
RENEWABLE PATHWAYS TOWARD DECARBONIZATION: PANEL EVIDENCE FROM EM7 COUNTRIES

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Abstract

Climate change driven by high CO₂ emissions has become a critical global challenge, particularly for emerging market economies that are experiencing rapid economic growth while remaining heavily reliant on fossil fuels. This study investigates the impact of the energy transition on CO₂ emissions in the seven largest emerging market economies (EM7), namely Brazil, China, India, Indonesia, Mexico, Russia, and Turkey, over the period 1990–2023, using panel data regression with a Fixed Effect Model. The empirical results indicate that energy intensity, GDP per capita, and population have a positive and statistically significant effect on CO₂ emissions, reflecting the environmental pressure from economic activity, population growth, and inefficient energy use. In contrast, renewable energy consumption has a negative and significant effect on CO₂ emissions, confirming the effectiveness of the energy transition in mitigating carbon output. These results highlight that expanding renewable energy adoption can offset the environmental impacts of economic and demographic growth, supporting the goals of the Paris Agreement and Sustainable Development Goal (SDG) 13 on climate action. The study provides important policy implications for governments, industry stakeholders, and society in emerging market economies, particularly in designing sustainable energy policies that balance economic growth with environmental sustainability.

Keywords: Energy Transition; CO₂ Emissions; Renewable Energy; Emerging Markets; GDP Per Capita; Population

INTRODUCTION

Climate change has become one of the most pressing global environmental challenges of the twenty-first century, with carbon dioxide (CO₂) emissions generated by human activities identified as the primary driver (Adedoyin et al., 2020). Empirical evidence on global warming is now widely accepted and no longer subject to scientific debate. Since the pre-industrial era, the global average surface temperature has increased by approximately 1.1°C (IPCC, 2021), and if current trends continue without sufficient mitigation efforts, projections indicate that the global temperature could rise by 3–5°C by 2100 (Burke et al., 2015).

This temperature increase is largely attributed to greenhouse gas emissions from anthropogenic activities (Nordhaus, 2019), with carbon dioxide accounting for 77% of total global emissions, followed by methane at 14% and nitrous oxide at 8% (Khan et al., 2014). The continuous accumulation of these gases in the atmosphere has led to significant and observable impacts on the Earth's climate system, including the melting of polar ice caps, rising sea levels, and an increasing frequency and intensity of extreme weather events.

These environmental consequences have strengthened the global consensus for urgent climate action, as reflected in the Paris Agreement. The agreement aims to limit the increase in global average temperature to well below 2°C above pre-industrial levels, while pursuing efforts to restrict it to 1.5°C. This target represents a collective international commitment to mitigate the adverse effects of climate change and to promote a more sustainable global development pathway.

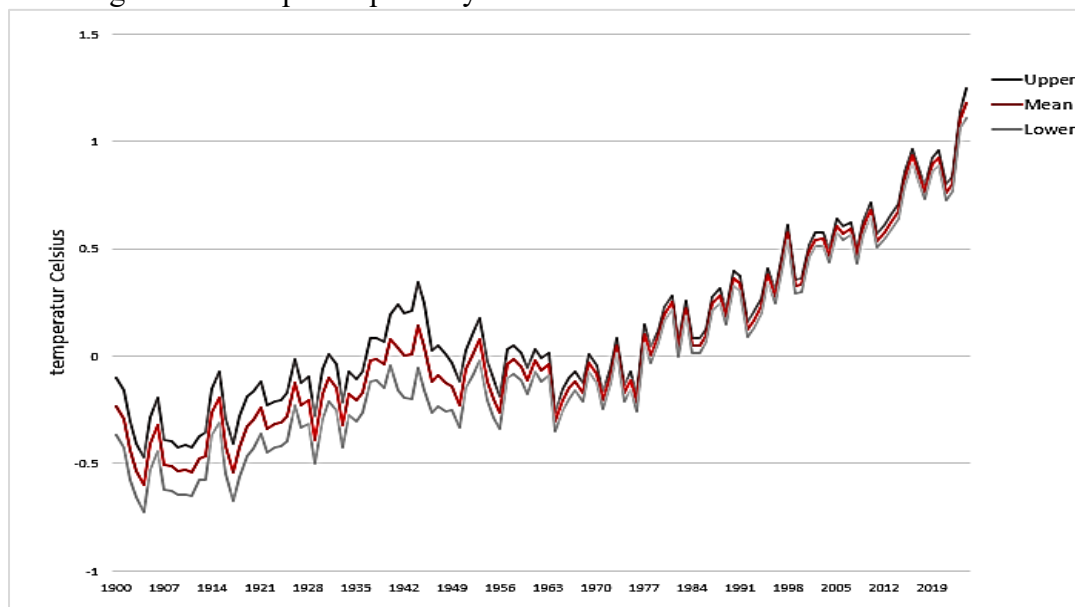


Figure 1.
Global Average Temperature on Land and Sea

Source: Our World in Data, 2026

The upward trend in carbon dioxide (CO₂) emissions has persisted since the 1970s (IPCC, 2014); however, the most pronounced increase occurred between 1990 and 2014, when global emissions rose from 33 billion tons to 48 billion tons of CO₂, representing an average annual growth rate of 1.5% over the period (Bárcena et al., 2019). One of the main

drivers of this increase is excessive energy consumption (Xue et al., 2022), with approximately 78% of total CO₂ emissions originating from the energy sector (69%) and industrial activities (9%), particularly in developing economies undergoing rapid industrialization (Hanif et al., 2022).

To date, fossil fuels including coal, oil, and natural gas continue to dominate the global primary energy mix, accounting for approximately 80% of total energy demand (Figure 2). This heavy reliance on fossil-based energy has intensified environmental pressures and contributed significantly to rising global emissions. These conditions have encouraged policymakers worldwide to pursue cleaner and more sustainable energy alternatives that can meet growing energy demand while simultaneously reducing CO₂ emissions in line with net-zero emission targets (Lee et al., 2023; Ulucak & Erdogan, 2022; Yahya & Lee, 2023). In the context of worsening climate change and the finite nature of fossil fuel reserves, the energy transition defined as the shift from fossil-based energy sources to renewable energy sources such as geothermal, biomass, hydropower, wind, and solar energy is widely recognized as a crucial strategy for ensuring energy security while substantially reducing CO₂ emissions (Z.-Z. Li et al., 2021; Pata, 2018).

Beyond emission reduction, the urgency of the energy transition also lies in strengthening national energy security, reducing dependence on fossil fuels, and improving environmental quality. High fossil fuel consumption contributes to severe air pollution, which increases the risk of respiratory, cardiovascular, and pulmonary diseases. The World Health Organization (WHO, 2024) reports that air pollution causes millions of premature deaths annually, with the highest burden falling on developing countries.

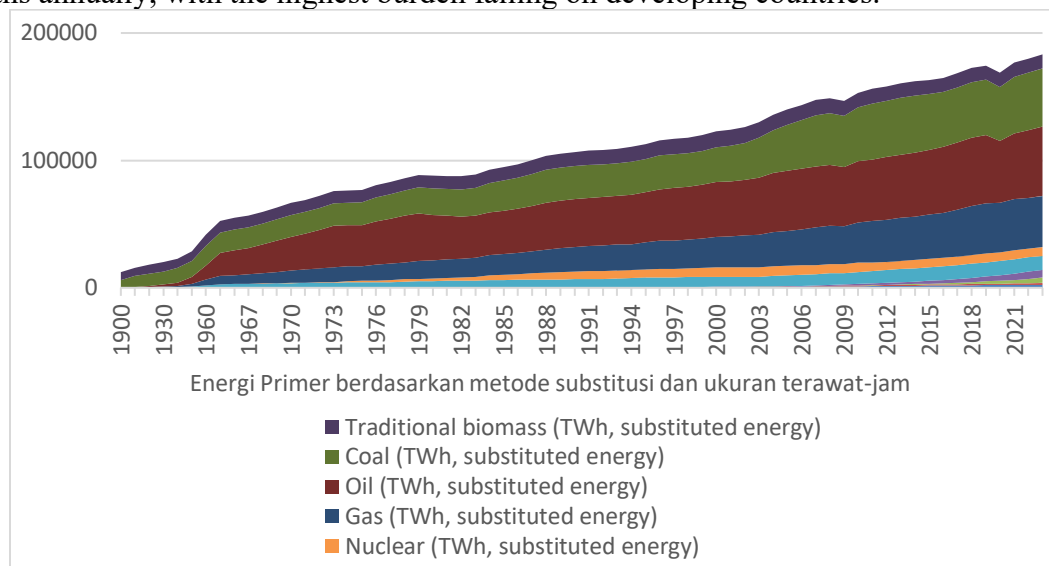


Figure 2.
Global Primary Energy Consumption by Source
Source: Our World in Data, 2026

The urgency of the energy transition has increased significantly amid accelerating industrialization and urbanization across countries (Dong et al., 2018). In this context, energy efficiency is not only a tool for reducing CO₂ emissions but also a strategic instrument for promoting sustainable economic growth and enhancing resilience to the impacts of climate

change. Throughout the twentieth century, both developed and developing countries have experienced a common pattern: rapid economic growth is often accompanied by increasing environmental degradation (Nathaniel & Khan, 2020). Importantly, the adverse effects of climate change are expected to be more severe in developing countries due to their limited institutional capacity and constrained resources for effective mitigation and adaptation (Li et al., 2021; Nkengfack & Fotio, 2019).

CO₂ emissions negatively affect economic growth through both direct and indirect channels (Bakhsh et al., 2017). High emission levels not only intensify the climate crisis but also contribute to natural resource depletion, rising energy costs, and infrastructure damage caused by increasingly frequent natural disasters. In addition, climate change undermines economic performance by reducing labor productivity and widening socio-economic inequality. Climate-sensitive sectors such as agriculture and fisheries are particularly vulnerable, often experiencing price volatility and supply disruptions that destabilize overall economic systems. In response to these challenges, the international community has developed cooperative frameworks through various environmental forums at both national and global levels (Luo et al., 2021). A key milestone is the 2016 Paris Agreement, which commits participating countries to reducing CO₂ emissions and encourages the implementation of mitigation and adaptation policies to address climate change (Ahmed et al., 2019).

Evidence of progress can be seen in the growing share of renewable energy. According to the Energy Institute, renewable energy accounted for approximately 30.3% of global electricity generation in 2023, up from 19% in 2015. This increase reflects the tangible outcomes of global efforts following the Paris Agreement to accelerate the energy transition and reduce CO₂ emissions in support of a sustainable energy system (Bogdanov et al., 2021). However, the transition still faces major challenges, including high initial investment costs, limited technological capacity, and structural dependence on fossil fuels, particularly in developing economies (Saqib et al., 2022).

Over the past two decades, developing countries have become increasingly important in the global economy (Huidrom et al., 2020), but they also account for approximately 60% of global CO₂ emissions (Lau et al., 2023). This study focuses on the seven largest emerging market economies—China, Russia, India, Brazil, Turkey, Mexico, and Indonesia—collectively known as the EM7, which represent around 80% of total economic output in developing countries (Huidrom et al., 2020). Among them, China and India are the world's largest greenhouse gas emitters and also rank among the most populous nations. For these countries, the main challenge is balancing economic growth with environmental sustainability. The adoption of low-carbon technologies and accelerated energy transition from fossil fuels to renewable energy offers a viable solution, with the potential to improve public health, foster industrial innovation, ensure long-term sustainability, and support the Paris Agreement target of reducing emissions by 60–65% by 2030 (Luo et al., 2021).

Previous studies on the relationship between energy transition and CO₂ emissions report mixed findings. Some evidence suggests that renewable energy consistently reduces emissions (Li et al., 2021; Pata, 2018), while other studies argue that the effect depends on a country's economic structure and institutional capacity (Li et al., 2021; Saqib et al., 2022). Moreover, most existing research focuses on developed countries or mixed global samples, overlooking the specific dynamics of emerging markets characterized by rapid growth and

persistent fossil fuel dependence (Hanif et al., 2022; Ulucak & Erdogan, 2022). EM7 countries exhibit distinct characteristics, including high industrialization, strong reliance on fossil energy, and sustained pressure to maintain economic growth (Huidrom et al., 2020; Lau et al., 2023), creating a policy dilemma between emission reduction commitments and development objectives. Addressing this gap, this study examines the impact of energy transition on CO₂ emissions in EM7 countries using a panel data approach. It aims to provide new empirical evidence and policy-relevant insights for emerging economies in designing effective energy transition strategies that support net-zero targets without compromising long-term economic growth.

REVIEW OF LITERATURE

The role of energy consumption and energy transition in economic growth has been widely examined in the empirical literature. However, the findings regarding the relationship between energy consumption and economic growth remain highly heterogeneous, largely due to differences in methodological approaches, types of energy considered, study periods, and the economic and regional characteristics of the countries analyzed.

In recent years, interest in CO₂ emissions has increased substantially in response to global efforts to address climate change (Wang et al., 2015; Wang & Zhao, 2015; Zhang et al., 2019). Advocates of the energy transition have proposed various strategic approaches to confront climate change challenges and mitigate greenhouse gas emissions (Kargari & Mastouri, 2011). Building on this foundation, a large body of research has examined the determinants of CO₂ emissions. For example, Doytch and Narayan (2021) and Nguyen and Kakinaka (2019) investigated the relationship between renewable energy consumption and CO₂ emissions across 107 countries and found a negative association, indicating that higher renewable energy use contributes to emission reductions, particularly in high- and middle-income economies. Similar results were reported by Koengkan and Fuinhas (2020), who showed that the renewable energy ratio, used as a proxy for energy transition, has a negative effect on CO₂ emissions in both the short and long run across Latin America and the Caribbean (LAC). This inverse relationship is further supported by Saqib et al. (2022) in the context of Gulf Cooperation Council (GCC) countries.

In addition to renewable energy, several studies have identified other key determinants of CO₂ emissions. Doğanlar et al. (2021) found evidence of a long-run relationship between energy consumption and CO₂ emissions in Turkey. Similarly, Diakoulaki and Mandaraka (2007), Li et al. (2023), and Sun et al. (2022) identified population, GDP per capita, energy intensity, and renewable energy share as major drivers of CO₂ emissions, noting that in Beijing, energy intensity plays a crucial role in achieving carbon neutrality by 2050. In contrast, Eyuboglu et al. (2025) reported that both economic growth and energy consumption exert a positive effect on CO₂ emissions in the short and long run. This variation in findings is likely explained by differences in stages of economic development and energy mix structures, where fossil fuel-dependent economies tend to experience higher emissions as energy consumption increases, while renewable-energy-oriented economies may exhibit weaker or even inverse relationships.

Furthermore, several studies emphasize the importance of renewable energy in the context of sustainable development. Eyuboglu et al. (2025), Gorus and Aydin (2019), and Lau et al. (2023) argue that the transition to renewable energy not only enhances

environmental sustainability but also fosters innovation and supports long-term economic growth. Interestingly, some studies suggest that CO₂ emissions are influenced not only by energy consumption but also by income per capita. Fatima et al. (2021), Hanif et al. (2022), and Lau et al. (2023) even find that renewable energy may be positively associated with CO₂ emissions in certain contexts. This counterintuitive result is often attributed to the early stages of energy transition, where the development of renewable energy infrastructure still relies on fossil-fuel-based inputs, temporarily limiting immediate emission reductions.

Overall, the literature indicates that the relationship between energy transition and CO₂ emissions is not uniform and depends heavily on country-specific conditions, development stages, and energy structure composition. While most studies support a negative relationship between renewable energy and CO₂ emissions, others report contrasting results, particularly in economies where the energy transition is still in its early phase. This inconsistency highlights the need for more focused empirical studies on relatively homogeneous groups of countries, such as the EM7 emerging market economies, to better understand the context-specific role of energy transition in reducing CO₂ emissions.

RESEARCH METHOD

This study examines the impact of the energy transition on the reduction of CO₂ emissions in emerging market economies, specifically the EM7 countries. The analysis incorporates several explanatory variables, including energy intensity, gross domestic product (GDP) per capita, population, and renewable energy consumption, while CO₂ emissions serve as the dependent variable. The research utilizes quantitative data obtained from secondary sources through a documentation approach, employing panel data that combines both cross-sectional and time-series dimensions. The study covers a 34-year observation period from 1990 to 2023. The primary data are collected from the World Bank and *Our World in Data*, and are further supported by relevant academic journals, articles, and institutional reports.

The population of this study includes countries that are signatories of the 2016 Paris Agreement and are classified as emerging market economies, namely Brazil, China, India, Indonesia, Mexico, Russia, and Turkey, collectively referred to as the EM7 group. To estimate the relationship between the independent and dependent variables, this study applies a panel data regression technique using EViews 12 software. The econometric model specification is presented as follows:

$$CO_2E = f(EI, PDB, POP, REC) \quad (1)$$

Subsequently, equation (1) is converted into its logarithmic form, a transformation commonly applied in econometric analysis to stabilize variance and interpret elasticities. The full panel data regression specification is then expressed in equation (3) as follows:

$$\ln CO_2E_{it} = \alpha_0 + \beta_1 EI_{it} + \beta_2 \ln PDB_{it} + \beta_3 \ln POP_{it} + \beta_4 REC_{it} + \varepsilon_{it} \quad (2)$$

Where:

lnCO₂E represents carbon dioxide emissions, proxied by per capita CO₂ emissions; lnEI denotes energy intensity; lnGDP represents economic development measured by real GDP per capita; lnPOP indicates total population; and lnREC refers to renewable energy consumption. The subscripts *i* and *t* represent the cross-sectional and time-series dimensions, respectively, while ε denotes the error term.

In panel data regression analysis, three standard estimation approaches are commonly applied, namely the Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM). To identify the most appropriate model based on the data characteristics, this study employs a series of specification tests, including the Chow test (to choose between CEM and FEM), the Hausman test (to choose between FEM and REM), and the Lagrange Multiplier test (to choose between CEM and REM). Before estimating the final model, this study also performs classical assumption tests to ensure that the regression model satisfies the requirements of the Best Linear Unbiased Estimator (BLUE). These tests include the multicollinearity test, which detects the presence of high correlations among independent variables that may bias estimation results, and the normality test, which examines whether the residuals are normally distributed as a prerequisite for valid statistical inference.

RESULTS AND DISCUSSION

The application of panel data regression analysis involves several sequential testing procedures to identify the most appropriate estimation model. The initial stage of model selection is carried out using the Chow test, Hausman test, and Lagrange Multiplier test, as reported in Table 1.

Table 1.
Model Selection Results

Model Selection Test	Probability (Prob.)	Result
Chow Test	0.000	Fixed Effect Model
Hausman Test	0.000	Fixed Effect Model

Source: EVIEWS 12 output (processed data results, 2026)

Based on the results generated using EVIEWS 12, the Chow test produces a cross-section Chi-square probability value of 0.000, which is below the 0.05 significance level. This indicates that the Fixed Effect Model (FEM) is preferred over the Common Effect Model (CEM). Following this result, the analysis proceeds with the Hausman test to choose between the Fixed Effect Model and the Random Effect Model, while the Lagrange Multiplier test is not required because the Chow test already suggests the suitability of FEM. The results of the Hausman test also show a cross-sectional chi-square probability value of 0.000 (< 0.05), confirming that the Fixed Effect Model is the most appropriate specification for this study.

Table 2.
Multicollinearity Test Results

Variables	IE	LNPDB	LNPOP	LNREC
IE	1.000000	0.100488	0.017760	0.289760
LNPDB	0.100488	1.000000	-0.641416	0.209958
LNPOP	0.017760	-0.641416	1.000000	0.492365
LNREC	0.289760	0.209958	0.492365	1.000000

Source: EVIEWS 12 output (processed data results, 2026)

After determining the most appropriate estimation model, this study proceeds with the classical assumption tests. The multicollinearity test is used to identify whether there is a strong linear correlation among the independent variables, as such relationships may distort the estimation results. A regression model is considered free from multicollinearity when the correlation coefficients between independent variables are below 0.90. Based on the results reported in Table 2, all correlations among the independent variables energy intensity (EI), GDP per capita (GDP), population (POP), and renewable energy consumption (REC) are below the 0.90 threshold. This indicates that there is no evidence of strong linear dependence among the explanatory variables. Therefore, it can be concluded that all variables used in this study satisfy the multicollinearity assumption.

Table 3.

Autocorrelation Test Results (Breusch–Godfrey Serial Correlation LM Test)

Test Statistic	Value	Probability
F-statistic	1.959181	0.0858
Obs*R-squared	10.01583	0.0748

Degrees of freedom: Prob. F(5,222); Prob. Chi-Square(5)

Source: EViews 12 output (processed data results, 2026)

As shown in Table 3, the autocorrelation test is conducted to verify whether the residuals of one observation are correlated with those of other observations, as such correlation may lead to biased estimation results. A model is considered free from autocorrelation when the probability value is greater than the 0.05 significance level. Based on the results of the Breusch Godfrey Serial Correlation LM Test presented in Table 3, the Chi-square probability value (Obs*R-squared) is 0.6796, which exceeds 0.05. This finding indicates that the regression model used in this study does not exhibit autocorrelation issues.

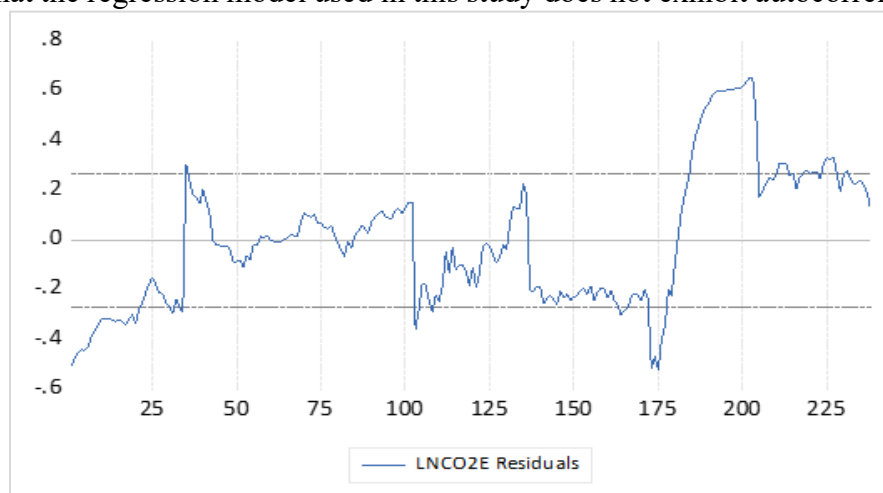


Figure 3.

Heteroskedasticity Test Results

Furthermore, the heteroskedasticity test is conducted to determine whether the regression model has constant error variance (homoskedasticity). Based on the residual plot shown in Figure 3, the residual values (indicated by the blue line) remain within the ± 500 range, suggesting that the variance of the residuals is relatively stable across all observations. Therefore, it can be concluded that the model does not experience heteroskedasticity issues.

Overall, the results of the three classical assumption tests confirm that the panel data regression model used in this study meets the requirements of the Best Linear Unbiased Estimator (BLUE). Hence, the model is considered appropriate for further analysis in examining the relationships among the variables.

Table 4 shows an R^2 value of 0.991, suggesting that the independent variables jointly explain about 99.1% of the variation in CO₂ emissions. This indicates an excellent model fit to the observed data. In addition, the F-statistic of 2,694.645 with a probability value below the 0.01 significance level confirms that all independent variables collectively have a statistically significant effect on CO₂ emissions. The regression results in Table 4 further reveal that energy intensity (EI), GDP per capita (GDP), population (POP), and renewable energy consumption (REC) all have significance levels below 0.05. This implies that each variable individually has a significant impact on CO₂ emissions across the seven emerging market (EM7) countries, highlighting the important role of economic, demographic, and energy-related factors in shaping emission levels within this group. Meanwhile, the constant term of -12.89 indicates that, holding EI, GDP, POP, and REC constant, CO₂ emissions are expected to decrease by 12.89%.

Table 4.
Fixed Effect Model Regression Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-12.89179	1.191599	-10.81890	0.0000
IE	0.124966	0.009476	13.18764	0.0000
LNPDDB	0.681049	0.031185	21.83888	0.0000
LNPOP	0.435620	0.063432	6.867508	0.0000
LNREC	-0.058638	0.024160	-2.427044	0.0160

Model Summary

Indicator	Value
R-Squared	0.991646
Adjusted R-Squared	0.991278
F-statistic	2694.645
Prob (F-statistic)	0.000000
Durbin-Watson stat	0.278329

Source: *EViews 12 output (processed data results, 2026)*

The coefficient for energy intensity (EI), which is 0.124, indicates that a 1% increase in energy intensity leads to a 0.124% rise in CO₂ emissions. Similarly, GDP per capita has a coefficient of 0.681, meaning that a 1% increase in GDP per capita results in a 0.681% increase in CO₂ emissions. The population (POP) variable also shows a positive relationship with emissions, where a 1% growth in population increases CO₂ emissions by 0.435%. In contrast, renewable energy consumption (REC) is negatively related to CO₂ emissions, indicating that a 1% increase in renewable energy use reduces CO₂ emissions by 0.058%.

Discussion

The empirical findings of this study reveal that energy intensity has a positive and statistically significant impact on CO₂ emissions in EM7 countries. This implies that increases in energy intensity lead to higher levels of carbon emissions. This result is in line with previous studies (Bhattacharya et al., 2016; Danish & Wang, 2018; Namahoro et al., 2021; Shahbaz et al., 2015), which identify energy intensity as a key determinant of environmental degradation. This relationship can be explained by the fact that energy intensity reflects the amount of energy required to produce one unit of economic output, while energy systems in EM7 countries remain largely dependent on fossil fuels. Consequently, higher energy intensity translates into greater fossil fuel consumption and, ultimately, increased CO₂ emissions.

Similarly, GDP per capita and population are found to significantly increase CO₂ emissions across EM7 countries. Rising GDP per capita, particularly in countries such as China, India, and Brazil, is closely associated with industrial expansion and growing energy demand. For instance, although China continues to invest in renewable energy, its industrial sector still relies heavily on coal, making emission reduction efforts more challenging (Hanif et al., 2022; Tao et al., 2021; Zhao et al., 2015). This indicates that economic growth continues to drive energy consumption at a pace that renewable energy adoption has not yet fully offset. These findings are consistent with Diakoulaki and Mandaraka (2007), G. Li et al. (2023), and Sun et al. (2022), who also identify GDP, population, and energy intensity as major drivers of CO₂ emissions.

Population growth further intensifies emission pressures in EM7 countries. Highly populated economies such as India and Indonesia experience rapidly increasing energy demand to support transportation, housing, and industrial activities. Nevertheless, despite these upward pressures, the results also show that renewable energy consumption has a negative and significant effect on CO₂ emissions. This indicates that greater use of renewable energy consistently contributes to emission reductions, even amid strong economic and demographic growth. This finding aligns with Doytch and Narayan (2021), Koengkan and Fuinhas (2020), Nguyen and Kakinaka (2019), and Saqib et al. (2022), who report similar results across different country groups.

Overall, energy transition plays a critical role in mitigating CO₂ emissions by replacing fossil fuels with cleaner energy sources such as solar, wind, and hydropower. These results highlight the importance of accelerating renewable energy adoption in EM7 countries to support Sustainable Development Goal (SDG) 13 and the Paris Agreement targets, while still accommodating economic and population growth without compromising long-term environmental sustainability.

CONCLUSION

This study investigates the impact of energy transition on CO₂ emission reduction in seven emerging market economies (EM7), namely Brazil, China, India, Indonesia, Mexico, Russia, and Turkey, over the period 1990–2023 using panel data regression analysis. The Fixed Effect Model (FEM) results show that energy intensity, GDP per capita, and population have a positive and significant effect on CO₂ emissions, while renewable energy consumption has a negative and significant effect. These outcomes suggest that economic expansion, population growth, and high energy intensity, still largely driven by fossil fuel dependence,

remain key contributors to rising emissions in EM7 countries. In contrast, the expansion of renewable energy use through energy transition effectively helps mitigate CO₂ emissions.

Overall, the results highlight a dual challenge faced by EM7 countries: maintaining economic growth while simultaneously reducing carbon emissions in accordance with Paris Agreement commitments. Energy transition emerges as a crucial mechanism for balancing these objectives, emphasizing the importance of strengthening renewable energy development as part of a broader sustainable development agenda in emerging economies.

Policy Implications

For governments, these findings highlight the urgency of accelerating energy transition policies through fiscal incentives such as tax reductions, subsidies for renewable energy investments, and the gradual elimination of fossil fuel subsidies. In addition, improving energy efficiency regulations, particularly in the industrial sector, is essential to reduce energy intensity, one of the main drivers of CO₂ emissions. Population management and urban planning policies that integrate energy efficiency principles are also needed, given the significant role of demographic growth in increasing energy demand. For industry players and other stakeholders, a stronger commitment is required to adopt cleaner energy sources and low-carbon technologies in production processes to reduce energy intensity. Financial institutions and investors also play a vital role by expanding access to green financing, which can help overcome the high initial costs of renewable energy development in emerging markets.

For the public, increasing awareness and understanding of energy efficiency and renewable energy use is essential. This can be achieved through education campaigns and energy-saving initiatives in daily life. Public participation, including the adoption of household renewable energy systems such as rooftop solar panels, will further strengthen the effectiveness of government policies in achieving sustained CO₂ emission reductions.

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