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From Degradation to Sustainability: The Dual Role of Globalization and Energy Consumption in MINT Economies

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Abstract: *This study examines the roles of globalization, energy use, information technology, and economic growth in shaping environmental sustainability in MINT economies. Using the load capacity factor as a sustainability indicator, the study analyzes annual panel data from 1993 to 2024. The empirical approach applies second-generation panel methods, including cross-sectional dependence, slope heterogeneity, CIPS unit-root tests, and Westerlund cointegration tests, followed by Driscoll-Kraay, FMOLS, and DOLS estimators. The study findings show that globalization, ICT, economic growth, and energy consumption initially decrease the load capacity factor, indicating pressure on environmental quality. However, in the long term, globalization and energy consumption become sustainability-enhancing, and ICT and economic growth continue to weaken ecological capacity. These study findings suggest that the MINT economies should pursue green globalization, cleaner energy systems, environmentally responsible digitalization, and resource-efficiency-based growth strategies. The study contributes to the globalization-energy-environment literature by shifting the focus to LCF- and MINT-specific sustainability dynamics.*

Introduction

Environmental sustainability has become a major concern in development economics, as economic growth increasingly relies on ecological systems already under stress. With emerging economies, the challenge is not just to raise income, industrial production, and infrastructure, but to do so without undermining the ecological base upon which long-term development depends (Ahmed et al., 2023; Safdar et al., 2026). It is particularly concerning because traditional growth models prioritize production, urbanization, trade, and energy consumption as the primary drivers. In contrast, in fact, environmental quality is directly affected by these factors. One explanation of this relationship is the Environmental Kuznets Curve (EKC), which suggests that environmental degradation can increase in the early stages of development and decrease in the later stages (Dijoo & Khurshid, 2022; Leal & Marques, 2022; Doğan et al., 2019). However, recent empirical evidence shows that this adaptation is not automatic or universal. Growth in most developing and emerging economies remains closely linked to the use of fossil fuels, energy-intensive production, and ecological pressures. Rahman et al. (2021) discovered that energy consumption is a major source of carbon emissions in BRICS economies. In contrast, Yilanci et al. (2023) showed that GDP is a significant contributor to ecological footprint across MINT economies. These results suggest that sustainability is not an automatic consequence of growth; it depends on the pattern of growth, the constitution of energy consumption, the quality of technology, and the form of global integration.

Besides, this background suggests that the load capacity factor offers a more policy-relevant indicator of environmental sustainability than conventional measures of degradation, such as CO2 emissions or the ecological footprint alone. CO2 emissions are among the largest sources of environmental pressure, and the ecological footprint quantifies the pressure on natural resources (Huang et al., 2025; Awosusi et al., 2026; Karim et al., 2025). The load capacity factor, however, relates ecological demand to ecological supply by measuring the ratio of bio-capacity to ecological footprint (Mallick, 2024; Nathaniel et al., 2025). This difference is significant for MINT economies, since their development issues are not only about reducing emissions but also about the broader question of whether their ecological potential can support further economic transformation. Akadiri et al. (2022) clearly recognized the shortcomings of using carbon emissions as the sole indicator of sustainability. They said that future studies used other sustainability indicators, such as the load capacity factor. Thus, choosing the load capacity factor as the dependent variable will enable this study to go beyond a limited degradation perspective and explore whether MINT economies are shifting towards or away from ecological sustainability. Figure 1 shows a decreasing trend in the load capacity factor across all MINT countries between 1993 and 2024, with Indonesia leading the pack. Other nations (Mexico, Nigeria, and Turkey) have lower, comparatively constant values with minor changes over time.

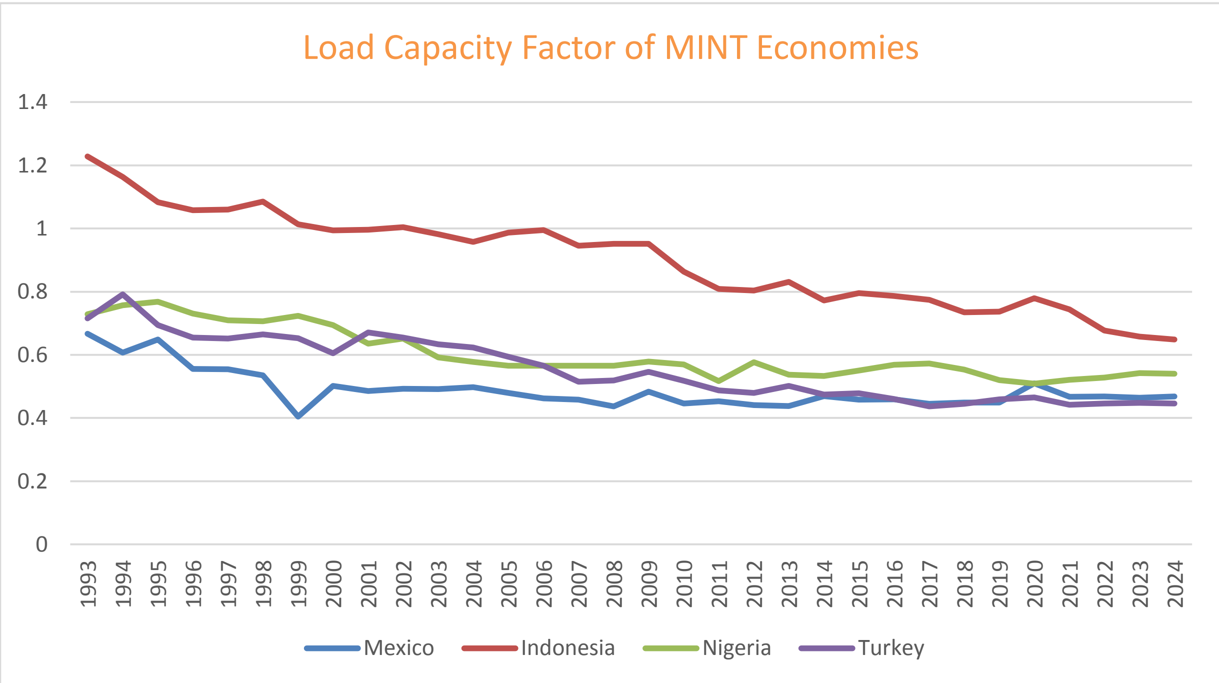

Figure 1: Load capacity Factor of MINT Economies (1993–2024)

The MINT economies of Mexico, Indonesia, Nigeria, and Turkey offer an excellent background for studying this sustainability paradox. These countries are renowned for their large populations, expanding markets, strategic geographic locations, and growing relevance in global trade and investment. Mexico is well-positioned to serve the United States market and the Latin American market; Indonesia is well-positioned to serve major growth centers in Asia; Nigeria has the potential to become a major economic hub in Africa; and Turkey links the networks of Europe, Asia, and energy routes. Their developmental patterns are closely tied to energy use, industrialization, urbanization, and externalization. Yilanci et al. (2023) observed that energy consumption has country-specific effects on the ecological footprint in Indonesia and Turkey, that GDP increases ecological footprint in all MINT economies, and those other drivers, such as FDI and urbanization, has country-specific effects. The reason they are important is that they have the same potential to grow but are anatomically complex because of their distinct energy systems, institutional capabilities, and environmental strains.

Although the literature on globalization, energy consumption, economic growth, and environmental degradation has grown, several significant gaps remain. To begin with, most studies use CO2 emissions or ecological footprint, whereas few use the load capacity factor as a direct indicator of sustainability. It creates confusion about whether economic and structural developments are simply altering the pattern of emissions or, in fact, enhancing ecological sustainability. Second, the current literature discusses globalization and energy separately, yet globalization can influence the environment, in part, by energy-intensive production, technology transfer, and structural change. Third, the use of information technology is inadequately mediated in the MINT sustainability literature, despite digital transformation becoming increasingly central to growth and energy demand. Fourth, evidence of specific to MINT is still scarce. Rahman et al. (2021), Rafindadi and Usman (2019), Akadiri et al. (2022), Oladipupo et al. (2022), Zenios (2024), and Nsair and Alzubi (2025) are important sources of evidence about BRICS, South Africa, Nigeria, ASEAN, and China. However, they do not provide an integrated MINT framework that combines load capacity factor, globalization, ICT, economic growth, and energy consumption.

Thus, this research aims to investigate the impact of globalization, information technology, economic growth, and energy consumption on the load capacity factor in MINT economies during the period 1993-2024. The study contributes by shifting the focus of studies on degradation-based indicators to a sustainability-based indicator, integrating digitalization into the globalization-energy-growth framework, and providing evidence on the group of emerging economies of strategic importance. The study uses panel methods that account for cross-sectional dependence, slope heterogeneity, heteroscedasticity, stationarity, and long-run cointegration, and then provides Driscoll-Kraay, FMOLS, and DOLS estimates. The other sections of the study are as follows: Section 2 is the literature review; Section 3 is the data, model, and method; Section 4 is the report and discussion of the empirical findings; and finally, Section 5 is the conclusion of the study with policy implications, limitations, and suggestions for future research.

Literature Review

Globalization and environmental Degradation/sustainability

Among the most controversial issues in environmental economics, globalization is not a linear process but a complex mix of competing processes. Theoretically, the scale effect suggests that trade growth, foreign investment, industrial integration, and participation in global markets intensify production and transportation activities, increasing energy consumption and emissions (Sarkodie et al., 2020; Tariq et al., 2022; Gul & Wahab, 2021). In contrast, the technique effect implies that globalization may improve environmental quality by facilitating the adoption of cleaner technologies, knowledge transfer from abroad, improved managerial performance, and stronger environmental standards (Hamdoun et al., 2018; Khurshid et al., 2024). The composition effect makes the situation even more complicated by suggesting that globalization may cause economies to drift towards either cleaner service-based activities or pollution-intensive industrial specialization (Wirtz et al., 2015; Ali et al., 2020). It is this theoretical vagueness that has led to inconsistent empirical findings across economies and methods in this unresolved debate, which is evident in the uploaded studies. Rahman et al. (2021) found that globalization reduces CO2 emissions, showing that global integration can improve the environment by enabling greater efficiency and the use of cleaner technologies. This finding is consistent with the pollution-halo argument, which holds that openness exposes domestic firms to better technologies and environmental practices. However, the history of Nigeria and South Africa disproves this sunny interpretation. Akadiri et al. (2022) found that, in Nigeria, globalization raises CO2 emissions in most quantiles. These findings are more in line with the pollution haven and scale-effect arguments, which hold that globalization increases the scale of carbon-intensive production and allows multinational corporations to take advantage of lax regulatory regimes. In this respect, it is not whether globalization is good or bad to the environment, but under which institutional, technological, and energy conditions globalization is either destructive or enhances sustainability (Rahman et al., 2021; Akadiri et al., 2022; Oladipupo et al., 2022).

Another limitation of the literature is that globalization is often discussed as an aggregate variable, even though its economic, social, political, trade, investment, and financial dimensions may have distinct environmental implications. Using a broader globalization index, Rafindadi and Usman (2019) found that, in the short run, globalization reduced environmental degradation in South Africa, but energy use was a stronger driver of degradation. The study by Zenios (2024), which looked at the uncertainty of financial globalization in ASEAN economies, found that its direct effect on energy consumption was statistically insignificant, although there exists a two-way causality between the uncertainty of financial globalization and energy consumption (Moridian et al., 2026; Zhang et al., 2023; Zhuo & Qamruzzaman, 2022). Through energy systems, investment uncertainty, and structural change, globalization may have an indirect effect on the environment rather than a direct channel for emissions. Thus, the literature is still theoretically full and empirically fragmented: globalization can enhance the production networks based on fossil fuels, but it can also further promote the development of green technologies when the institutions of the national policy are weak (Rafindabi & Usman, 2019; Zenios, 2024)

Energy consumption and environmental effect

Although energy consumption is often listed among the basic causes of environmental degradation, its definition requires more than a simple positive correlation with emissions. The nexus of energy and growth recognizes energy as a necessary input to industrialization, infrastructure, urbanization, transportation, and welfare enhancement. However, this very growth-enabling factor predisposes energy to be a major source of environmental pressure when fossil fuels control the energy system. It is not a question of whether energy matters, but whether a disconnection is made between energy consumption and environmental degradation without affecting growth (Menegaki et al., 2017; Wang et al., 2024; Weldengus & Berhe, 2026). The data from the uploaded research substantially prove the environmental costs of traditional energy consumption. Rahman et al. (2021) found that energy consumption is a major contributor to CO2 emissions in BRICS economies, leading them to identify energy use as the key driver of environmental degradation in the region. Akadiri et al. (2022) also came to the same conclusion in Nigeria, where environmental degradation across quantiles increased with energy consumption, globalization, real income, and urbanization. Rafindadi and Usman (2019) in South Africa observed an increase in environmental degradation, largely due to excessive use of fossil fuels.

These results support the growth hypothesis in the energy-growth nexus: energy supports economic activity, but in fossil-fuel-dependent economies, it also increases emissions. Meanwhile, the continued existence of mixed causality results in the larger literature, growth, conservation, feedback, and neutrality hypotheses, which point to the inability of energy policy to be generalized across countries without considering structural dependence, income level, and industrial composition (Rafindadi & Usman, 2019; Rahman et al., 2021; Akadiri et al., 2022; Nepal et al., 2022; Bozatli & Akca, 2024; Onifade, 2022; Ahmad et al., 2026; Fatima et al., 2023; Khan et al., 2023). Besides, it severely affected the health policies of the states (Abdulwahab et al., 2026).

The Environmental Kuznets Curve (EKC) offers a helpful yet incomplete perspective on this debate. The EKC posits that the rate of environmental degradation increases in the early stages of development and decreases in the later stages. However, the studies uploaded indicate that the EKC is not always supported. Rahman et al. (2021) failed to confirm the EKC of BRICS economies, whereas Yilanci et al. (2023) found that GDP growth has an ecological footprint across all MINT countries. This undermines the premise that growth inherently generates environmental enhancement. Income growth in emerging economies may still increase environmental pressure as industrial growth, fossil-fuel consumption, and urbanization outpace technological upgrading and environmental governance. Therefore, the EKC should be considered a conditional hypothesis rather than a universal law of development (Umair et al., 2025; Rahman et al., 2021; Desket & Pata, 2023; Yilanci et al., 2023; Miao et al., 2025; Zafar et al., 2026).

Renewable vs non-renewable energy effects

The distinction between renewable and non-renewable energy is crucial, as aggregate energy consumption masks the conflicting environmental effects of these sources. Non-renewable energy, particularly coal, oil, and gas, directly contributes to emissions through combustion and indirectly maintains carbon-intensive production structures. Renewable energy is likely to reduce environmental degradation by reducing the intensity of carbon emissions in electricity, transport, and production. The empirical literature does not show a straightforward reduction in emissions from renewables.

There is fairly consistent evidence on non-renewable energy. In most quantiles, Oladipupo et al. (2022) found that the use of non-renewable energy sources contributes to environmental degradation in South Africa. The same evidence is found in Nigeria, where reliance on fossil fuels and insufficient electricity infrastructure drive households and firms towards carbon-intensive substitutes (Akadiri et al., 2022; Miao et al., 2025; Hamdoun et al., 2018; Rehman et al., 2023; Riaz et al., 2024; Safdar et al., 2026). The use of fossil fuels is repeatedly associated with deterioration in environmental quality, as evidenced by Turkey, where they contribute to increased CO_2 emissions (Yilanci et al., 2023). These results show that non-renewable energy remains the most direct pathway through which growth and globalization are translated into environmental degradation in emerging economies (Akadiri et al., 2022; Oladipupo et al., 2022).

The literature on renewable energy is more subtle. Some studies on MINT reviewed by Yilanci et al. (2023) found that renewable energy can reduce CO_2 emissions in both the short- and long-term. However, as Oladipupo et al. (2022) found, renewable energy did not consistently reduce emissions across all quantiles in South Africa. The counterintuitive finding that the use of renewable energy sources in China actually increased CO_2 emissions was also reported by Nsair and Alzubi (2025). These contradictions do not imply that the environmental value of renewables is invalid; rather, they show that renewable energy can enhance environmental quality only when it replaces fossil fuels on a large scale. Where renewables only complement the growing total energy demand, emissions can still increase despite the growth in clean energy (Sarkodie et al., 2020; Tariq et al., 2022; Zafar et al., 2025;

Muhammad et al., 2025; Khan et al., 2023).

Interaction between globalization and energy

A major limitation of the existing literature is that globalization and energy are examined as parallel determinants rather than interacting forces. Yet the environmental effect of globalization is likely mediated by the structure of energy consumption. Globalization may increase emissions as trade, FDI, and industrial integration expand energy-intensive, fossil-fuel-based production. Conversely, it may reduce emissions by enabling investment in renewable energy, adopting cleaner production technologies, improving energy efficiency, and implementing environmental regulations. The same process of globalization can therefore produce opposite environmental outcomes depending on whether the host economy's energy system is carbon-intensive or transition-oriented.

Rahman et al. (2021) found that globalization lowers emissions in BRICS. However, energy consumption escalates emissions, which is why globalization can be beneficial for the environment, though reliance on fossil fuels partially neutralizes these gains. Zhang et al. (2024) found that, in the short term, globalization reduced environmental degradation in South Africa through the dominant channel of fossil-fuel energy. Conversely, Oladipupo et al. (2022) found that both globalization and non-renewable energy contributed to the worsening of emissions in South Africa, suggesting that globalization can become an environmental problem when implemented in a fossil-fuel-intensive economy. Zenios (2024) also reached this conclusion in Nigeria, where both globalization and energy consumption contribute to increased degradation.

These studies suggest that globalization cannot be assessed without the energy structure, as environmental outcomes depend on whether it reinforces the expansion of fossil fuels is a transition to clean energy (Rafindadi & Usman, 2019; Rahman et al., 2021; Akadiri et al., 2022; Oladipupo et al., 2022; Safdar et al., 2022; Ahmad et al., 2024). This interaction has not empirically developed. Most studies include globalization and energy variables in a single model (Ozcan & Temiz, 2022; Shahbaz et al., 2023; Adebayo et al., 2026).

Although they have not explicitly tested whether the energy composition moderates the relationship between globalization and the energy environment, most studies examine globalization using KOF indices, trade openness, or FDI. However, few examine how global integration encourages renewable investment or expands fossil-fuel-based production. This exclusion is critical to MINT economies, as these nations are also open to trade, investment, urbanization, and increased energy demand. The literature risks overstating the independent effect of each variable and understating the structural pathway through which environmental degradation occurs (Dai et al., 2025; Raihan et al., 2023; Akusta, 2026).

The Experience in the emergent and MINT economies

The evidence on emerging economies is helpful, as they face the most trade-offs among growth, energy security, and environmental sustainability. The BRICS (Gao et al., 2024; Awosusi, 2022), ASEAN (Zenios, 2024), South Africa (Smaoui, 2025; Oladipupo et al., 2022), Nigeria (Akadiri et al., 2022), China (Nsair & Alzubi, 2025) and MINT (Udo et al., 2025a, 2025b; Adebayo et al., 2022; Aziz et al., 2021; Bekun et al., 2025) that the interaction of the growth of income, globalization, energy dependency, urbanization, and the capacity of the institutions determine the environmental outcomes. However, the results are not applied to blocks. The evidence of BRICS shows that globalization can reduce emissions, evidence in Nigeria and South Africa indicates that it increased degradation, evidence in the ASEAN region shows that it have an indirect or weak energy effect, and evidence in China highlights the paradox of renewable expansion and rising emissions (Udo et al., 2024; Rahman et al., 2021; Akadiri et al., 2022; Oladipupo et al., 2022; Zenios, 2024; Nsair & Alzubi, 2025; Jamal et al., 2024; Ullah et al., 2023; Shahid et al., 2025). The MINT economies, Mexico, Indonesia, Nigeria, and Turkey, are especially significant as they have a high potential for growth, large populations, strategic geography, and strong investment prospects. Yilanci et al. (2023) highlight that MINT economies are likely to become increasingly important in the global economy because of their large markets, young labor forces, and geographic advantages. However, this potential growth is ecologically weak because it is directly linked to energy consumption. They discovered that GDP leads to higher ecological footprints across all four MINT economies; energy consumption increases ecological footprints in Indonesia and Turkey; FDI worsens ecological footprints in Indonesia; and urbanization has country-specific effects. These observations suggest that MINT economies are not treated as a uniform bloc; their environmental trajectories differ according to their energy mixes, urbanization levels, production models, and investment patterns (Yilanci et al., 2023). Similar past studies that were MINT-oriented also reveal serious contradictions. Some evidence suggests the EKC is valid in some MINT countries, though other studies have either dismissed it or found it valid only in some cases. Nathaniel and Adedoyin (2021) studied that evidence of the EKC was found in Mexico and Turkey, but not in Nigeria and Indonesia. Other MINT studies reviewed by Yilanci et al. (2023) report that trade has an ecological footprint in multiple countries, that renewable energy has decreased emissions in several countries, and that fossil-fuel use has increased emissions. These conflicting results point to the fact that the MINT literature has not yet consistently explained how globalization and energy interact to contribute to environmental degradation. The evidence is hopeful but not comprehensive; it identifies the important drivers. However, it did not provide a comprehensive explanation of the dual role of globalization and energy as both sources of degradation and of sustainability (Yilanci et al., 2023).

Literature Gap

The literature has made significant progress, but several gaps remain unaddressed. First, there is no unanimous consensus on whether globalization has a positive or negative effect on the environment. The evidence ranges from emissions-reducing effects in BRICS to emissions-increasing effects in Nigeria, South Africa, and China. This inconsistency suggests that the impact of globalization is conditional rather than universal. However, many studies continue to treat it as an independent variable rather than a mechanism that operates through energy systems, sectoral change, and institutions. Second, the energy literature is more likely to confirm the harmful effects of fossil fuel consumption but is less decisive about the benefits of renewable energy. There is a common belief that renewable energy will positively affect the environment. However, empirical evidence shows that this impact can be weak, asymmetric, or even positive on the emissions front when renewable expansion is not used to replace fossil fuels. This generates a serious policy distinction: an energy transition is not the same as adopting renewable energy unless the transition decreases the portion and intensity of non-renewable energy. Third, MINT-specific evidence is not yet well-integrated. The existing literature on MINT focuses on ecological footprint, GDP, energy consumption, FDI, urbanization, trade, and renewable energy, yet globalization is not placed at the center of the analysis. In the meantime, the study of the globalization-energy-environment nexus is too BRICS-centric, i.e., it focuses on South Africa, Nigeria, ASEAN, or China as opposed to the MINT bloc. It leaves a conceptual and empirical gap at the intersection of globalization, renewable and non-renewable energy, and environmental degradation in Mexico, Indonesia, Nigeria, and Turkey. The obvious research gap is thus the lack of a MINT-oriented study that jointly analyzes the forces of globalization and energy as drivers of both degradation and sustainability. The globalization of the global economy enhances or worsens environmental quality, and renewable energy may or may not do so, depending on whether dependence on fossil fuels is maintained. However, these insights have not been properly synthesized into a coherent MINT framework that considers energy composition, exposure to globalization, heterogeneous country dynamics, and long-run sustainability implications. This research is warranted since MINT economies are in a critical position in the emerging-market development environment: they are growth-oriented, globalization-exposed, energy-dependent, and environmentally vulnerable. The research can help answer whether these economies are still caught in the trap of degradation-intensive growth or can redirect global integration and the energy transition towards sustainable development by examining the dual role of globalization and energy.

Methodology

Data Sources

This study uses balanced panel data from MINT countries, including Mexico, Indonesia, Nigeria, and Turkey, over the period 1993 to 2024. Table 1 presents the variable descriptions, data sources, and measurements.

Table 1: Variable Description

Variable	Symbol	Measurement	Source
Load Capacity Factor	lnLCF	Ratio of bio capacity to ecological footprint	Global Footprint Network
Globalization	lnGLOB	KOF Globalization Index	KOF Institute
Information Technology	lnICT	Internet users (% of population)	WDI
Economic Growth	lnGDP	GDP per capita (current US$)	
Energy Consumption	lnEnergy	Energy use (kg of oil equivalent per capita)	

Model Specification

The baseline model is specified as:

$$lnLCF_{it}=\alpha + \beta_1 lnGLOB_{it} + \beta_2 lnICT_{it} + \beta_3 lnGDP_{it} + \beta_4 lnEnergy_{it} + \varepsilon_{it}$$

Where i represent country and t denotes time period and ε_{it} captures unobserved factor affecting environmental sustainability, such as policy differences, institutional quality, or technological variation.

Estimation Strategies

The study follows a step-by-step approach: testing for CSD, heterogeneity, and stationarity, followed by cointegration analysis. Based on these results, appropriate estimators are applied for short and long-run analysis. Figure 2 illustrate the stepwise methodological procedure adopted in this study.

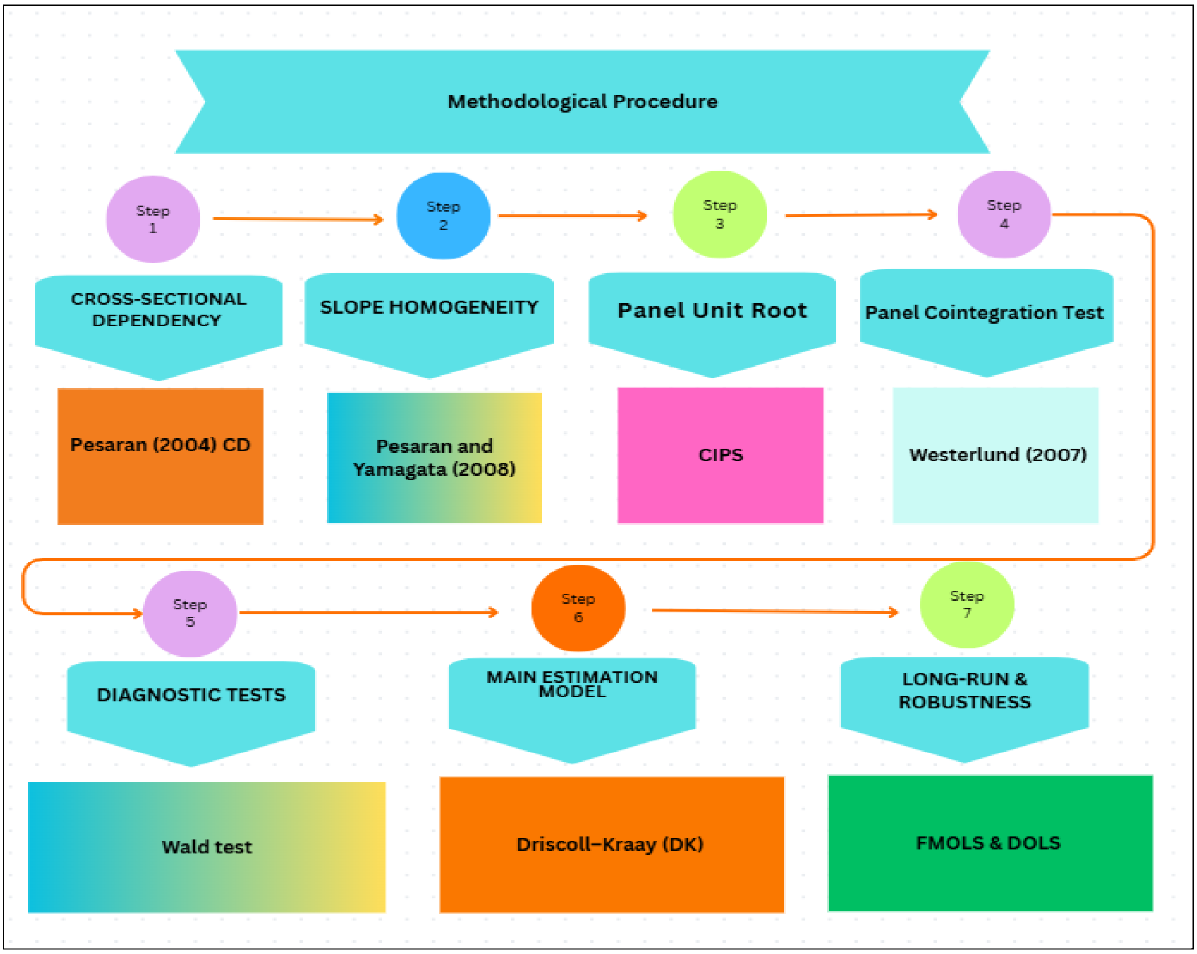

Figure 2: Empirical Strategies

Cross-sectional dependency

The CSD is applied Pesaran (2004)

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{J=i+1}^{N} \hat{\rho}_{ij}$$

The tests investigate whether the countries are interdependent. The test results confirmed the presence of CSD.

Slope of Heterogeneity

To uses the slope heterogeneity by Pesaran and Yamagata (2008).

$$\Delta = \sqrt{N}\left(\frac{\hat{S}-k}{\sqrt{2k}}\right)$$

The slope coefficient across countries is checked through this test. The outcomes show heterogeneity.

Diagnostic test (Heteroscedasticity)

Heteroscedasticity is tried assumed the modified form of the Wald Test:

$$H_0: \sigma_i^2 = \sigma^2$$

The H_0 is rejected, showing the non-constant variance among panels.

Cointegration Test (CIPS)

To measure for CSD, the CIPs test (Pesaran, 2007) is applied:

$$\text{CIPS} = \frac{I}{N}\sum_{i=1}^{N} \text{CADF}_i$$

The outcomes indicate I (0) and I (1) [Mixed-Integrated order].

Westerlund Cointegration Test

The LR-relationship is check to use Westerlund (2007)

$$\Delta y_{it} = a_i + \beta_i(y_{it-1} - \theta_i x_{it-1}) + \sum \gamma_{ij}\,\Delta y_{it-j} + \sum \delta_{ij}\,\Delta x_{it-j} + \epsilon_{it}$$

The cointegration presence if $\beta_i < 0$. The outcomes confirm a LR-relationship.

Main Model (Driscoll-Kraay)

The aforementioned the heteroscedasticity and CS, **DK-Approach** is used

$$\hat{\beta}_{DK} = (X'X)^{-1}X'Y$$

The approach offers robust SE in the existence of CSD and heteroscedasticity.

Long-Run (FMOLS)

The approach corrects for endogeneity and serial correlation

$$\hat{\beta}_{FMOLS} = (\sum X_i'X_i)^{-1} = (\sum X_i'Y_i^*)$$

Robustness check (DOLS)

$$Y_{it} = \alpha + \beta X_{it} + \sum_{k=-q}^{q} \gamma_k \Delta\, X_{it-k} + \varepsilon_{it}$$

This ensures robustness of long-run estimates.

Results and Discussion

This section reports the findings and their discussion. The descriptive statistics provides the basic knowledge about the dataset (Gul et al., 2023; Table 1 presents the Descriptive statistics, which indicate that the mean value of LCF (-0.49) indicates relatively low environmental quality across MINT economies. The SD indicates moderate variability, specifically for ICT, reflecting uneven digital development. Moreover, the correlation matrix in Table 2 indicates that globalization, GDP, ICT, and energy are negatively correlated with LCF. Notably, GDP and ICT exhibit a strong negative interconnection, suggesting that economic development and digitalization may initially enhance environmental pressure. These preliminary outcomes are consistent with the EKC hypothesis.

Table 1: Descriptive Statistics

Variable	Observation	Mean	SD	Min	Max
lnLCF	128	-0.49	0.272	-0.904	0.206
lnGLOB	128	4.072	0.136	3.664	4.263
lnICT	128	1.732	2.67	-6.849	4.469
lnGDP	128	8.415	0.749	7.237	9.642
lnEnergy	128	6.705	0.673	5.549	7.563

Table 2: Correlation Matrix

Variable	(1)	(2)	(3)	(4)	(5)
(1) lnLCF	1.000				
(2) lnGLOB	-0.384	1.000			
(3) lnICT	-0.577	0.701	1.000		
(4) lnGDP	-0.745	0.729	0.643	1.000	

(5) lnEnergy	-0.452	0.784	0.399	0.843	1.000

Before estimation, the CSD test presented in Table 3 strongly rejects the null hypothesis of independence. This implies that shocks in one country affect others, reflecting the interconnected nature of the selected sample. Similarly, Table 4 reports slope heterogeneity, confirming that coefficients differ across countries and indicating heterogeneous responses to globalization, ICT, and GDP. Figure 3 further illustrates the SH across the panel. Moreover, Table 5 reports the Modified Wald test results, confirming the presence of heteroscedasticity. These results indicate that variance is not constant across panels, further justifying the use of robust estimation techniques. Therefore, to address these issues, the Drscoll-Kraay estimator is employed, as it provides robust, reliable estimates in the presence of such panel data problems.

Table 3: CD Test

Variables	CD statistic	p-value
lnLCF	10.649***	0.000
lnGLOB	11.109***	0.000
lnICT	12.928***	0.000
lnGDP	10.620***	0.000
lnEnergy	3.525***	0.000

Table 4: Slope Heterogeneity (SH)

	Delta	3.603***
	Adj. Delta	3.997***
H0: slope coefficients are homogenous		

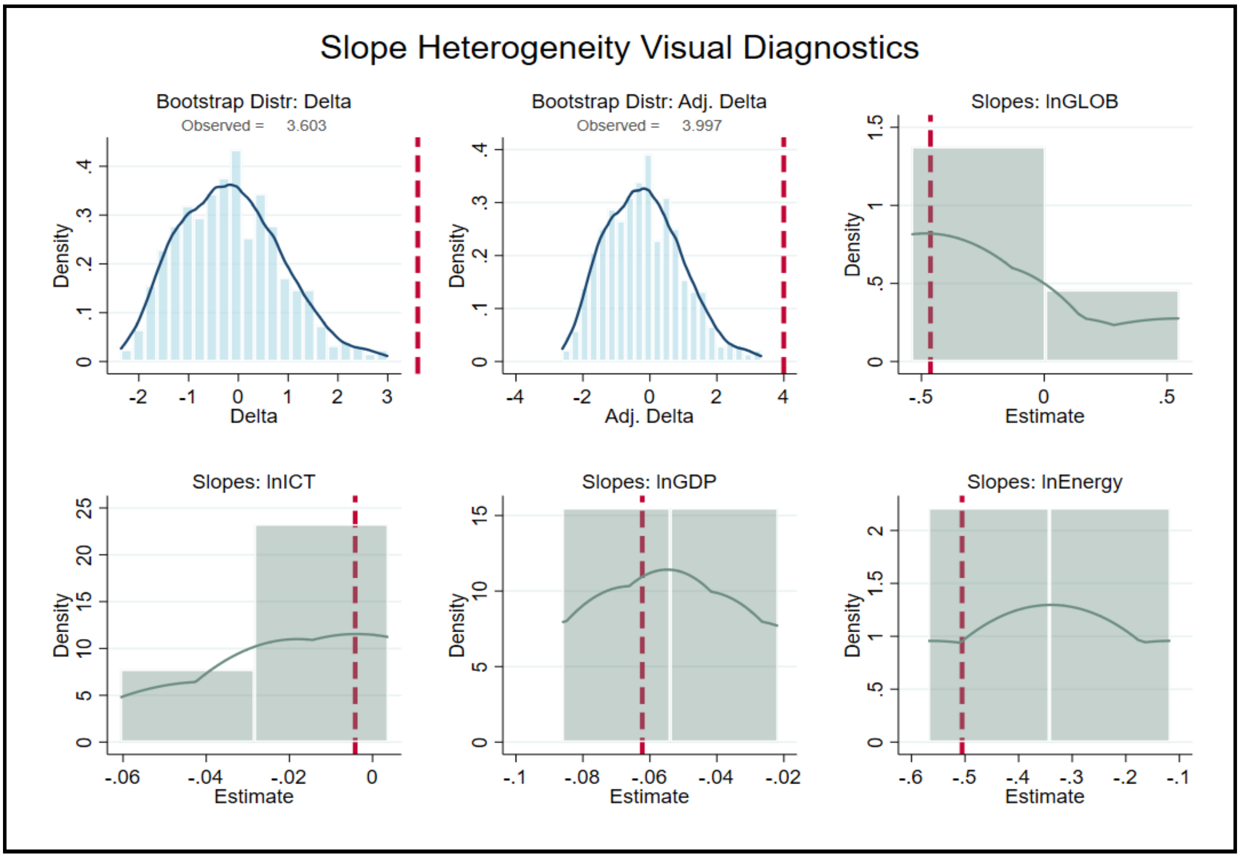

Figure 3: Slope Heterogeneity Visualization

Table 5: Diagnostic Test

Heteroscedasticity Test (Modified Wald Test)		
Test	statistic	decision
chi2 (4)	45.75	Exist
Prob > chi2	0.000	

To ensure the stationarity of the study variables, the CIPS 2nd –generation cointegration test is used, as reported in Table 6. The findings reveal a mixed order of integration, which justifies the use of 2nd-generation panel techniques that account for CSD. Moreover, Table 7 reports Westerlund (2007) cointegration results. The significance of the Gt and Pt statistics provides strong evidence of long-run interplay between the variables, confirming that all explanatory variables are cointegrated with the dependent variable.

Table 6: Unit Root Test

CIPS			
Variable	level	1st-diff	Decision
lnLCF	-3.562***	-6.218***	
lnGLOB	-2.843**	-5.615***	I(0)
lnICT	-2.792*	-5.547***	
lnGDP	-2.508	-5.631***	I(1)
lnEnergy	-2.306	-5.121***	

*Note: ***, **, * denotes significance at 1%, 5%, and 10% levels, respectively; critical values are −3.06 (1%), −2.84 (5%), and −2.73 (10%); the CIPS test includes both constant and trend.*

Table 7: Westerlund Cointegration test

statistic	value	p-value
Gt	-1.750	0.006***
Ga	-5.319	0.997
Pt	-3.900	0.017**
Ga	-5.393	0.864

Table 8 reports the baseline results using the DK estimator, which accounts for CSD, SH, and heteroscedasticity. The findings indicate that globalization has a negative, weakly significant effect on LCF, suggesting that increased global integration initially reduces LCF. These findings reflect the pollution haven hypothesis, which holds that developing countries attract environmentally risky production activities. This study aligns with the work of Shahbaz et al. (2015) and Ahmed et al. (2022). The effects of ICT on LCF are negative and significant, showing that digital development increases environmental pressure for higher energy demand and electronic waste. These results align with those of Zhang et al. (2019) and Salahuddin et al. (2016). Similarly, GDP hurts LCF, supporting the early stage of the EKC hypothesis, in which growth intensifies environmental degradation. The result is consistent with that of Bekun et al. (2019). Likewise, energy consumption negatively affects LCF, confirming that fossil-fuel-based energy use significantly reduces environmental quality. The study aligns with Apergis and Payne (2014) and Dong et al. (2018). These consequences intensify the view that MINT economies are currently in a resource-intensive, environmentally unsustainable phase of development.

Table 9 reports long-run FMOLS findings, indicating a clear shift in the effects of globalization and energy utilization. Globalization becomes positive and significant, showing that over time, it improves environmental quality through technological transfer and efficiency gains. This study aligns with Destak and Sarkodie (2019) and Ahmed et al (2022). Similarly, turning energy use positive signifies that improvements in energy efficiency and the adoption of cleaner energy support sustainability. In contrast, ICT and GDP remain negative and significant, indicating that digitalization and economic development continue to exert long-term environmental pressure. Finally, we applied the DOLS model for a robustness check. The findings are consistent with those of FMOLS, confirming the reliability and stability of long-run estimates. The consistency between the two models strengthens the robustness of the study and confirms the stable long-run interconnectedness. Collectively, these findings reveal a clear short-run divergence. While lnGLOB and energy utilization initially harm environmental quality, they become beneficial in the long run because of technological development and efficiency gains. In contrast, ICT and GDP consistently exert environmental pressure, signifying that MINT economies remain in a transitional phase toward sustainable development. Figure 4 presents long-run elasticities estimated using FMOLS, while figure 5 results obtained from the DOLS estimator.

Table 8: Regression with Driscoll-Kraay (DK) standard errors

Method: Fixed-effects regression			
Variable	Coefficient	SE (t-value)	p-value
lnGLOB	-0.314*	0.162(-1.950)	0.061
lnICT	-0.014**	0.005(-2.740)	0.010
lnGDP	-0.047***	0.0119(-4.180)	0.000
lnEnergy	-0.465***	0.057(-8.150)	0.000
Constant	4.319***	0.783(5.520)	0.000

***, **, * denotes significance at 1%, 5%, and 10% levels, respectively.

Table 9: Long Run Estimation Results (FMOLS)

Variable	Coefficient	SE	p-value
lnGLOB	0.650***	0.131	0.000
lnICT	-0.030***	0.005	0.000
lnGDP	-0.819***	0.036	0.000
lnEnergy	0.619***	0.044	0.000
Constant	-0.34	0.451	0.439

***, denote significance at 1%, levels.

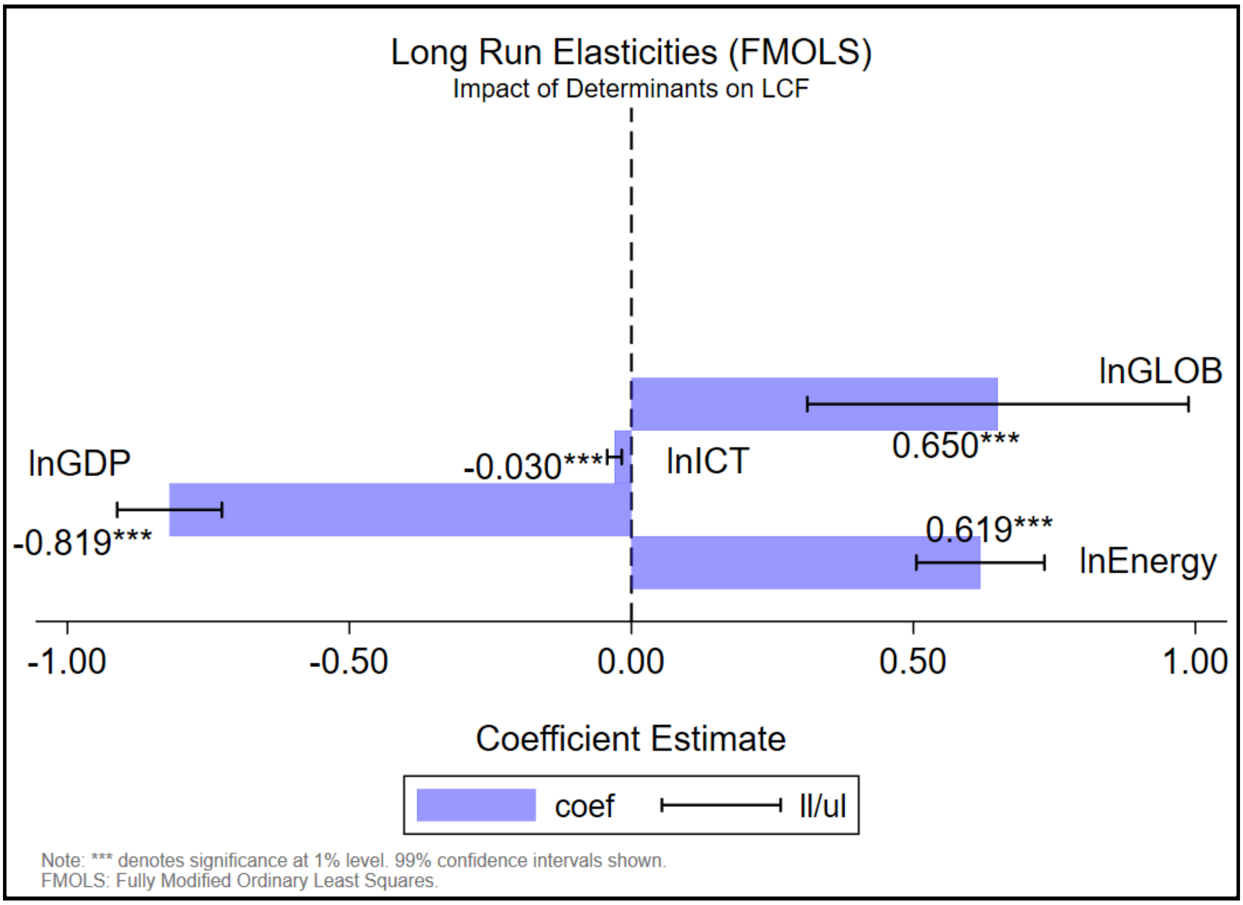

Figure 4: FMOLS Long-Run Elasticities

Table 10: Robustness DOLS

Variable	Coefficient	SE	p-value
lnGLOB	0.739***	0.229	0.001
lnICT	-0.030***	0.009	0.001
lnGDP	-0.810***	0.057	0.000
lnEnergy	0.591***	0.071	0.000
Constant	-0.598	0.797	0.453

***, denote significance at 1%, levels.

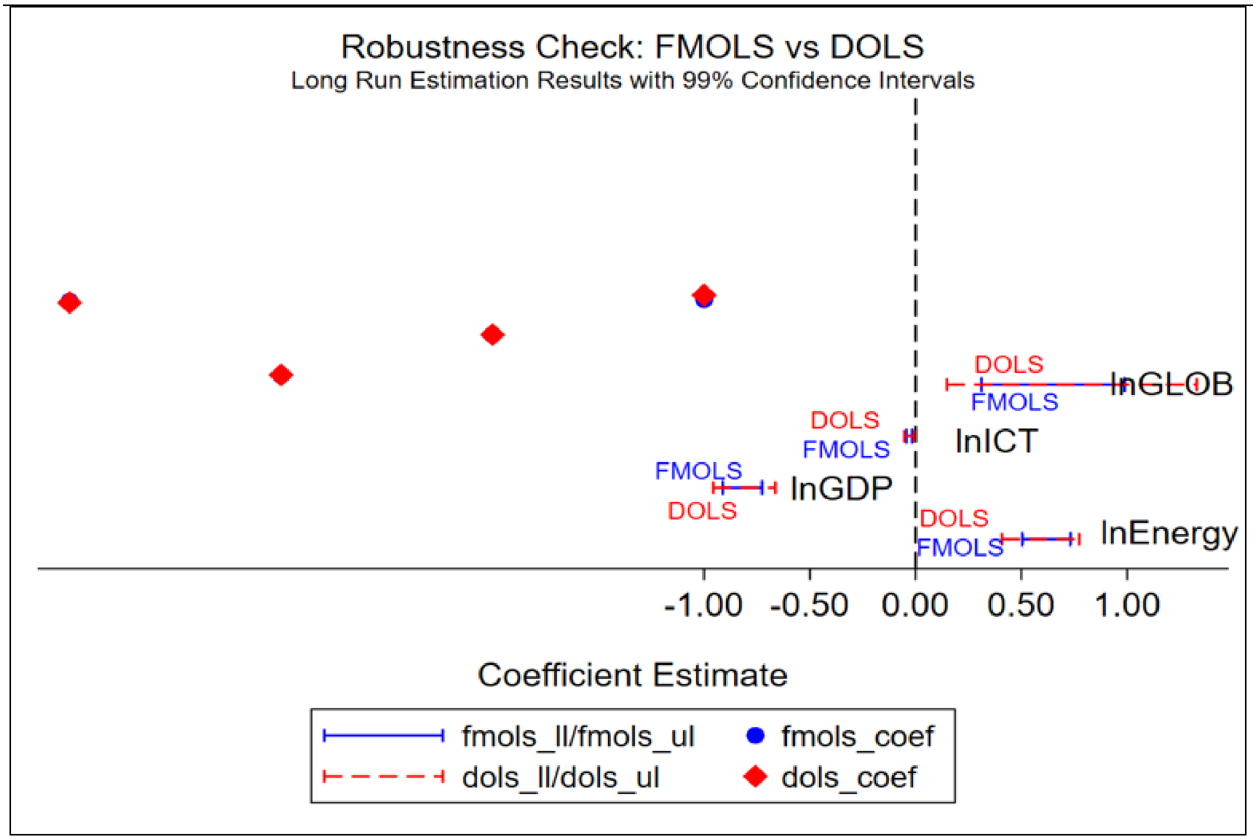

Figure 5: Robustness check (FMOLS &DOLS)

Conclusion

This study examines the roles of globalization, energy use, information technology, and economic growth in shaping environmental sustainability in MINT economies. Using the load capacity factor as a sustainability indicator, the study analyzes annual panel data from 1993 to 2024. The empirical approach applies second-generation panel methods, including cross-sectional dependence, slope heterogeneity, CIPS unit-root tests, and Westerlund cointegration tests, followed by Driscoll-Kraay, FMOLS, and DOLS estimators. The study findings show that globalization, ICT, economic growth, and energy consumption initially decrease the load capacity factor, indicating pressure on environmental quality. However, in the long term, globalization and energy consumption become sustainability-enhancing, and ICT and economic growth continue to weaken ecological capacity. According to the Driscoll-Kraay estimates, globalization, ICT, GDP, and energy consumption reduce the load capacity factor in the base model, meaning that current trends in global integration, digital expansion, income growth, and energy consumption put pressure on ecological sustainability. The long-run results convey a subtler meaning.

The FMOLS and DOLS estimates indicate that globalization can contribute to long-run sustainability by facilitating technology transfer, increasing efficiency, and improving production quality. The long-run energy consumption is also positive, implying that energy use can promote environmental sustainability when accompanied by efficiency improvements and the adoption of cleaner energy sources. However, ICT and economic growth are negative and significant, showing that digitalization and income growth in MINT economies continue to occur through resource-intensive channels. These findings show that the process of degradation towards sustainability is only partially successful: globalization and energy can improve the ecological situation in the long run, whereas ICT and GDP only increase ecological pressure.

The policy implications are evident. MINT economies should not aim to globalize, digitalize, grow, and expand energy without protecting the environment. Green investment, technology transfer, and stringent environmental standards should be associated with globalization policies. The energy policy must focus on renewable energy, energy efficiency, grid modernization, and less reliance on fossil fuels. The negative effects of ICT mean the need for green digital infrastructure, renewable-powered communication systems, and effective e-waste management. Similarly, the negative long-run effect of GDP suggests that MINT countries' growth policies should be revised to emphasize resource efficiency, environmentally friendly industrialization, and environmental resilience. Theoretically, this paper shows that globalization and energy can be both beneficial and detrimental, depending on the time horizon and the structure. It defines the load capacity factor as a more general measure of sustainability. It bears witness to the architecture of combined policies in trade, technology, growth, and energy systems. The study has its limitations: it uses an aggregate measure of energy use and uses internet users as a proxy for ICT.

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