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Unveiling the Transformative Nexus of Energy Efficiency, Renewable Energy, and Economic Growth on CO_2 Emission in MINT Countries

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ABSTRACT

This study explores the nexus between energy efficiency, renewable energy, and economic growth and its impact on CO2 emissions in the MINT countries of Mexico, Indonesia, Nigeria, and Turkey from 1990 to 2023. Despite the significance of energy efficiency in environmental policy formulation, the heavy reliance on fossil energy in these countries has led to significant environmental challenges due to concerns about climate change. Previous studies have predominantly used the symmetric model, arguing for a linear nexus and neglecting possible asymmetric contributions between renewable and nuclear energy on economic growth and urbanization as CO2 emission stimulators. This study adopted the asymmetric panel non-linear autoregressive distributed lag (PNARDL) model to argue for an asymmetric nexus. The key findings revealed an asymmetric nexus indicating that green energy sources reduce CO2 emissions and improve ecological quality through energy efficiency and renewable energy. The nexus between economic growth and CO2 emissions supports the Environmental Kuznets Curve (EKC) hypothesis, indicating that ecological quality deteriorates during the early phase of economic growth and improves as the economy evolves to prioritize environmental quality. The negative nexus between nuclear energy and CO2 emissions highlights a deficiency in nuclear energy generation to effectively mitigate CO2 emissions. Based on these findings, the study recommends prioritizing renewable energy policies, streamlining the regulatory approval process for nuclear energy projects, and providing incentives for investment in nuclear power infrastructure to achieve the 2030 Sustainable Development Goals (SDGs) for environmental quality and sustainability.

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1. INTRODUCTION

The increasing challenge of meeting energy demand and supply for socio-economic development while preserving environmental quality in the 21st century has become progressively urgent due to climate change concerns. The geometric increase in energy consumption triggered by industrialization and the widening energy demand-supply gap has led to significant environmental dilapidation, mainly through fossil fuel usage, which contains approximately 75% to 85% of carbon dioxide (CO_2). According to the International Energy Agency (IEA) report of 2022, Mexico generated approximately 476 million metric tons of CO_2 emissions, Indonesia approximately 633 million metric tons, Nigeria approximately 94 million metric tons, and Turkey approximately 384 million metric tons. Developing economies, particularly high-income oil-producing ones, contribute about 60% to 67% of CO_2 emissions due to population growth rates and high energy demands for rapid economic industrialization (See Figure 1: sectoral CO_2 emissions). The energy sector, through fossil fuels, provides 80% of global energy needs, contributing 66.667% to total greenhouse gas (GHG) CO_2 emissions globally (Umar et al., 2021). Regardless of this significant contribution of fossil fuels in bridging the energy demand-supply gap, the ripple effect of CO_2 emissions has led to ocean acidification, global warming, and air and water pollution, causing respiratory diseases, cardiovascular problems, and adversely impacting marine life, ecosystems, and biodiversity, thereby impacting agriculture and food security (see Figure 2).

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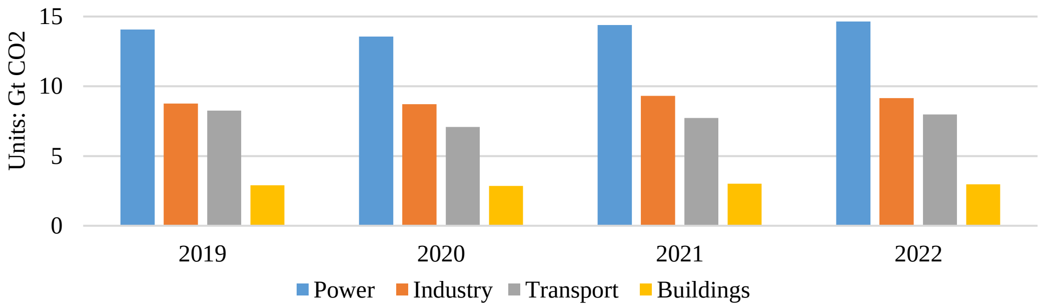

Figure 1. Sectoral CO_2 Emissions (Source: International Energy Agency (IEA) (2022))

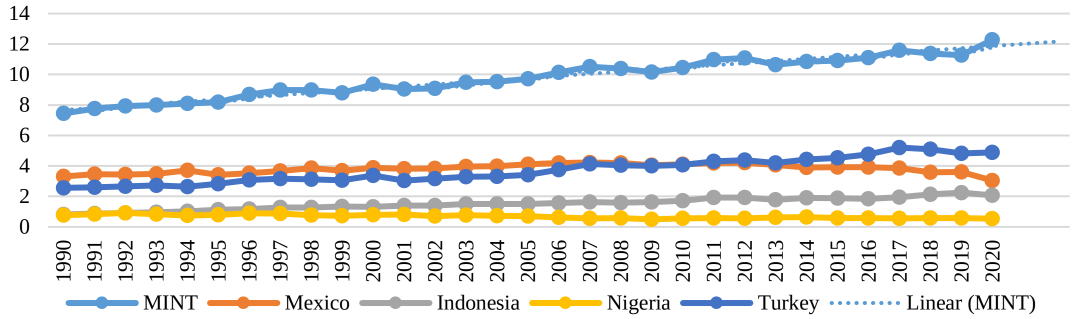

Figure 2. Carbon Emissions Stemming from Fossil Fuels in MINT Countries (Sources: World Bank Index (2022))

Given the adverse ecological concerns and health effects of CO_2 emissions, the transition to green energy sources such as solar, wind, hydroelectric, and geothermal is crucial for mitigating ecological concerns for sustainable development in MINT countries.

Efficient Energy (EEF) measures the effectiveness of energy generation and distribution. In this context, green energy sources such as Renewable Energy (REN) and Nuclear Energy (NUE) are utilized to achieve desired outcomes such as improving urbanization (URB), economic growth (EG), environmental quality, and reducing energy-related CO_2 emissions, particularly in MINT countries endowed with immense green energy sources. Mexico and Turkey possess significant solar and wind energy potential. In 2022, Mexico's solar capacity exceeded 3.5 GW, with a wind capacity of over 6 GW. Turkey accounted for about 7 GW of solar and over 10 GW of wind capacity in 2020. Indonesia ranks third in geothermal energy, with over 2.1 GW capacity. Nigeria's solar capacity was approximately 0.3 GW in 2020. These resources offer MINT countries opportunities to reduce fossil fuel dependence, mitigate environmental impacts, and combat climate change (See Figure 3). As such, Mexico and Turkey generally show increasing trends in renewable energy consumption over the years, from 1990 to 2022, indicating a growing emphasis on green energy sources. Indonesia and Nigeria exhibit fluctuations in renewable energy consumption, attributed to policy instability, economic volatility, budget constraints, infrastructural challenges, technological barriers, political instability, governance challenges, reliance on traditional energy sources, and investment climate through fluctuations in foreign direct investment, among others.

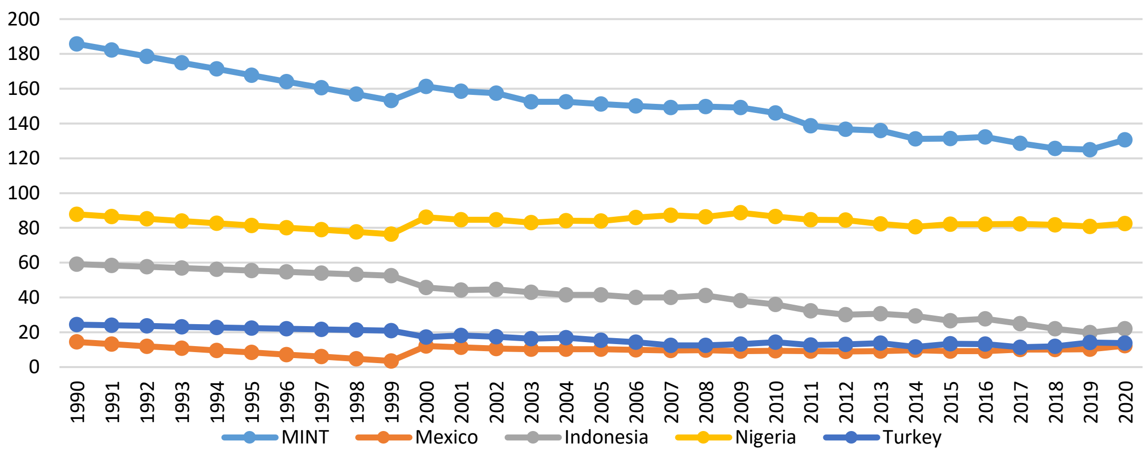

Figure 3. Renewable Energy Consumption in MINT Countries (Sources: World Bank Index (2022))

Economist Jim O'Neill (2013) acknowledges MINT countries as the budding and evolving economic bloc of the world economy, taking over BRIC countries of Brazil, Russia, India, and China due to their rapid economic growth triggered by their growing young population, remittance inflow, among other factors. Odugbesan et al. (2021) revealed that Nigeria and Mexico in MINT nations fell within the top ten remittance-receiving economies in 2020. World Bank 2023 statistics report showed that MINT nations roughly account for an estimated 720 million populations: Nigeria (223.8 million), Mexico (126.60 million), Indonesia (284.3 million), and Turkey (85.3 million). The proximity of individual countries to developed ones can lead to economic stability and development in MINT countries. Mexico is influenced economically and socially by development in America, China influences the Indonesian economy, the European Union influences Turkey's economy, and Nigeria is considered Africa's economic hub. The positive and significant impact of this proximity to developed countries on individual MINT countries is evident in the World Bank economic ranking of 2018, ranking Mexico 15th, Indonesia 16th, Turkey 18th, and Nigeria 31st. In June 2021, based on the GDP ranking, Mexico ranked 15th, Indonesia ranked 16th, Turkey ranked 19th, and Nigeria ranked 27th (World Bank, 2021). In light of these distinctive economic traits, this study envisages that by the end of 2023, MINT countries will rank among the top 20 economies in the world for the next three decades, with Mexico ranked 15th, Indonesia 16th, Turkey 17th, and Nigeria 20th. Odugbesan and Rjoub's (2020) findings support this prediction and further collaborate with the 2014 Goldman Sachs stable growth progression forecast for MINT countries until 2020. Similarly, Dogan et al. (2019) forecasted a 5% annual growth in MINT. Despite these distinctive economic traits and forecasts for industrialization, human capital development, political stability, population, and urbanization growth rates, trade, and export diversification, among other country-specific heterogeneous factors grouped under economic, income per capita, energy, finance, and socio-political significantly impede and truncate MINT countries' realization of the United Nations 2030 Sustainable Development Goals (SDGs) of environmental quality, clean energy consumption, and climate action, as indicated in Goals 7, 13, 12, and 17 and Millennium Development Goals (MDGs) (Akram et al., 2020; Dogan et al., 2019; Ahmad et al., 2020a; Abner et al., 2021).

The EKC hypothesis propounded by Grossman and Krueger (1995) supports the country-specific heterogeneous factor under income per capita, revealing an inverted U-shaped nexus. The EKC hypothesis argues that a unit rise in the income per capita of a nation surges CO_2 emissions at the early growth stage to a slanting point, from which CO_2 emissions diminish to improve environmental quality (Jakada et al., 2022). Similarly, the inverse U-shaped model suggests that a unit increase in economic prosperity causes environmental quality decline through increased greenhouse gas (GHG) and CO_2 emissions (Jakada et al., 2022).

In the bid to reduce CO_2 emissions caused by fossil energy consumption, MINT countries must tailor their economic agenda towards eco-friendly social and financial activities to mitigate the effects of global warming and promote sustainable urbanization (Akram et al., 2020; Dogan et al., 2019). Empirically, the European Commission report reveals that energy efficiency has the potential to boost natural resource sustainability, enhance the realization of the SDGs and MDGs, reduce GHG, CO_2 emissions, and overdependence on fossil fuels to improve energy security (European Commission, 2016; Shahbaz et al., 2019).

Interestingly, the factors influencing environmental changes have been actively researched. Cheng et al. (2019) and Danish Baloch et al. (2019), among others, reveal that efficient climate change management and ecological quality improvement are anchored to energy efficiency. Energy efficiency denotes the capacity to increase or retain production using the same amount of Joule (J) energy. Investment in energy efficiency through green energy sources has substantial ecological and economic sustainability growth benefits (Huang et al., 2021; Dong et al., 2018). By developing abundant green energy sources such as solar, wind, geothermal, hydroelectric power, and biomass energy embedded in MINT countries, implementing an all-inclusive environmental regulation aims to close the energy gap and stimulate eco-friendly industrialization.

Empirical studies examining the three constructs of EEF, REN, and EG on CO_2 emissions in MINT countries are scarce. Existing ecological literature has largely regarded economic growth, agricultural activities, financial development, and foreign direct investment as prime stimulants of CO_2 emissions (Nwabueze et al., 2023; Udo et al., 2021; Abner et al., 2021). Studies in ecological literature omit the contributive impact of EEF and NEU on EG and environmental quality in MINT countries. The effect of their contributive influence on environmental quality is yet to be thoroughly investigated.

This study is one of the very few empirical studies in MINT countries investigating these constructs to bridge the knowledge gap in the previous ecological literature, which primarily used the symmetric model and argued on a linear nexus while focusing on conventional factors such as economic growth, industrial activities, and trade patterns as drivers of CO_2 emissions and neglecting the significant role of EEF and REN in environmental quality. This study introduces a novel perspective to literature by assessing the contributive effect of EEF, REN, and EG on CO_2 emissions in the MINT countries as its primary objective. It also sheds light on pathways toward environmental sustainability and eco-friendly economic development. This study tested the extent to which EEF and increased use of REN sources influence CO_2 emissions reduction and the extent to which economic growth initially exacerbates CO_2 emissions and improves environmental quality following an Environmental Kuznets Curve (EKC) pattern. Extant ecological literature based its findings on various linear modeling techniques, such as the classical linear regression, while other models adopted include the fully modified ordinary least square, Dong et al. (2018); Autoregressive Distributive Lag (ARDL); Udo et al. (2020); Abner et al. (2021),

Extant studies have criticized the predominant use of the linear estimation technique for neglecting operational fluctuations and short-run differences in their studies. Mack, Gunst and Mason (1981, pp. 167–206) upheld that drawing inferences based on a single method is statistically untenable. Time series are typically leptokurtic (heavy-tailedness) and skewed (asymmetry) (Brooks, 2014), and the spikes accompanying the oscillatory movements render the predominantly used linear model incapable of a conclusive estimation. Nam et al. (2002) recommends adopting an alternative model to provide an all-encompassing inference.

This study uniquely contributed by adopting the dynamic asymmetric PNARDL model to capture the nonlinearities, threshold effects, and heterogeneity dynamics of EEF, REN, and CO_2 emissions in MINT countries. The model is a novel methodology introduced in this study, and it offers a robust framework and accounts for operational fluctuations and short-run differences to address country-specific effects variations in CO_2 emissions trends and provide insights into the drivers of environmental sustainability across different contexts.

The motivation for this study arises from the urgent need to address climate change and ecological degradation concerns, particularly in rapidly evolving economic blocs like MINT countries, and to explore the perspective of EEF and REN in promoting sustainable development pathways. This study offers actionable developmental pathways for sustainable growth. This study is significant for MINT countries with substantial renewable energy potential. By examining the specific context of this bloc, this study offers tailored insights to support the transition towards ecological development and contribute to a more holistic understanding of environmental sustainability and eco-friendly economic development in MINT countries.

2. LITERATURE REVIEW

2.1 Economic Growth and CO_2 Emissions Nexus

The first school of thought discusses the CO_2 emissions-economic growth nexus, employing the EKC hypothesis of an inverted U-shaped relationship (Grossman & Krueger, 1995). The EKC hypothesis posits that the nexus between CO_2 emissions and economic growth follows an inverted U-shaped curve. Accordingly, a unit increase in economic growth in the initial phase decreases environmental quality; as income per capita reaches a certain threshold point, the trend reverses, and ecological quality improves through investment in renewable energy consumption for enhanced energy efficiency, a structural shift from manufacturing-based to service-oriented economies, technological advancements, and increased environmental awareness and regulations.

A threshold point in the Environmental Kuznets Curve (EKC) hypothesis indicates that ecological degradation is not a permanent consequence of economic growth but can be mitigated as societies become wealthier and more technologically advanced. Soytas et al. (2007), Dinda (2004), Iwata et al. (2010), and others have revealed that the EKC hypothesis upholds three diverse inferences about the CO2 emissions-economic growth nexus. Technological innovation, environmental policies, cultural attitudes towards the environment, and economic structures influence the shape and existence of the EKC. The diverse inferences drawn by Soytas et al. (2007), Dinda (2004), Iwata et al. (2010), and Dietz and Rosa (1994) contribute to the nuanced understanding of the EKC hypothesis. They underscore the complexity of the nexus, arguing that while a general pattern may exist, its manifestation and wide variations depend on several factors.

Holtz-Eakin et al. (1995) reported an "N-shaped" influence on the long-run nexus between CO_2 emissions and per capita income, rather than an inverted U-shaped nexus. This implies that initially, an increase in per capita income leads to an increase in CO_2 emissions. However, beyond a certain threshold, CO_2 emissions decrease as income per capita further increases, due to a prioritization of environmental concerns. According to Stern (1993), potential variable bias is a significant hindrance associated with previous Environmental Kuznets Curve (EKC) studies, which is instigated by the omission of variables in statistical models.

2.2 Energy Consumption-Economic Growth Link

Kraft et al. (1978) advanced the second school of thought by arguing that the link between energy consumption and economic growth can be evaluated under four premises, as revealed by Ozturk (2010):

a) The growth hypothesis envisions energy consumption through guidelines that may throttle economic growth (Stem, 1993; Damette et al., 2013). Such restrictions on energy consumption, whether through policy measures, supply constraints, or high costs, can significantly impede economic growth. Energy, in whatever form, is the fundamental driver of economic growth.

b) The protection hypothesis reveals a non-energy consumption-economic growth effect; as such, energy conservation policies have no adverse impact on actual economic growth (Lee, et al. 2005).

c) The feedback hypothesis school of thought reveals complementary interaction (Tang et al. 2014).

d) The neutral hypothesis reveals a non-causal nexus; energy conservation policies' influence on economic growth is limited (Ozturk, 2010; Agras & Chapman, 1999; Doğan, 2018).

According to the school of thought on the 3Es' energy consumption (ENC), economic growth, and CO_2 emissions, incorporating these variables circumvents the potential variable bias problem associated with the first school of thought.

The results of the 3Es study indicate that income per capita in the U.S. causes an increase in energy consumption (ENC) but not in CO_2 emissions. In six Central American countries, from 1971 to 2004, Apergis et al. (2009) observed a positive long-term equilibrium nexus between energy consumption and CO2 emissions, while the Environmental Kuznets Curve (EKC) hypothesis supports an inverted U-shaped relationship with real GDP. In the BRIC countries from 1971 to 2005, Pao and Tsai (2011) observed a substantial and mild bidirectional causal relationship between energy consumption and CO_2 emissions in Brazil, India, and China, as well as between energy consumption and economic growth, except for Russia from 1990 to 2005.

In China, Brazil, India, and Indonesia, Alam et al. (2016) utilized the AutoRegressive Distributed Lag (ARDL) model from 1970 to 2012 and found that income and energy consumption lead to an increase in CO_2 emissions. Waheed et al. (2018), using the ARDL model from 1990 to 2004, observed that renewable energy significantly influenced CO_2 emissions in the long run. Dong, Sun, and Hochman (2017) found that a unit increase in renewable energy and natural gas usage increases environmental quality by 0.26% and 0.16%, respectively, in the BRICK countries.

2.3 Renewable Energy and CO2 Emissions

The nexus between REN (Renewable Energy) and CO_2 emissions established in the literature argues that REN consumption is crucial in reducing CO_2 emissions. Using the Generalized Method of Moments, Khan et al. (2021) observed that REN improves ecological quality. The findings of Mohsin et al. (2021) in 25 Asian countries collaborate with these findings on CO_2 emissions positively impacting economic growth using the FMOLS model.

In Brazil, amid COVID-19, Magazzino et al. (2021) observed a positive correlation between economic growth and REN consumption. The findings of Magazzino and Mele (2022), using the LSTM model, corroborate the claims of Magazzino et al. (2021) on REN. In Pakistan, the results of both symmetric and asymmetric models indicate that economic growth and FDI upsurge CO_2 emissions symmetrically. In the short run, oil prices upsurge CO_2 emissions and reduce them in the long run.

The asymmetric results show that, in the long run, an increase in oil prices diminishes CO_2 emissions through energy efficiency and implementation of carbon pricing. Similarly, a unit decrease in oil price increases energy consumption, stimulates economic growth and CO_2 emissions, and delays the transition to renewable energy (Malik et al., 2020). In contrast, empirical findings revealed mixed results, indicating that renewable energy sources, such as hydropower in Brazil, may not reduce CO_2 emissions (Hdom and Fuinhas, 2020).

2.4 Evidence from MINT Countries

Studies on MINT countries are scarce, highlighting a significant gap in the literature. Preliminary studies indicate diverse results due to variations in methodology, datasets, measurement variables, and scope. The relationship between Renewable Energy (REN) and CO2 emissions is underexplored in Nigeria, with limited evidence suggesting that increased REN usage could mitigate CO_2 emissions. In Mexico, renewable energy and forest conservation are pivotal components of the environmental policy agenda, offering potential benefits in mitigating climate change and preserving biodiversity (Waheed et al., 2018). The country's geographical location provides ample opportunities for harnessing solar energy for renewable energy development, while its extensive coastline offers favorable conditions for wind power generation. The findings of Waheed et al. (2018) revealed a positive link between REN and CO_2 emission reduction. In forest conservation efforts, the country's rich biodiversity and diverse ecosystems are crucial for preserving habitat integrity, safeguarding endangered species, and mitigating climate change through carbon sequestration. While the existing literature suggests the potential benefits of renewable energy and forest conservation, there is a notable dearth of Mexico-specific studies comprehensively assessing their efficacy and possible synergies.

In Indonesia and Turkey, Akram et al. (2021) observed a significant and positive link between economic growth and CO_2 emissions in Indonesia. Pradhan et al. (2020) revealed that energy consumption, mainly from fossil fuels, has led to increased CO_2 emissions. These findings underscore the necessity of stringent environmental regulations and sustainable development policies. Transitioning from fossil fuels to renewable energy (REN) sources is pivotal in reducing Indonesia's carbon footprint and fostering long-term ecological sustainability. Koc et al. (2020) and Yilmaz et al. (2021) recommended balancing economic expansion with environmental conservation efforts in Turkey. The findings of Ozcan et al. (2021), Karabulut et al. (2022), emphasize the importance of diversifying the energy mix to alleviate environmental degradation.

From the review of the extent of ecological literature, previous studies specifically on MINT countries and assessing the effects of EEF, REN, and EG on CO2 emissions are scarce. Methodological diversity, particularly the predominant use of the symmetric model, significantly influences the results of previous studies. Adopting the asymmetric model provides nuanced insights into EG, REN, EEF, and CO_2 emissions dynamics. This study uniquely offers interdisciplinary insights and the significance of international collaboration in addressing global environmental challenges, informs ecological policy formulation, and sheds light on the economic implications of energy transitions and environmental governance in emerging economies.

3. METHODOLOGY

This study assessed the asymmetric nexus between EEF, REN, and EG constructs on CO_2 emissions in MINT nations from 1990 to 2022. As previously argued, the nexus may not always follow a linear pattern in the context of REN, EEF, EG, and CO2 emissions. The asymmetric model captures threshold effects, where changes in REN, EEF, and EG on CO_2 emissions may differ depending on the direction or magnitude of the change. The model provides insights relevant to policy formulation and implementation while accounting for structural changes in MINT countries' economies. This is evidenced in the findings of Malik et al. (2020), Waheed et al. (2018), Dong et al. (2017), Karabulut et al. (2022), and Khan et al. (2021). Within the sample period of this study, several global events, such as the COVID-19 pandemic, caused shocks that spread to the MINT nations. The shock moments are not stationary but are felt on diverse fronts.

The annualized dataset was extracted and collated from the World Development Indicators (WDI) from 1990 to 2022 to comprehensively analyze and observe trend patterns and provide insights into the dynamics of the nexus within the MINT countries. This timeframe captures shifts in economic structures, consumption patterns, societal values, and milestones in technological advancements in REN technologies, EEF measures, and sustainable development practices, such as the signing of the Kyoto Protocol in 1997 and the Paris Agreement on energy and environmental policies in 2015. Over the decades, extant ecological literature has widely explored this nexus; these studies attached little or no importance to energy efficiency in managing climate change in MINT countries. This study expands the frontiers of Dong et al. (2017) by capturing energy efficiency measured by energy intensity as a contributing factor to CO_2 emissions. Economic growth is empirically considered a prime instigator of CO2 emissions. Table 1 presents the designated variables.

3.1 Model Specification

This study introduced an asymmetric model to question the symmetric assumption that saturates previous ecological literature. Linear specification of variables

$$CO2 = f\,(EG, EEF, REN, URB, NUE) \tag{1}$$

The variables in (Eq1) are transformed into natural logarithm forms and expressed as

$$LCO2_{it} = \beta_0 + \beta_1 LEG_{it} + \beta_2 LEEF_{it} + \beta_3 LREN_{it} + \beta_4 LNUE_{it} + \beta_4 LURB_{it} + \varepsilon_{it} \tag{2}$$

Where: t = time, I = cross-section unit, CO2 = carbon emission, EG = economic growth, EEF = energy efficiency, REN = renewable energy, NUE= nuclear energy, URB = urbanization, and ε = error term.

3.2 Cross-sectional Dependency Test

We conducted the Breusch-Pagan Lagrange (1980) multiplier and the Pesaran-scaled Lagrange (2007) tests to assess cross-sectional dependence due to nations' interconnection through globalization triggered by economic, social, and cultural networks. The second-generation unit root was conducted using cross-sectional augmented IPS (CIPS) and cross-sectional Augmented Dickey-Fuller (ADF) (CADF) to ascertain the stationarity of the series. The equation:

$$\Delta S_{i,t} = \varphi_i + \varphi_i S_{i,t-1} + \varphi_i S_{t-1} + \sum_{I=0}^{p} \varphi_{il} S_{t-1} + \sum_{I=0}^{p} \varphi_{il} S_{t-1} + \mu_{it} \quad (3)$$

Where:
$\Delta S_{i,t}$ = cross-sectional averages.
CIPS test:

$$CIPS = \frac{1}{N}\sum_{i=1}^{n} CDF_i \quad (4)$$

Where: CDF = cross-sectionally Augmented Dickey–Fuller.

3.3 Panel Non-linear Autoregressive Distributed Lag (PNARDL)

We adopted the PNARDL model that Shin et al. (2014) developed to assess the long- and short-term effects of EEF, REN, and EG on CO2 emissions. Empirical studies using a linear model revealed that y_t and χ_t resulted in a long-short-run symmetric change, where y_t and χ_t become non-linear and χ_t initiates an asymmetric impact on y_t. PNARDL revealed asymmetries in the panel due to heterogeneous traits triggered by country-specific effects.

The linear ARDL model expansion is initiated by disaggregating χ_t into positive and negative partial sums, as

$$\chi_t = \chi_0 + \chi_t^+ + \chi_t^- \quad (5)$$

where χ_t^+ and χ_t^- are the partial sum processes of positive and negative changes in χ_1

$$\chi_t^+ = \sum_{j=1}^{t} \Delta R_j^+ = \sum_{j=1}^{t} max\ (\Delta R_j, o) \quad (6)$$

and

$$\chi_t^- = \sum_{j=1}^{t} \Delta R_j^- = \sum_{j=1}^{t} min\ (\Delta R_j, o) \quad (7)$$

The PNARDL Equation:

$$\Delta Y_{it} = \alpha_0 + \alpha_1 Y_{it}\text{-}1 + \alpha_2^+ EG^+_{it-1} + \alpha_2^- EG^-_{it-1} + \alpha_3^+ EEF^+_{it-1} + \alpha_3^- EEF^-_{it-1} + \alpha_4^+ REN^+_{it-1} + \alpha_4^- REN^-_{it-1} + \alpha_5^+ URB^+_{it-1} + \alpha_5^- URB^-_{it-1} + \alpha_6^+ NUE^+_{it-1} + \alpha_6^- NUE^-_{it-1} + \sum_{K=1}^{P} \beta_k \Delta Y_{it-k} + \sum_{K=0}^{q1} (Y_k^+ \Delta EG^+_{it-k} + Y_k^- \Delta EG^-_{it-k}) + \sum_{K=0}^{q2} (\varphi_k^+ \Delta EEFP^+_{it-k} + \varphi_k^- \Delta EFF^-_{it-k}) + \sum_{K=0}^{q3} (\delta_k^+ \Delta REN^+_{it-k} + \delta_k^- \Delta REN^-_{it-k}) + \sum_{K=0}^{q4} (\psi_k^+ \Delta URB^+_{it-k} + \psi_k^- \Delta URB^-_{it-k}) + \sum_{K=0}^{q5} (\tau_k^+ \Delta NUE^+_{it-k} + \tau_k^- \Delta NUE^-_{it-k}) + \mu_i + \varepsilon_{it} \quad (8)$$

where p and q are the respective lags; μ_i is the country-wise effect; ε_{it} = error term; the coefficients α_{1-} $\alpha_6^{+ \text{ and } -}$ and φ_k^+, φ_k^-, δ_k^+, δ_k^-, ψ_k^+, ψ_k^-, τ_k^+, τ_k^-, =, and short-run asymmetries, respectively. Equation (6) can be re-expressed in the form of an error correction model (ECM):

$$\Delta Y_{it} = \alpha_0 + \rho\varepsilon_{it\text{-}1} + \sum_{K=1}^{p} \beta_k \Delta Y_{it-k} + \sum_{K=0}^{q1} X (\Upsilon_k^+ \Delta EG^+_{it-1} + \Upsilon_k^- \Delta EG^-_{it-1}) + \sum_{K=0}^{q2} (\varphi_k^+ \Delta EEF^+_{it-1} + \varphi_k^- \Delta EEF^-_{it-1}) + \sum_{K=0}^{q3} (\delta_k^+ \Delta REN^+_{it-1} + \delta_k^- \Delta REN^-_{it-1}) + \sum_{K=0}^{q4} (\psi_k^+ \Delta URB^+_{it-1} + \psi_k^- \Delta URB^-_{it-1}) + \sum_{K=0}^{q5} (\tau_k^+ \Delta NUE^+_{it-1} + \tau_k^- \Delta NUE^-_{it-1}) + \mu_i + \varepsilon_{it} \quad (9)$$

where ε_{it} = non-linear ECM term, and ρ = convergence speed to long-run equilibrium from equilibrium deviation.

Table 1. Variable Description and Unit.

Variables	Unit	Justification	Source
Carbon Emission (CO_2)	Mt	CO_2 is central to climate change and environmental dilapidation. Mitigating these emissions is pivotal for global climate targets and sustainable development.	World Bank Development Indicator (WDI, 2022)
Economic Growth (EG)	Constant US$ 2015	Economic growth drives heightened energy consumption and industrial output, resulting in elevated emissions at the preliminary stage of economic growth.	
Energy Efficiency (EEF)	Terawatt hour (TWh)	Energy efficiency denotes the effective unitization of performing specific tasks and achieving desired outcomes. It is calculated as EEF= (useful energy output/total energy input x100)	International Energy Agency (IEA)
Renewable Energy (REN)	%	Renewable energy aids carbon reduction targets, mitigates climate change, and diversifies energy sources and resilience.	World Development Indicators (WDI, 2022)
Urbanization (URB)	%	Urbanization management and sustainable planning lower per capita emissions and improve environmental and life quality.	
Nuclear energy (NUE)		Nuclear energy represents a low-carbon alternative to fossil fuels and reduces carbon emissions (Bunn et al., 2017).	
The integration of these variables into the study model, the complex interactions and trade-offs between EG, EEF, REN, NUE and URB are analyzed to inform evidence-based policies and strategies for achieving a low-carbon and resilient future.			

Source: Author, (2023)

This study adopted E.views version 13 econometric software for the empirical analysis. The following section presents the empirical results of this study.

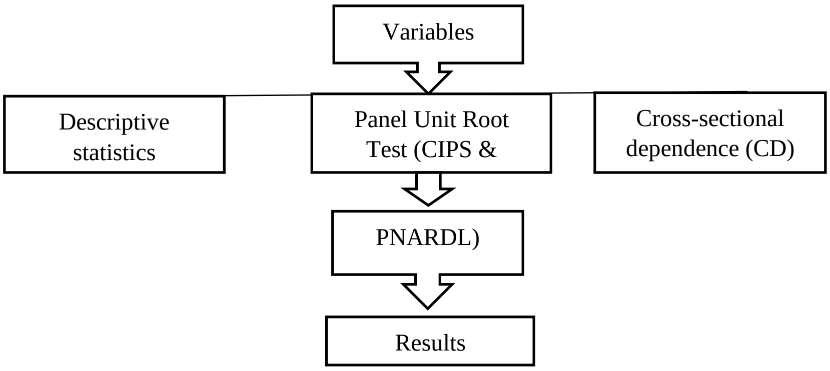

Figure 4. Conceptual Framework

4. RESULTS AND DISCUSSION

Table 2 presents panel- and country-specific descriptive statistics results. The mean and median values of the observations were closely aligned, suggesting no extreme projections. In all cases, the mean values indicated a positive mean return, suggesting a propensity for CO_2 emissions increase. In the panel, the mean results show that MINT countries emit approximately 2.41 million metric tons of CO_2 emissions on average from various sources, including fossil fuel combustion, industrial processes, and land-use changes. EEF is approximately 4.44 terawatt-hours (TWh), signifying significant energy demand within the MINT countries, which may primarily be met through fossil fuels. EG, approximately $4582.88 per capita, mirrors the level of economic development and industrialization within the MINT countries. NUE, approximately 2.19%, indicates inefficiency in nuclear energy production, distribution, and consumption, leading to wastage and increased environmental footprint. The mean value of approximately 38.26% for renewable energy penetration in MINT countries signifies a transition to a greener and more sustainable energy mix. The mean value of approximately 57.83% for URB poses significant challenges to environmental quality due to increased energy demand, waste generation, and pollution. These findings underscore the need to address environmental concerns and promote eco-friendly activities in MINT countries. In country-specific analysis, Turkey and Mexico show high mean CO_2 emissions values, indicating industrialization and high energy consumption, contributing to environmental degradation and global warming. Mexico leads in energy efficiency (EEF), followed by Turkey, Indonesia, and Nigeria, indicating efficient energy utilization to minimize emissions per unit of economic output. Higher EG in Turkey and Mexico correlates with increased industrial activity, while Nigeria emphasizes renewable energy sources due to their high mean value. The high urbanization mean value in Mexico, Nigeria, Turkey, and Indonesia underscores the need for sustainable urban planning to mitigate emissions and pollution. The low standard deviation values compared with the mean values indicate that the variables are not highly volatile around the mean. The kurtosis of the series is platykurtic (<3).

Table 2. A Descriptive Summary of the Variables

Panel	**CO_2 (Mt)**	**EEF (TWh)**	**EG ($)**	**NUE (%)**	**REN (%)**	**URB (%)**
Mean	2.414373	4.443953	4582.884	2.194157	38.26185	57.82992
Median	2.430808	3.720000	3399.603	2.179286	23.98000	58.56850
Maximum	5.066379	10.01000	12507.59	6.654301	88.68000	81.30000
Minimum	0.491388	2.490000	270.0275	0.274464	8.970000	29.68000
Std. Dev.	1.428488	1.838587	3644.866	1.822680	29.86250	16.35514
Skewness	0.065671	1.200684	0.603842	0.492656	0.680358	-0.176607
Kurtosis	1.450192	3.570844	1.944413	1.900953	1.813935	1.611349
Turkey	**CO_2**	**EEF**	**EG**	**NUE**	**REN**	**URB**
Mean	3.630098	2.866818	7020.584	4.705316	16.84194	68.36385
Median	3.397843	2.920000	7686.445	4.695301	15.34000	68.45000
Maximum	5.066379	3.270000	12507.59	6.654301	24.37000	77.02200
Minimum	2.562358	2.490000	2241.290	3.686443	11.40000	59.20300
Std. Dev.	0.762448	0.238655	3552.940	0.752722	4.417619	5.476959
Skewness	0.258965	0.051113	0.014877	0.671840	0.493154	-0.030732
Kurtosis	1.828935	1.713972	1.366007	3.215137	1.750453	1.729012
Indonesia	**CO_2**	**EEF**	**EG**	**NUE**	**REN**	**URB**
Mean	1.503207	4.164762	2063.770	0.677244	40.26290	45.84230
Median	1.503529	4.260000	1411.098	0.664507	41.46000	46.73800
Maximum	2.299258	5.420000	4332.709	0.947815	59.18000	57.93400
Minimum	0.815391	3.120000	459.1919	0.408720	19.77000	30.58400
Std. Dev.	0.388363	0.832488	1366.144	0.132313	11.39554	8.201688
Skewness	0.021504	0.115180	0.369080	0.098053	-0.120769	-0.298911
Kurtosis	2.252458	1.529652	1.425662	2.468091	2.035559	1.923122

Mexico	CO_2	EEF	EG	NUE	REN	URB
Mean	3.834793	3.575909	7812.123	2.895868	10.99581	76.55809
Median	3.863596	3.680000	8213.381	2.866289	10.27000	76.61600
Maximum	4.220763	4.010000	11076.09	3.517211	14.41000	81.30000
Minimum	3.298753	3.040000	3196.919	2.095645	8.970000	71.41900
Std. Dev.	0.270406	0.317005	2322.557	0.367749	1.662973	2.930232
Skewness	-0.268156	-0.452619	-0.467796	-0.275293	0.437443	-0.059864
Kurtosis	2.003003	1.820419	1.992318	2.497797	1.745744	1.834453
Nigeria	**CO_2**	**EEF**	**EG**	**NUE**	**REN**	**URB**
Mean	0.689395	7.284762	1435.057	0.369686	84.94677	40.55542
Median	0.707257	6.840000	1451.280	0.350200	84.67000	39.94300
Maximum	0.916428	10.01000	3200.953	0.462855	88.68000	53.52100
Minimum	0.491388	6.040000	270.0275	0.274464	80.64000	29.68000
Std. Dev.	0.122509	1.178077	929.6829	0.055246	2.349114	7.558128
Skewness	0.217515	1.112608	0.229683	0.173346	-0.218425	0.188245
Kurtosis	1.786132	3.169703	1.591907	1.927411	1.917926	1.701737

Source: Author, (2023)

4.1 Unit Root Test

The unit root test was conducted to determine whether the time series follows a stochastic trend or possesses a unit root, indicating non-stationarity. The second generational unit model was adopted for its ability to handle cross-sectional dependence, improved efficiency in heterogeneous panels, increased power and precision, and enhanced modeling of common shocks and interactions. These benefits make second-generation panel unit root tests suitable for this study and contribute to more accurate and reliable statistical analysis of panel data.

Table 3. Second generational Panel Unit Root Test for MINT countries.

Panel A: Second generational Panel Unit Root					Panel B: Cross-Sectional Dependence	
	CIPS		CADF			
Variables	Level I(0)	1st Difference I(1)	Level I(0)	1st Difference I(1)	Breusch–Pagan LM	Pesaran-scaled LM
CO2	-4.345*	-7.879**	-2.901**	-3.341*	101.314* (0.0000)	27.514* (0.000)
EEF	-1.876	-5.812**	-3.901**	-4.998**	78.074* (0.000)	20.8060* (0.000)
EG	-3.993*	-5481*	-2.100	-4.101*	154.189* (0.0000)	42.778* (0.0000)
NUE	-4.981**	-5.120*	-2.082	-4.019*	17.985** (0.0006)	3.459** (0.0005)
REN	-2.351	-4834**	-4.808**	-3.998*	99.562* (0.0000)	27.009* (0.0000)
URB	-3.879*	-6.872**	-5.940**	-6.933**	195.292* (0.0000)	54.643* (0.0000)

**Depicts 1% significance and ** 5% significance.*

Source: Author, (2023)

The results in Panel A of Table 3 reveal that the series exhibit stationarity at both I(1) and I(0) orders of integration, thus lending credibility to our adopted model. Stationarity implies that the variables do not show a trend over time and are suitable for analysis using time-series techniques. CO_2 emissions, EEF, EG, NUE, REN, and URB are stationary at either I(1) or level I(0). This implies that the variables demonstrate stability and do not display significant trends over time after accounting for potential differences. The CD test results in Panel B of Table 3 provide evidence of cointegration. By implication, shocks to EEF, REN, EG, NUE, and URB in one MINT country can have long-lasting effects on the ecosystem and potentially influence other countries within the economic bloc. This finding underscores the interconnectedness of environmental dynamics across MINT countries and highlights the significance of considering cross-country influences in environmental policy formulation and analysis.

Table 4 Panel Non-linear Autoregressive Distributed Lag (PNARDL)

Variable	Coefficient
Long Run Equation	
EEF	0.158036 (21.08802)**
LOGEG	-0.629431 (-35.28668)**
LOGREN	0.291188 (3.040891)***
LOGURB	41.70791 (37.90307)**
NUE	-0.154501 (-12.95905)**
Short Run Equation	
COINTEQ01	-0.823129 (9.146690)**
D(CO2(-1))	0.556121 (0.864059)

Variable	Coefficient
D(CO2(-2))	0.089065 (1.253174)
D(EEF)	0.232650 (1.151602)
D(LOGEG)	-0.228724 (-0.436219)
D(LOGREN)	0.902707 (0.855377)
D(LOGURB)	-2761.722 (-1.033508)
D(NUE)	-0.309089 (-1.454755)
C	157.5026 (1.042695)
Log-likelihood	197.9649

Source: Author, (2023)

Discussion of PNARDL Results

The PNARDL model in Table 4 provides significant insights into the behavioral patterns of CO_2 emissions in MINT countries. Level I(0) variables explain the behavioral pattern of the series in the long run. In contrast, by considering the variance, the I(1) series describes the short-run effect adjustment for one year. The ECM was correctly signed and was negative and significant—inferring convergence to equilibrium from a short-run shock. The long-run equilibrium and short-run adjustment mechanisms indicate a complex interplay between economic variables and environmental effects. Presenting the asymmetric equilibrium link, a positive and significant influence on CO_2 emissions ensues due to a positive shock in energy efficiency, urbanization, and economic growth stimulated by technological advancement, industrialization, and urban immigration in MINT nations.

Energy Efficiency and Renewable Energy on CO_2 emission

Results show that a 1% decrease in CO_2 emissions increases EEF and REN and improves environmental quality by 0.158% and 0.291% in the long and short run, respectively (0.232% and 0.902%). These results imply that policies to reduce carbon emissions will improve EEF and REN utilization in the long run. MINT countries will transition towards cleaner and more sustainable energy systems. The short-run results indicate that MINT countries must prioritize short-term measures to accelerate the adoption of REN sources and improve their EEF to meet climate targets. Ensuring long-term sustainability requires prioritizing investments in renewable energy infrastructure and technology, stable and supportive policy and regulatory frameworks, institutional capacity, public awareness, and economic diversification that prioritize sustainable growth and environmental conservation.

These findings align with prior results of Ahmed et al. (2019) and Abner, et al. (2021), among others, who attribute the decrease in environmental corrosion and climate change to EEF and REN. These findings emphasize the importance of sustainable energy practices in mitigating environmental dilapidations and addressing climate change concerns. Jacobs's (1993) findings also substantiate the study result, stating that between 2010 and 2020, CO_2 emissions were estimated to be reduced by 0.4-0.9 billion tonnes. The Intergovernmental Panel Report on Climate Change (IPCC) in 2019 also substantiates the study results, noting that an 80% penetration of REN sources by 2050 will aid in combating climate change (Masson-Delmotte et al., 2018). The results of Cheng et al. (2019), among others, advocate for efficient management of climate change and ecological quality improvement anchors for REN generation, distribution, and consumption. These findings underscore the pivotal role of EEF and REN in reducing CO_2 emissions in the MINT countries.

Economic Growth and Environmental Decoupling on CO_2 emissions

Economic growth is a critical factor in improving environmental quality in the long term. A 1% decrease in economic growth in the short run increases CO_2 emissions and is reduced by 62% for every 1% increase in economic growth through REN in the long run. EEF MINT countries showed signs of a U-shaped curve, which implies that economic growth is decoupled from environmental degradation. These findings indicate that environmental quality is realized when economies prioritize ecological conservation and sustainability. These results support the EKC hypothesis and the findings of Marques et al. (2019) in the MENA region. Natural and artificial catastrophes promote climate change through CO_2 emissions, sulfur hexafluoride (SF6), nitrous oxide (N_2O), and methane (CH_4) (Udemba, 2020). In summary, these findings indicate that economic maturity has led to the prioritization of environmental conservation for sustainable development.

Urbanization on CO2 emissions

Urbanization (URB) through population growth and economic expansion in MINT nations is expected to significantly impact EEF and CO_2 emissions via REN. A unit change in economic expansion ignited by EEF and REN reduces CO_2 emissions by 29.1% in the long run as a result of environmental prioritization. This is evident in Mexico's rise from the 19^{th} ranking in the energy efficiency IEA scorecards of 25 nations in 2016 to the 12^{th} ranking in the 2018 IEA scorecards. In the industrial energy efficiency program, Turkey, collaborating with the IEA, implemented the National Energy Efficiency Action Plan to save $30.2 billion in energy consumption with an investment plan of approximately $11 million in energy efficiency in 2023; Mexico saved 3%, Indonesia saved 7% (Presidency of the Republic of Turkey, I. O. (Producer), 2019).

EEF implementation in Nigeria is still in its preliminary stages due to non-existing regulations spurred by a lack of commitment, diversification of energy sources, and adoption of new technology to reduce energy wastage and save costs. The Council of Renewable Energy of Nigeria revealed that power outages led to an annual income loss of approximately ₦126 billion (US$ 984.38 million) and increased health hazards through CO_2 emissions. The results of this study on REN-CO2 emission clarify the asymmetric nexus within MINT countries. A 1% rise in REN sources through technological advancement and favorable eco-friendly government policies reduces CO_2 emissions by 0.291% in the long run and 0.902% in the short run.

In Turkey, the findings of Sugiawan and Managi (2016) corroborate the study results, suggesting that REN, through green energy sources, reduces CO2 emissions and enhances MINT counties' environmental standards. The availability of green energy sources places MINT countries in advantageous positions. This is evident in Mexico's 2012 energy reform, which increased green and nuclear energy from 35% by 2024 to 50% by 2050 (Defilippe, 2018). In addition, launching online green energy certificates is considered a critical policy path for green energy and renewable energy transformation.

Contemporary forecasts in Turkey reveal that the high REN source will increase green energy generation to 30% by 2027. The IEA 2019 report showed that Turkey is projected to rank among Europe's top five renewable energy countries with 50% existing capacity, reaching 63 GW by 2024 (IEA, 2019). Similarly, Indonesia's energy reform targets 788,000 MW in renewable energy generation and a 23% renewable energy increase by 2025 to close the energy demand-supply gap for their burgeoning population. Renewable energy generation, distribution, and consumption in Nigeria are in the developmental phase because of limited funding. Notwithstanding the financial challenges hampering the effective implementation of renewable energy programs in Nigeria, investment in solar energy in recent times has stood at approximately 20 million U.S. dollars.

Nuclear Energy on CO_2 emission

The nexus between nuclear energy (NUE) and CO_2 emissions in MINT countries during the review period of this study shows a negative and non-significant correlation, which can be attributed to factors such as safety concerns stemming from past nuclear accidents (such as Chernobyl and Fukushima), limited nuclear energy infrastructure, financial constraints, regulatory barriers, and the availability of alternative energy sources such as solar, wind, and hydroelectric power, which are considered greener compared to nuclear energy. These factors diminish the perceived need for nuclear energy in the energy mix of MINT countries, leading to the absence of a significant correlation. However, the relevance of the negative and non-significant correlation for future energy policies lies in several critical considerations, including energy diversification, advancements in nuclear technology (e.g., small modular reactors (SMRs) and advanced fuel cycles), international collaboration, regulatory frameworks, safety standards, and waste management practices. Nuclear energy remains vital for future energy sustainability and efforts to mitigate climate change despite the adverse and non-significant correlation. This underscores the significance of strategic investments, technological innovations, and international cooperation in shaping the energy landscape of MINT countries.

4.2 Country-Specific Asymmetric Effects

The Non-Linear panel ARDL model was adopted to assess the energy shock in MINT countries due to distinct economic structures, policy environments, and institutional frameworks. Identifying country-specific asymmetric effects is essential in this study and for practical and actionable recommendations.

Table 5. Non-Linear panel ARDL Asymmetric Effects

Indonesia		Mexico	Nigeria	Turkey
Log-Run				
Variable	Coefficient	Coefficient	Coefficient	Coefficient
EG	-0.000184 (-10.94706)	-0.004363 (-0.033347)	-6.57E-05 (-3.162827)	0.261741 (2.055742)
EEF	0.110420 (4.934837)	6.017589 (0.033347)	0.022106 (1.710433)	0.581012 (10.72278)
NUE	-0.615061 (-13.76609)	-37.81883 (-0.035127)	-0.414607 (-2.143587)	-0.223516 (-4.650069)
REN	0.000436 (0.268014)	18.47957 (0.035123)	0.002283 (0.284262)	0.165506 (3.252301)
URB	0.025899 (9.926183)	-0.980708 (-0.043469)	0.011732 (1.252631)	0.322075 (11.63200)
C	0.094567 (0.363433)	65.55707 (0.025501)	4.804761 (10.27587)	24.06755 (7.159049)
Short-Run				
COINTEQ01	-0.829731 (-102.4395)**	-0.030811 (-17.97617)**	-0.586933 (-87.68135)**	-0.555653 (-33.02299)**

** at 0.05 level of significance.
Source: Author, (2023)

The country-specific results in Table 5 provide insights into MINT countries' asymmetric relationships between EEF, REN, EG, and CO2 emissions. The negative correlation between EG and CO_2 emissions in Mexico, Indonesia, Nigeria, and Turkey reveals a potential Environmental Kuznets Curve (EKC) effect, where a 1% initial increase in EG leads to an increase in CO_2 emissions, which decreases as the economy evolves to prioritize environmental quality. The non-significant correlation in Mexico suggests that cultural lifestyle influences the relationship, among other non-economic factors.

Nigeria's low nexus between energy efficiency and CO_2 emissions is attributed to its inability to generate, distribute, and consume efficient energy to achieve environmental goals. Similarly, Nigeria ranks low in renewable energy generation, as evidenced by the nexus between REN and CO_2 emissions, validating the effectiveness of ecological policies in nations with high CO_2 emissions. Mexico, Turkey, and Indonesia outperform Nigeria in renewable energy generation, distribution, and consumption. Goals 7, 12, and 13 of the U.N. 2030 Sustainable Development Goals (SDGs) are directly relevant to this study. The negative and statistically significant correlation between nuclear energy use (NUE) and CO_2 emissions for all countries indicates that reliance on nuclear energy contributes to lower CO_2 emissions in the long run, aligning with the EKC hypothesis.

The positive and significant correlation between urbanization and CO_2 emissions suggests that urbanization improves ecological quality in the long run across MINT countries, consistent with the EKC hypothesis, which posits that energy consumption and industrial activities increase with urban development. Notably, the results of (COINTEQ01) show the convergence speed from disequilibrium in the energy sector to long-run equilibrium in MINT countries. These findings offer valuable insights into the complex relationships among EG, EEF, REN, and environmental sustainability in MINT countries.

5. Conclusion

This study empirically assessed the asymmetry between energy efficiency (EEF), renewable energy (REN), economic growth (EG), and CO_2 emissions in MINT countries using the PNARDL model. The findings indicate that EEF and REN, facilitated by green energy sources, reduce CO_2 emissions and improve the quality of MINT countries' ecosystems. In contrast, the nexus between EEF, REN, EG, CO_2 emissions, and NUE within the study period had a non-significant and negative influence on CO_2 emissions, indicating insufficient generation and consumption of NUE in each MINT country as a result of safety concerns, particularly in light of nuclear accidents such as Chernobyl and Fukushima, limited nuclear energy infrastructure, financial resources, regulatory barriers, and political and regulatory framework uncertainties, among others. Economic growth through sustainable energy sources reduces CO_2 emissions for every 1% increase in EG. The variations in the nexus across MINT countries can be attributed to their heterogeneous economic structure, resource endowment, energy mix, policy framework, institutional capacity, infrastructure, and technological innovation. As such, Nigeria's reliance on oil exports contrasts with Turkey's industrialization, leading to variations in environmental awareness and policy priorities. The composition of energy sources and natural resource endowments also influences the nexus dynamics. Indonesia has abundant renewable energy resources such as geothermal and hydropower, whereas Nigeria relies heavily on oil and gas. The availability and accessibility of renewable energy sources affect the feasibility and effectiveness of renewable energy integration and energy efficiency measures.

The study's findings reveal a vital policy inference for MINT countries: the effectiveness of strategies enhancing EEF and REN adoption depends on each MINT country's policy framework and institutional capacity. To advance energy technology and ease the legal requirements for energy efficiency, particularly nuclear energy technology adoption and implementation, to achieve the U.N. 2030 SDGs in MINT economies. Mexico implemented various regulatory mechanisms and incentive programs for renewable energy efficiency and development. In contrast, Nigeria faces governance, corruption, and institutional capacity challenges, which hinder policy implementation and enforcement. There is a dire need to strengthen institutional frameworks, enhance regulatory mechanisms, and promote public-private partnerships to overcome barriers to sustainable energy development.

The current policy framework in MINT countries, particularly Nigeria, lacks adequate integration between REN and EEF initiatives and incentives, such as tax breaks, subsidies, and grants to encourage investments in REN infrastructure and technology. This policy gap over the period deterred private sector involvement and slowed the adoption of REN sources. NUE presents a low-carbon option. The cumbersome regulatory process significantly limits the diversification of energy sources and hinders environmental quality improvement efforts. MINT countries can boost energy sustainability and improve ecological quality by underscoring REN procedures and EEF. This approach aligns with the UN 2030 Sustainable Development Goals (SDGs) for mitigating climate change.

The level of infrastructure development and technological innovation also influence the nexus dynamics in MINT countries. With relatively advanced infrastructure and technological capabilities, renewable energy technologies in MINT countries vary based on factors such as geographical conditions, resource availability, policy incentives, technological advancements, and energy demand profiles. These technologies include Photovoltaic (PV) Solar Panels, solar water heating systems, wind turbines, hydroelectric, biomass, and geothermal power plants, biodiesel and bioethanol, tidal barrages, and wave energy converters. This study recommends country-specific infrastructural development, innovation, and investments to facilitate the transition towards a more sustainable and low-carbon economy specific to MINT countries.

This study also recommends streamlining the regulatory approval process for nuclear energy projects and providing incentives for investment in the nuclear power infrastructure as a reliable and low-carbon source of electricity to reduce CO_2 emissions and enhance energy diversity. This study also recommends the inclusion of cultural variables such as social, institutional, and political indicators to shape energy transitions and environmental sustainability efforts of MINT countries. By accounting for cultural nuances and contextual factors, context-specific policy can be designed to promote EEF, expand REN deployment, and mitigate CO_2 emissions through social acceptance of sustainable energy practices, regulatory frameworks, administrative efficiency, political leaders' commitment to addressing climate change, and the diverse needs and preferences of local communities.

This study recommends country-specific research and integration of technological innovation, government policies, or international trade dynamics in future research. The study's limitations include temporal variations in economic and social conditions, geopolitical events, and global policy frameworks on energy dynamics.

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References

1. Abner, I., P., Izuchukwu, O., Eneoli O., C., & Udo E., S., (2021) Energy Consumption Effect on Economic Growth in Nigeria: Multivariate Framework. *International Journal of Economics, Management and*

Accounting 29, 2 (2021): 519-542. DOI: https://doi.org/10.31436/ijema.v29i2.932

2. Ahmad, A.U., Ismail, S., Ahmad, I.M., Adamu, I.M., Jakada, A.H., Farouq, I.S., & Danmaraya, I.A. (2020a), Pollutant emissions, renewable energy consumption and economic growth: An empirical review from 2015-2019. *Journal of Environmental Treatment Techniques*, 8(1), 323-335. Journal weblink: http://www.jett.dormaj.com

3. Ahmed, Z., & Wang, Z. (2019). Investigating the impact of human capital on the ecological footprint in India: An empirical analysis. *Environmental Science and Pollution Research*, 26(26), 26782–26796. https://doi.org/10. 1007/s11356-019-05911-7.

4. Akram, R., Chen, F., Khalid, F., Huang, G., & Irfan, M. (2020). Heterogeneous effects of energy efficiency and renewable energy on the economic growth of BRICS countries: A fixed effect panel quantile regression analysis. Energy 215, 119019. https://doi.org/10.1016/j.energy.2020.119019

5. Alam MM, Murad MW, Noman AHM, & Ozturk I (2016). Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia. *Ecological Indicators*. 2016; 70:466–79. https://doi.org/10.1016/j.ecolind.2016.06.043

6. Agras, J., & Chapman, D. (1999). A dynamic approach to the Environmental Kuznets Curve hypothesis. Ecological economics, 28(2), 267-277. https://doi.org/10.1016/S0921-8009(98)00040-8

7. Apergis, Nicholas & Payne, James E., 2009. "Energy consumption and economic growth in Central America: Evidence from a panel cointegration and error correction model," Energy Economics, Elsevier, vol. 31(2), pages 211-216. https://doi.org/ 10.1016/j.eneco.2008.09.002.

8. Breusch, T. S., & Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. The Review of Economic Studies, 47(1), 239. https://doi.org/10.2307/2297111

9. Bunn, M., Makhijani, A., & Holdren, J. P. (2017). The Future of Nuclear Power. Daedalus. https://energy.mit.edu/research/future-nuclear-power/

10. Brooks, C. (2014) Introductory Econometrics for Finance. 3rd Edition, Cambridge University Press, Cambridge. Business Management. 4,(3) pp114-122. (2014). https://doi.org/10.1016/JBM.2016.114.10252.

11. Cheng, C., Ren, X., Wang, Z., & Yan, C., (2019). Heterogeneous impacts of renewable energy and environmental patents on CO2 emissions-Evidence from the BRIICS. Science of the Total Environment, 668, 1328–1338. https://doi.org/10.1016/j.scitotenv.2019.02.063

12. Defilippe, M., (2018). Mexico grows as a world leader in energy reform and renewables. Retrieved from https://www.renewableenergyworld.com/2018/04/12/mexico-reform-and-renewables

13. Dogan, E., Taspinar, N., & Gokmenoglu, K.K., (2019). Determinants of ecological footprint in MINT countries. Energy & Environment, 30(6), 1065–1086. https://doi.org/10.1177/0958305x19834279.

14. Damette, O., & Seghir, M. (2013). Energy as a driver of growth in oil exporting countries?. Energy Economics, 37, 193–199. https://doi.org/10.1016/j.eneco.2012.12.011.

15. Danish Baloch M.A., Mahmood N., Zhang J.W. (2019) Effect of natural resources, renewable energy and economic development on CO2 emissions in BRICS countries. Science of the Total Environment, 678, 632–638. https://doi.org/10.1016/j.scitotenv.2019.05.028.

16. Dietz, T., & Rosa, E. A. (1994). Rethinking the environmental impacts of population, affluence and technology. *Human ecology review*, *1*(2), 277-300. https://www.jstor.org/stable/24706840.

17. Dinda, S. (2004) Environmental Kuznets Curve Hypothesis: A Survey. Ecological Economics, 49, 431-455. https://doi.org/10.1016/j.ecolecon.2004.02.011.

18. Dong K, Sun R, & Hochman G (2017). Do natural gas and renewable energy consumption lead to less C.O. emission? Empirical evidence from a panel of BRICS countries. Energy, 141, 1466–1478. https://doi.org/10.1016/j.energy.2017.11.092.

19. Dong K, Sun R, Jiang H, & Zeng X (2018). CO2 emissions, economic growth, and the environmental Kuznets curve in China: What roles can nuclear and renewable energy play? Journal of Cleaner Production, 196, 51–63. https://doi.org/10.1016/j.jclepro.2018.05.271.

20. European Commission, (2016). The macroeconomic and other benefits of energy efficiency. Retrieved from https://ec.europa.eu/energy/sites/ener/files/ documents/final_report_v4_final.pdf.

21. Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. The Quarterly Journal of Economics, 110(2), 353–377. https://doi.org/10.2307/2118443.

22. Mack G. A., Gunst, R. F., & Mason, R. L. (1981, August). Regression Analysis and Its Application: A Data-Oriented Approach. Technometrics, 23(3), 309. https://doi.org/10.2307/1267800

23. Hdom H,A,D, & Fuinhas J,A (2020). Energy production and trade openness: Assessing economic growth, CO2 emissions and the applicability of the cointegration analysis. Energy Strategy Reviews, 30, 100488. https://doi.org/10.1016/j.esr.2020.100488

24. Holtz-Eakin, D., & Selden, T. M. (1995). Stoking the fires? CO2 emissions and economic growth. Journal of Public Economics, 57(1), 85–101. https://doi.org/10.1016/0047-2727(94)01449-x

25. Huang, Y., Xue, L., & Khan, Z. (2021). What abates carbon emissions in China: Examining the impact of renewable energy and green investment. Sustainable Development. https://doi.org/10.1002/sd.2177.

26. IEA, (2019). Renewables 2019. Retrieved from https://www.iea.org/reports/renewables-2019.

27. Iwata, H., Okada, K., & Samreth, S. (2010). Empirical study on the environmental Kuznets curve for CO2 in France: the role of nuclear energy. Energy Policy, 38(8), 4057–4063. https://doi.org/10.1016/j.enpol.2010.03.031.

28. Jacobs M (1993). The Green Economy: Environment: Sustainable Development and the Politics of the Future. Environmental Values 2 (1):77-79. https://doi.org/10.5860/choice.29-4616.

29. Jakada, A.H., Mahmood, S., Ahmad, A.U., Muhammad, I.G., Danmaraya, I.A., & Yahaya, N.S. (2022a), Driving forces of CO2 emissions based on impulse response function and variance decomposition: A case of African countries. Environmental Health Engineering and Management, 9(3), 223–232. https://doi.org/10.34172/ehem.2022.23.

30. Jim O Neill, (2013). Who are You Calling a BRIC? Retrieved from https://www.bloomberg.com/opinion/articles/2013-11-12/who-you-calling-a-bric-.

31. Karabulut, G., & Aydin, C. (2022). The asymmetric impact of renewable energy consumption and financial development on CO2 emissions: Empirical evidence from Turkey. *Sustainable Cities and Society*. https://doi.org/10.4018/978-1-7998-8482-8.ch013

32. Khan, M. A., Abbas, Q., Naeem, M. A., & Jadoon, M. M. (2021). Assessing the asymmetric effects of renewable energy consumption, energy efficiency, and economic growth on environmental quality: Evidence from selected SAARC countries. *Environmental Science and Pollution Research*. https://doi.org/10.1108/IJESM-07-2022-0009

33. Koc, S., & Bulus, G. C. (2020). Testing validity of the EKC hypothesis in South Korea: role of renewable energy and trade openness. Environmental Science and Pollution Research, 27(23), 29043-29054. https://doi.org/10.1007/s11356-020-09172-7

34. Kraft, J., Kraft, A. (1978), On the relationship between energy and GNP. Journal of Energy and Development, 3(2), 401-403. https://www.jstor.org/stable/24806805

35. Lee C.C, Chang C.P., (2005). Structural breaks, energy consumption and economic growth revisited: evidence from Taiwan. Energy Economics 27, 857–872. https://doi.org/10.1016/j.eneco.2005.08.003

36. Magazzino C, & Mele M (2022). A new machine learning algorithm to explore the CO2 emissions-energy use economic growth trilemma. Annals of Operations Research. 2022. https://doi.org/10.1007/s10479-022-04787-0

37. Magazzino C, Marco M, & Morelli G (2021). The Relationship between Renewable Energy and Economic Growth in a Time of Covid-19: A Machine Learning Experiment on the Brazilian Economy. Sustainability, 13(3), 1285. https://doi.org/10.3390/su13031285

38. Malik, I., Ullah, I., Zaman, K., & Shoukry, A. M. (2020). Asymmetric impacts of energy consumption, economic growth, globalisation, and environmental policy on carbon emissions in Pakistan: Evidence from ARDL and non-linear ARDL approach. Science of the Total Environment, 726, 138421. https://doi.org/10.1016/j.scitotenv.2020.138421.

39. Masson-Delmotte V, Zhai P, Po¨rtner H-O, Roberts D, Skea J, & Shukla PR, (2018). Global warming of 1.5 C. An IPCC Special Report on the impacts of global warming. 2018; 1(5). https://dlib.hust.edu.vn/handle/HUST/21737

40. Mohsin M, Kamran HW, Atif Nawaz M, Sajjad Hussain M, & Dahri AS (2021). Assessing the impact of transition from nonrenewable to renewable energy consumption on economic growth-environmental nexus from developing Asian economies. J Environ Manage. 2021; 284:111999. https://doi.org/10.1016/j.jenvman. 2021.111999 PMID: 33556829.

41. Nam, K., Pyun, C.S., Arize, C.A. (2002) Asymmetry Mean-Reversion, and Contrarian Profits: ANSTGARC Approach. Journal of Empirical Finance, 9 (8), pp563-58 (2002) https://doi.org/10.1016/S0927-5398(02)00011-7

42. Nwabueze, E, E., Abner, I, P., Inim, V, E., Nwude, C. E., Samuel., O. J., Udo, E. S., (2023) Financial Development, Foreign Direct Investment and CO2 emissions. Journal of Hunan University Natural Sciences, 50(6). https://doi.org/10.55463/issn.1674-2974.50.6.12.

43. Odugbesan, J.A., Sunday, T.A., & Olowu, G. (2021). The asymmetric effect of financial development and remittance on economic growth in MINT economies: an application of panel NARDL. Future Business Journal, 7(1). https://doi.org/10.1186/s43093-021-00085-6.

44. Odugbesan, J. A., & Rjoub, H. (2020). Relationship among economic growth, energy consumption, CO2 emission, and urbanization: evidence from MINT countries. Evidence From MINT Countries. SAGE Open, 10(2), 215824402091464. https://doi.org/10.1177/2158244020914648

45. Ozturk I. & Acaravci, A (2010). “CO2 emissions, energy consumption and economic growth in Turkey,” Renewable and Sustainable Energy Reviews, Renewable and Sustainable Energy Reviews, 14(9), 3220–3225. https://doi.org/10.1016/j.rser.2010.07.005

46. Ozcan, B., & Soytas, U. (2021). Renewable energy consumption-economic growth nexus in Turkey: A bootstrap ARDL bounds testing approach. Renewable and Sustainable Energy Reviews, 104, 30–37. https://doi.org/10.1016/j.rser.2019.01.020

47. Pao, H.-T., & Tsai, C.-M., (2011). Multivariate Granger causality between CO2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. Energy, 36(1), 685–693. https://doi.org/10.1016/j.energy.2010.09.041

48. Pesaran, M.H., (2007). A simple panel unit root test in the presence of cross-section dependence. J. Appl. Econometrics 22, 265–312. http://dx.doi.org/10.1002/jae.951.

49. Pradhan, R. P., Arif, S. A., & Bhanja, N. (2020). Impact of energy consumption on CO2 emissions in Indonesia: A cointegration analysis. *Journal of Cleaner Production*.

50. Presidency of the Republic of Turkey I. O. (Producer), 2019. Energy. Retrieved from https://www.invest.gov.tr/en/sectors/pages/energy.aspx.

51. . Shahbaz M, Balsalobre-Lorente D, & Sinha A (2019). Foreign Direct Investment–CO2 emissions nexus in the Middle East and North African countries: Importance of biomass energy consumption. Journal of Cleaner Production, 217, 603–614. https://doi.org/10.1016/j.jclepro.2019.01.282

52. Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling Asymmetric Cointegration and Dynamic Multipliers in an ARDL Framework. In: Horrace, W.C., Sickles, R.C. (eds), Festschrift in Honor of Peter Schmidt. Springer Science and Business Media, New York. https://doi.org/10.1007/978-1-4899-8008-39

53. Stern, D. I. (1993). Energy and economic growth in the USA: a multivariate approach. *Energy Economics, 15(2), 137–150. https://doi.org/10.1016/0140-9883(93)90033*.

54. Soytas U, Sari R, & Ewing BT (2007). Energy consumption, income, and carbon emissions in the United States. Ecological Economics, 62(3–4), 482–489. https://doi.org/10.1016/j.ecolecon.2006.07.009

55. Sugiawan, Y., & Managi, S., (2016). The environmental Kuznets curve in Indonesia: Exploring the potential of renewable energy Environmental Science and Pollution Research, 27(23), 29043–29054. https://doi.org/10.1007/s11356-020-09172-7.

56. Tang, Z., Shang, J., Shi, C., Liu, Z., & Bi, K. (2014). Decoupling indicators of CO2 emissions from the tourism industry in China: 1990–2012. Ecological Indicators, 46, 390–397. https://doi.org/10.1016/j.ecolind.2014.06.041

57. Udemba, E. N. (2020). A sustainable study of economic growth and development amidst ecological footprint: new insight from a Nigerian perspective. Science of the Total Environment, 732, 139270. https://doi.org/10.1016/j.scitotenv.2020.139270

58. Udo, E., S., Idamoyibo, H., R., Inim, V., Akpan, J., E., & Ndubuaku, V., (2021). Energy Consumption and Sectorial Value Addition on Economic Growth in Nigeria," *Universal Journal of Accounting and Finance, 9(1), 74–85. https://doi.org/10.13189/ujaf.2021.090108*

59. Umar, M., Ji, X., Kirikkaleli, D., & Alola, A.A., (2021). The imperativeness of environmental quality in the United States transportation sector amidst biomass-fossil energy consumption and growth. Journal of Cleaner Production, 285, 124863. https://doi.org/10.1016/j.jclepro.2020.124863

60. Waheed, R., Zhang, Y., Liu, Y., & Niu, X. (2018). The asymmetric impact of renewable energy consumption on environmental quality: Evidence from Pakistan. *Journal of Cleaner Production*.

61. World Bank, 2022. World Development Indicators.

62. World Bank (2021) Projected GDP Ranking. from World, Bank International Monetary Fund World Economic Outlook (April - 2021)

63. Yilmaz, B., & Demir, E. (2021). Economic growth and carbon dioxide emissions in Turkey: ARDL bounds and wavelet coherence evidence. *Environmental Science and Pollution Research*. https://www.researchgate.net/publication/313846380_Economic_Growth_and_CO2_Emissions_in_Turkey