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The heterogeneous effect of carbon emissions, renewable energy consumption, and urbanization in MINT countries: Evidence from panel quantile regression

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ABSTRACT

This study examines the relationships between CO2 emissions, renewable energy consumption, and urbanization in MINT countries (Mexico, Indonesia, Nigeria, Turkey) from 1990 to 2021. Using World Development Indicator data, we conducted cross-section dependence testing, first-generation unit root tests confirming stationarity in the first difference, cointegration analysis, and panel quantile regression to address heterogeneity and outliers. Carbon emissions are negatively influenced by urban population and renewable energy consumption, except at the highest urban population quantiles. Renewable energy consumption is negatively affected by carbon emissions and urban living standards. Carbon emissions positively impact urbanization at lower quantiles but negatively at medium/high quantiles. Renewable energy consumption consistently shows negative effects on urbanization across all quantiles. Complex, quantile-dependent relationships exist between variables, with significant variations across distribution levels in MINT countries. Governments should implement fiscal incentives promoting renewable energy technology adoption as alternatives to fossil fuels, enhancing affordability for urban populations while improving environmental quality.

Contribution/ Originality: This study uniquely applies panel quantile regression to analyze the complex nonlinear relationships between carbon emissions, renewable energy consumption, and urbanization across different distribution levels in MINT countries, revealing previously unidentified threshold effects and quantile-specific policy implications.

1. INTRODUCTION

The relationship between carbon dioxide (CO_2) emissions, renewable energy consumption, and urbanization has been a major focus of environmental and economic research due to its implications for sustainable development and climate change mitigation. Rising CO_2 emissions, largely driven by fossil fuel consumption, have contributed to global warming, prompting increased attention on renewable energy sources such as solar, wind, hydro, and biomass (Ahmed, Ali, Ciocia, & D'Angola, 2024; Khan, Hussain, Bano, & Chenggang, 2020). At the same time, rapid urbanization is reshaping energy demand and environmental dynamics. Urban growth has traditionally been associated with rising energy consumption and emissions; however, cities also present opportunities for clean energy integration and sustainability initiatives. While extensive literature has explored these relationships, existing studies suffer from several critical limitations.

First, many prior studies have relied on conventional regression techniques such as ordinary least squares (OLS) or panel fixed effects models (Adebayo, Rjoub, Akinsola, & Oladipupo, 2022; Destek & Sarkodie, 2019), which assume homogeneous effects across all observations. However, these methods fail to capture the heterogeneous impact of urbanization and renewable energy consumption on CO_2 emissions across different levels of economic development and energy consumption patterns. This limitation is particularly relevant for MINT countries (Mexico, Indonesia, Nigeria, and Turkey), which exhibit diverse economic structures, energy policies, and urbanization trends.

Second, while some studies have examined the role of renewable energy consumption in reducing emissions, they often overlook the nonlinear and distributional effects across quantiles (Menyah & Wolde-Rufael, 2010; Xie, Liu, Jiang, & Wang, 2024). Understanding how these factors interact at different levels of emissions and energy consumption is crucial for designing targeted policies. Existing research has also struggled to disentangle the complex relationship between urbanization and environmental sustainability, with some studies suggesting a negative impact (Creutzig, Baiocchi, Bierkandt, Pichler, & Seto, 2015; Güneralp et al., 2017) while others argue for a neutral or even positive effect due to improved energy efficiency in urban areas (Kennedy, Ramaswami, Carney, & Dhakal, 2011).

Third, despite growing interest in emerging economies, the bulk of empirical research on environmental sustainability has focused on developed nations, particularly OECD and BRICS countries (Dogan & Seker, 2016; Le, Chang, & Park, 2020). MINT economies, identified for their economic potential and growing energy demands, remain understudied despite their significant role in the global climate agenda. Addressing this gap, this study provides new empirical insights into the interplay between carbon emissions, renewable energy consumption, and urbanization in MINT countries using panel quantile regression. Unlike traditional approaches, this method accounts for distributional heterogeneity, allowing for a more nuanced understanding of how these factors interact across different levels of emissions. By applying a panel quantile regression fixed effects model, this study makes three key contributions. First, it offers a more comprehensive assessment of the heterogeneous effects of urbanization and renewable energy consumption on CO_2 emissions, moving beyond average effects to capture variation across quantiles. Second, it provides new empirical evidence on the role of renewable energy in shaping urban environmental outcomes in MINT economies, contributing to the broader debate on sustainability transitions in emerging markets. Third, it enhances the methodological toolkit for environmental economics by demonstrating the advantages of quantile regression in capturing nonlinear relationships and unobserved heterogeneity.

The paper is organized as follows: Section 2 reviews the related literature, Section 3 introduces the methodology and data, Section 4 presents the empirical results and discussion, and finally, Section 5 presents the conclusion and policy recommendations.

2. RELATED LITERATURE REVIEW

A robust understanding of the interplay between CO2 emissions, renewable energy consumption, and urbanization is essential for formulating effective environmental and economic policies in MINT countries. The existing literature on this subject can be categorized into three key research strands: (1) the relationship between carbon emissions and energy consumption, (2) the impact of urbanization on carbon emissions, and (3) the role of foreign direct investment (FDI) in shaping environmental and energy consumption patterns. While significant work has been done in each of these areas, there remains a need for a more integrative approach that critically assesses the varying findings and methodological gaps in the literature.

2.1. Carbon Emissions and Energy Consumption

A widely studied area in environmental economics is the relationship between carbon emissions and energy consumption. Studies such as those by Yateh, Li, Tang, Li, and Xu (2024) and Jianchao, Minghua, and Malin (2024) emphasize the lack of standardized principles governing energy use and carbon emissions, underscoring the complexity of regulatory frameworks. Balcilar, Ozdemir, Ozdemir, and Shahbaz (2018) and Martínez-Zarzoso and Maruotti (2011) argue that the relationship between carbon emissions and energy consumption is highly sensitive to methodological choices and data heterogeneity. This suggests that panel-based methodologies, such as panel quantile regression, may provide a more nuanced understanding of the impact across different economic contexts.

Notably, empirical evidence presents conflicting findings. For instance, studies by Adewuyi and Awodumi (2017) and Jebli, Youssef, and Ozturk (2016) support the hypothesis that renewable energy consumption significantly reduces CO_2 emissions, while other works (Le et al., 2020; Zeeshan et al., 2021) show that the transition to renewable energy is often constrained by economic and policy-related barriers, particularly in developing economies. The inconsistencies suggest that while renewable energy has the potential to mitigate carbon emissions, its efficacy is conditional on structural economic and institutional factors.

2.2. Urbanization and Carbon Emissions

The relationship between urbanization and carbon emissions is another area of active debate. While some scholars argue that urbanization leads to higher emissions due to increased energy consumption (Al-Mulali, Sab, & Fereidouni, 2012; Ali, Abdul-Rahim, & Ribadu, 2017) others posit that urbanization can improve energy efficiency and reduce emissions in the long run due to better infrastructure and technology diffusion (Liu, You, Cifuentes-Faura, & Peng, 2024; Qiao, Xie, Liu, & Huang, 2024). This suggests a non-linear relationship, where urbanization initially exacerbates emissions but later contributes to their reduction—a pattern consistent with the Environmental Kuznets Curve hypothesis (Sharma, 2011; Zhu, You, & Zeng, 2012). A significant gap in literature is the regional specificity of urbanization's impact. For instance, Zhu et al. (2012) found an inverted U-shaped relationship between urbanization and emissions in emerging economies, whereas Saidi and Mbarek (2017) found no significant relationship in low-income nations. This divergence highlights the need for region-specific analyses, as factors such as industrial composition, governance quality, and energy mix influence the urbanization-emission nexus.

2.3. Foreign Direct Investment, Environmental Pollution, and Energy Consumption

FDI is often seen as a double-edged sword in the context of environmental sustainability. On one hand, it facilitates the transfer of cleaner technologies and enhances energy efficiency (Roy, 2023; Tang & Tan, 2015). On the other hand, it can lead to environmental degradation if investment is concentrated in pollution-intensive industries, as shown by Li, Dong, Huang, and Failler (2019) and Kaya, Kayalica, Kumaş, and Ulengin (2017). The pollution haven hypothesis, which suggests that developing countries with lax environmental regulations attract high-pollution industries, is supported by findings from To, Nguyen, and Pham (2019) and Kacar and Kayalica (2014).

However, the empirical evidence remains inconclusive. Bilalli, Gollopeni, Beka, and Gara (2024) argue that in developed economies, FDI contributes positively to renewable energy adoption and emission reductions, whereas in developing countries, its impact is contingent on regulatory and institutional frameworks. This highlights the importance of governance quality and policy interventions in mediating FDI's environmental impact.

Despite the extensive literature on carbon emissions, renewable energy, and urbanization, significant gaps remain. First, much of the existing research adopts a single-equation approach, failing to account for the bidirectional relationships between these variables. Second, while studies have explored the impact of urbanization on emissions, few have considered the potential for reverse causality—where environmental degradation influences urban migration patterns. Third, the role of energy policies and institutional quality in shaping these relationships is often overlooked, despite evidence suggesting their significance (Dogan & Seker, 2016; Kahia, Ben Jebli, & Belloumi, 2019).

Addressing these gaps requires a more integrated analytical framework that combines advanced econometric techniques with region-specific analyses. This study contributes to the literature by applying panel quantile regression to capture the heterogeneity of these relationships across different levels of economic development within

MINT countries. Furthermore, it emphasizes the role of governance and policy interventions in shaping sustainable energy transitions.

3. DATA AND METHODOLOGY

3.1. Data Description

This study analyzes the interrelationships among carbon dioxide emissions, renewable energy consumption, and urbanization in the MINT countries: Mexico, Indonesia, Nigeria, and Turkey. The key variables examined include carbon dioxide emissions measured in metric tons per capita, renewable energy consumption expressed as a percentage of total final energy, and urbanization defined by the ratio of the urban population to the total population. The dynamic econometric models include control variables such as foreign direct investment (net inflows as a percentage of GDP), trade openness (percentage of GDP), labor force participation, and merchandise trade (percentage of GDP). The dataset used for this empirical analysis spans from 1990 to 2021, consisting of 32 observations, and is derived from the World Development Indicator (WDI). All variables were transformed into natural logarithm values, with data reported on an annual basis. Table 2 outlines the description and measurement of the dataset, whereas Table 1 offers a summary of the variables utilized.

Table 1. Variable description.

Variables	Description
CO_2	Carbon dioxide emissions (Metric tons per capita)
REC	Renewable energy consumption (% of total final energy)
URB	Urban population (% of total population)
FDI	Foreign direct investment (Net inflows as a percentage of GDP)
TO	Trade openness (% of GDP)
LB	Labor force
MT	Merchandise trade (% of GDP)

Table 2 presents the summary statistics of all variables. The logarithmic mean value of the labor force is the highest, followed by urbanization, while that of FDI is the lowest. Trade openness is less volatile than other variables, with a standard deviation of 0.286, and renewable energy consumption shows high volatility. The variables that exhibit poor force show a positive bias, while the remaining variables exhibit the opposite. The distribution of the seven series is asymmetrical and more concentrated than a normal distribution. Additionally, the results of a Jarque-Bera test indicate that the unconditional distributions of all variables, except for trade openness (TO) and merchandise trade (MT), are non-normal. In quantile regression analysis, the normality assumption is entirely dropped (Wenz, 2018). Quantile regression via moment estimations performs well even if the errors exhibit skewness and kurtosis (Machado & Silva, 2019). Additionally, the partial correlation matrix results illustrated in Table 3 indicate that carbon dioxide emissions are positively correlated with all variables except for renewable energy consumption and the labor force. Renewable energy consumption is positively correlated only with the labor force, while urbanization is negatively correlated with the labor force.

Table 2. Summary statistics.

Variables	Mean	Std. dev.	Min.	Max.	Skewness	Kurtosis	J-B
CO_2	0.659	0.740	-0.695	1.634	-0.420	1.649	13.498***
RE	3.307	0.826	2.193	4.485	0.826	1.498	12.950***
URB	4.007	0.308	3.390	4.394	-0.444	1.862	11.109***
FDI	0.341	0.746	-2.601	1.756	-1.032	4.083	29.026***
TO	3.844	0.286	3.031	4.566	-0.367	3.258	3.240
LB	17.679	0.554	16.783	18.751	0.304	2.095	6.337**
MT	3.713	0.311	2.833	4.496	-0.196	3.123	0.906

Note: *** and ** denote significance at 1% and 5% level, respectively. 128 observations.

Table 3. Correlation matrix.

Variables	CO2	REC	URB	FDI	TO	LB	MT
CO_2	1						
REC	-0.973*	1					
URB	0.877*	-0.925*	1				
FDI	0.172*	-0.251*	0.144	1			
TO	0.465*	-0.471*	0.305*	0.265*	1		
LB	-0.378*	0.305*	-0.357*	0.157*	0.170*	1	
MT	0.339*	-0.355*	0.160*	0.450*	0.874*	0.183*	1

Note: * denotes significance at 5% level.

3.2. Econometric Techniques

The initial phase of the econometric methodology entails assessing cross-section dependence. Subsequently, an appropriate unit root test is selected, followed by the application of a panel quantile regression model to examine the interrelationships among CO_2 emissions, renewable energy consumption, and urbanization in MINT countries. The panel quantile regression methodology is employed to address potential heterogeneity (Dogan, Altinoz, & Tzeremes, 2020) and to estimate parameters at various points of conditional carbon dioxide emissions, renewable energy consumption, and urbanization. This method demonstrates superior performance compared to ordinary least squares (OLS) estimators, particularly in the presence of outliers and when the error terms deviate from a normal distribution. OLS estimations may produce spurious results (Machado & Silva, 2019) while quantile regression estimation is robust to outliers and non-normal distribution (Koenker & Bassett Jr, 1978). Traditional regression methodologies can sometimes result in the overestimation or underestimation of relevant coefficients and may not effectively identify significant relationships, as these techniques primarily concentrate on mean effects (Binder & Coad, 2011).

The panel quantile approach was introduced by Koenker and Bassett Jr (1978). The conditional distribution of the dependent variable specifies the τ^{th} quantile based on a set of independent variables$X_{i,t}$.

$$Q_{yi}(\tau|X_i) = X_i^{'}\beta_\tau \quad (1)$$

This paper utilizes panel quantile fixed effects to examine conditional heterogeneity and unobserved individual heterogeneity. Following Galvao Jr (2011); Lamarche (2010), and Koenker (2004), considering econometric theory, fixed effect panel data quantile regression can be illustrated as follows:

$$Q_{yi}(\tau_k|\alpha_i, X_{it}) = \alpha_i + X_{it}^{'}(\tau_k) \quad (2)$$

Where $i = 1, \dots, N$, $t = 1, \dots, T$, k represents the k-th quantile, α_i have a pure location shift effect on the conditional quantiles of the response. Panel quantile regression with fixed effects has a major problem, which is the incidental parameters problem when fixed observations of each cross-section go to infinity (Lancaster, 2000; Zhu, Li, & Guo, 2018). The parameters were estimated as follows:

$$\left(\hat{\beta}(\tau_k, \lambda), \{\alpha_i(\lambda)\}_{i=1}^{N}\right) = argmin \sum_{k=1}^{K} \sum_{t=1}^{T} \sum_{i=1}^{N} w_k \rho_{\tau k}\left(y_{it} - \alpha_i - X_{it}^{'}\beta(\tau_k)\right) + \lambda \sum_{i}^{N} |\alpha_i| \quad (3)$$

Where i and t represent the country and year indexes, respectively, $\rho_{\tau k}$ is the quantile loss function, w_k is the relative weight given to the k-th quantile, controlling the k-th quantile contribution to the fixed effects estimations, where it was considered equally weighted quantiles $\left(w_k = \frac{1}{k}\right)$ of Alexander, Harding, and Lamarche (2011).

Additionally, λ denotes the tuning parameter utilized to enhance the estimation of β while minimizing individual effects to zero. When λ equals 0, the penalty term is eliminated, resulting in the traditional fixed effects estimator. Conversely, when λ approaches infinity, we arrive at a model estimate devoid of individual effects, which is classified as a pooled model. In this study, λ has been established at a value of 1 (Damette & Delacote, 2012). The quantile specification corresponding to τ can be expressed as follows:

$$Q_{yi}(\tau|\alpha_i, \xi_t, X_{it}) = \alpha_i + \xi_t + \beta_{1\tau}REC_{it} + \beta_{2\tau}URB_{it} + \beta_{3\tau}FDI_{it} + \beta_{4\tau}TO_{it} + \beta_{5\tau}LB_{it} + \beta_{6\tau}MT_{it} \quad (4)$$

$$Q_{yi}(\tau|\alpha_i, \xi_t, X_{it}) = \alpha_i + \xi_t + \beta_{1\tau}CO2_{it} + \beta_{2\tau}URB_{it} + \beta_{3\tau}FDI_{it} + \beta_{4\tau}TO_{it} + \beta_{5\tau}LB_{it} + \beta_{6\tau}MT_{it} \quad (5)$$

$$Q_{yi}(\tau|\alpha_i, \xi_t, X_{it}) = \alpha_i + \xi_t + \beta_{1\tau}CO2_{it} + \beta_{2\tau}REC_{it} + \beta_{3\tau}FDI_{it} + \beta_{4\tau}TO_{it} + \beta_{5\tau}LB_{it} + \beta_{6\tau}MT_{it} \quad (6)$$

Where i and t represent countries and time, respectively. y_{it} represents the carbon dioxide emissions, renewable energy consumption and urbanization in Equations 4-6. CO_2 refers to carbon dioxide emissions, REC stands for renewable energy, URB indicates urbanization, FDI means foreign direct investment, TO represents trade openness, LB is the labor force, and MT pertains to merchandising in the equations.

4. EMPIRICAL RESULTS AND DISCUSSION

This section presents the results of the cross-section dependence test, unit root test, and cointegration test. Subsequently, the results of panel quantile regression are presented.

4.1. Results of Different Tests

The cross-section dependence test was utilized to ensure the accuracy of statistical results in the estimation of panel data. Neglecting cross-sectional correlation during panel data estimation can lead to significant consequences. Table 4 illustrates the results of three tests for cross-sectional dependence: the Breusch-Pagan LM test, the Pesaran scaled LM test, and the Pesaran (2004) test.

It is generally assumed that disturbances in panel data models are independent across sections. However, the findings presented in Table 4 indicate that we cannot reject the null hypothesis of cross-section independence based on the results from the Breusch and Pagan (1980) LM test, the Pesaran scaled LM test, and the Pesaran CD test. Consequently, we can proceed with the first generation of unit root tests.

Table 10 presents the results of the multicollinearity test using the Variance Inflation Factor (VIF) analysis for the variables in the study. The findings indicate potential multicollinearity concerns with renewable energy consumption (REC) and urbanization (URB), which have VIF values of 10.53 and 9.08 respectively, slightly exceeding the conventional threshold of 10.53 and 9.08 respectively, slightly exceeding the conventional threshold of 10. The remaining variables—foreign direct investment (FDI), trade openness (TO), labor (LB), and manufacturing/technology (MT)—demonstrate acceptable VIF values below 2, suggesting no multicollinearity issues with these predictors.

The mean VIF of 5.79 suggests moderate overall multicollinearity in the model. The 1/VIF values (tolerance) further confirm these findings, with lower values for REC and URB indicating greater collinearity concerns compared to the other variables.

Table 4. Cross-section dependence tests.

Tests	CO_2 (Dep. var.)	REC (Dep. var.)	URB (Dep. var.)
Breusch-Pagan LM	24.125	4.056	40.384
Pesaran scaled LM	5.232	-0.561	9.925
Pesaran CD	-1.840*	0.803	5.572

Note: * denote significance at the 10% level. The null hypothesis states that there is no cross-sectional dependence (correlation) in the residuals.

Table 5 shows the first generation of unit root tests, namely IPS (Im, Pesaran, & Shin, 2003), LLC (Levin, Lin, & Chu, 2002), Fischer PP (Phillips & Perron, 1988), and Fisher Augmented Dickey-Fuller (Maddala & Wu, 1999) tests.

The findings at this level indicate that not all tests agree. The results demonstrate that the null hypothesis of a unit root cannot be rejected at the level for all tests. However, the null hypothesis is rejected at a significant level of 1% for all four tests at the first difference.

Table 5. Panel unit root tests.

Level	ADF	PP	LLC	IPS
CO_2	1.103	0.983	1.804	-0.144
REC	4.108	5.806	-0.758	0.794
URB	10.202	57.689***	-2.867***	-0.518
FDI	20.256***	26.501	-1.923**	-2.381***
TO	8.347	9.728	-1.651**	-0.432
LB	7.673	7.117	-2.406***	0.612
MT	3.942	6.817	-0.406	0.794
First difference	ADF	PP	LLC	IPS
ΔCO_2	72.548***	114.279***	-8.440***	-7.768***
ΔREC	74.867***	111.746***	-5.580***	-8.825***
ΔURB	8.004	15.729**	0.543	0.536
ΔFDI	78.219***	133.620***	-7.972***	-9.224***
ΔTO	69.299***	114.322***	-7.865***	-8.214***
ΔLB	33.260***	67.201***	-3.878***	-4.251***
ΔMT	61.844***	116.491***	-7.060***	-7.432***

Note: *** and ** represent 1% and 5% rejections, respectively.

As variables are I (1), we can investigate their long-term relationship using the variance ratio test and Pedroni (1999) cointegration test. Table 6 displays the results of panel cointegration tests for the dependent variables (CO_2 emissions, REC energy consumption and URB). The null hypothesis of no cointegration is rejected for both the variance ratio and Pedroni residual cointegration tests, confirming the existence of a long-term association among the variables.

Table 6. Cointegration test.

Test	CO_2 (Dep. var)	REC (Dep. var)	URB (Dep. var)
Variance ratio	2.557***	1.289*	3.501***
Modified PP t	-0.113	0.262	1.432*
PP t	-2.665***	-1.522*	0.258**
ADF t	-2.495***	-1.642**	0.071***

Note: ***, **and * indicate the statistical significance at 1%, 5% and 10% level respectively. PP and ADF denote Phillips-Perron and Augmented Dickey-Fuller.

4.2. Panel Quantile Regression Results

4.2.1. The Effect of Renewable Energy Consumption and Urbanization on CO2 Emission

Table 7 illustrates the impact of renewable energy consumption and urbanization on carbon emissions, utilizing panel quantile regression estimation. The analysis employs percentile distribution for each dependent variable, ranging from the 5th to the 95th percentiles, revealing heterogeneous behavior among the dependent variables.

The findings presented in Table 7 indicate that renewable energy consumption has a negative relationship with CO2 emissions, with results being robust across different quantiles at a significant level of 1%. This indicates that an increase in renewable energy consumption correlates with a decrease in carbon dioxide emissions. This conclusion aligns with the research conducted by Khan et al. (2020), who employed a quantile approach within a global panel of 192 countries, affirming the adverse effect of renewable energy consumption on CO2 emissions. Our results also corroborate those of Adebayo, Udemba, Ahmed, and Kirikkaleli (2021), who demonstrated a significant reduction in CO2 emissions in Sweden because of renewable energy consumption, utilizing the quantile-on-quantile approach.

Moreover, our analysis reveals that urbanization exerts a negative and highly statistically significant impact on CO2 emissions in MINT countries, except at the 90th and 95th quantiles. This observation may be reflective of the relatively low level of urbanization in MINT countries or the adoption of cleaner energy sources and practices. This finding echoes the conclusions drawn by Fan, Liu, Wu, and Wei (2006) and Saidi and Mbarek (2017) which recognized a negative correlation between urbanization and CO2 emissions; however, contrasting results were reported by Yu, Zhang, and Kim (2020) and Xie, Yan, Zhang, and Wei (2020).

In line with renewable energy consumption, the estimated coefficient for foreign direct investment (FDI) is also highly statistically significant and negative across all quantiles, indicating that an increase in FDI is associated with a reduction in CO2 emissions, thereby supporting the halo pollution hypothesis. Khan et al. (2020) attribute this outcome to the tendency of foreign enterprises to invest in less polluting sectors within host countries, contributing to a decrease in environmental issues. Multinational companies often utilize advanced technologies that minimize ecological harm, ultimately enhancing technological levels and improving environmental quality. These findings are further supported by research of Asghari (2013) in selected MENA countries and Atici (2012) regarding ASEAN countries.

The estimated coefficient for trade openness exhibits heterogeneity, presenting a positive yet statistically insignificant effect, which does not provide strong evidence for the pollution halo hypothesis. However, at the 95th percentile quantile, trade openness demonstrates a significant positive impact on environmental quality, suggesting that it may contribute to environmental degradation in high-emission countries. These conclusions are consistent with the studies conducted by Fang et al. (2019), whereas previous works by Kahia et al. (2019) and Zhu et al. (2018) reported a negative relationship between trade openness and CO2 emissions. Furthermore, the coefficient for the labor force is statistically significant and negative at the 1% level, indicating that a larger labor force positively influences environmental quality. Additionally, the coefficient for merchandise trade is statistically significant and negative, but only at the 40th quantile in middle-emission countries, highlighting that merchandise trade may also contribute to CO_2 emissions in MINT countries.

4.2.2. The Effects of CO2 Emissions and Urban Population on Renewable Energy Consumption

Table 8 illustrates that environmental pollution exerts a highly significant negative impact on renewable energy consumption at a 1% significance level across all quantiles. This finding indicates that an increase in carbon emissions is associated with a decline in the use of renewable energy. Many researchers examining the relationship between renewable energy consumption and CO2 emissions have identified an inverse correlation. These results are in alignment with the findings of Kirikkaleli and Adebayo (2021) for India, as well as those of Liu, Ma, Ren, and Zhao (2020) for the BRICS nations, Sharif, Baris-Tuzemen, Uzuner, Ozturk, and Sinha (2020) and Sarkodie, Adams, Owusu, Leirvik, and Ozturk (2020).

Furthermore, it is noteworthy that the urban population also demonstrates a statistically significant negative effect on renewable energy utilization across all quantiles, suggesting that a growing urban population correlates with a decrease in renewable energy consumption.

The coefficient for foreign direct investment (FDI) is similarly significant and negative across all quantiles, indicating that FDI is associated with a reduction in renewable energy use. In contrast, the coefficient for trade openness is significant only at the lower quantiles, specifically the 10th and 20th, suggesting that trade openness positively influences renewable energy consumption. This can be attributed to the fact that trade openness facilitates the import of new technologies and energy sources that have a lesser environmental impact. Conversely, the labor force presents a statistically significant negative correlation with renewable energy usage in low and middle consumption countries at the 1% level. Additionally, the coefficient for merchandise trade is also negatively associated with renewable energy utilization across the 10th, 20th, 40th, 50th, and 60th quantiles.

4.2.3. The Effects of CO_2 Emissions and Urbanization Population on Urbanization

Table 9 presents varied outcomes. The estimated coefficient for CO2 is statistically significant and positive at the 5th and 10th quantiles, while it is insignificant at the 20th and 30th quantiles. Conversely, for the remaining quantiles, the coefficient is negative and significant, indicating that increases in CO2 emissions have a detrimental effect on urbanization at lower quantiles. The positive effect is confirmed, ceteris paribus, suggesting that CO_2 emissions may promote economic growth and urbanization. However, the negative impact observed at middle and high quantiles implies that elevated CO_2 levels can lead to the development of atmospheric pollutants, such as ozone and particulate matter. This indicates that reliance on non-renewable energy sources may adversely affect human health and decrease the attractiveness of urban areas for living and working.

The coefficient for renewable energy consumption is statistically significant and negative at the 1% level across all quantiles, suggesting that greater use of renewable energy correlates with a decline in urban population. In terms of foreign direct investment, its coefficient displays a negative and significant association with urban areas at both low quantiles (5th and 10th) and high quantiles (70th, 80th, 90th, and 95th), indicating that increases in foreign direct investment likely contribute to a decrease in urban areas.

Moreover, the coefficient for trade openness is statistically significant and negative at low quantiles (5th and 10th) but positive at middle and high quantiles (50th, 60th, 70th, 80th, and 95th). The coefficient is not significant at the 20th, 30th, 40th, and 90th quantiles. The coefficient for the labor force is insignificant at low quantiles but shows significant negativity from the 50th to the 95th quantiles. In contrast, the coefficient for merchandise trade is significantly positive at the 5th and 10th quantiles, insignificant at the 20th quantile, and significantly negative from the 30th to the 95th quantiles.

Table 7. The effects of renewable energy consumption and urbanization on CO_2 emissions.

D. Var.CO2	Quantiles										
	5th	10th	20th	30th	40th	50th	60th	70th	80th	90th	95th
Rec	-0.967***	-0.876***	-1.039***	-1.128***	-1.161***	-1.186***	-1.169***	-0.182***	-0.153***	-0.818***	-0.862***
Urb	-0.350***	-0.494***	-0.619***	-0.858***	-0.932***	-1.003***	-0.924***	-0.877***	-0.733***	0.028	-0.082
Fdi	-0.044**	-0.034*	-0.0531**	-0.082***	-0.074***	-0.070**	-0.098***	-0.088***	-0.107***	-0.061**	-0.048***
To	0.048	0.145	0.173	0.137	0.224	0.059	0.085	0.104	0.025	0.132	0.215***
Llb	-0.338***	-0.301***	-0.251***	-0.177***	-0.175***	-0.170***	-0.150***	-0.109***	-0.074***	-0.094***	-0.108***
Mt	0.012	-0.123	-0.137	-0.128	-0.243*	-0.130	-0.022	0.008	0.151	0.094	0.036
Cst	10.848***	11.045***	10.774***	10.857***	11.355***	11.880***	10.703***	9.695***	8.239***	4.268***	5.004***

Note: ***, ** and * represent 1%, 5% and 10% rejections respectively.

Table 8. The effects of CO2 emissions and urbanization on renewable energy consumption.

D.Var.Rec	Quantiles										
	5th	10th	20th	30th	40th	50th	60th	70th	80th	90th	95th
CO_2	-0.938***	-0.907***	-0.857***	-0.823***	-0.755***	-0.755***	-0.739***	-0.710***	-0.726***	-0.734***	-0.729***
Urb	-0.563***	-0.669***	-0.767***	-0.873***	-1.014***	-1.007***	-1.040***	-1.045***	-0.941***	-0.866***	-0.800***
Fdi	-0.061**	-0.046**	-0.067***	-0.063**	-0.059***	-0.054**	-0.056***	-0.080***	-0.086***	-0.079***	-0.063***
To	0.029	0.209*	0.230*	0.149	0.121	0.122	0.056	0.041	-0.002	0.003	-0.012
Llb	-0.274***	-0.234***	-0.131***	-0.141***	-0.119***	-0.110***	-0.075***	-0.048	-0.034	-0.025	-0.022
Mt	-0.036	-0.209*	-0.238**	-0.199	-0.210**	-0.215**	-0.176*	-0.084	0.011	0.031	0.062
Cst	10.909***	10.580***	9.207***	9.993***	10.302***	10.137***	9.775***	9.059***	8.274***	7.726***	7.392***

Note: ***, ** and * represent 1%, 5% and 10% rejections respectively.

Table 9. The effects of CO2 emissions and renewable energy consumption on urbanization.

D. Var.Urb	Quantiles										
	5th	10th	20th	30th	40th	50th	60th	70th	80th	90th	95th
CO_2	0.249***	0.284***	0.021	-0.034	-0.112*	-0.306***	-0.384***	-0.383***	-0.316***	-0.251***	-0.239***
Rec	-0.288***	-0.249***	-0.392***	-0.414***	-0.463***	-0.589***	-0.647***	-0.651***	-0.581***	-0.519***	-0.517***
Fdi	-0.043***	-0.033**	-0.023	-0.008	-0.006	-0.007	-0.020	-0.034*	-0.042**	-0.080***	-0.110***
To	-0.252***	-0.211***	0.021	0.127	0.113	0.176**	0.158*	0.168*	0.147*	0.137	0.153***
Llb	0.017	0.034	-0.034	-0.022	-0.027	-0.051**	-0.053**	-0.037*	-0.049**	-0.061***	-0.064***
Mt	0.153***	0.116**	-0.079	-0.197*	-0.179***	-0.252***	-0.254***	-0.237***	-0.194**	-0.151*	-0.171***
Cst	4.776***	4.314***	6.052***	6.001***	6.318***	7.340***	7.717***	7.373***	7.249***	7.147***	7.226***

Note: ***, ** and * represent 1%, 5% and 10% rejections respectively.

Table 10. Multicollinearity test.

Variables	VIF	1/VIF
REC	10.53	0.094
URB	9.08	0.110
FDI	1.55	0.646
TO	1.55	0.165
LB	1.36	0.735
MT	6.19	0.161
Mean VIF	5.79	0.172

5. CONCLUDING REMARKS

The objective of this study is to explore the relationship among CO2 emissions, renewable energy consumption, and urbanization in MINT countries, specifically Mexico, Indonesia, Nigeria, and Turkey. The empirical analysis utilizes a dataset covering the period from 1990 to 2021, comprising 32 observations, sourced from the World Bank (2021). To fulfill our research objectives, we conducted tests for cross-section dependence, panel unit root, and cointegration, while including control variables to mitigate omitted variable bias. The cross-section dependence test did not reject the null hypothesis of cross-section independence. First-generation unit root tests indicated that all variables are stationary at the first difference across all tests (ADF, PP, LLC, and IPS). The cointegration analyses reveal long-term relationships among the variables studied. To address unobserved individual heterogeneity, distributional heterogeneity, and outliers, we employed panel quantile regression. The results of the quantile regression were notably heterogeneous. In the first case, the findings indicate that urban population and renewable energy usage negatively and significantly correlate with carbon emissions, except for the last two quantiles of urban population, where the effects are not significant. In the second case, carbon emissions and the standard of living in urban areas negatively and significantly impact the utilization of renewable energies. In the third case, carbon emissions exert a positive and significant influence on urbanization at lower quantiles (5th and 10th), whereas a significantly negative impact is observed at middle and high quantiles (40th, 50th, 60th, 70th, 80th, 90th, and 95th). Furthermore, renewable energy consumption adversely affects urbanization across all quantiles.

These findings are critical for policymakers when designing interventions in the specified countries. The analysis suggests that nations should consider implementing fiscal incentives to promote the adoption of renewable and clean energy technologies as an alternative to fossil fuels. Possible measures may include reducing import taxes on clean energy technologies and making these options more accessible to urban populations, thereby enhancing environmental quality. In terms of reducing CO_2 emissions, it is recommended to focus on improvements in foreign direct investment, labor force engagement, and merchandise trade.

A limitation of this study lies in the selection of explanatory variables, as other factors, such as financial development and infrastructure spending, could also significantly influence CO_2 emissions.

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