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Energy Efficiency, Renewable Energy and Economic Growth Nexus on CO2 Emission: Evidence from MINT Countries

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Abstract

This study scrutinises the energy efficiency (EEF), renewable energy (REN), and economic growth (GDP) nexus on CO_2 emissions in the MINT countries of Mexico, Indonesia, Nigeria, and Turkiye from 1990-2022. Using the novel asymmetric technique of the non-linear panel ARDL on the nexus between the EEF as CO_2 emission stimulator, with REN, GDP, nuclear energy (NUE), and urbanization (URB), which previous studies ignored to use the symmetric model predominantly. Despite the importance of EEF in ecological policy formulation and management, its mitigating influence on CO_2 emissions is yet to be expansively examined in the ecological literatures in MINT countries. Results and findings revealed an asymmetric long-short nexus between EEF, REN, through green energy sources, reducing the CO2 emission effect in MINT countries. The GDP-CO2 emission nexus supports the environmental Kuznets curve (EKC) hypothesis. The nuclear energy-CO2 emission nexus is negative and non-significant. Indicating that MINT countries at present are not generating significant mega electron volts of nuclear energy to reduce CO2 emissions. The study recommends prioritising REN policies through EEF, advancement in energy technology, and easing of the legal requirements for EEF, particularly NUE technology adoption, and implementation, to achieve the 2030 UN SDGs of environmental quality sustainability.

1. INTRODUCTION

Globally the increasing energy demand for socio-economic development and the supply gap thereof, is one of the core burdens of the 21st century due to its impact on environment quality. The decline in environmental quality and energy demand-supply gap impact on climate change is trace to the continuous consumption of fossil energy which contains about 75%-85% of carbon (CO2) (Ahmed, et, al 2019; Abner, et, al 2021; Ahmed, et, al 2020; Omojolaibi, et, al 2020). Developing economies particularly high-income oil-producing contribute about 60%-67% of CO2 due to population growth rates and high energy demands for rapid economic industrialization.

The energy sector through fossil fuel provides 80% of global energy needs, which contributes 66.667% to total greenhouse gas (GHG) CO2 emissions globally (International Energy Agency (IEA), 2013; Umar et al., 2021).

Efficient energy generation and distribution through green sources is key to improving environmental quality, plummeting energy-related CO2 emissions and stimulating green economic and financial development in particularly in MINT countries endowed with immense REN and green energy sources. Mexico and Turkiye are blessed with significant solar and wind energy due to geographical location; Indonesia's abundant geothermal resource offers a colossal green energy production opportunity and Nigeria's substantial sunlight also offers a solar energy production opportunity.

According to Economist Jim ONeill (2013), the MINT countries are the budding and evolving economic bloc of the world economy taking over from BRIC countries as a result of their rapid economic growth stimulated by their growing young population, and remittances inflow among others. Nigeria and Mexico in MINT nations fall within the top 10 remittances-receiving nations (Odugbesan et al., 2021). According to 2023 World Bank statistics report, MINT nations roughly account for an estimated 720 million populations; Nigeria (223.8 million), Mexico (126.60 million), Indonesia (284.3 million), and Turkiye (85.3) million. The stable and healthy growth trend in MINT countries can be attributed to individual country proximity to developed countries. Nigeria is globally regarded as the economic hub of Africa, economic and social development in America influences the Mexican economy, China influences Indonesia, and the European Union influences Turkiye.

The positive and significant impact of this proximity to developed countries on the individual MINT countries is evident World Bank economic ranking of 2018, ranking Mexico 15th, Indonesia 16th, Turkiye 18th, and Nigeria 31st. In June 2021, based on GDP, ranking Mexico 15th, Indonesia 16th, Turkiye 19th, and Nigeria 27th (World Bank, 2021).

However, in light of these distinctive economic traits, this study envisages that by the end of 2023, the MINT countries will rank among the top 20 economies in the world for the next three decades, with Mexico ranked 15th, Indonesia 16th, Turkiye 17th, and Nigeria 20th. This prediction is supported by the findings of Odugbesan and Rjoub (2020) and others and further collaborate the 2014 Goldman Sachs stable growth progression forecast for MINT countries till 2020.

Similarly, the United States report investment according to Dogan et al., (2019) forecast a 5% annual growth in MINT. Despite these distinctive economic traits and forecast for industrialization, human capital development, political stability, population and urbanization growth rates, resource endowment, trade and export diversification among others. Various country specific heterogeneous factors group under; economic, income per capita, energy, finance and sociopolitical significantly impedes their individual and collective economic expansion, and also truncate the achievement of UN 2030 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., 2020a; Dogan et al., 2019; Ahmad, et al., 2020a; Jakada et al., 2020a; Abner, et, al., 2021).

Theoretically, the EKC hypothesis propounded by Grossman and Krueger (1995) support country specific heterogeneous factor under income per capita revealing an inverted U-shaped nexus. The EKC hypothesis states a rise income per capita of a nation increases CO_2 emissions at the initial stage of development to a slanting point, from which CO_2 emissions diminishes to improve environmental quality (Jakada et al., 2022a). Similarly, the inverse U-shaped model suggests a unit increase in economic prosperity causes environmental quality decline through increased in greenhouse emission (GHG) and CO2 emissions (Jakada et al., 2022b).

In the bid to reduce CO2 emissions by caused fossil energy consumption for industrialisation, and reduce the GHG caused by population and urbanisation growth rates. It’s vital for MINT economies to tailor their economic agenda towards green economic industrialisation, population and urbanisation growth rates, to mitigate the effects of global warming (Akram, et, al 2020;

Dogan, et, al 2019).

Empirically, the European Commission report, reveals that a unit in EEF has the potential to boost natural resource sustainability, enhance the realisation of the SDGs and MDGs, reduce GHG and CO2 emissions, diminish the over-dependence on fossil fuels to bridge the energy demand-supply gap and improve energy security (European Commission, 2016; Bayar & Gavriletea, 2019; Shahbaz et al., 2019).

Interestingly, factors instigating environmental changes have been an active research area. Cheng et al., (2019); Danish Baloch et al., (2019); among others, revealed that efficient management of climate change and ecological quality improvement anchor on energy efficiency. Energy efficiency denote the capacity to increase or retain production level using the same Joule (J) of energy. Investment in energy efficiency through green sources of energy, has colossal ecological and economic sustainability growth benefit (Huang et al., 2021; Dong et al., 2018a,b). Energy efficiency through the development of the abundant green energy sources embedded in MINT countries and the implementation of an all-inclusive environmental regulations is aim at closing the energy gap, and spur raid green industrialization.

Empirical studies examining the three constructs of EEF, REN and GDP on CO2 emissions in MINT nations are scanty. Extant ecological literatures have largely regarded economic growth, agricultural activities, financial development and foreign direct investment as prime stimulant of CO2 emission (Nwabueze, et, al, 2023; Salman, et al., 2019; Liu et al., 2017), while Udo, et, al (2012); Abner, et, al (2021) Shao et al., (2019) Haug and Ucal, (2019) and other examined the energy consumption, trade openness nexus. This studies relatively omitted in ecological literatures the contributive influence of energy efficiency and green energy development. As such, their contributive influence on environmental quality in MINT countries is yet to be broadly investigated in detail. 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 literatures.

Extant ecological literature based their findings on various linear modelling techniques such as the classical linear regression while others adopted the dynamic ordinary least square (Balsalobre-Lorente et al., (2019a,b; Dong et al., 2018a,b) and the fully modified ordinary least square, Dong et al., (2018a,b); Shao et al., (2019) Dong et al., 2018a,b; Pata, (2018a,b) autoregressive distributive lag (ARDL); Udo, et, al (2020); Abner, et, al (2021) Dong et al., (2018a,b); Pata, (2018a,b), among other.

Extant studies have criticise the predominate used of the linear estimation technique for neglecting operational fluctuations and the short-run differences in their studies. Gunst and Mason, (1980: 167–206) upheld that, it is statistically untenable to draw inferences based on a single strand. Nam, et, al (2002), recommended the adoption of an alternative model to provide an all-encompassing inference. On this nexus a non-linear model was adopted. Time series are typically leptokurtic and skewed (Brooks, 2014). The spikes and the oscillatory movement accompanying them renders the linear model inept for a conclusive estimation.

This study adds to the extant studies by employing the asymmetric model of ‘‘non-linear panel ARDL (NPARDL)’’. According to Kumar (2017), the asymmetric behaviour of economic time series can be trace to economic uncertainty. The asymmetric model, specifically the NPARDL, is a novel methodology in this study area that is highly dominated by linear models. It addresses the asymmetry and heterogeneity influence on the long-short run panel dynamics caused by country-specific effect. This study is significant in the context of MINT countries given their abundant green energy resources to reduce GHG emission and manage climate change which has not been extensively examined in extant ecological literatures. This study introduced energy efficiency and green energy as core factors of GHG and CO2 emission. The study findings and results significantly add to developing apt energy policies for MINT nations to improve environmental quality, enhance economic growth through green energy generation and consumption.

2. Literature Review

Generally, extant ecological literature focuses on four literatures classifications of; economic growth, renewable energy, energy consumption, and CO2 emissions. The first school of thought discourses CO2 emissions-economic growth (income per capita) nexus, with Grossman and Krueger (1995) EKC hypothesis of an inverted U-shaped nexus. The findings of Soytas et al. (2007), Dinda (2004); Iwata et al. (2010), among others, revealed that the EKC hypothesis upholds three diverse inferences on the CO2 emissions-economic growth nexus. According to Dietz and Rosa (1994) and Özokcu and Özdemir (2017), there is an "inverted U-shape theory". Friedl and Getzner (2003) and Holtz-Eakin, et, al (1995) reported a N or other shape in the CO2 emissions-per-capita income long-run nexus and not an inverted U nexus. According to Stern (1993), the major hindrance associated with previous EKC studies is that of potential variable bias. Instigated by a statistical model variable omission.

Kraft, et, al (1978), advanced the second school of thought arguing on energy consumption-economic growth link. Ozturk (2010) revealed that the energy consumption-economic growth link can be assess under four premises: a) the growth hypothesis, envisages that energy consumption through energy guidelines may throttle economic growth (Stem, 1993; Damette, et, al 2013); b) the protection hypothesis reveals a non-energy consumption-economic growth effect, as such energy conservation policies have no negative effect on actual GDP (Jamil & Ahmad, 2010; Lee, 2005); c) the feedback hypothesis, school of thought revealed complementary interaction (Tang, et,al, 2014; Belloumi, 2009); d) neutral hypothesis revealed a non-causal nexus, arguing that the influence of energy conservation policies on economic growth is limited (Ozturk, 2010; Agras & Chapman, 1999; Doğan;2018).

According to the 3Es "energy consumption (ENC), economic growth, and CO_2 emissions" school of thought, the incorporation of this variables is to circumvent potential variable bias problem associated with the first school of thought. The 3Es results show that income per capita in the US causes ENC and not CO_2 emissions. In 6 Central American countries from 1971–2004, Apergis and Payne (2009) observed a positive energy consumption–CO2 emissions long-term equilibrium nexus, while the EKC hypothesis support an inverted U-shape nexus with real GDP. In BRIC from 1971–2005, Pao and Tsai (2010) observed both a strong and mild bidirectional causal nexus in Brazil, India, and China between ENC and CO2 emissions; ENC and economic growth, except for Russia from 1990–2005. Similarly, a short-run unidirectional link between CO2 emissions, ENC, and economic growth was also observed.

In China, Brazil, India, and Indonesia, Alam ,et, al (2016), using the ARDL model from 1970–2012, observed that significant caused nexus between income and energy consumption increasing CO2 emissions. Waheed, et, al (2018), using the ARDL model from 1990–2004, observed that renewable energy and forest areas significantly influence CO2 emissions in the long run in Pakistan. Dong, Sun, and Hochman (2017) revealed that a unit increase in REN usage and natural gas usage decreases environmental quality by 0.2601% and 0.1641%, respectively in BRICK countries.

Using the fixed effect and GMM estimators, Khan et al. (2021) observed that REN improves ecological quality. This finding was upheld in the findings of Mohsin et al. (2021) in 25 Asian countries. On the contrary, in Brazil, Hdom and Fuinhas, (2020) revealed that REN, hydropower, and GDP negatively affect CO_2 emissions. CO_2 emissions impact positively on GDP using the FMOLS model.

In Brazil, Magazzino et al. (2021), amidst COVID-19, observed economic growth via REN consumption. The findings of Magazzino and Mele (2022) using the LSTM model, collaborate with the claims of Magazzino et al. (2021) on renewable energy. In Pakistan, using symmetric and asymmetric models' results indicates that in the long-short run economic growth and FDI upsurges CO_2 emissions symmetrically. In the short-run, oil prices upsurge CO_2 emissions and reduce them in the long-run. The asymmetric result shows that in the long run, oil prices reduce CO_2 emissions, and the decrease in oil prices intensifies CO_2 emissions (Malik et al. 2020).

3. Methodology

This study assesses the asymmetric nexus between the three constructs of EEF, REN, and GDP on CO_2 Emissions in MINT nations from 1990-2022. Within the sample period of this study, several global events such as Covid-19 pandemic wielded shock, that spread to MINT nations. The shock moments are not stationary, as they are felt in diverse front.

The study dataset was extracted and collated from the WDI. Extant ecological literature over the decades has widely explored this nexus, however, these studies attached less or no importance to energy efficiency in managing climate change in MINT countries. This study expands the frontiers of the study of Dong et al. (2017) to capture energy efficiency measured by energy intensity as a contributing factor to CO_2 emissions. Economic growth is empirically considered one of the prime instigators of CO_2 emissions. Table 1 describes the designated study variables.

3.1 Cross-sectional Dependency Test

To determine whether relevant variables exhibit cross-sectional dependence (CD), the Breusch-Pagan Lagrange multiplier and the Pesaran-scaled Lagrange multiplier were performed as a result of nations' interconnection through globalisation triggered by economic, social, and cultural networks. The second-generation unit root was conducted using the cross-sectionally augmented IPS (CIPS) and cross-sectionally augmented ADF to ascertain stationarity of the series. The equation is given:

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

Where: □ = cross-sectional averages.

CIPS test statistic: CIPS $= \frac{1}{N}\sum_{i=1}^{n}$ CDF_i…………………….. (Eq 2)

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

3.2 Model Specification

The present study introduced the asymmetric model to questioned the symmetric assumption that saturates the pervious ecological literatures. The linear specification of the variables is expressed as

CO2 = *f* (GDP, EEF, REN, URB, NUE)…………………………. (Eq 3)

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

$LCO2_{it} = \beta_0 + \beta_1 LGDP_{it} + \beta_2 LEEF_{it} + \beta_3 LREN_{it} + \beta_4 LNUE_{it} + \beta_4 LURB_{it} + \varepsilon_{it}$…………(Eq 4)

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

3.3 Non-linear Panel Autoregressive Distributed Lag (NPARDL)

Shin, et, al (2014) developed the NPARDL model and was employed to examine the asymmetric effect of EEF, REN and GDP on CO2 emissions in the long-short run. Empirical studies employing the linear combination, revealed that y_t and χ_t result in a long-short run symmetric-change. Where y_t and χ_t become non-linear, χ_t initiates an asymmetric impact on y_t. The NPARDL revealed asymmetries in panel, as a result of heterogeneous and heterogeneity traits, triggered by country-specific effects, in contrast to asymmetric effects in prior studies.

The model is linear ARDL expansion initiated by disaggregating χ_t into positive and negative partial sums as: $\chi_t = \chi_0 + \chi_t^+ + \chi_t^-$ ……………….(Eq 5)

Where: χ_t^+ and χ_t^- = partial sum processes of positive and negative changes in χ_1

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

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

The NPARDL Equation is specified as:

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

where p and q = the respective lags; μ_i = country-wise effect and ε_{it} = error term; the coefficients α_{1}- $\alpha_6^{+\text{ and }-}$ and $\varphi_k^+, \varphi_k^-, \delta_k^+, \delta_k^-, \psi_k^+, \psi_k^-, \tau_k^+, \tau_k^-$, =and short-run asymmetries. Equation (6) is reexpressed in the form of an error correction model (ECM):

$$\Delta Y_{it} = \alpha_0 + \rho\varepsilon_{it-1} + \sum_{K=1}^{p} \beta_k \Delta Y_{it-k} + \sum_{K=0}^{q1} X(\Upsilon_k^{+}\Delta GDP^{+}_{it-1} + \Upsilon_k^{-}\Delta GDP^{-}_{it-1}) + \sum_{K=0}^{q2} (\varphi_k^{+}\Delta EEF^{+}_{it-1} + \varphi_k^{-}\Delta EEF^{-}_{it-1}) + \sum_{K=0}^{q3} (\delta_k^{+}\Delta REN^{+}_{it-1} + \delta_k^{-}\Delta REN^{-}_{it-1}) + \sum_{K=0}^{q4} (\psi_k^{+}\Delta URB^{+}_{it-1} + \psi_k^{-}\Delta URB^{-}_{it-1}) + \sum_{K=0}^{q5} (\tau_k^{+}\Delta NUE^{+}_{it-1} + \tau_k^{-}\Delta NUE^{-}_{it-1}) + \mu_i + \varepsilon_{it} \quad \text{....(Eq 7)}$$

where ε_{it} = non-linear ECM term; ρ = speed of convergence to long-run equilibrium from equilibrium deviation. The pooled mean group ARDL model was adopted as the most suitable model for this study as it offers the short-long-term coefficients for every cross-sectional unit.

Table 1: Variable description and Unit.

Variables	Unit	Source
Carbon Emission (CO2)	Mt	World bank development indicator (WDI)
Economic Growth (GDP)	Constant US$ 2015	
Energy Efficiency (EEF)	Terawatt hour (TWh)	International energy agency (IEA)
Renewable Energy (REN)	%	World Development Indicators
Urbanization (URB)	%	
Nuclear energy (NUE)		

Source: Author, (2023)

4. RESULTS AND DISCUSSION

The descriptive statistics output of the study variables is reported in Table 2. The table show the panel and country-specific results. The mean and median values of the observations, are not far from each other. Indicating no extreme projection. The mean values in all cases show a positive mean return, indicating a positive increasing propensity effect of CO2. The low standard deviation values compared to 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	CO2	EEF	GDP	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
Turkiye	CO2	EEF	GDP	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	CO2	EEF	GDP	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	CO2	EEF	GDP	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	CO2	EEF	GDP	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

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**		**Breusch–Pagan LM**	**Pesaran-scaled LM**
Variables	**Level I(0)**	**1st Difference I(1)**	**Level I(0)**	**1st Difference I(1)**		
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)

GDP	-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 second-generation unit root results presented in Panel A of Table 3 show that the series is stationary at (1) and I (0) order of integration, thus giving creditability to our adopted model. The CD test results in Panel B of Table 3 designate evidence of CD. By implication, shocks to EFF, REN, GDP, NUE, and URB from any country under investigation have a lifelong influence on the ecosystem. The null hypothesis of ‘‘No CD’’ was rejected. However, policy actions cannot be deduced at this point.

Table 4 Non-linear panel ARDL

Variable	Coefficient
Long Run Equation	
EEF	0.158036 (21.08802)**
LOGGDP	-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)
D(CO2(-2))	0.089065 (1.253174)
D(EEF)	0.232650 (1.151602)
D(LOGGDP)	-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)

The NPARDL results in Table 4 show that the level I(0) variables explain the behavioural pattern of the series in the long run, while the I (1) series describe the short-run effect adjustment for 1 year by taking the variance. The ECM is rightly signed that is negative and significant. Inferring converge to equilibrium from short-run shock. Presenting a non-linear nexus and a long-term asymmetric equilibrium link. A significant positive influence on CO2 emissions ensues due to a positive shock in energy efficiency, urbanisation, and economic growth stimulated by advancement in technology, industrialization, and urban immigration in MINT nations.

The findings show that a unit improvement in energy efficiency and renewable energy reduces the use of unsustainable energy sources and also reduces CO2 emissions and climate change by 0.158% and 0.291% in the long and short run, respectively (0.232% and 0.902%). These results substantiate the findings of (Akram et al. 2019; Liobikiene and Butkus, 2017; Ahmed and Wang, 2019; Abner, Ogbodo, Eneoli, and Udo (2021); among others, attributing the increasing environmental deterioration and climate change to unsustainable energy generation and distribution sources. The findings of Jacobs (1993) also substantiate the study result stating that between 2010 and 2020, CO2 emissions are 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 result noting that 80% penetration of REN sources by 2050 will aid in combating climate change (Masson-Delmotte, et, al 2018).

The empirical findings of Cheng et al., (2019); Danish Baloch et al., (2019) among others, posit that efficient management of climate change and ecological quality improvement anchor on efficient energy and renewable energy generation, distribution, and consumption. Economic growth in the long-run is a key factor in reducing CO2 emissions. A 1% decrease in economic growth through unsustainable energy sources in the long run reduces CO2 emissions for every 1% increase in GDP through REN and EEF. MINT countries showed signs of a U-shaped curve.

These results, support the EKC hypothesis, and the findings of Marques et al. (2019), in MENA region. As such, natural and man-made catastrophes instigate climate change (Udemba, 2020) Carbon dioxide (CO2), sulphur hexafluoride (SF6), nitrous oxide (N_2O), and methane (CH4) are some of the gases that contribute to global warming because of human activities such as deforestation, industrial smoke, and fossil fuel burning. From the results, we can infer that EEF, and REN are the fulcrum for CO2 emissions in MINT countries, largely due to increasing energy demand for industrialization and their other unique economic features to achieve their economic vision for the next three decades.

Urbanisation through population growth and economic growth in MINT nations is expected to significantly impact energy efficiency and CO_2 emissions through renewable energy. A 1% increase in economic expansion and population growth rate requires excessive EEF and REN resources to reduce CO_2 emissions. This is evident in Mexico's rise from 19th in ranking in the energy efficiency IEA scorecards of 25 nations in 2016 to 12th position in the 2018 IEA scorecards. In the industrial energy efficiency programme, Mexico saved 3%; Indonesia saved 7%; and Turkiye, collaborating with the IEA to reduce energy consumption, implemented the National Energy Efficiency Action Plan to save $30.2 billion in energy consumption by 2023 through an investment plan of approximately $11 million in energy efficiency (Presidency of the Republic of Turkiye, I. O. (Producer), 2019).

Energy efficiency implementation in Nigeria is still very much at the primary stage due to non-existing regulations spurred by a lack of commitment. However, the government is exerting efforts to meet the growing energy demand through diversification of energy sources and adopting newly available technology to cut energy wastage and save costs. The Council of Renewable Energy of Nigeria revealed that power outages led to an income loss of about ₦126 billion (US$ 984.38 million) annually and also increased health hazards through CO_2 emissions. The renewable energy-CO_2 emission results from this study clarify the asymmetric nexus within the MINT countries. A 1% rise in renewable energy sources through technological advancement and favourable eco-friendly government policy reduces CO_2 emissions by 0.291% in the long run and 0.902% in the short run.

In Turkiye, the findings of Sugiawan and Managi (2016) collaborate the study results, upholding that REN through green energy sources reduces CO_2 emissions and enhances MINT counties' environmental standards. The availability of green energy sources places the MINT countries in an advantageous position. 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). Also, the launch of online green energy certificates is considered a key policy path to green energy and renewable energy transformation.

Turkiye accounts for high renewable energy sources to increase green energy generation to 30% by 2027. The IEA, 2019 report revealed that Turkiye is projected to rank among Europe’s top 5 renewable energy countries with 50% existing capacity, to reach 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 budding population. Renewable energy generation, distribution, and consumption in Nigeria are in the developmental phase due to limited funds. Notwithstanding, the financial challenges hampering the effective implementation of renewable energy programmes in Nigeria, investment in solar energy in recent times has stood at approximately 20 million US dollars. The Nuclear energy-CO2 emission nexus in MINT countries within the review period of this study is negative and non-significant. Hence, there is no asymmetric nexus, as MINT countries at present are not generating significant mega electron volts (meV) of nuclear energy to reduce CO2 emissions.

4.2 Country-Specific Asymmetric Effects

Table 5 Non-Linear panel ARDL Asymmetric Effects

Indonesia		**Mexico**	**Nigeria**	**Turkiye**
Log-Run				
Variable	Coefficient	Coefficient	Coefficient	Coefficient
GDP	-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 demonstrate the presence of asymmetric effects. EEF and REN had a nonlinear impact on CO2 emission. In Nigeria, the energy efficiency-CO2 emission nexus is low due to Nigeria's inability to generate, distribute and consume efficient energy to achieve its environmental goals in the short term. Similarly, Nigeria ranks low in renewable generation this is evident in the REN and CO2 emission nexus, the result validates the proficiency of ecological policies in nations with high CO2 emission. Mexico, Turkiye, and Indonesia are way ahead of

Nigeria in renewable energy generation, distribution, and consumption. Goals 7; 12 and 13 of the UN 2030 SDGs are all directly relevant to this study. Notably, the (COINTEQ01) results show the speed of convergence from disequilibrium in the energy sector to long-run equilibrium in MINT countries.

5. Conclusion

This study empirically assesses the asymmetric between EEF, REN and GDP on CO2 emission in MINT countries using the NPARDL model via the PMG model. The finding of this study revealed that EEF and REN through green energy sources reduces CO2 emission and improve the quality of MINT countries' eco-system. Contrarily, the nexus between EEF, REN, GDP, CO2 emission, and NUE within the period of this study negatively and non-significantly influenced CO2 emissions. Suggesting the insufficient generation and consumption of NUE in each MINT country. The results support the U-shaped curve of the EKC hypothesis. Economic growth through stainable energy sources in the long-short run reduces CO2 emissions for every 1% increase in GDP through REN and EEF sources.

In specific MINT country estimate the nexus varies as heterogeneous properties among the MINT economies are observed. The study findings revealed a vital policy inference for the MINT countries. To prioritize their renewable procedures through energy efficiency, advancement in energy technology, and easing of the legal requirements for energy efficiency particularly nuclear energy technology adoption and implementation to achieve the NUN 2030 SDGs in MINT economies. Similarly, this study recommends government policy on non-renewable energy consumption reduction along with a micro-finance proposal for hydrological and biomass generation to increase the green energy ratio in MINT countries. This study also recommends the inclusion of cultural variables such as social, institutional, and political indicators, to assess this nexus and their impact on CO2 emission in emerging economies or economic blocs for future research. These variables have different preferences in specific countries.

COMPETING INTERESTS

The authors have no competing interests to declare.

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