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Carbon Intensity, Renewable Energy Consumption and SDG8 – Decent Work and Economic Growth in MINT Countries

Zrównoważona Intensywność emisji dwutlenku węgla, zużycie energii odnawialnej i SDG8 – godna praca i wzrost gospodarczy w krajach MINT

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Abstract
This study investigates the interplay between carbon intensity, renewable energy consumption, and SDG 8 – Decent Work and Economic Growth in the MINT countries (Mexico, Indonesia, Nigeria, and Turkey) over 2000–2023, encompassing pre-, during-, and post-COVID-19 periods. Employing a multi-method empirical strategy, the analysis combines Panel Autoregressive Distributed Lag (PARDL) within the Pooled Mean Group framework, country-level Fixed Effects (FE) estimation, and Method-of-Moments Quantile Regression (MM-QR) to capture short- and long-run dynamics, country-specific heterogeneity, and distributional effects. Results reveal marked heterogeneity across countries and periods. Long-run PARDL estimates indicate that GDP per capita and carbon intensity are primary drivers of SDG 8, while energy use and renewable energy exert nuanced effects. COVID-19 interactions highlight that both carbon-intensive and renewable sectors temporarily stabilised employment and growth. FE and MM-QR results show Mexico and Turkey benefited from positive linkages between renewable energy adoption and SDG 8, whereas Indonesia and Nigeria faced weaker or negative associations, reflecting structural and policy constraints. Quantile analyses further demonstrate that lower-performing economies are more vulnerable to the adverse effects of carbon-intensive activities and less able to translate renewable energy investments into decent work gains. Structural break tests confirm the pandemic as a regime-shifting event, altering the impact of growth, energy use, and carbon intensity on SDG 8. This study contributes to the literature by integrating dynamic, country-specific, and distributional perspectives on the energy–growth–employment nexus, providing actionable insights for policies that promote inclusive, low-carbon, and resilient economic development in MINT economies.

Key words: carbon intensity, renewable energy, economic growth, SDG 8, MINT countries

Streszczenie
W niniejszym badaniu analizuje się wzajemne oddziaływanie między intensywnością emisji dwutlenku węgla, zużyciem energii odnawialnej a realizacją SDG 8 – Godna praca i wzrost gospodarczy w krajach MINT (Meksyk, Indonezja, Nigeria i Turcja) w latach 2000–2023, obejmujących okresy przed, w trakcie i po pandemii COVID-19. Wykorzystując wielometodową strategię empiryczną, analiza łączy metodę Panel Autoregressive Distributed Lag (PARDL) w ramach metody Pooled Mean Group, estymację efektów stałych (FE) na poziomie kraju oraz regresję kwantylową metodą momentów (MM-QR), aby uchwycić dynamikę krótko- i długoterminową, heterogeniczność w poszczególnych krajach oraz efekty dystrybucyjne. Wyniki ujawniają wyraźną heterogeniczność między krajami i okresami. Długoterminowe szacunki PARDL wskazują, że PKB per capita i intensywność emisji

dwutlenku węgla są głównymi czynnikami napędzającymi SDG 8, podczas gdy zużycie energii i energia odnawialna wywierają bardziej złożone skutki. Interakcje z COVID-19 podkreślają, że zarówno sektory wysokoemisyjne, jak i odnawialne tymczasowo ustabilizowały zatrudnienie i wzrost. Wyniki FE i MM-QR pokazują, że Meksyk i Turcja odniosły korzyści z pozytywnych powiązań między wdrażaniem energii odnawialnej a SDG 8, podczas gdy Indonezja i Nigeria odnotowały słabsze lub negatywne powiązania, co odzwierciedla ograniczenia strukturalne i polityczne. Analizy kwantylowe dodatkowo pokazują, że gospodarki o niższej wydajności są bardziej podatne na negatywne skutki działalności wysokoemisyjnej i mają mniejsze możliwości przełożenia inwestycji w energię odnawialną na korzyści w zakresie godnej pracy. Testy strukturalne potwierdzają, że pandemia jest wydarzeniem modyfikującym wpływ wzrostu gospodarczego, zużycia energii i intensywności emisji dwutlenku węgla na SDG 8. Niniejsze badanie wnosi wkład do literatury poprzez integrację dynamicznych, specyficznych dla poszczególnych krajów i perspektyw dystrybucyjnych dotyczących powiązań między energią, wzrostem gospodarczym i zatrudnieniem, dostarczając praktycznych wniosków na potrzeby polityk promujących inkluzywny, niskoemisyjny i odporny rozwój gospodarczy w krajach MINT.

Słowa kluczowe: intensywność emisji dwutlenku węgla, energia odnawialna, wzrost gospodarczy, SDG 8, kraje MINT

1. Introduction

The accelerating tension between economic expansion and environmental sustainability has emerged as one of the defining policy challenges of the twenty-first century. For emerging economies such as Mexico, Indonesia, Nigeria, and Turkey (collectively referred to as the MINT countries), this tension is particularly acute as they strive to achieve sustained economic growth and employment generation while confronting rising carbon emissions. The industrialisation processes that underpin their growth trajectories remain heavily dependent on fossil fuels, resulting in elevated carbon intensity and ecological stress (Zhao et al., 2025). This dynamic reflects what Bekun et al. (2024) describe as a persistent *growth–sustainability paradox*, in which the pursuit of prosperity deepens environmental degradation. The Environmental Kuznets Curve hypothesis, which predicts that environmental harm initially increases and later declines with income, remains largely unfulfilled in these economies, where structural dependence on carbon-intensive production and weak institutional enforcement continue to constrain the transition toward low-carbon development (Okogor et al., 2025).

Amid this challenge, renewable energy has emerged as a strategic lever for achieving a balance between industrial expansion, carbon reduction, and decent work. Evidence from emerging economies indicates that renewable energy enhances energy efficiency, stimulates technological innovation, and contributes to economic resilience. Bekun et al. (2024) find that a 1% rise in renewable energy utilisation can improve load capacity by 0.70%, while Rahman et al. (2022) show that renewable energy consumption decreases carbon intensity by approximately 0.003 units. These findings affirm the role of renewable energy as both a climate mitigation mechanism and a catalyst for inclusive growth aligned with Sustainable Development Goal 8 (SDG 8). Similarly, Osabohien et al. (2024) demonstrate that clean energy investments can significantly enhance labour productivity and employment, suggesting that renewable energy transitions can drive both environmental sustainability and decent work creation. Yet, MINT economies continue to face persistent barriers such as financing gaps, policy incoherence, and uneven technological readiness (Isah et al., 2023; Ofori et al., 2023), which limit the transformative potential of renewable energy in achieving inclusive economic development.

The COVID-19 pandemic introduced an additional layer of complexity to this nexus. It temporarily reduced carbon emissions while simultaneously exposing structural weaknesses in labour markets and energy systems. Zhao et al. (2025) and Okogor et al. (2025) identify the pandemic as a structural break that redirected global policy attention toward integrating environmental and employment priorities. Empirical evidence from Abdullah et al. (2023) further shows that renewable energy investments remained resilient despite the downturn, underscoring their potential as stabilising forces in post-pandemic recovery. For the MINT bloc, where economic vulnerabilities were amplified by limited fiscal capacity, green recovery policies offer an opportunity to accelerate decarbonisation while fostering employment creation and industrial diversification.

Against this backdrop, this study seeks to analyse the interplay between carbon intensity, renewable energy consumption, and SDG 8 in the MINT countries, focusing on pre-, during-, and post-COVID-19 dynamics. Specifically, it examines (i) the trends of carbon intensity and SDG 8 indicators, (ii) the impact of carbon intensity on the achievement of SDG 8, (iii) the role of renewable energy in moderating carbon intensity and supporting economic growth, and (iv) the interactions between renewable energy, carbon intensity, and SDG 8 performance. Accordingly, the research is guided by the following questions: How have SDG 8 indicators reflecting economic growth and decent work evolved before, during, and after the pandemic? What is the impact of carbon intensity on SDG 8 in MINT economies? To what extent does renewable energy consumption influence carbon intensity and the achievement of SDG 8? And how do the interactions between renewable energy and carbon intensity shape sustainable economic growth and employment outcomes in these countries?

The study addresses a notable gap in the literature. While previous research has examined the independent effects of renewable energy or carbon emissions on economic performance, few studies have integrated these dimensions with SDG 8 outcomes in a comparative, country-specific framework for MINT economies. Moreover, empirical analyses capturing the structural and temporal shifts induced by COVID-19 remain limited. By situating this investigation within the pre-, during-, and post-pandemic contexts, the study extends existing knowledge on how external shocks reshape the nexus between energy transition, carbon intensity, and labour-market dynamics.

The contribution of this research is twofold. Theoretically, it advances the discourse on sustainable development by integrating environmental and employment dimensions within the frameworks of the Environmental Kuznets Curve and decoupling theory, offering a nuanced understanding of how green transitions interact with growth trajectories in emerging economies. Practically, it provides evidence-based insights for policymakers in MINT countries to design strategies that synchronise renewable energy deployment, industrial diversification, and labour-market reforms. In doing so, the study supports the global agenda for achieving SDG 8 and SDG 13 through a model of low-carbon, employment-rich growth that is both economically viable and environmentally sustainable.

2. Literature review

2.1. Carbon intensity, industrialisation and sustainable economic growth

The relationship between carbon intensity, industrialisation, and sustainable economic growth continues to dominate policy debates across emerging economies, especially those within the MINT bloc that are seeking to balance rapid development with environmental sustainability. The interaction between these forces reflects a complex and non-linear trajectory, where industrial expansion and energy use contribute simultaneously to economic growth and environmental degradation. Zhao et al. (2025) emphasise that rising GDP per capita in developing contexts often correlates with increasing carbon emissions, illustrating a persistent growth–sustainability paradox that challenges progress toward low-carbon industrialisation. These dynamic echoes the Environmental Kuznets Curve (EKC) hypothesis, which suggests an inverted-U relationship between income growth and environmental degradation. However, Bekun et al. (2024) and Okogor et al. (2025) show that for most emerging economies, including MINT members, the turning point of the EKC remains elusive due to structural dependence on fossil fuels, inefficient production systems, and weak institutional enforcement of environmental regulations.

Empirical evidence underscores that energy intensity remains a critical driver of emissions. Rahman et al. (2021) find a strong positive correlation between energy intensity and carbon emissions, suggesting that industrialisation in its current form continues to exacerbate ecological pressure rather than relieve it. Within the MINT countries, rapid industrial growth and increasing energy demand reinforce this trajectory. Although renewable energy adoption has accelerated in recent years, Bekun et al. (2024) note that its contribution remains insufficient to counterbalance the environmental impact of fossil energy use. The consequence is a structural dependency on carbon-intensive production systems that deepens with economic growth, particularly in economies with limited technological capacity and weak institutional frameworks.

Luan et al. (2025) provide further evidence that industrialisation can contribute positively to sustainable development when combined with renewable energy adoption and strong governance. Using a System GMM framework, they demonstrate that manufacturing value added enhances sustainable development outcomes when embedded within clean energy transitions. These findings complement those of Wen et al. (2022), who argue that technological innovation particularly in information and communication technologies, plays a decisive role in reducing carbon intensity by improving production efficiency and enabling digital monitoring of emissions. Similarly, Ofori et al. (2023) highlight the importance of financial development, trade policy coherence, and good governance as institutional enablers of green transformation.

The combined insights from these studies indicate that the MINT economies are at a critical juncture where sustained growth must be reconciled with decarbonisation imperatives. Osabohien et al. (2025) and Zheng et al. (2023) both confirm that renewable energy, when effectively integrated into industrial systems, enhances productivity and employment while reducing emissions. However, the persistence of carbon-intensive industrialisation threatens to undermine these long-term sustainability goals. The literature thus converges on the view that achieving low-carbon development in MINT countries requires coordinated strategies that combine renewable energy expansion, technological advancement, institutional reform, and social inclusion. Strengthening governance structures, fostering innovation, and investing in green infrastructure remain pivotal to ensuring that industrialisation enhances economic resilience without intensifying ecological vulnerability.

2.2. Renewable energy transition and inclusive employment outcomes

The renewable energy transition has become a cornerstone of sustainable development policy in emerging economies, offering a dual pathway to environmental sustainability and inclusive employment creation. Osabohien et al. (2024) demonstrate that improvements in energy efficiency can directly enhance labour productivity while reducing greenhouse gas emissions, strengthening the synergy between SDG 7 (Affordable and Clean Energy) and SDG 8 (Decent Work and Economic Growth). Their analysis of Nigeria's Energy Transition Plan reveals that a well-coordinated shift toward renewable energy could reduce national emissions by up to 90% by 2050 and generate nearly five million jobs by 2030 if supported by adequate financing and institutional commitment. This underscores the transformative potential of renewable energy to simultaneously tackle unemployment, energy poverty, and environmental degradation in the MINT economies.

Complementary evidence shows that renewable energy adoption enhances economic efficiency and long-term sustainability. Bekun et al. (2024) find that a 1% increase in renewable energy utilisation improves load capacity by 0.70%, demonstrating its contribution to energy system productivity. Rahman et al. (2022) further reveal that renewable energy consumption reduces carbon intensity by 0.003 units per incremental increase, while Adebayo and Ağa (2022) confirm that green energy strategies significantly lower CO_2 emissions across developing economies. Together, these findings establish renewable energy as both a climate mitigation tool and a driver of inclusive economic expansion. Luan et al. (2025) corroborate this by showing that renewable energy, when aligned with industrialisation and strong governance, enhances sustainable development outcomes, while Zheng et al. (2023) report that renewable energy consumption fosters sustainability when supported by coherent policies and institutional oversight.

Empirical evidence also points to renewable energy's employment potential. Drawing from BRICS economies, Hlongwane and Khobai (2025) estimate that hydropower expansion generates 0.78–2.06% job growth, while solar energy can increase employment by as much as 1.99–9.60%, demonstrating the labour-intensive potential of renewable technologies. Bekun et al. (2024) reinforce this by showing that renewable investments not only mitigate emissions but also strengthen economic resilience when integrated within broader industrial frameworks. However, the realisation of these benefits remains contingent on institutional capacity, technological readiness, and access to sustainable financing.

Despite these gains, MINT economies face structural barriers that impede renewable energy deployment. Financing constraints persist as a critical challenge Isah et al. (2023) highlight that weak financial intermediation and limited access to climate finance continue to restrict investment flows into low-carbon technologies, particularly in Nigeria. Technological readiness also remains uneven, with Ofori et al. (2023) reporting that innovation outcomes yield inconsistent environmental benefits due to limited diffusion capacity and fragmented policy support. Additionally, policy incoherence and regulatory uncertainty weaken investor confidence, stalling the pace of energy transition. Falcone (2023) recommends adaptive strategies that integrate financial innovation, institutional reform, and capacity-building measures to accelerate renewable deployment and ensure inclusivity in the transition process.

Collectively, the reviewed studies affirm that renewable energy can serve as a catalyst for green growth and job creation in MINT and other emerging economies. However, achieving this potential demands coherent governance, sustained investment, and technological innovation capable of bridging existing financing and institutional gaps. By aligning environmental and economic priorities, renewable energy transitions can promote both decent work and sustainable industrialisation, driving progress toward SDGs 7, 8, and 13.

2.3. Interlinkages between energy transition, carbon reduction, and SDG 8 performance

The interlinkages between energy transition, carbon reduction, and SDG 8 performance have become a defining issue for sustainable development policy in emerging economies. Okogor et al. (2025) provide strong empirical evidence that high carbon intensity undermines both environmental and social progress, as economies heavily dependent on fossil fuels exhibit weaker performance on SDG 8 and SDG 13. While the pandemic temporarily lowered emissions, it did not alter the underlying structural relationship between carbon intensity, employment creation, and inclusive growth, highlighting the need for long-term policy measures that integrate decarbonisation and labour-market resilience.

Across countries, renewable energy has emerged as a key enabler of this integration, driving both economic and environmental transformation. Proença and Fortes (2020) report that a 1% increase in renewable power generation capacity raises employment by 0.48%, demonstrating the sector's strong labour absorption potential. Similarly, Dirma et al. (2024) find that renewable energy investments stimulate economic growth by fostering technological innovation, improving productivity, and attracting both private and public sector financing. Rahman et al. (2022) further confirm that renewable energy utilisation significantly reduces carbon emissions, while Rahman et al. (2021) estimate that renewable energy consumption can reduce carbon intensity by approximately 0.003 units per unit increase. These findings collectively demonstrate that energy transitions can simultaneously advance emission reductions and employment creation, aligning directly with SDG 8's objectives for productive and inclusive growth.

Chou et al. (2023) add that renewable energy expansion is positively associated with GDP growth and industrial productivity, suggesting that the clean energy transition supports sustainable industrialisation rather than constraining it. However, the degree of these effects varies across national contexts. Ofori et al. (2023) show that the impact of technological innovation and trade openness on renewable energy performance differs across BRICS and MINT countries, revealing institutional and structural heterogeneity in how these economies translate energy transitions into labour-market and environmental gains. Luan et al. (2025) similarly note that renewable energy adoption yields stronger development outcomes when supported by robust institutional frameworks and industrial coherence, while Zheng et al. (2023) highlight that policy misalignment and reliance on carbon-intensive entrepreneurship can weaken these benefits.

Overall, the evidence suggests that the energy transition functions as both an environmental and economic catalyst in emerging economies. For the MINT bloc, success in achieving low-carbon and inclusive growth depends on the coherence of policy frameworks that integrate clean energy adoption, industrial diversification, and institutional governance. By aligning energy transition strategies with employment-oriented development, these countries can strengthen their progress toward SDG 8 while advancing the broader sustainability agenda.

2.4. The COVID-19 shock, structural transitions, and green recovery pathways

The COVID-19 pandemic reshaped the global landscape of energy systems, emissions, and employment, revealing deep interconnections between environmental sustainability and economic resilience. For emerging economies such as the MINT bloc, the crisis disrupted industrial output, labour markets, and investment flows, yet simultaneously stimulated discussions around renewable energy and green recovery as pathways to sustainable growth. Abdullah et al. (2023) observe that renewable energy demand and investment remained resilient despite the global downturn, demonstrating the sector's capacity to stabilise economies and sustain employment in periods of volatility. Similarly, Proença and Fortes (2020) estimate that a 1% increase in renewable power generation capacity corresponds to a 0.48% rise in employment, underscoring the sector's potential to drive inclusive recovery and decent work in line with SDG 8.

Zhao et al. (2025) document that although the pandemic temporarily reduced global carbon emissions, these declines were not sustained after economic activities resumed, reaffirming the structural dependence on fossil fuels. Okogor et al. (2025) reach a similar conclusion, identifying COVID-19 as a structural break that exposed systemic vulnerabilities but also redirected policy attention toward integrating carbon reduction with labour-market recovery. Dafnomilis et al. (2021) demonstrate that allocating even 1% of global GDP annually to green stimulus measures could reduce global CO_2 emissions by up to 15.5% below pre-pandemic projections by 2030, highlighting the substantial decarbonisation potential of coordinated fiscal efforts. However, Yiming et al. (2024) note that fiscal constraints limited many emerging economies' ability to pursue these measures fully, constraining the scope of their green recovery programmes.

Osabohien et al. (2023) provide further insight into the social dimensions of this transition, showing that pre-existing vulnerabilities, such as weak social protection and informal employment, magnified the pandemic's economic and environmental impacts in Nigeria. Households with access to welfare support were better able to manage shocks, illustrating how inclusive policy frameworks underpin both economic resilience and sustainable recovery. In this context, Falcone (2023) advocates the creation of targeted green-finance instruments and institutional reforms to bridge investment gaps and align short-term stimulus with long-term sustainability objectives.

Taken together, the literature converges on the view that COVID-19 acted both as a disruption and as a catalyst for structural change. For the MINT economies, the pandemic highlighted the urgency of embedding renewable energy, green financing, and institutional reform within recovery strategies. By aligning low-carbon investments with employment creation and industrial diversification, these countries can transform post-crisis recovery into a foundation for long-term sustainable and inclusive growth consistent with SDG 8 and SDG 13.

3. Methodology

This study on carbon intensity and Decent Work and Economic Growth in MITN countries is anchored in several interrelated theoretical perspectives, chiefly the Environmental Kuznets Curve (EKC) hypothesis, the Decoupling Theory, and Sustainable Development Theory. The Environmental Kuznets Curve (Grossman and Krueger, 1991, Managi and Jena, 2008) posits an inverted-U relationship between environmental degradation and economic growth, suggesting that in the early stages of economic development, carbon emissions and environmental harm increase as economies prioritize industrialization and job creation. However, beyond a certain income threshold, further economic growth leads to structural changes, technological innovation, and stricter environmental policies, ultimately reducing environmental impacts, including carbon intensity. This theoretical lens explains why the MINT countries, each at varying stages of industrialization and income levels, might display different dynamics in the link between growth and emissions (Ang 2007).

Complementing the EKC is the Decoupling Theory, which emphasizes the possibility of delinking economic growth from environmental degradation through technological innovation, energy efficiency, and sustainable consumption and production patterns. Under this framework, the relationship between carbon intensity and decent work becomes pivotal, as economic activities can be redesigned to generate employment while minimizing environmental impacts. In MINT countries, where economic growth remains a critical policy objective, the challenge lies in achieving *absolute decoupling*, where carbon emissions decline even as the economy expands, ensuring progress toward without exacerbating environmental risks.

Also, the Sustainable Development Theory (WCED, 1987) underscores the integration of economic, social, and environmental goals, advocating for development paths that meet present needs without compromising future generations. This theory frames decent work not only as employment quantity but also quality, encompassing fair wages, safe working conditions, and social protection. Within the MINT context, sustainable development requires transitioning toward green economies, where investments in renewable energy, green technologies, and low-carbon industries simultaneously reduce carbon intensity and create decent jobs, fostering inclusive economic growth. These theoretical perspectives collectively inform the present study's hypotheses that sustainable economic policies, technological innovation, and sectoral shifts can reduce carbon intensity without hindering employment growth in MINT countries (Managi and Jena, 2008). They guide the empirical analysis in exploring whether the anticipated decoupling trends manifest across these economies and how green growth strategies might influence both environmental and labour market outcomes, aligning economic aspirations with the global SDG agenda.

3.1. Data sources and variables

This study utilises secondary data spanning the period 2000–2023 for the MINT economies— Mexico, Indonesia, Nigeria, and Turkey, sourced from internationally recognised databases, including the World Bank's World Development Indicators (WDI) and the International Labour Organization's ILOSTAT. The variables were carefully selected to capture the multifaceted links between economic growth, energy consumption, environmental sustainability, and employment outcomes.

SDG 8 indicators serve as a comprehensive measure of economic and social development, encompassing metrics related to employment, labour productivity, and inclusive work conditions, thereby providing an umbrella indicator for decent work and economic growth. Carbon intensity, measured as CO_2 emissions per unit of GDP, reflects the environmental efficiency of economic output and indicates the extent to which growth is carbon-intensive or environmentally sustainable. Renewable energy consumption captures the transition toward low-carbon energy sources, signalling the adoption of cleaner energy technologies that can potentially mitigate carbon intensity while supporting sustainable development. Energy use per capita represents the scale of energy dependence and the intensity of development, highlighting the resource requirements of economic and industrial activities.

Table 1. A table summarizing the variables used and their measurement, source: Author`s compilation

Variable	Measurements/indicators	Sources
SDG8 (G8)-decent work and economic growth.	Composite indicators including: Unemployment rate (%); labour productivity; Informal employment share-Youth NEET rate. Measuring it provides insight into how carbon-related policies and energy used affect human well-being and inclusive prosperity.	-UN SDG indicators; Database-ILOSTAT (ILO)-World Bank
Carbon intensity of GDP (CARBONINT)	$C0_2$ emissions per unit of GDP (e.g. kg $C0_2$ per USD of GDP. It captures how much $C0_2$ is emitted to produce one unit of economic output, being a critical environmental metric. It proxies for the environmental sustainability of economic growth and allows evaluation of whether decarbonization and economic expansion can occur simultaneously to generate green growth.	World Bank-International Energy Agency (IEA); Climate Watch (WRI)
Renewable energy consumption (RENEW).	Share of renewables in total final energy consumption (%) per capita kWh or toe. It shows the level of degree to which a country is transitioning to cleaner energy sources. It is proved that higher renewable shares are often linked with lower carbon intensity and more sustainable growth models.	World Bank (World Bank Indicators -WDI
Energy use (kg of oil equivalent per capita) (EUSECAP)	Kilograms of oil equivalent per capita. This measures the total energy consumed per person and reflects industrialization, living standard, and energy intensity. It guides in assessing whether increases in energy demand are leading to economic growth or are simply resulting in higher emissions. In combination with carbon intensity, it helps differentiate between clean and polluting growth.	World Bank (World Bank Indicators -WDI
GDP per capita (constant 2015 US$) (GDPPC)	GDP per capita (constant 2015 US$) is included as a control variable in this study to account for the overall level of economic development across MINT countries. It is measured as the total gross domestic product of a country divided by its population, adjusted for inflation to 2015 US dollars to ensure comparability over time and across countries.	World Bank (World Bank Indicators -WDI
Dummy variable (DUM)	To capture the effect of COVID 19. This is important because COVID 19 pandemic caused shocks to both energy demand and economic output.	0=Pre-COVID 19 (2000-2018), 1 = During/Post COVID 19 (2019-2023)

Together, these variables allow for a nuanced assessment of sustainability trade-offs and synergies in MINT countries, particularly as they navigate energy and labour transitions under both structural and exogenous shocks, such as the COVID-19 pandemic. This integrated dataset provides a robust framework to evaluate whether Indonesia, Mexico, Nigeria, and Turkey are progressing toward green, inclusive, and resilient economies, or whether efforts to enhance environmental sustainability may come at the expense of growth and employment. Annual data for all selected variables were employed to capture both short- and long-term dynamics in the analysis.

3.2. Estimation techniques

This study examines the dynamic interrelationships among carbon intensity, renewable energy consumption, energy use, economic growth, and SDG 8 – Decent Work and Economic Growth – in MINT countries through a multi-method empirical strategy designed to provide robust and comprehensive evidence. The analytical framework is structured into four complementary stages.

First, the Panel Autoregressive Distributed Lag (PARDL) model within the Pooled Mean Group (PMG) framework is applied to investigate both short- and long-run relationships between the explanatory variables and SDG 8 outcomes. This approach is particularly suitable for heterogeneous panels, as it allows short-run coefficients and error variances to differ across countries while constraining long-run coefficients to be homogeneous, thereby providing insights into persistent structural relationships.

Second, to address concerns regarding the reliance on aggregate measures and the potential masking of country-specific heterogeneity, we employ an OLS Fixed-Effects (FE) estimation at the country level. This approach allows for the disaggregation of the analysis, capturing within-country variations and controlling for unobserved, time-invariant heterogeneity across countries. In addition, the Method-of-Moments Quantile Regression (MM-QR) is applied to examine distributional heterogeneity in the effects of key determinants on SDG 8. By assessing how explanatory variables influence different points of the conditional SDG 8 distribution, MM-QR complements the PARDL/PMG results and uncovers effects that may remain hidden when focusing solely on mean outcomes. Together, these methodologies enhance the robustness and granularity of the analysis, providing both country-specific insights and distributional perspectives.

Third, the study explicitly investigates the extent to which the COVID-19 pandemic induced structural changes in these relationships. Pre- and post-COVID regression analyses are conducted using interaction terms between a COVID-19 dummy variable and the principal regressors. This approach allows the estimation of differential impacts of economic growth, carbon intensity, energy use, and renewable energy consumption before and after the pandemic, thereby highlighting shifts in their influence on SDG 8 outcomes.

Finally, the presence of a structural break is formally evaluated using a Chow test by comparing restricted models (excluding post-COVID interactions) with unrestricted models (including interaction terms). The significant test results confirm that COVID-19 materially altered the slopes of GDP per capita, carbon intensity, and energy use, evidencing a regime shift in the determinants of SDG 8.

Together, this combination of dynamic panel estimation, quantile regression, and structural break analysis provides a rigorous and comprehensive econometric strategy. It ensures that the study captures average effects, heterogeneous distributional impacts, and pandemic-induced structural shifts, offering nuanced insights for policy design and sustainable development in MINT economies.

$$SDG8_t = \lambda 0 + \lambda 1\mathrm{CARBONINT}_{it} + \lambda 2\mathrm{RENEW}_{it} + \lambda 3\mathrm{EUSECAP}_{it} + \lambda 4\mathrm{COVID}_{it} * \mathrm{CARBONINT}_{it} + \lambda 5 COVID_{it} * RENEW_{it} + \lambda 6\mathrm{GDPPC}_{it} + \varepsilon_{it} \quad (1)$$

Here, $SDG8_t$ represents the dependent variable, Sustainable Development Goal 8 (Decent Work and Economic Growth), while the explanatory variables include CARBONINT (carbon intensity of GDP), RENEW (renewable energy consumption), EUSECAP (energy use, kg of oil), and the interaction term between the COVID-19 dummy and carbon intensity. The model allows for the examination of potential structural shifts associated with the pandemic's impact on the economy and environmental variables.

4. Results presentation and discussion

4.1. Result presentation

4.1.1. Descriptive statistics

The descriptive statistics presented in Table 2 provide a detailed overview of the key variables underpinning the relationship between carbon intensity, renewable energy consumption, and SDG 8 (decent work and economic growth) across the MINT economies. For the full sample, the mean value of SDG 8 is 66.97, with a standard deviation of 3.20, ranging from 62.03 to 76.00. This indicates that, on average, MINT countries have made moderate progress towards promoting inclusive economic growth and employment. However, the observed variation highlights notable heterogeneity, with Mexico and Indonesia achieving higher average SDG 8 scores of 67.86 and 70.83, respectively, suggesting relatively stronger performance in fostering decent work. Conversely, Nigeria and

Turkey record lower averages of 64.95 and 64.24, signalling persistent structural challenges in achieving equitable labour market outcomes.

GDP per capita (GDPPC), expressed in constant 2015 US dollars, exhibits a mean of 6,127.25 with substantial dispersion (standard deviation of 3,863.32), ranging from 1,421.68 to 14,713.57. Country-specific analysis reveals significant economic heterogeneity: Mexico and Turkey present higher means of 9,720.81 and 9,705.07, reflecting comparatively advanced economic development, whereas Indonesia and Nigeria display much lower averages of 2,903.82, highlighting constraints in fiscal capacity to invest in renewable energy infrastructure and decarbonisation policies. These disparities suggest that the ability of MINT countries to pursue low-carbon economic growth and achieve SDG 8 outcomes is uneven and contingent on national economic structures.

Carbon intensity of GDP (CARBONINT) averages 0.46 across the full sample, with a standard deviation of 0.15 and values spanning 0.23 to 0.79. Heterogeneity is evident across countries: Indonesia records the highest mean of 0.66, reflecting a continued reliance on carbon-intensive production processes, while Mexico exhibits the lowest mean of 0.41, indicating relatively greater efficiency in decoupling economic growth from emissions. Turkey and Nigeria present intermediate levels of 0.47 and 0.31, respectively, signalling variation in energy efficiency and industrialisation stages across the bloc. This heterogeneity underscores the differing capacity of MINT economies to transition towards low-carbon development pathways.

Energy use per capita (EUSECAP) shows a full-sample mean of 1,018.07 kg of oil equivalent, ranging from 260.36 to 1,894.63, with a standard deviation of 551.76. Country-specific patterns highlight substantial disparities in energy consumption relative to population size. Mexico and Turkey record high per capita energy use of 1,554.66 and 1,502.84, reflecting intensive industrial and urban activity, while Indonesia and Nigeria show considerably lower values of 700.94 and 313.97, respectively. These differences suggest that the energy intensity of economic activities varies significantly across the MINT economies, influencing the effectiveness of renewable energy adoption and decarbonisation strategies.

Renewable energy consumption (RENEW) averages 34.90 across the full sample, with a standard deviation of 29.60 and a range of 9.00 to 88.10. Considerable heterogeneity emerges at the country level: Indonesia demonstrates the highest average share of renewable energy at 32.46, while Nigeria and Mexico remain at lower levels of 14.13 and 10.00, respectively, reflecting limited penetration of clean energy technologies. Turkey records a mean of 83.04, indicating proactive investment in renewables and potential alignment with low-carbon growth objectives. This variation highlights the uneven progress in adopting renewable energy across MINT countries, with implications for both carbon intensity and SDG 8 achievement.

Overall, the descriptive statistics reveal significant heterogeneity across MINT countries in terms of economic development, energy use, carbon intensity, and renewable energy adoption. These differences shape the interplay between carbon intensity, renewable energy consumption, and SDG 8 outcomes, suggesting that policy interventions must be tailored to national circumstances. High-income and energy-intensive economies, such as Mexico and Turkey, may prioritise structural reforms and low-carbon transitions, whereas lower-income countries, notably Nigeria and Indonesia, require targeted support to enhance renewable energy deployment and foster inclusive economic growth. The observed variation underscores the importance of country-specific strategies to simultaneously advance decarbonisation and sustainable employment, thereby promoting equitable progress towards SDG 8.

Table 2. Descriptive statistics, source: Authors' computation

	Full Sample		Mexico		Indonesia		Nigeria		Turkey	
Variables	Mean (SD)	Min [Max]	Mean (SD)	Min [Max]	Mean (SD)	Min [Max]	Mean (SD)	Min [Max]	Mean (SD)	Min [Max]
SDG8	66.97 (3.200)	62.03 [76.00]	67.86 (1.40)	66.71 [70.00]	70.83 (3.06)	68 [76.00]	64.95 (0.96)	62.72 [66.51]	64.24 (1.140)	62.03 [66.23]
GDPPC	6127.246 (3,863.32)	1421.68 [14713.57]	9720.81 (358.10)	9074.12 [10296.87]	2903.82 (762.55)	1828.1 [4192.65]	2903.82 (762.55)	1421.68 [2585.73]	9705.073 (2,621.93)	5887.69 [14713.57]
CARBONINT	0.46 (0.15)	0.23 [0.79]	0.41 (0.03)	0.36 [0.45]	0.66 (0.08)	0.56 [0.79]	0.31 (0.10)	0.23 [0.56]	0.47 (0.05)	0.35 [0.55]
RENEW	34.90 (29.60)	9 [88.10]	10 (0.758)	9 [12.20]	32.46 (9.36)	19.8 [45.60]	83.04 (2.56)	79.9 [88.10]	14.13 (1.880)	11.4 [18.10]
EUSECAP	1018.07 (551.76)	260.36 [1894.63]	1554.66 (102.75)	1349.95 [1711.48]	700.94 84.00]	585.79 [850.27]	313.97 (30.01)	260.36 (367.07)	1502.84 (266.34)	1060.57 [1894.63]

4.1.2. Correlation analysis

The correlation results reported in Table 3a provide important insights into the interrelationships among carbon intensity, renewable energy consumption, energy use, economic development, and SDG 8 outcomes across the MINT economies. For the full sample (Table 3a), SDG 8 exhibits a moderate positive correlation with carbon intensity (0.428), suggesting that higher carbon-intensive economic activities are, on average, associated with stronger economic growth and employment. This reflects the prevailing structure of industrialisation in several MINT countries, where growth continues to rely heavily on fossil-fuel-based production processes. In contrast, SDG 8 shows a weak negative correlation with renewable energy consumption (-0.160) and a modest positive association with energy use per capita (0.092), indicating that, at current levels of adoption, renewable energy has yet to translate substantially into measurable improvements in decent work and economic growth, while higher energy consumption is only slightly aligned with better SDG 8 outcomes.

Table 3a: Correlation analysis for full sample, source: Authors' computation

	lnSDG8	lnGDPPC	lnCARBONINT	lnEUSECAP	lnRENEW
lnSDG8	1.000				
lnGDPPC	-0.083	1.000			
lnCARBONINT	0.428	-0.009	1.000		
lnEUSECAP	0.0918	0.9417	0.3103	1.000	
lnRENEW	-0.1595	-0.9288	-0.2982	-0.9798	1.000

Table 3b: Correlation analysis for Mexico, source: Authors' computation

	lnSDG8	lnGDPPC	lnCARBONINT	lnEUSECAP	lnRENEW
lnSDG8	1.000				
lnGDPPC	-0.479	1.000			
lnCARBONINT	0.737	-0.537	1.000		
lnEUSECAP	0.703	-0.294	0.915	1.000	
lnRENEW	0.337	-0.116	-0.304	-0.327	1.000

Table 3c: Correlation Analysis for Indonesia, source: Authors' computation

	lnSDG8	lnGDPPC	lnCARBONINT	lnEUSECAP	lnRENEW
lnSDG8	1.000				
lnGDPPC	0.861	1.000			
lnCARBONINT	-0.800	-0.945	1.000		
lnEUSECAP	0.895	0.950	-0.834	1.000	
lnRENEW	-0.936	-0.968	0.885	-0.969	1.000

Table 3d: Correlation analysis for Nigeria, source: Authors' computation

	lnSDG8	lnGDPPC	lnCARBONINT	lnEUSECAP	lnRENEW
lnSDG8	1.000				
lnGDPPC	0.394	1.000			
lnCARBONINT	-0.388	-0.953	1.000		
lnEUSECAP	0.205	0.703	-0.554	1.000	
lnRENEW	-0.645	-0.566	0.386	-0.620	1.000

Table 3e: Correlation analysis for Turkiye, source: Authors' computation

	lnSDG8	lnGDPPC	lnCARBONINT	lnEUSECAP	lnRENEW
lnSDG8	1.000				
lnGDPPC	0.491	1.000			
lnCARBONINT	-0.592	-0.911	1.000		
lnEUSECAP	0.403	0.981	-0.820	1.000	
lnRENEW	-0.061	-0.628	0.340	-0.694	1.000

Examination of the interrelationships among explanatory variables in the full sample reveals pronounced structural patterns. GDP per capita is strongly positively correlated with energy use per capita (0.942) but highly negatively correlated with renewable energy consumption (-0.929), suggesting that wealthier economies within the MINT bloc consume more energy overall while relying less on renewable sources. Carbon intensity is moderately positively associated with energy use per capita (0.310) and negatively correlated with renewable energy (-0.298), indicating that higher energy demand and carbon-intensive production tend to coincide with lower adoption of clean energy. These full-sample correlations underscore the complex and sometimes countervailing dynamics between economic growth, energy consumption, and environmental sustainability (Table 3a).

Country-specific analyses highlight substantial heterogeneity in these relationships. In Mexico (Table 3b), SDG 8 is strongly positively correlated with carbon intensity (0.737) and energy use per capita (0.703), while also showing a positive correlation with renewable energy (0.337). These patterns suggest that, in Mexico, economic growth and employment remain closely tied to carbon-intensive production, though renewable energy may be beginning to support SDG 8 outcomes. GDP per capita is negatively correlated with SDG 8 (-0.479) and carbon intensity (-0.537), indicating that periods of higher income do not automatically translate into stronger performance in decent work and growth.

Indonesia (Table 3c) presents a contrasting profile. SDG 8 is strongly positively correlated with GDP per capita (0.861) and energy use per capita (0.895) but strongly negatively correlated with carbon intensity (-0.800) and renewable energy consumption (-0.936). This suggests that, although economic growth and energy use contribute to employment and output, the limited penetration of renewables and high reliance on carbon-intensive processes may hinder the transition to sustainable growth.

In Nigeria (Table 3d), SDG 8 exhibits moderate positive associations with GDP per capita (0.394) and energy use per capita (0.205), alongside negative correlations with carbon intensity (-0.388) and renewable energy (-0.645). These findings indicate that while economic activity and energy consumption support decent work and growth, the low adoption of renewables and structural inefficiencies in energy systems may constrain sustainable development. GDP per capita shows a strong negative correlation with carbon intensity (-0.953), highlighting opportunities for efficiency improvements despite the persistent challenges in scaling renewable energy.

Turkey (Table 3e) displays a mixed pattern, with SDG 8 moderately positively correlated with GDP per capita (0.491) and energy use per capita (0.403), weakly negatively associated with carbon intensity (-0.592), and minimally correlated with renewable energy (-0.061). This suggests that economic development and energy consumption contribute to employment and growth outcomes, whereas renewable energy adoption has yet to emerge as a significant driver of SDG 8 in the country. GDP per capita in Turkey is highly correlated with energy use (0.981) and negatively associated with renewable energy (-0.628), reflecting continued dependence on fossil-fuel-based energy in higher-income contexts.

Overall, the correlation analysis underscores the heterogeneous relationships among economic growth, energy consumption, carbon intensity, and renewable energy adoption across the MINT countries. The positive association between carbon intensity and SDG 8 in the full sample and in specific countries such as Mexico indicates that fossil-fuel-based growth remains a key contributor to employment and output. Meanwhile, negative correlations with renewable energy highlight the challenges of achieving low-carbon growth without compromising short-term labour and economic outcomes. These patterns emphasise the need for tailored, country-specific strategies that integrate renewable energy expansion with policies promoting inclusive economic growth, reflecting the trade-offs and synergies inherent in achieving SDG 8 amidst ongoing structural and energy transitions.

4.1.3. Cross-sectional dependence test (CD test)

The results of Pesaran's (2004) cross-sectional dependence test indicate the presence of significant cross-sectional dependence in the panel. The test statistic (2.638) is statistically significant at the 1% level (p = 0.0083), thereby rejecting the null hypothesis of cross-sectional independence. The average absolute correlation of 0.296 further confirms non-negligible contemporaneous correlation among cross-sectional units. Consequently, the use of first-generation unit root tests, which assume cross-sectional independence, would be inappropriate. Instead, second-generation unit root tests such as Pesaran's CIPS or CADF are more suitable for the analysis.

4.1.4. Unit root test results

The unit root tests presented in Table 4 assess the stationarity properties of the study variables using both the Levin–Lin–Chu (LLC) and Im–Pesaran–Shin (IPS) approaches, which are standard for panel data analysis. Stationarity is crucial to ensure valid inference in panel regressions, as non-stationary series can produce spurious results.

The results indicate that SDG 8, the dependent variable, is non-stationary at level under both LLC and IPS tests but becomes stationary after first differencing, as indicated by the strongly significant negative statistics (LLC: -4.7378***, IPS: -5.0755***). This suggests that shocks to SDG 8 have persistent effects and that differencing is necessary to stabilise the series.

GDP per capita (GDPPC) exhibits mixed behaviour. It is stationary under the IPS test at level but requires first differencing under LLC, indicating that the series is generally I(1) and that its dynamic evolution should be accounted for in the estimation process.
Carbon intensity (CARBONINT) is non-stationary at level but becomes stationary after first differencing (LLC: -4.0344***; IPS: -1.6777**), reflecting evolving trends in environmental efficiency over time. Similarly, energy use per capita (EUSECAP) and renewable energy consumption (RENEW) are non-stationary at level but stationary at first difference, highlighting that their trajectories change over time, likely due to policy interventions and structural economic shifts.
Economically, these findings indicate that most key variables in the study follow an I(1) process, except for GDPPC, which shows partial stationarity. The mixed integration orders (I(0) and I(1)) suggest that a modelling approach capable of handling both short-run dynamics and long-run relationships, such as a panel ARDL (PARDL) framework, is appropriate. This ensures that the estimated relationships between SDG 8, carbon intensity, renewable energy, and energy use are robust and not affected by non-stationarity, while also capturing potential long-term equilibrium effects in MINT countries.

Table 4. Stationarities of the variables, source: Authors' computation

Variable	Levin–Lin–Chu		Im–Pesaran–Shin	
	I(0)	I(1)	I(0)	I(1)
SDG 8	1.2222	-4.7378***	0.5496	-5.0755***
GDPPC	-1.2781	-3.7028***	-2.2392***	
CARBONINT	0.6447	-4.0344***	-1.6777**	
EUSECAP	0.5707	-4.5977***	-1.4666*	
RENEW	0.1117	-4.5643***	-0.2659	-4.6246***

Note: ***, ** and * illustrate the 1 %, 5 % and 10 % significance levels, respectively.

4.1.5. Panel cointegration test

The panel cointegration results in Table 5 suggest the presence of a long-run equilibrium relationship among SDG 8, carbon intensity, renewable energy consumption, and energy use in MINT economies. While the test statistics are not uniformly significant at the 5% level, the Phillips–Perron and modified Phillips–Perron t-values approach conventional significance thresholds (p = 0.0755 and 0.094, respectively), indicating a tendency towards cointegration. The Augmented Dickey–Fuller t-statistic further supports this view (p = 0.058). Collectively, these results imply that despite short-run fluctuations, the variables are likely to converge towards a stable long-run equilibrium, underscoring the potential for coordinated policies on renewable energy adoption and carbon management to sustainably enhance economic growth and employment outcomes in MINT countries.

Table 5. Panel cointegration result, source: Authors' computation

	Statistic	p-value
Modified Phillips–Perron t	1.3167	0.094
Phillips–Perron t	-1.4358	0.0755
Augmented Dickey–Fuller t	-1.5716	0.058

4.1.6. The Panel Autoregressive Distributed Lag (PARDL)/Pool Mean Group (PMG)Results

The PARDL/Pool Mean Group results reported in Table 6 provide insights into the short- and long-run dynamics between carbon intensity, renewable energy consumption, energy use, GDP per capita, and SDG 8 outcomes in MINT countries. The error correction term (__ec) is negative and highly significant at –0.394 ($p < 0.01$), indicating a strong adjustment mechanism towards long-run equilibrium following short-term deviations in SDG 8.
In the short-run, changes in GDP per capita (D.lnGDPPC) and carbon intensity (D.lnCARBONINT) are negative but statistically insignificant, suggesting that short-term fluctuations in overall economic output and carbon-intensive activities do not immediately affect SDG 8 outcomes. In contrast, short-term changes in energy use per capita (D.lnEUSECAP) are positive and significant at 0.069 ($p < 0.05$), implying that increased energy availability contributes to improvements in economic growth and employment in the short run. Short-term renewable energy consumption (D.lnRENEW) is negative but not statistically significant, while the interactions with the COVID-19 period reveal notable effects: D.covid_lnCARBONINT is positive and significant at 0.194 ($p < 0.05$), and D.covid_lnRENEW is positive and highly significant at 0.041 ($p < 0.01$), suggesting that during the pandemic, the influence of both carbon intensity and renewable energy on SDG 8 was amplified.
In the long run, GDP per capita (lnGDPPC) exhibits a positive and highly significant coefficient of 0.218 ($p < 0.01$), highlighting the persistent contribution of overall economic development to SDG 8 outcomes. Carbon intensity (lnCARBONINT) is also positive and significant at 0.100 ($p < 0.01$), reflecting the enduring association

between carbon-intensive economic activities and measured growth and employment levels. Energy use per capita (lnEUSECAP) enters with a negative and significant coefficient of –0.137 ($p < 0.01$), indicating that excessive energy consumption without efficiency gains may constrain long-term SDG 8 outcomes. Long-run renewable energy (lnRENEW) is positive but statistically insignificant, while the COVID interactions (covid_lnCARBONINT and covid_lnRENEW) show small positive effects, with covid_lnRENEW significant at the 10% level, suggesting that renewable energy adoption during the pandemic contributed modestly to sustaining SDG 8 outcomes.
The constant is positive and highly significant (1.317, $p < 0.01$), reflecting the baseline level of SDG 8 in the absence of explanatory variables. Overall, the PARDL results indicate that MINT economies exhibit strong long-run adjustment towards SDG 8 equilibrium, with GDP per capita and carbon intensity being the principal long-term drivers, while energy use and renewable energy exert more nuanced short- and medium-term effects. The significant COVID interactions further underscore the structural shifts in the relationship between energy, carbon intensity, and economic growth induced by the pandemic.

Table 6. Short-Run and Long-Run Estimation Results from PARDL, source: Authors' computation

VARIABLES	Long-run	Short-run
__ec		-0.394***
		(0.137)
D.lnGDPPC		-0.161
		(0.115)
D.lnCARBONINT		-0.052
		(0.050)
D.lnEUSECAP		0.069**
		(0.029)
D.lnRENEW		-0.024
		(0.048)
D.covid_lnCARBONINT		0.194**
		(0.091)
D.covid_lnRENEW		0.041***
		(0.015)
lnGDPPC	0.218***	
	(0.062)	
lnCARBONINT	0.100***	
	(0.031)	
lnEUSECAP	-0.137***	
	(0.052)	
lnRENEW	0.011	
	(0.044)	
covid_lnCARBONINT	0.073	
	(0.056)	
covid_lnRENEW	0.031*	
	(0.018)	
Constant		1.317***
		(0.461)
Observations	92	92

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4.1.7. Disaggregating SDG 8 drivers in MINT countries using Fixed-Effects estimation

The results of the country-level Fixed Effects (FE) estimations, presented in Table 7, provide nuanced insights into the determinants of SDG 8 outcomes across the MINT economies and the full sample. The Hausman specification test supports the choice of the FE estimator over the Random Effects model ($\chi^2 = 57.59$, $p = 0.0000$), indicating that unobserved individual-specific effects are correlated with the regressors and that the FE estimates are consistent and robust.

For the full sample, GDP per capita (lnGDPPC) is positive but statistically insignificant (0.0584, $p > 0.05$), suggesting that, when aggregated, economic growth exhibits a modest association with decent work and economic growth, although the relationship does not reach conventional significance levels. Carbon intensity (lnCARBONINT) also shows a positive but insignificant effect (0.0169), indicating that higher carbon-intensive production is weakly aligned with SDG 8 outcomes at the aggregate level. Energy use per capita (lnEUSECAP) and renewable energy consumption (lnRENEW) both display negative and insignificant coefficients (-0.0175 and -0.0128, respectively), suggesting that, on average, variations in energy intensity and renewable energy adoption do not significantly explain SDG 8 outcomes across the MINT bloc. The COVID-19 interaction terms—covid_lnCARBONINT and covid_lnRENEW—are both positive and statistically significant (0.114*** and 0.0405***, respectively), reflecting the notable short-term influence of pandemic-related disruptions on the relationship between energy indicators and SDG 8 performance. Overall, the full-sample model explains approximately 61.3% of the variation in SDG 8 ($R^2 = 0.613$), indicating moderate explanatory power.

Country-specific estimations reveal substantial heterogeneity, underscoring the importance of disaggregated analysis. In Mexico, lnGDPPC (0.0332) is positive but insignificant, while lnCARBONINT (0.179**) and lnRENEW (0.185***) are both positive and significant, suggesting that higher carbon-intensive activity and renewable energy adoption are associated with stronger SDG 8 outcomes, reflecting a dual pathway in which economic and energy policies simultaneously influence growth and employment. Energy use per capita (0.0896) is positive but not statistically significant, and COVID-19 interactions are negative and insignificant, indicating a limited pandemic effect on Mexico's SDG 8 trajectory during the study period.

Indonesia exhibits contrasting dynamics. Both lnGDPPC (-0.219**) and lnRENEW (-0.207***) are negative and significant, while lnCARBONINT (-0.188*) is also negative, suggesting that economic growth and renewable energy adoption are inversely associated with SDG 8 outcomes in this context. Energy use per capita (0.0982) is positive but insignificant, and COVID-19 interaction terms are negative yet not significant. These results may reflect structural challenges in translating economic growth and renewable energy deployment into inclusive labour market outcomes in Indonesia.

In Nigeria, the coefficients on lnGDPPC (-0.0723), lnCARBONINT (-0.0517), lnEUSECAP (-0.0477), and lnRENEW (-0.387) are all negative and statistically insignificant, except for lnRENEW which approaches marginal relevance. The COVID-19 interactions, covid_lnCARBONINT (0.0479) and covid_lnRENEW (0.0173), are positive but not significant. These findings indicate that SDG 8 outcomes in Nigeria are largely insulated from variations in energy consumption, carbon intensity, and renewable energy adoption, potentially reflecting broader structural constraints in the labour market and economic system.

Turkey displays a distinct pattern. GDP per capita (0.604*) and lnRENEW (0.125*) are positive and significant, suggesting that higher economic output and renewable energy adoption contribute meaningfully to decent work and economic growth. In contrast, lnEUSECAP (-0.548*) is negative and significant, reflecting that excessive energy consumption, potentially from carbon-intensive sources, may impede SDG 8 progress. Carbon intensity (0.428) is positive but not statistically significant. COVID-19 interactions are negative and insignificant, suggesting a muted pandemic effect on SDG 8 dynamics in Turkey.

Table 7. Fixed Effect Regression result

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**FULL**	**MEXICO**	**INDONESIA**	**NIGERIA**	**TURKIYE**
lnGDPPC	0.0584	0.0332	-0.219**	-0.0723	0.604*
	(0.0374)	(0.0728)	(0.0805)	(0.138)	(0.292)
lnCARBONINT	0.0169	0.179**	-0.188*	-0.0517	0.428
	(0.0235)	(0.0836)	(0.0914)	(0.0738)	(0.263)
lnEUSECAP	-0.0175	0.0896	0.0982	-0.0477	-0.548*
	(0.0368)	(0.0672)	(0.119)	(0.0439)	(0.273)
lnRENEW	-0.0128	0.185***	-0.207***	-0.387	0.125*
	(0.0231)	(0.0234)	(0.0549)	(0.249)	(0.0706)
covid_lnCARBONINT	0.114***	-0.123	-0.206	0.0479	-0.0979
	(0.0233)	(0.207)	(0.299)	(0.161)	(0.110)
covid_lnRENEW	0.0405***	-0.0536	-0.0338	0.0173	-0.0383
	(0.00766)	(0.0881)	(0.0546)	(0.0511)	(0.0385)
Constant	3.878***	2.987***	5.987***	6.649***	2.643***
	(0.221)	(0.568)	(0.825)	(1.890)	(0.823)
Observations	96	24	24	24	24
R-squared	0.613	0.916	0.931	0.659	0.506
Number of c_id	4	1	1	1	1

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Collectively, these FE estimation results highlight pronounced heterogeneity across the MINT countries in the drivers of SDG 8. While full-sample estimates indicate modest aggregate associations, country-specific results reveal that carbon intensity, renewable energy consumption, and economic growth interact differently with decent work and economic outcomes depending on structural and policy contexts. Mexico and Turkey demonstrate positive pathways linking renewable energy and growth to SDG 8, whereas Indonesia and Nigeria exhibit weaker or negative associations, reflecting challenges in translating energy transitions and economic growth into inclusive employment. These findings underscore the necessity of tailored, country-specific policy interventions to promote sustainable and inclusive economic growth, while accounting for energy system heterogeneity and structural differences across the MINT bloc.

4.1.8. Method-of-Moments Quantile Regression Result

The distributional heterogeneity captured through the Method-of-Moments Quantile Regression (MM-QR) in Table 8 provides complementary insights to the PARDL results, highlighting how the effects of carbon intensity, renewable energy consumption, and energy use vary across the SDG 8 distribution in MINT countries. At the 25th quantile (Q25), the coefficients for lnGDPPC (–0.240, $p < 0.01$) and lnCARBONINT (–0.116, $p < 0.01$) are negative and significant, suggesting that in lower-performing economies, higher economic output and carbon-intensive activities may be associated with weaker SDG 8 outcomes in the short run, which contrasts with the PARDL findings where long-run GDP per capita and carbon intensity exhibited positive effects. Conversely, lnEUSECAP is positive and significant at Q25 (0.137, $p < 0.01$), indicating that energy availability remains critical for supporting economic growth and employment among weaker performers, aligning with the positive short-run impact of energy use observed in the PARDL model.

Renewable energy consumption (lnRENEW) shows a negative and significant effect at Q25 (–0.107, $p < 0.01$), suggesting that, for lower quantiles, higher shares of renewable energy have not yet translated into measurable gains in SDG 8 outcomes. This partially mirrors the PARDL results where long-run renewable energy was largely insignificant, highlighting structural or transitional limitations in the energy mix. The COVID-period interactions are consistently positive and significant across Q25, Q50, and Q75 for both carbon intensity (covid_lnCARBONINT) and renewable energy (covid_lnRENEW), with elasticities ranging from 0.131 to 0.141 and 0.051 to 0.054 respectively (all $p < 0.01$). This reinforces the PARDL finding that the pandemic amplified the short-term effects of both energy and carbon variables on SDG 8, suggesting that COVID-19 acted as a structural modifier in these relationships.

At the median (Q50) and upper quantile (Q75), the negative impact of lnCARBONINT diminishes slightly (–0.0956 and –0.0742, $p < 0.05$–0.01), while the positive effect of lnEUSECAP persists, indicating that higher-performing economies are less constrained by carbon-intensive production but still benefit from adequate energy use. Renewable energy retains a negative and significant effect across all quantiles, although the magnitude weakens toward the upper quantile (–0.0926, $p < 0.01$), consistent with the PARDL indication that renewable energy's long-run contribution to SDG 8 remains limited, particularly in countries with stronger SDG 8 outcomes.

Overall, the MM-QR results highlight that the influence of carbon intensity, renewable energy, and energy use is heterogeneous across the SDG 8 distribution in MINT countries. While PARDL captures the general short- and long-run dynamics, MM-QR reveals that the magnitude and even direction of these effects differ depending on whether countries are lower-, median-, or upper-performing in SDG 8. The consistently positive COVID-period interactions confirm that the pandemic modified these relationships across all quantiles, emphasizing the importance of considering distributional heterogeneity when designing policies to promote decent work and sustainable economic growth in the MINT bloc.

Table 8. Method-of-Moments Quantile Regression result

VARIABLES	Qtile__25	Qtile__5	Qtile__75
lnGDPPC	-0.240***	-0.214***	-0.187***
	(0.0311)	(0.0335)	(0.0443)
lnCARBONINT	-0.116***	-0.0956***	-0.0742**
	(0.0234)	(0.0253)	(0.0334)
lnEUSECAP	0.137***	0.119***	0.101**
	(0.0342)	(0.0371)	(0.0488)
lnRENEW	-0.107***	-0.1000***	-0.0926***
	(0.0181)	(0.0197)	(0.0258)
covid_lnCARBONINT	0.141***	0.136***	0.131***
	(0.0227)	(0.0247)	(0.0324)
covid_lnRENEW	0.0540***	0.0526***	0.0512***
	(0.00689)	(0.00750)	(0.00984)
Constant	5.541***	5.449***	5.354***
	(0.223)	(0.242)	(0.318)
Observations	96	96	96

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4.1.9. Assessing structural breaks in economic growth, energy use, and carbon intensity on SDG8 outcomes: evidence from pre- and post-COVID regression analysis

The pre- and during/post-COVID estimation results in Table 9 provide a nuanced extension of the earlier PARDL findings, highlighting both continuities and shifts in the determinants of SDG8 outcomes.

Pre-COVID baseline effects align closely with the PARDL results. lnGDPPC carries a negative and statistically significant coefficient of -0.280 ($p < 0.01$), indicating that prior to the pandemic, higher GDP per capita was associated with a decline in SDG8 performance. This suggests that economic growth alone did not translate into inclusive employment or sustainable development gains, consistent with the PARDL observation that GDP growth's immediate effect on SDG8 was limited. lnEUSECAP, with a positive coefficient of 0.116 ($p < 0.01$), supports SDG8, reaffirming that energy use capacity underpins productive activity and employment generation, echoing the PARDL indication that energy availability is a key enabler of economic resilience. Conversely, lnCARBONINT_c (-0.141; $p < 0.01$) and lnRENEW_c (-0.157; $p < 0.01$) demonstrate negative pre-COVID effects, mirroring the PARDL finding that carbon-intensive industrialisation and the transitional costs of renewable investments can constrain inclusive growth, particularly when adjustment frictions are present.

Direct COVID shock effects reveal a departure from the baseline patterns. Both covid_lnCARBONINT (1.757; $p < 0.01$) and covid_lnRENEW (0.133; $p < 0.01$) exhibit positive and significant effects, indicating that during the pandemic, short-term reliance on carbon-intensive sectors and renewable energy investments temporarily supported SDG8. This aligns with the PARDL observation of sectoral resilience during shocks, suggesting that economic activity in both fossil and renewable energy sectors acted as buffers against COVID-induced employment and production disruptions.

Table 9: Pre- and post-COVID regression analysis, source: Authors' computation

VARIABLES	POSTCOVID
lnGDPPC	-0.280***
	(0.037)
lnEUSECAP	0.116***
	(0.042)
lnCARBONINT_c	-0.141***
	(0.028)
lnRENEW_c	-0.157***
	(0.025)
covid_lnCARBONINT	1.757***
	(0.504)
covid_lnRENEW	0.133***
	(0.038)
0b.postCOVID#co.lnGDPPC	0.000
	(0.000)
1.postCOVID#c.lnGDPPC	0.468**
	(0.235)
0b.postCOVID#co.lnCARBONINT_c	0.000
	(0.000)
1.postCOVID#c.lnCARBONINT_c	-1.292**
	(0.503)
0b.postCOVID#co.lnEUSECAP	0.000
	(0.000)
1.postCOVID#c.lnEUSECAP	-0.428
	(0.288)
0b.postCOVID#co.lnRENEW_c	0.000
	(0.000)
1o.postCOVID#co.lnRENEW_c	0.000
	(0.000)
Constant	5.795***
	(0.233)
Observations	96
R-squared	0.721

Note: Estimates are based on interaction terms between the post-COVID indicator and the explanatory variables. The reported coefficients for the main regressors (e.g., lnGDPPC, lnEUSECAP) represent their effects during the pre-COVID period. Rows labeled 0b. correspond to the base category (pre-COVID) and are normalized to zero; hence, they are not estimated. The coefficients labeled 1.postCOVID#… capture the incremental change in the effect of each variable in the post-COVID period relative to the pre-COVID baseline, thereby identifying structural

Post-COVID interaction terms highlight structural shifts. The interaction postCOVID × lnGDPPC (0.468; $p < 0.05$) indicates that the net effect of GDP per capita on SDG8 turned positive post-pandemic, moving from –0.280 pre-COVID to +0.188 after COVID. This suggests that growth became more inclusive, potentially reflecting adaptive policy responses, stimulus measures, and recovery-oriented investments that improved employment and productivity outcomes. In contrast, postCOVID × lnCARBONINT_c (–1.292; $p < 0.05$) magnifies the negative impact of carbon intensity on SDG8, with a net effect of –1.433, indicating that the pandemic reinforced the detrimental consequences of unsustainable industrial practices. The postCOVID × lnEUSECAP coefficient (–0.428; not significant) implies a weakening of energy use capacity's pre-COVID positive effect, though the change is not statistically robust. Due to collinearity, post-COVID shifts in renewable energy impacts could not be directly estimated.

Overall, these results reinforce the PARDL narrative that pre-COVID economic growth and energy use were uneven in supporting SDG8, that the pandemic temporarily altered sectoral contributions, and that structural shifts post-COVID improved the inclusivity of growth while exacerbating the negative effects of carbon-intensive development. This underscores the importance of targeted policies that balance growth, energy transition, and sustainability in post-pandemic recovery strategies.

4.1.10. Evidence of a COVID-19 Induced Structural Break in Determinants of SDG8: Insights from Restricted and Unrestricted Regression Analysis

The results from the restricted and unrestricted regression models, combined with the Chow test, provide strong empirical evidence of a structural break associated with the COVID-19 pandemic.

Table 10. Pre- and post-COVID regression results with chow test for structural break, source: Authors' computation

VARIABLES	Restricted	Unrestricted
lnGDPPC	-0.210***	-0.280***
	(0.036)	(0.037)
lnEUSECAP	0.117***	0.116***
	(0.043)	(0.042)
lnCARBONINT_c	-0.092***	-0.141***
	(0.028)	(0.028)
lnRENEW_c	-0.099***	-0.157***
	(0.018)	(0.025)
covid_lnCARBONINT	0.135***	1.757***
	(0.028)	(0.504)
covid_lnRENEW	0.052***	0.133***
	(0.009)	(0.038)
0b.postCOVID x lnGDPPC		0.000
		(0.000)
1.postCOVID x .lnGDPPC		0.468**
		(0.235)
0b.postCOVID x lnCARBONINT_c		0.000
		(0.000)
1.postCOVID x lnCARBONINT_c		-1.292**
		(0.503)
postCOVID x lnEUSECAP		0.000
		(0.000)
1.postCOVID x lnEUSECAP		-0.428
		(0.288)
0b.postCOVID x lnRENEW_c		0.000
		(0.000)
1o.postCOVID x lnRENEW_c		0.000
		(0.000)
Constant	5.195***	5.795***
	(0.163)	(0.233)
Observations	96	96
R-squared	0.659	0.721

Note: Estimates are based on interaction terms between the post-COVID indicator and the explanatory variables. The reported coefficients for the main regressors (e.g., lnGDPPC, lnEUSECAP) represent their effects during the pre-COVID period. Rows labeled 0b. correspond to the base category (pre-COVID) and are normalized to zero; hence, they are not estimated. The coefficients labeled 1.postCOVID#… capture the incremental change in the effect of each variable in the post-COVID period relative to the pre-COVID baseline, thereby identifying structural breaks. Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

The restricted model, which excludes post-COVID interaction terms, shows the baseline effects of the explanatory variables on SDG8 outcomes. Here, lnGDPPC is negative and significant (–0.210; $p < 0.01$), indicating that higher GDP per capita was associated with lower SDG8 performance before accounting for potential post-pandemic shifts. lnEUSECAP remains positively significant (0.117; $p < 0.01$), reflecting the supportive role of energy use capacity on economic and employment outcomes. Both lnCARBONINT_c (–0.092; $p < 0.01$) and lnRENEW_c (–0.099; $p < 0.01$) exhibit negative pre-COVID effects, consistent with earlier PARDL findings that carbon-intensive growth and transitional costs of renewables may constrain inclusive development.

The unrestricted model, which incorporates interaction terms between the explanatory variables and a post-COVID dummy, allows the coefficients to vary after the onset of the pandemic, effectively capturing potential structural shifts. In this specification, several changes are evident. The post-COVID interaction for GDP per capita (0.468; $p < 0.05$) indicates that the net effect of GDPPC on SDG8 became positive post-pandemic (–0.280 + 0.468 = +0.188), suggesting that growth became more inclusive or that policy responses enhanced its impact on SDG8. Conversely, the interaction term for carbon intensity (–1.292; $p < 0.05$) amplifies its negative effect, yielding a net coefficient of –1.433, signalling that the pandemic heightened the detrimental effects of carbon-intensive development. Energy use capacity exhibits a reduction in its positive impact post-COVID (interaction = –0.428; not significant), indicating a possible weakening of its influence, while post-COVID shifts in renewable energy could not be directly estimated due to collinearity.

The Chow test formally evaluates whether these interaction coefficients are jointly different from zero, testing the null hypothesis that COVID did not alter the effects of any regressor on SDG8. The test yields $F(3, 86) = 6.36$ with a p-value of 0.0006, leading to rejection of the null at the 1% significance level. This provides statistically robust confirmation that the pandemic constitutes a structural break, as the slopes of GDPPC, carbon intensity, and energy use capacity changed post-COVID.

In combination, the regression and Chow test results reinforce the narrative observed in the earlier PARDL analysis: COVID-19 induced a regime shift in the determinants of SDG8 outcomes. Economic growth became more positively aligned with inclusive development, while the negative effects of carbon-intensive growth were magnified. Energy use capacity's role weakened slightly, and the structural impact of renewable energy could not be fully assessed, highlighting the need for targeted post-pandemic policy interventions that balance growth, sustainability, and resilience.

4.1.11. Chow Test result

- **Null hypothesis (H_0): All interaction coefficients = 0**

(i.e., COVID did not change the effect of any regressor on lnSDG8)

- $F(3, 86) = 6.36$
- p-value = 0.0006

5. Discussion of results

Our study provides a comprehensive empirical analysis of the interplay between carbon intensity, renewable energy consumption, and SDG 8 (Decent Work and Economic Growth) across the MINT countries—Mexico, Indonesia, Nigeria, and Turkey, covering pre-, during-, and post-COVID-19 periods. The results reveal that economic growth and carbon-intensive activities are key long-run drivers of SDG 8 outcomes, while renewable energy and energy use exert more nuanced and temporally differentiated effects. Specifically, the PARDL/PMG results indicate that GDP per capita and carbon intensity significantly and positively influence SDG 8 in the long run, while energy use negatively affects it, suggesting that inefficient or excessive energy consumption constrains sustainable economic performance. In the short run, energy use supports SDG 8, reflecting its role in maintaining productive capacity. Importantly, COVID-19 interaction terms for both carbon intensity and renewable energy are positive and significant, confirming that during the pandemic, these sectors contributed to stabilising employment and output. The Fixed Effects estimations further uncover marked heterogeneity across the MINT economies: while Mexico and Turkey show positive linkages between renewable energy and SDG 8, Indonesia and Nigeria display weaker or negative associations, revealing structural disparities in how energy systems translate into inclusive growth. The MM-QR results complement these findings by demonstrating that the effects of carbon intensity, renewable energy, and energy use vary across the SDG 8 distribution, with lower-performing countries facing stronger constraints from carbon intensity and transitional costs of renewables. Finally, the regression-based structural break and Chow tests confirm a statistically significant COVID-induced regime shift, where post-pandemic growth became more inclusive while the negative effects of carbon intensity intensified. Collectively, these findings not only answer the research questions but also underscore the novelty of the study's multi-method and disaggregated approach in capturing temporal, structural, and distributional heterogeneity across the MINT bloc.

These results align with and extend existing empirical evidence on the complex relationship between energy, emissions, and sustainable economic growth. Consistent with Zhao et al. (2025) and Bekun et al. (2024), our findings reaffirm the growth–sustainability paradox in emerging economies, where increases in GDP per capita are often accompanied by higher emissions due to fossil-fuel-dependent industrialisation. The positive long-run association between carbon intensity and SDG 8 mirrors the early-stage industrial development pattern described by Rahman et al. (2021), in which carbon-intensive expansion temporarily sustains output and employment before its environmental costs emerge. Conversely, the long-run insignificance of renewable energy in the aggregate model, coupled with its heterogeneous country-level effects, supports the observation by Osabohien et al. (2025) and Luan et al. (2025) that renewable energy's developmental dividends depend critically on institutional capacity and technological readiness. The pandemic-period findings corroborate the work of Okogor et al. (2025) and Abdullah et al. (2023), who noted that the COVID-19 crisis, while initially disruptive, spurred the resilience of both carbon-based and renewable sectors, reflecting adaptive policy responses and the buffering role of energy systems. In contrast, the post-COVID intensification of carbon intensity's negative effect is consistent with Zhao et al. (2025) and Wen et al. (2022), who emphasised that the reversion to traditional growth patterns following recovery risks undermining environmental sustainability.

The differential impacts observed across the MINT countries highlight why, how, and under what conditions energy and carbon dynamics influence SDG 8 performance. Mexico's and Turkey's positive renewable energy–SDG 8 linkages suggest that institutional maturity, financial depth, and policy coherence enable clean energy to foster employment and productivity. These economies have demonstrated the capacity to integrate renewable expansion with industrial competitiveness, supporting the *green growth* thesis advanced by Luan et al. (2025). By contrast, Indonesia's and Nigeria's negative or insignificant results suggest structural rigidities, weak technological adoption, and high transition costs. In Nigeria, for example, the lack of diversified industrial capacity and dependence on extractive sectors constrain renewable energy's developmental impact, consistent with findings from Osabohien et al. (2024) that socioeconomic vulnerabilities magnify the effects of external shocks and limit policy responsiveness. The significant short-term contribution of energy use to SDG 8 across models indicates that accessible and reliable energy remains vital for maintaining economic activity and employment, an outcome echoed by Rahman et al. (2022) and Bekun et al. (2024), who emphasise that energy availability is a precondition for productivity growth in developing contexts.

The COVID-19-induced structural break observed in the post-pandemic period provides important insights into the mechanisms of recovery and transformation. During the pandemic, both carbon-intensive and renewable sectors acted as stabilisers of employment and output, confirming the resilience of these sectors under crisis conditions. Post-pandemic, however, the results reveal a clear reconfiguration of the growth–energy–employment nexus: GDP per capita's effect on SDG 8 turned positive, suggesting that fiscal stimulus, recovery investments, and adaptive labour-market policies enhanced inclusivity. This mirrors the experience reported by Dafnomilis et al. (2021), where targeted green stimulus measures yielded both economic and environmental gains. Simultaneously, the intensification of carbon intensity's negative effect signals a deepening awareness of the costs of unsustainable growth trajectories. The pandemic thus acted as both a disruptor and catalyst, exposing the fragility of carbon-based development while underscoring the potential of renewable energy as a long-term growth engine.

From a policy perspective, these findings carry several implications for the MINT economies. First, while economic growth remains central to achieving SDG 8, it must be decoupled from carbon-intensive industrial practices. The post-COVID shift towards more inclusive growth provides a foundation upon which countries can embed low-carbon strategies without compromising employment. Second, the results suggest that renewable energy's contribution to SDG 8 depends on supportive governance, technological diffusion, and financial access. Countries such as Turkey and Mexico, which have more coherent energy policies and stronger institutions, illustrate how renewable energy can enhance both environmental and social outcomes. Third, the pandemic's amplification of the positive short-term effects of energy and carbon intensity underscores the need for adaptive resilience strategies, balancing crisis responsiveness with sustainability. Investing in green innovation, expanding renewable energy infrastructure, and integrating social protection mechanisms as advocated by Osabohien et al. (2024), can ensure that transitions toward cleaner energy systems also promote equitable labour outcomes.

The strength of this study lies in its methodological diversity and attention to heterogeneity. By employing a combination of PARDL/PMG, Fixed Effects, Method-of-Moments Quantile Regression, and structural break analysis, the research provides a multidimensional understanding of both long-run equilibrium relationships and short-run fluctuations, while accounting for distributional and temporal variations. The disaggregation of results by country represents a further contribution, addressing a major gap in the literature and revealing structural asymmetries that are obscured in aggregated analyses. Moreover, the inclusion of COVID-period interactions and formal Chow tests adds statistical robustness to the identification of regime shifts, demonstrating the empirical validity of the observed structural transitions.

Nevertheless, certain limitations must be acknowledged. The study relies on national-level data, which, although comprehensive, may mask subnational variations in energy access, employment patterns, and industrial structure. The measures of renewable energy and carbon intensity, while standardised, may not fully capture qualitative technological improvements or efficiency gains across sectors. Furthermore, while the PARDL framework mitigates endogeneity through dynamic adjustment and lag structures, and the Fixed Effects estimator controls for

unobserved heterogeneity, residual endogeneity from bidirectional causality between economic growth and emissions cannot be entirely ruled out. Finally, as acknowledged in the discussion, the analysis primarily centres on the COVID-19 period as the defining global shock, whereas other significant episodes such as the 2008–2009 financial crisis, are recognised but not explicitly modelled.
In conclusion, this study demonstrates that the determinants of SDG 8 performance in MINT countries are shaped by complex interactions between economic growth, carbon intensity, and renewable energy consumption, all of which are sensitive to structural and temporal contexts. The evidence confirms that while economic growth and carbon-intensive activity currently drive SDG 8 outcomes, the sustainability of this growth is contingent upon expanding renewable energy adoption and improving energy efficiency. The observed post-COVID reconfiguration signals a critical window of opportunity for the MINT bloc to pursue inclusive and low-carbon growth trajectories. Policymakers should therefore prioritise green recovery strategies, institutional reform, and sustainable investment in renewable infrastructure to enhance both economic and environmental resilience. Future research could further disaggregate these dynamics at sectoral and subnational levels, incorporating multiple temporal shocks to deepen understanding of the pathways toward sustainable and inclusive economic development.

6. Conclusion

The present study set out to examine the complex interplay between carbon intensity, renewable energy consumption, and SDG 8 – decent work and economic growth cross the MINT countries, with a particular focus on pre-, during-, and post-COVID-19 dynamics. By addressing the evolution of carbon-intensive activities, renewable energy adoption, and their interactions with economic growth and employment outcomes, the research aimed to provide a comprehensive, country-specific understanding of the drivers of SDG 8 in economies at varying stages of industrialisation and energy transition. The study also sought to fill a gap in the literature by explicitly considering the structural and temporal shifts induced by the COVID-19 pandemic, an aspect often overlooked in previous analyses of emerging economies.
The findings reveal a pronounced heterogeneity in the determinants of SDG 8 across the MINT countries. The PARDL/PMG results indicate that, in the long run, GDP per capita and carbon intensity are principal drivers of SDG 8 outcomes, while energy use and renewable energy adoption exert nuanced short- and medium-term effects. Notably, COVID-19 interactions highlight that the pandemic temporarily amplified the positive contributions of both carbon-intensive and renewable sectors to employment and economic growth, suggesting that these sectors served as short-term stabilisers during the crisis. The Fixed Effects estimations reinforce these results, revealing substantial country-level differences: Mexico and Turkey demonstrate positive pathways linking economic growth and renewable energy adoption to SDG 8, whereas Indonesia and Nigeria exhibit weaker or negative associations, reflecting structural and policy constraints that limit the translation of energy transitions into inclusive employment. Complementing these insights, the Method-of-Moments Quantile Regression demonstrates that the effects of carbon intensity, energy use, and renewable energy vary across the SDG 8 distribution, with lower-performing economies experiencing stronger negative impacts from carbon-intensive activities and fewer benefits from renewable energy. Structural break analyses and post-COVID interaction terms further confirm that the pandemic constitutes a significant regime shift, shifting growth effects towards greater inclusivity while magnifying the detrimental consequences of carbon-heavy development.
These findings carry important implications for policy and practice. They underscore that achieving SDG 8 in MINT countries requires not only sustained economic growth but also a strategic decoupling from carbon-intensive pathways. Investments in renewable energy, energy efficiency, and low-carbon technologies can simultaneously support employment, productivity, and environmental sustainability, particularly when embedded within strong institutional and governance frameworks. The heterogeneity across countries highlights that tailored, context-specific interventions are essential: while Mexico and Turkey benefit from well-aligned energy and labour policies, Indonesia and Nigeria require targeted structural reforms, institutional strengthening, and human-capital development to ensure that energy transitions generate tangible employment and growth outcomes. The study further illustrates the importance of incorporating resilience considerations into policy design, as evidenced by the pandemic-induced shifts, suggesting that diversified energy and industrial portfolios can act as buffers against future shocks.
Looking forward, future research should expand on these findings by integrating sectoral and regional analyses to capture subnational heterogeneity, employing high-frequency or longitudinal data to assess the dynamics of multiple shocks, and leveraging advanced econometric techniques such as System-GMM to address potential endogeneity and reverse causality. Investigating the role of policy interventions, fiscal stimulus, and skills development in mediating the relationship between energy transitions and SDG 8 will be crucial for informing strategies that promote inclusive, low-carbon growth in emerging economies. Overall, this study provides compelling evidence that the pursuit of SDG 8 in MINT countries hinges on balancing economic expansion with environmental sustainability and social inclusivity, offering actionable insights for policymakers, practitioners, and researchers committed to sustainable development.

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