansion, implying that increases in exports (a component of trade openness) lead to economic expansions, which can affect the trade balance.

Moreover, the results establish a bidirectional causative link between the ER and TOPEN. This observation concurs with earlier studies by [47], who explored the connections between trade conditions and currency exchange policies. Their results imply a relationship between fixed ER regimes and increased TOPEN, illuminating a possible connection between ER strategies and TOPEN. Furthermore, the findings identify a mutual causal relationship between the LFP rate and TOPEN. This finding is consistent with prior studies; [48] find that trade liberalization positively affects labor market outcomes, including higher LFP.

The 1% significance threshold indicates that the null hypothesis, which states that POP does not cause TOPEN, is rejected, with a p-value of 0.00. This outcome underscores a causal association between POP and TOPEN within MINT economies. The discovered relationship between POP and TOPEN is identified as unidirectional. This finding supports the research by [49], which identified a positive correlation between a skilled workforce and trade openness (TOPEN). A skilled population enhances productivity and innovation, leading to increased competitiveness in international markets. This dynamic fosters a unidirectional causal relationship, where a more skilled workforce drives trade openness. The implications suggest that investments in education and training can facilitate greater integration into global trade networks.

The Granger causality results for Model 2, which examines the impact of macro trade drivers REC, are detailed in Table 7. These results indicate that TR do not Granger-cause REC. The findings reveal that there is neither a unidirectional nor bidirectional relationship between TR and renewable REC. The study findings indicate that in the MINT countries, a

Table 7 Granger causality test results

Alternate hypotheses	Null hypotheses	W-statistic	Zbar-Stat	Prob
TB is not Granger Cause TOPEN	No causation	1.19	−0.82	0.41
TOPEN is not Granger Cause TB	TOPEN→TB	5.45	2.55	0.01
TR is not Granger Cause TOPEN	TR→TOPEN	6.11	3.08	0.00
TOPEN does not Granger Cause TR	No causation	1.718	−0.41	0.68
ER is not Granger Cause TOPEN	ER→TOPEN	6.11	3.08	0.00
TOPEN is not Granger Cause ER	TOP→ER	4.98	2.18	0.02
LF is not Granger Cause TOPEN	LF TOPEN	6.33	3.26	0.00
TOPEN is not Granger Cause LF	TOPEN→LF	5.60	2.67	0.00
POPEN is not Granger Cause TOP	POPEN→TOPEN	13.09	8.63	0.00
TOPEN is not Granger Cause POP	TOPEN→POPEN	1.45	−0.61	0.53
REC Model II				
TR is not Granger Cause REC	No causation	3.19	0.75	0.44
REC is not Granger Cause TR	No causation	1.73	0.40	0.68
ER is not Granger Cause REC	No causation	2.88	0.52	0.60
REC is not Granger Cause ER	ER→REC	4.93	2.14	0.03
LF is not Granger Cause REC	No causation	4.18	1.54	0.12
REC is not Granger Cause LF	REC→LF	6.79	3.62	0.00
POP does not Granger Cause REC	No causation	6.77	3.22	0.00
REC is Granger Cause POP	REC→POP	2.31	0.06	0.94
TB is not Granger Cause REC	No causation	2.67	0.34	0.72
REC is not Granger Cause TB	REC→TB	4.64	1.91	0.04

**Significance: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$ denotes significance level respectively

unidirectional relationship exists between REC and ER, meaning changes in renewable energy production and usage directly influence ER, but not vice versa. This implies that fluctuations or growth in the renewable energy sector in these countries can impact their currency values, potentially through mechanisms such as energy trade balances, investment flows into renewable sectors, or changes in economic activity related to energy. However, ER fluctuations do not significantly affect the renewable energy sector, possibly due to the sector's resilience to short-term currency changes. This result is in line with the study by [50], which shows that there is a bidirectional relationship between Brazil's use of REC and ER through the use of Error Correction Model (ECM) analysis. Their results show that, over time, the exchange rate affects the use of renewable energy sources, and the exchange rate is affected by the use of renewable energy sources.

Subsequent research revealed a unidirectional association between the LF and REC in MINT countries. This indicates that while changes in the LF have little impact on REC, changes in the REC directly affect it. Specifically, an increase in REC in these countries can lead to higher LF, potentially through the creation of jobs in the renewable energy sector, improved economic stability from energy security, and better health outcomes from cleaner energy sources, which enhance workforce productivity and participation. This result is in contrast with the study conducted by [51], which looks at how India's employment situation is affected by the expansion of renewable energy sources, especially solar photovoltaic (PV) technology. Despite large investments in solar PV technology, according to their analysis, the number of jobs in the industry fell marginally from 164,000 in 2017 to 114,000 in 2018. The analysis indicates that employment levels do not significantly respond to changes in installed capacity, with an estimated employment elasticity of just 0.004.

The study also reveals a one-way relationship between POP and REC, implying that POP changes have a direct impact on REC but not vice versa. This suggests that as the POP increases, the REC also rises, possibly due to higher energy demand from a larger population requiring more electricity for residential, commercial, and industrial uses. However, changes in REC do not significantly impact POP growth, meaning that while a growing population drives the need for more renewable energy, the amount of renewable energy consumed does not influence population size. This finding supports the research by [52], which argues for moderating population growth and expanding renewable energy usage in the ASEAN region.

The study also reveals a unidirectional association between renewable REC and TB in MINT countries. This implies that changes in renewable energy consumption directly influence the trade balance, with REC Granger causing TB. In other words, increased REC in these countries can lead to improvements in their trade balance, potentially by reducing the need

for energy imports, increasing energy exports, or enhancing economic efficiency and competitiveness. Changes in the trade balance, however, have little effect on the use of renewable energy. Further, trade balance can influence renewable energy consumption by affecting national income, allowing for increased investment in renewable projects. A positive trade balance reduces reliance on imported fossil fuels, encouraging domestic energy development. It also promotes supportive policies through enhanced government revenue, and facilitates technology transfer via international trade agreements. Overall, these factors contribute to a greater emphasis on sustainable energy practices. The findings [53], who discovered both long- and short-term cointegrating associations, are in line with this outcome. Their findings show that whereas REC has a positive long-term effect on tuberculosis, it has a detrimental short-term effect.

The pivotal findings derived from the panel regression examination are comprehensively outlined in Table 8, covering results from four different categories of examinations. Among these, the FEM emerges as the most robust modelling. The Fixed Effects Model (FEM) exhibits a level of significance of less than 0.01, along with an F-test statistic of 54.70, signifying a statistically meaningful model fit. Additionally, the adjusted R-squared value stands at 73%, indicating a substantial proportion of explained variance within the model. When employing stepwise variable selection using regression, only five elements are found with statistically significant estimated parameters. These variables, recognized as the principal catalysts of commerce in the Mint countries, involve trade surplus, TR, ER, LF, and POP. This innovative discovery enriches the understanding of crucial macro factors influencing TOPEN, consistent with previous research.

Table 8 Summary of panel regression results

Dep. Var. is TO	SR	Pooled	FEM	FMOLS
Constant	−151.76*** (−4.59)	−138.76*** (8.56)	−93.66*** (−2.91)	
TB	0.59*** (3.45)	0.59*** (3.45)	0.56*** (3.23)	0.66** ()
TR	1.02*** (4.69)	1.02*** (4.69)	1.20*** (4.97)	1.75*** (4.90)
ER	−0.00*** (10.42)	−0.00 *** (10.42)	−0.00*** (−5.68)	0.43*** (2.48)
LF	1.17*** (7.67)	1.17 *** (7.67)	0.85 *** (2.53)	2.29*** (2.20)
POP	2.01*** (1.26)	2.01*** (1.26)	1.37 *** (2.57)	2.17*** (4.38)
Adj R^2	0.73	0.73	0.75	0.76
F-test	54.70***	54.70***	35.92***	
B-P-LM		298.09***		
Hausman chi^2			27.44***	
REC Model II				
Constant	407.08*** (21.32)	407.08*** (21.32)	121.17*** (11.13)	
TB	0.29 (1.19)	0.29 (1.19)	0.125*** (2.12)	2.14*** (3.99)
TR	1.49*** (4.83)	1.49*** (4.83)	0.44*** (5.30)	0.64*** (0.89)
ER	−0.00*** (−9.16)	−0.00*** (−9.16)	−0.00*** (−11.82)	−0.00*** (−3.44)
LF	0.63*** (2.96)	0.63*** (2.96)	0.19*** (1.62)	2.29*** (5.82)
POP	−5.75*** (−22.86)	−5.75*** (−22.86)	−1.55*** (−8.59)	−1.76*** (−4.43)
Adj R^2	85.82	85.82	0.88.43	0.45
F-test	182.3***	182.3***	2222.54***	
B-P-LM		234.01***		
Pesaran CD statistics	−0.036			
Hausman chi^2			23.44***	

Significance level ***p < 0.01; **p > 0.05. * P < 0.1 respectively

The results of the study also showed a substantial and positive impact of the trade balance on TOPEN. At the significance threshold of 1%, the coefficient estimates of $\beta = 0.56$ ($p < 0.01$) highlight the noteworthy impact of the trade balance on the TOPEN of MINT countries. This favorable association suggests that increased TOPEN can have a beneficial impact on the trade surplus of MINT nations. It suggests that measures promoting TOPEN present opportunities for improving a MINT nation's trade surplus, leading to improved trade results. This result resonates with earlier research by [54], which provides evidence supporting the notion that trade surpluses are positively linked to trade openness, indicating that nations exhibiting greater trade surpluses tend to participate more extensively in international trade. These investigations offer robust empirical backing for the positive association between trade surplus and TOPEN.

The present investigation unveils a notable and meaningful connection between TR and TOPEN, indicating that nations boasting greater TR display an enhanced inclination towards participating in foreign trade. This indicates that TR wields a substantial impact on the TOPEN of MINT countries, as demonstrated by a coefficient with a value of $\beta = 1.20$ ($p < 0.01$) at a significance level of 1%. This research presents proof of a notable and meaningful link between TR and TOPEN within MINT counties, underscoring the vital function of TR in enabling global trade. These observations correspond with previous investigations conducted by [55] to find empirical evidence supporting the notion that higher TR is associated with increased TOPEN, indicating a positive relationship between the two factors.

Upon analyzing the impact of the exchange rate ER on trade openness in MINT countries with unrestricted trade, we discovered that the ER's coefficient value is $\beta = 0.00$ ($p < 0.1$), suggesting that there is no statistical significance. This finding suggests that trade openness in MINT countries is not significantly impacted by the ER). This result casts doubt on the widely held notion that the ER is crucial in determining TOPEN. Upon reviewing the research on the connection between international trade and currency exchange rates, [56] determined that the impact of ER on foreign trade is complex and can be noteworthy under specific circumstances. However, it is not consistently clear-cut or significant. This complexity arises from various factors, including the elasticity of demand for traded goods, which affects how responsive trade volumes are to exchange rate changes; the distinction between short-term and long-term effects, where immediate adjustments may not persist as other variables gain prominence; and the influence of market expectations, which can lead to volatility in exchange rates that doesn't reflect fundamental economic conditions. Additionally, the effects of exchange rate fluctuations can vary widely among countries based on their unique economic structures and trade relationships. Thus, a nuanced and context-specific analysis is essential for understanding the impact of exchange rates on trade dynamics, which can inform effective policy responses.

Our results unveil a favorable and noteworthy connection between LF and TOPEN in MINT nations as demonstrated by a coefficient with a value of $\beta = 0.19$ ($p < 0.01$) at a significance level of 1%. This study observed that the influence of labour force participation on TOPEN is notably pronounced within MINT economies. Nations exhibiting elevated LF typically showcase a more extensive embrace of trade. This inclination can be ascribed to the premise that a proficient workforce is more adept at capitalizing on the prospects afforded by global trade. Proficient laborers in MINT nations can produce superior goods and services at competitive prices within worldwide markets. Moreover, they can easily adjust to novel technologies and manufacturing approaches, empowering them to maintain competitiveness on a global scale. This discovery corresponds with earlier investigations carried out by [57], which showed a positive association between workforce skills and a nation's export efficiency. Further this observation aligns with a previous study by [48], which finds that trade liberalization positively affects employment market results, such as increased rates of labor force participation.

The results reveal a positive significant impact of Population on TOPEN in MINT nations. This discovery aligns with prior research by [57], which shows that labor expertise is positively associated with a nation's export effectiveness. Additionally, the study observed that the impact of POP on TOPEN is specifically remarkable in MINT economies. The parameter for the POP was determined to be 1.37 ($p < 0.01$). Nations with larger populations often exhibit more extensive engagement in trade. This tendency can be ascribed to the premise that a proficient populace is superior and poised to capitalize on the possibilities afforded by global trade. The significance of the POP in MINT countries in enhancing TOPEN is noteworthy. A larger POP can contribute to increased TOPEN, as it provides a substantial consumer base and market demand. With a sizable population, MINT countries have the potential to attract more international trade activities, fostering economic interactions and trade partnerships. Additionally, a larger population may signify a diverse and skilled labor force, aiding in the manufacturing of a variety of goods and services, and further boosting TOPEN. Overall, the demographic size of MINT countries plays a crucial role in shaping and expanding their engagement in international trade.

Table 8 encompasses outcomes from four distinct types of tests for model 2. The FEM appears as the most reliable explanatory model among these. The FEM model produces a p-value of less than 0.01, which, together with the F-test result of 2222.54, indicates a statistically significant model fit. Furthermore, the corrected R-squared value of 88.43% indicates a high level of explained variation within the model.

The findings from Model 2 revealed that the trade balance has a positive and considerable impact on the REC of MINT economies. This demonstrates that an improved trade balance, which reflects a surplus or reduced deficit in the country's trade transactions, positively influences the REC. A healthier trade balance can lead to greater financial stability and increased resources available for investment in renewable energy projects. It also boosts investor confidence and facilitates the import of advanced technologies and materials necessary for renewable energy development. Thus, enhancing the trade balance can be a strategic approach for these countries to support and expand their REC. [58] highlight the significant influence of economic growth, energy imports, consumption, and the current account balance on renewable energy generation. Economic growth drives higher energy demand, prompting investments in renewable technologies. Increased energy imports can diversify sources and enhance domestic renewable capacity. Additionally, consumption patterns necessitate a transition to sustainable energy options. A favorable current account balance provides financial resources crucial for supporting investments in renewable energy infrastructure, emphasizing the need for integrated energy policies.

The findings reveal that TR considerably promotes the REC in MINT countries. This shows that rising investment and consumption in the renewable energy industry are a direct result of higher levels of trade reserves, which indicate a nation's ability to handle foreign commerce and maintain economic stability. The positive relationship between trade reserves and renewable energy development in MINT countries can be attributed to increased financial capacity, bolstered investor confidence, and easier access to critical technology and materials for renewable infrastructure. By strengthening trade reserves, MINT countries are better positioned to accelerate the shift to renewable energy, supported by improved financial stability and a dependable source of capital for essential imports. Additionally, trade reserves help stabilize currency fluctuations, reducing cost volatility for imported renewable assets. This stability not only enhances investor trust but also supports sustainable long-term planning in MINTs' renewable energy sectors, contributing to broader economic resilience and growth. This outcome is consistent with the previous study undertaken. by [59], which showed that TR and renewable energy in 19 of the Asia Cooperation Dialogue's member countries are causally related over the long term.The finding that trade reserves (TR) and renewable energy are causally related over the long term, as shown by [59], has important implications for understanding the dynamics between economic stability and sustainable energy development. This relationship suggests that higher levels of trade reserves may provide countries with the financial stability necessary to invest in renewable energy projects.

Further study findings indicate that the exchange rate has a significantly negative impact on the renewable energy consumption of MINT countries. This suggests that as the exchange rate depreciates, making foreign currency more expensive, the consumption of renewable energy decreases, possibly due to higher costs for importing renewable energy technologies and materials. However, despite this significant impact, the size of the coefficient is effectively zero, implying that while the relationship is statistically significant, the actual effect size is negligible. Further, exchange rate fluctuations can negatively impact renewable energy by increasing the cost of imported technology, which is crucial for renewable projects reliant on foreign equipment like solar panels and wind turbines. Currency depreciation raises these import costs, making renewable energy investments less attractive due to heightened project expenses. Additionally, exchange rate volatility can deter foreign investors, who may view these fluctuations as financial risks, thus reducing capital flows into the sector. Higher operational costs for maintenance and imported spare parts further burden renewable projects, potentially limiting profitability and growth. This result is consistent with earlier research by [60], which found a comparable correlation between the use of renewable energy and exchange rates in Bangladesh, India, and Sri Lanka. Rehman et al. identified that fluctuations in exchange rates can significantly influence the cost of importing renewable energy technologies and components in these South Asian countries. When the exchange rate is favorable, it reduces the cost of purchasing advanced renewable energy technologies from international markets, making it more feasible for countries to invest in and implement renewable energy projects. Conversely, when exchange rates are unfavorable, the increased cost of imports may hinder the growth and adoption of renewable energy, as projects may become financially unviable or less attractive compared to conventional energy sources.

The findings also uncover that labor force participation significantly impacts renewable energy consumption in MINT economies. This suggests that higher labor force participation rates lead to increased consumption of renewable energy, likely because a more active workforce drives greater economic activity and energy demand, including for renewable sources. Additionally, a robust labor force can support the creation and upkeep of infrastructure for renewable energy, which will increase usage even further. These observations emphasize how critical it is to develop a robust labour market to facilitate the expansion of renewable energy in these nations. This finding is in line with that of [61] research from 2022, which showed that labour and power consumption have positive but inelastic effects in Nigeria.In the context of Nigeria, this suggests that while expanding the labor force and increasing energy consumption are crucial for driving economic

growth, the impact may be limited due to structural inefficiencies or other constraints within the economy. Factors such as inadequate infrastructure, energy supply issues, or regulatory challenges may impede the effective utilization of labor and energy, resulting in a less-than-proportional boost to overall economic productivity.

Further outcomes indicate that POP significantly negatively impacts REC in MINT economies. This suggests that as the population increases, the per capita renewable energy consumption decreases, possibly due to higher overall energy demand outpacing the growth in renewable energy capacity. Additionally, larger populations may strain existing infrastructure and resources, leading to a reliance on more readily available non-renewable energy sources.In MINT economies, the negative relationship between population and renewable energy may arise from high energy demands in densely populated regions, where conventional energy sources often dominate due to established, lower-cost infrastructure. Population pressures may also shift resources toward immediate energy needs, reducing renewable investments, while urbanization can create spatial constraints, limiting the feasible expansion of renewable projects. These findings highlight the challenges MINT countries face in scaling renewable energy to fulfil the needs of an expanding populace and underscore the need for policies that promote substantial investment in renewable energy infrastructure to ensure sustainable development. This finding supports prior research by [52] indicated that the shift towards renewable energy has a significant impact on carbon dioxide emissions. Specifically, the utilization of renewable energy sources, such as solar, wind, and hydropower, can lead to a reduction in CO2 emissions compared to traditional fossil fuels. As populations grow and countries expand their renewable energy infrastructure, the transition to cleaner energy sources can help mitigate the environmental impact associated with increased energy consumption.This interconnectedness implies that effective energy policies promoting renewable energy adoption in response to population growth can contribute to lower CO2 emissions, supporting global efforts to combat climate change. Therefore, the findings reinforce the importance of integrating population dynamics into energy planning and policy frameworks to achieve sustainable energy goals while minimizing carbon emissions.

4.2 Policy implication

The finding that trade balance, as a driver of TOPEN, has a positive effect on REC in MINT economies carries significant policy implications. Policy-makers should focus on strategies that enhance the trade balance to promote renewable energy consumption. This can be achieved by boosting exports, reducing trade deficits, and improving the overall economic environment to attract foreign investments in the renewable energy sector. Strengthening trade policies to support these goals will not only improve the trade balance but also provide the financial stability needed to invest in renewable energy infrastructure. Additionally, encouraging partnerships and trade agreements that facilitate the exchange of renewable energy technologies and expertise can further drive the growth of the renewable energy sector. Overall, policies that improve the trade balance can play a critical role in accelerating the transition to renewable energy and achieving sustainable development goals in MINT economies.

The finding that trade reserves, as a driver of trade openness, have a positive impact on renewable energy consumption in MINT economies—has important policy implications. Policymakers should focus on strategies to build and maintain robust trade reserves to promote renewable energy consumption. This can be achieved by encouraging exports, optimizing foreign exchange earnings, and maintaining a favorable balance of payments. Policies that strengthen the economic framework, reduce trade deficits, and attract foreign investments will enhance trade reserves, providing the financial resources necessary for investing in renewable energy infrastructure and technologies. Additionally, leveraging trade reserves to import advanced renewable energy technologies and expertise can accelerate the transition to sustainable energy sources. Ensuring stable and ample trade reserves can help MINT economies buffer against economic shocks and currency fluctuations, thereby supporting consistent and long-term investment in renewable energy. Overall, enhancing trade reserves should be a strategic priority for policy-makers aiming to boost renewable energy consumption and achieve sustainable development goals.

The finding that LF, as a driver of trade openness, has a positive impact on REC in MINT economies—suggests several policy implications. Policy-makers should prioritize initiatives that enhance labor force participation to support the expansion of REC. This can be accomplished by offering educational and career-training programs that give workers the skills required in the renewable energy industry, encouraging creativity and the development of new technologies. Additionally, labor market reforms that promote job creation, especially in renewable energy industries, can further increase labor force participation and, consequently, renewable energy consumption. Policies that improve working conditions, ensure fair compensation, and provide social safety can all help to increase worker participation rates. By

focusing on these areas, MINT economies can create a robust labor force that supports the development and expansion of renewable energy, contributing to sustainable economic growth and environmental sustainability.

The finding that POP, as a driver of trade openness, hurts renewable energy consumption in MINT economies—suggests several key policy implications. Policy-makers should consider implementing measures to manage population growth in a way that mitigates its adverse effects on renewable energy consumption. This can involve investing in family planning programs, improving access to education, particularly for women, and enhancing healthcare services to reduce birth rates and manage population size sustainably. Additionally, policies should focus on increasing the efficiency of renewable energy systems to ensure that growing populations can be supported without disproportionately increasing energy demand. Encouraging the development of smart grid technologies, improving energy storage solutions, and promoting energy-saving practices can help offset the negative impact of population growth on REC. By addressing the challenges posed by population growth, MINT economies can better support the expansion of REC and ensure sustainable economic and environmental outcomes.

The finding that exchange rates, as a driver of Trade openness, have a substantial negative influence on the REC in MINT economies implies several important policy implications. Policy-makers should focus on strategies to stabilize exchange rates to mitigate their adverse effects on REC. This can be achieved through sound macroeconomic policies that reduce volatility, such as maintaining prudent fiscal and monetary policies, building robust foreign exchange reserves, and improving overall economic stability. Additionally, reducing reliance on imported renewable energy technologies by fostering local production and innovation can buffer the negative impacts of ER fluctuations. Encouraging FDI in the renewable energy sector and promoting trade agreements that favor the import of necessary technologies at more stable and predictable exchange rates can also help. By implementing these measures, MINT economies can enhance the resilience of their renewable energy sectors to exchange rate volatility, ensuring more consistent and sustainable growth in renewable energy consumption.

MINT countries can better manage exchange rate volatility by adopting flexible exchange rate regimes that adjust to market conditions, minimizing external shocks. Establishing currency stabilization funds may help buffer short-term fluctuations and improve investor confidence. Additionally, prioritizing bilateral and regional trade agreements can secure stable foreign exchange inflows. Strengthening macroeconomic policies to control inflation and fiscal deficits will also enhance trade balances. Together, these strategies create a stable economic environment, promoting increased investments in renewable energy.

4.3 Examination employing alternative metrics

To confirm the trustworthiness of our results, we conducted further analyses. Applying various estimate approaches, such as stepwise regression, the assertion that "The FMOLS estimator produces dependable and accurate estimations of the short-term parameters while addressing endogeneity apprehensions" is grounded in the seminal research conducted by Phillips and Hansen (1990), in which they established the limiting properties of FMOLS and illustrated its reliability and effectiveness under certain circumstances. The outcomes of these estimation techniques are presented in Table 8. Through the SR, Poole OLS, and FMOLS methodology, we consistently observed a favorable and statistically significant relationship between trade surplus, trade reserves, currency exchange rate, LFP, and population size with TOPEN. The reliability observed across different estimation techniques bolsters the credibility of our primary conclusions. It is particularly noteworthy to mention that, throughout all four estimation methods (Stepwise Regression, Pooled OLS, FEM, and FMOLS, the coefficient for the exchange rate remained uniformly zero. This indicates that the currency exchange rate lacks economic importance as a determinant of trade in MINT countries [62]. As a result, we contend that our primary results remain unchanged when applying alternative estimation techniques, as illustrated in Table 8. In Model 2, all estimation methods indicated that TB, TR, and LF have positive and significant impacts on REC in MINT economies, while POP and ER have significant negative impacts on REC. Consequently, we contend that our primary results in Models 1 and 2 remain unchanged with the application of alternative estimation techniques, as illustrated in Table 8.

4.4 Constraints and future directions

Similar to any academic endeavor, this study possesses inherent constraints that may pave the way for future investigations. The findings of this study are contingent on the accuracy and reliability of the secondary data utilized. The credibility of this study depends on the dataset's accessibility, magnitude, and temporal scope. Thus, securing the precision, dependability, and integrity of the data gathering and evaluation methods is crucial for the achievement of the study and

the applicability of its findings. The limited availability and partial nature of essential macroeconomic data prior to 1995 restrict the analysis of trade openness and its determinants within the MINT nations. Therefore, the dataset time-frame is set from 1995 to 2022. This cross-national investigation utilizes a diverse modeling approach to analyze data concerning trade openness and its predicted influences within the MINT economies. This strategy paves the way for groundbreaking findings and fosters additional investigative pursuits. For instance, assessing the efficacy and dependability of the suggested diverse modeling technique across various global regions, like the Gulf countries and the SAARC areas, offers a compelling research direction. Hence, this investigation motivates academics to investigate further variables identified by trade theories that could impact trade openness in different global settings. The information for this research was derived from the World Trade Organization.

5 Conclusion

This research examines the relationship between trade openness (TOPEN) and five key macro indicators—trade balance, trade reserves, exchange rate, population, and labor force participation—over the short and long term. It investigates both unidirectional and bidirectional Granger causality between TOPEN and these indicators, emphasizing a cause-effect relationship. Stepwise regression is used to identify primary factors affecting trade openness, followed by robust validation through FMOLS, Pooled OLS, and FEM panel regression methods. Pedroni cointegration analysis confirms long-term relationships, while Granger causality tests validate directional causality among these variables. The analysis covers data from 1995 to 2020.

The findings confirm that macro trade factors significantly impact trade openness and renewable energy consumption in MINT economies, consistent with prior research. As trade openness increases, trade balance, trade reserves, exchange rate, population, and labor force exhibit a positive trend, with population as the most influential factor. Trade openness is minimally affected by exchange rate. For renewable energy consumption, trade balance, trade reserves, and labour force participation rate have a positive impact, while exchange rate and POP have negative effects. Notably, TR shows no directional relationship with REC, whereas trade balance, exchange rate, population, and labour force participation rate display unidirectional connections to renewable energy consumption in these economies [63, 64]. The findings of this study underscore the critical influence of macro trade factors on both trade openness and renewable energy consumption in MINT economies. Policy-makers should prioritize enhancing trade reserves, promoting favorable trade balances, and leveraging population dynamics to boost renewable energy initiatives [65–67]. Moreover, given the minimal impact of exchange rates on trade openness and renewable energy consumption, a focus on stable trade policies could facilitate long-term economic growth and energy sustainability in these regions. Clear strategies that align trade policies with renewable energy goals are essential for fostering a resilient and sustainable economic environment [68–72].

Author contributions Dr. Shhaida Suleman significantly contributed to the conceptualization of the research and was responsible for writing the Introduction and Methodology sections. Hassanuddin Mohd provided critical contributions to the Literature Review section, ensuring a comprehensive examination of relevant prior research. Dr. Farrukh Nawaz played a key role in data collection, data setup, variable definition, and model construction, laying the groundwork for robust analysis. Dr. Ahmet Faruk and Umar Kayani were instrumental in organizing the tables and conducting the analytical procedures, contributing to the Analysis section of the paper. Mis Mariam Sohail contributed to the development of policy implications and also provided substantial editing to enhance the clarity and coherence of the manuscript. Dr. Arslan was responsible for writing the Conclusion and Abstract, encapsulating the research findings and their significance. All authors participated in the review and proofreading of the manuscript to ensure its accuracy and quality before submission.

Data availability Data will be available upon request.

Declarations

Competing interests The authors declare no competing interests.

References

1. Adebayo TS, Akadiri SS, Radmehr M, Awosusi AA. Re-visiting the resource curse hypothesis in the MINT economies. Environ Sci Pollut Res. 2023;30(4):9793–807. https://doi.org/10.1007/s11356-022-22785-4.
2. Joshi M, Klein JR. Global business in the age of transformation. Oxford: Oxford University Press; 2021.
3. Strielkowski W, Civín L, Tarkhanova E, Tvaronavičienė M, Petrenko Y. Renewable energy in the sustainable development of electrical power sector: a review. Energies. 2021;14(24):8240. https://doi.org/10.3390/en14248240.
4. Nastasi B, Markovska N, Puksec T, Duić N, Foley A. Renewable and sustainable energy challenges to face for the achievement of sustainable development goals. Renew Sustain Energy Rev. 2022;157: 112071. https://doi.org/10.1016/j.rser.2022.112071.
5. Adebayo TS, Ullah S, Kartal MT, Ali K, Pata UK, Ağa M. Endorsing sustainable development in BRICS: The role of technological innovation, renewable energy consumption, and natural resources in limiting carbon emission. Sci Total Environ. 2023;859: 160181. https://doi.org/10.1016/j.scitotenv.2022.160181.
6. Awosusi AA, Rjoub H, Dördüncü H, Kirikkaleli D. Does the potency of economic globalization and political instability reshape renewable energy usage in the face of environmental degradation? Environ Sci Pollut Res. 2023;30(9):22686–701. https://doi.org/10.1007/s11356-022-23665-7.
7. Siddik AB, Khan S, Khan U, Yong L, Murshed M. The role of renewable energy finance in achieving low-carbon growth: contextual evidence from leading renewable energy-investing countries. Energy. 2023;270:126864. https://doi.org/10.1016/j.energy.2023.126864.
8. Barbini, G. The Commodity Market and Terms of Trade: Focus on Africa 2023.
9. Bildirici M, Kayıkçı F. Renewable energy and current account balance nexus. Environ Sci Pollution Res. 2022;29(32):48759–68. https://doi.org/10.1007/s11356-022-19286-9.
10. Li B, Haneklaus N. The role of clean energy, fossil fuel consumption, and trade openness for carbon neutrality in China. Energy Rep. 2022;8:1090–8. https://doi.org/10.1016/j.egyr.2022.02.092.
11. Dai J, Hiung EYT, Destek MA, Ahmed Z. Green policymaking in top emitters: assessing the consequences of external conflicts, trade globalization, and mineral resources on sustainable development. Int J Sustain Dev World Ecol. 2024. https://doi.org/10.1080/13504509.2024.2319136.
12. Zheng S, Ahmed D, Xie Y, Majeed MT, Hafeez M. Green growth and carbon neutrality targets in China: do financial integration and ICT matter? J Cleaner Prod. 2023. https://doi.org/10.1016/j.jclepro.2023.136923.
13. Liu F, Su CW, Qin M, Umar M. Is renewable energy a path toward sustainable development? Sustain Dev. 2023;31(5):3869–80. https://doi.org/10.1002/sd.2631.
14. Castrejon-Campos O. Evolution of clean energy technologies in Mexico: a multi-perspective analysis. Energy Sustain Dev. 2022;67:29–53. https://doi.org/10.1016/j.esd.2022.01.003.
15. Chanchangi YN, Adu F, Ghosh A, Sundaram S, Mallick TK. Nigeria's energy review: focusing on solar energy potential and penetration. Environ Dev Sustain. 2023;25(7):5755–96. https://doi.org/10.1007/s10668-022-02308-4.
16. Dindar S. A comprehensive analysis of strategies, challenges, and policies on Turkish sustainable energy development. J Eng Technol Appl Sci. 2023;7(3):231–50. https://doi.org/10.30931/jetas.1132618.
17. Qamruzzaman M, Karim S. Clarifying the relationship between green investment, technological innovation financial openness, and renewable energy consumption in MINT. Heliyon. 2023. https://doi.org/10.1016/j.heliyon.2023.e21083.
18. Mai MTT. The dissemination of non-tariff measures in ASEAN and some implications. VNU Univ Econ Bus. 2023. https://doi.org/10.5711/vnujeb.v3i4.213.
19. Kylili A, Thabit Q, Nassour A, Fokaides PA. Adoption of a holistic framework for innovative sustainable renewable energy development A case study. Energy Sources Part A: Recover Util Environ Effects. 2021. https://doi.org/10.1080/15567036.2021.1904058.
20. Usman FO, Ani EC, Ebirim W, Montero DJP, Olu-lawal KA, Ninduwezuor-Ehiobu N. Integrating renewable energy solutions in the manufacturing industry: challenges and opportunities a review. Eng Sci Technol J. 2024;5(3):674–703. https://doi.org/10.5159/estj.v5i3.865.
21. Yang C, Song X. Assessing the determinants of renewable energy and energy efficiency on technological innovation: role of human capital development and investment. Environ Sci Pollut Res. 2023. https://doi.org/10.1007/s11356-022-24907-4.
22. Khan I, Gunwant DF. An impact analysis of macroeconomic factors on South Asia's renewable energy output. Int J Energy Sect Manag. 2024;18(3):539–58. https://doi.org/10.1108/IJESM-01-2023-0013.
23. Alam MM, Murad MW. The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries. Renew Energy. 2020;145:382–90. https://doi.org/10.1016/j.renene.2019.06.054.
24. Khan YA, Ahmad M. Investigating the impact of renewable energy, international trade, tourism, and foreign direct investment on carbon emissions in developing as well as developed countries. Environ Sci Pollut Res. 2021. https://doi.org/10.1007/s11356-021-12937-3.
25. Srdelić L, Dávila-Fernández MJ. International trade and economic growth in Croatia. Struct Chang Econ Dyn. 2024;68:240–58. https://doi.org/10.1016/j.strueco.2023.10.018.
26. Saqib N, Abbas S, Ozturk I, Murshed M, Tarczyńska-Łuniewska M, Alam MM, Tarczyński W. Leveraging environmental ICT for carbon neutrality: analyzing the impact of financial development, renewable energy, and human capital in top polluting economies. Gondwana Res. 2024;2024(126):305–20. https://doi.org/10.1016/j.gr.2023.09.014.
27. Agbede EA, Bani Y, Azman-Saini WW, Naseem NM. The impact of energy consumption on environmental quality: empirical evidence from the MINT countries. Environ Sci Pollut Res. 2021;28(38):54117–36. https://doi.org/10.1007/s11356-021-14407-2.
28. Rahman A, Murad SW, Mohsin AKM, Wang X. Does renewable energy proactively contribute to mitigating carbon emissions in major fossil fuels consuming countries? J Clean Prod. 2024;452: 142113. https://doi.org/10.1016/j.jclepro.2024.142113.

29. Hieu VM, Mai NH. Impact of renewable energy on economic growth? Novel evidence from developing countries through MMQR estimations. Environ Sci Pollut Res. 2023;30(1):578–93. https://doi.org/10.1007/s11356-022-21956-7.
30. Elom CO, Onyeneke RU, Ankrah DA, Deffor EW, Ayerakwa HM, Uwaleke CC. Achieving carbon neutrality in Africa is possible: the impact of education, employment, and renewable energy consumption on carbon emissions. Carbon Research. 2024;3(1):24. https://doi.org/10.1007/s44246-024-00102-7.
31. Zhong Z, Hu W, Zhao X. Rethinking electric vehicle smart charging and greenhouse gas emissions: renewable energy growth, fuel switching, and efficiency improvement. Appl Energy. 2024;361: 122904. https://doi.org/10.1016/j.apenergy.2024.122904.
32. Deng X, Lv T, Meng X, Li C, Hou X, Xu J, Liu F. Assessing the carbon emission reduction effect of flexibility option for integrating variable renewable energy. Energy Econ. 2024. https://doi.org/10.1016/j.eneco.2024.107461.
33. Yang Z, Zhang M, Liu L, Zhou D. Can renewable energy investment reduce carbon dioxide emissions? Evidence from scale and structure. Energy Econo. 2022;112: 106181. https://doi.org/10.1016/j.eneco.2022.106181.
34. Haldar A, Sethi N. Environmental Effects of Information and Communication Technology the roles of renewable energy, innovation, trade, and financial development. Renew Sustain Energy Rev. 2022;153: 111754. https://doi.org/10.1016/j.rser.2021.111754.
35. Veeramani C. Unraveling the complexity of vertical specialization and fragmentation trade a survey of patterns, drivers, implications, and evolving dynamics. In: Contemporary issues in international trade. Bingley: Emerald Publishing Limited; 2024.
36. Van Neuss L. The drivers of structural change. J Econ Surv. 2019;33(1):309–49. https://doi.org/10.1108/978-1-83797-320-020241002.
37. Ma J, Yang L, Wang D, Li Y, Xie Z, Lv H, Woo D. Digitalization in response to carbon neutrality: Mechanisms, effects, and prospects. Renew Sustain Energy Rev. 2024;191: 114138. https://doi.org/10.1016/j.rser.2023.114138.
38. Lu L, Liu P, Yu J, Shi X. Digital inclusive finance and energy transition towards carbon neutrality: evidence from Chinese firms. Energy Econ. 2023;127: 107059. https://doi.org/10.1016/j.eneco.2023.107059.
39. Jiang Y, Usman A. How do energy technology innovation, financial inclusion, and does digital trade help to achieve carbon neutrality targets? Environ Sci Pollut Res. 2023;30(46):102853–61. https://doi.org/10.1007/s11356-023-29174-5.
40. Chishti MZ, Dogan E. Analysing the determinants of renewable energy: the moderating role of technology and macroeconomic uncertainty. Energy Environ. 2024;35(2):874–903. https://doi.org/10.1177/0958305X221137567.
41. Khan K, Su CW, Rehman AU, Ullah R. Is technological innovation a driver of renewable energy? Technol Soc. 2022;202270: 102044. https://doi.org/10.1016/j.techsoc.2022.102044.
42. Koengkan M, Kazemzadeh E, Fuinhas JA, Tash MNS. Heterogeneous impact of eco-innovation on premature deaths resulting from indoor and outdoor air pollution: empirical evidence from EU29 countries. Environ Sci Pollut Res. 2023;30(1):2298–314. https://doi.org/10.1007/s11356-022-22423-z.
43. Koengkan M, Fuinhas JA, Kazemzadeh E. Do financial incentives for renewable energy development increase the economic growth in Latin American and Caribbean countries? J Sustain Financ Invest. 2024;14(1):161–83.
44. Kazemzadeh E, Fuinhas JA, Salehnia N, Koengkan M, Silva N. Exploring necessary and sufficient conditions for carbon emission intensity: a comparative analysis. Environ Sci Pollut Res. 2023;43:97319–38. https://doi.org/10.1007/s11356-023-29260-8.
45. Arize AC, Malindretos J, Ghosh D. Purchasing power parity-symmetry and proportionality: evidence from 116 countries. Int Rev Econ Financ. 2015;37:69–85. https://doi.org/10.1016/j.iref.2014.11.014.
46. Greene, W.H, Econometric Analysis", Pearson Education India, 2003; New Delhi.
47. Pesaran, M. H. 2003. General diagnostic tests for cross-section dependence in panels. University of Cambridge Faculty of Economics, United Kingdom. Cambridge Working Papers in Economics. https://doi.org/10.1002/1348- 9585.12021
48. Granger CW. Some properties of time series data and their use in econometric model specification. J Econom. 1981;16(1):121–30.
49. Bahmani-Oskooee M, Ratha A. The J-curve: a literature review. Appl Econ. 2004;36(13):1377–98. https://doi.org/10.1080/0003684042000201794.
50. Feenstra RC, Hanson GH. The impact of outsourcing and high-technology capital on wages: estimates for the United States, 1979–1990. Q J Econ. 1999. https://doi.org/10.1162/003355399556179.
51. Acemoglu D, Angrist JD. Consequences of employment protection? The case of the Americans with disabilities Act. J Polit Econ. 2001;109(5):915–57. https://doi.org/10.1086/322836.
52. Deka A, Cavusoglu B, Dube S, Rukani S, Kadir MO. Examining the effect of renewable energy on the exchange rate in the emerging economies with dynamic ARDL bounds test approach. Renew Energy Focus. 2023;44:237–43.
53. Muniyoor K. Is there a trade-off between energy consumption and employment: evidence from India. J Clean Prod. 2020;255: 120262. https://doi.org/10.1016/j.jclepro.2020.120262.
54. Vo DH, Vo AT. Renewable energy and population growth for sustainable development in the Southeast Asian countries. Energy Sustain Soc. 2021. https://doi.org/10.1186/s13705-021-00304-6.
55. Mohammed Idris F, Seraj M, Özdeşer H. Renewable energy consumption, CO2 emissions and trade balance nexus in OECD countries: evidence from ARDL bounds approach. Int J Energy Sect Manage. 2023;17(4):645–60. https://doi.org/10.1108/IJESM-02-2022-0009.
56. Chor D, Manova K. Off the cliff and back? Credit conditions and international trade during the global financial crisis. J Int Econ. 2012;87(1):117–213. https://doi.org/10.1016/j.jinteco.2011.04.001.
57. Chinn MD, Ito H. Global current account imbalances: American fiscal policy versus East Asian savings. Rev Int Econ. 2008;16(3):479–98. https://doi.org/10.1111/j.1467-9396.2008.00741.x.
58. Auboin M, Ruta M. The relationship between exchange rates and international trade: a literature review. World Trade Rev. 2013;12(3):577–605. https://doi.org/10.1017/S1474745613000025.
59. Zhang S, Huang Y, Chen S, Liu H. How does human capital affect trade competitiveness? Empirical evidence from China". Sustainability. 2020. https://doi.org/10.1177/21582440231212040.
60. Bildirici ME, Castanho RA, Kayıkçı F, Genç SY. ICT, energy intensity, and CO2 emission nexus. Energies. 2022;15(13):4567. https://doi.org/10.3390/en15134567.
61. Ali Q, Khan MTI, Khan MNI. Dynamics between financial development, tourism, sanitation, renewable energy, trade and total reserves in 19 Asia cooperation dialogue members. J Clean Prod. 2018;179:114–31. https://doi.org/10.1016/j.jclepro.2018.01.066.

62. Rahman MR, Rahman MM, Akter R. Exploring the link between green energy, CO_2 emissions, exchange rate and economic growth: perspective from emerging South Asian countries. Int J Renew Energy Dev. 2023. https://doi.org/10.14710/ijred.2023.53168.
63. Apinran MO, Usman N, Akadiri SS, Onuzo CI. The role of electricity consumption, capital, labor force, carbon emissions on economic growth: implication for environmental sustainability targets in Nigeria. Environ Sci Pollut Res. 2022;29(11):15955–65. https://doi.org/10.1007/s11356-021-16584-6.
64. Kayani UN, Aysan AF, Gul A, Haider SA, Ahmad S. Unpacking the asymmetric impact of exchange rate volatility on trade flows: a study of selected developed and developing Asian economies. PLoS ONE. 2023;18(10): e0291261. https://doi.org/10.1371/journal.pone.0291261.
65. Kayani UN, Sadiq M, Aysan AF, Haider SA, Nasim I. The impact of investment, economic growth, renewable energy, urbanisation, and tourism on carbon emissions: Global evidence. Int J Energy Econ Policy. 2023;13(1):403–12. https://doi.org/10.32479/ijeep.14042.
66. Nasim I, Boukhris M, Kayani UN, Bashir F, Haider SA. Exploring the links between renewable energy, FDI, environmental degradation, and international trade in selected developing countries. Int J Energy Econ Policy. 2023;13(6):418–29. https://doi.org/10.3247/ijeep.14948.
67. Suleman S, Thaker HMT, Hoh CCW. Magnetic macro drivers of trade openness a study of BRICS economies. South Asian J Macroecon Public Finance. 2024. https://doi.org/10.1177/22779787241288940.
68. Choudhury T, Kayani UN, Gul A, Haider SA, Ahmad S. Carbon emissions, environmental distortions, and impact on growth. Energy Econ. 2023;126: 107040. https://doi.org/10.1016/j.eneco.2023.107040.
69. Suleman S, Nawaz F, Sohail M, Kayani U, Thaker HMT, Hoh CCW. An empirical analysis of trade market dynamics on CO2 Emissions a study of GCC economies. Int J Energy Econ Policy. 2024;14(6):114–26. https://doi.org/10.3247/ijeep.16704.
70. Suleman S, Thas Thaker HM, Hoh Cheong Wing, C. Is trade relevant to the macro drivers of carbon dioxide emissions? A study of high- and low-trade openness economies. Nat Res Forum. 2024. https://doi.org/10.1111/1477-8947.12543.
71. Suleman S, Thaker HMT, Ariff M, Cheong CWH. Relevance and drivers of trade openness a study of GIPSI countries. J Econ Adm Sci. 2023. https://doi.org/10.1108/JEAS-01-2023-0014.
72. Suleman S, Boukhris M, Kayani UN, Thaker HMT, Cheong CW, Hadili A, Tehseen S. Are trade openness drivers relevant to carbon dioxide emissions? A study of emerging economies. Int J Energy Econ Policy. 2024;14(2):183–96. https://doi.org/10.3247/ijeep.15665.