CARBON EMISSION DRIVERS IN E-7 ECONOMIES: THE ROLE OF RENEWABLE ENERGY, ECO-TOURISM, NATURAL RESOURCES, AND E-COMMERCE

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(Received 10th Jul 2025; accepted 8th Sep 2025)

Abstract. Achieving carbon neutrality while sustaining economic growth remains a key challenge for emerging economies, particularly those undergoing rapid expansion in tourism and digital commerce. This study explores the nonlinear and interactive effects of tourism, renewable energy, natural resource dependence, E-commerce activity, governance quality, and human capital on carbon emissions across emerging economies from 2000 to 2022. Using Method of Moments Quantile Regression (MMQR), along with Fully Modified OLS (FMOLS), Dynamic OLS (DOLS), and the Dumitrescu-Hurlin panel causality test, we uncover both distributional and long-run effects. Results reveal significant inverted U-shaped relationships for tourism and natural resource rents, suggesting threshold effects where environmental degradation eventually declines with sustainable practices. Renewable energy consumption consistently exerts a significant negative effect on emissions, especially at higher quantiles, confirming its crucial role in decarbonization. The interaction between E-commerce and governance quality demonstrates that stronger institutional frameworks reduce the environmental impact of digital economic activity. Governance quality and human capital also show robust emission-reducing effects across quantiles. These findings underscore the importance of integrated policies that promote renewable energy adoption, institutional strengthening, and sustainable digital transformation to support low-carbon growth pathways in emerging economies.
Keywords: *sustainable development, climate change mitigation, institutional quality, human capital, digital economy, low-carbon growth, E7 economies*

Introduction

Tourism is a key driver of economic growth, fostering job creation, infrastructure development, and international exchange. However, it is also a substantial contributor to carbon dioxide (CO_2) emissions (CE), especially through transportation, accommodation, and tourism-related activities. The aviation industry alone accounts for nearly 12% of total transport-related CE, while hotels and recreational infrastructure further exacerbate environmental degradation (Depren et al., 2023). As the tourism sector expands, its ecological footprint intensifies, reinforcing the need for sustainable tourism models that balance economic benefits with environmental preservation.

Given the intensifying environmental challenges facing the E-7 economies—Brazil, China, India, Indonesia, Mexico, Russia, and Turkey—this study investigates the complex interplay between tourism, natural resource dependence, E-commerce activity, renewable energy consumption, governance quality, and human capital in shaping carbon emissions. While both international and domestic tourism contribute to carbon emissions, this study focuses on international tourist arrivals due to two reasons. First, international

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1088910911

tourism provides a standardized and consistently available indicator across all E-7 countries, allowing reliable cross-country comparison. Comparable data on domestic tourism are either unavailable or inconsistent, especially over a long time frame. Second, international arrivals are strongly linked with long-distance transportation, particularly aviation, which is one of the most carbon-intensive components of the tourism sector. By focusing on international tourism, the analysis captures a major source of emissions that is both globally relevant and empirically comparable across the E-7 economies (Chen et al., 2025; He et al., 2025). Nevertheless, we acknowledge that domestic tourism—particularly in large countries such as China, India, and Russia—also plays a significant role, and future research could extend the analysis to account for its environmental impacts once harmonized data become available.

In emerging economies, economic growth often relies on intensive energy consumption and natural resource use, which heighten environmental pressures (Dorn et al., 2020). The Intergovernmental Panel on Climate Change (IPCC) warns that power-related CE could increase by 41–109% by 2030. CE, representing 82% of total greenhouse gas (GHG) emissions, is at the core of global climate concerns (IPCC 2021). International frameworks such as the Sustainable Development Goals (SDGs) and the Paris Agreement (COP-21) urge nations to decouple economic expansion from environmental harm by adopting clean energy technologies and reducing carbon intensity (Meng et al., 2023; Duan, 2025).

Natural resource (NR) exploitation is a principal factor behind increasing CE. Globally, natural resource exploitation accounts for over 80% of energy consumption and 51% of CE (Zhang et al., 2020; Dong and Yu, 2024). Studies attribute 91% of environmental degradation to resource extraction and processing. Over the past three decades, global resource consumption has nearly tripled, driven by growing energy demand and industrial activity (Ding et al., 2021). Despite progress in renewable energy (RE) deployment, fossil fuel reliance remains high, particularly in emerging economies, which demands innovations to improve resource efficiency and reduce emissions (Bhutto et al., 2022; Saqib et al., 2024).

Within this landscape, the rise of digital platforms and E-Commerce (ECOM) has introduced new dynamics into the environmental sustainability discourse (Sun et al., 2025; Zhou et al., 2025). E-Commerce enables faster, more convenient consumer transactions but also influences energy use, packaging waste, and supply chain logistics—factors that may either reduce or intensify emissions. While digitalization is often associated with efficiency gains, its environmental implications depend on the governance of digital infrastructure, consumption behavior, and integration with sustainable practices.

Governance quality (GOV) and human capital (HC) also play crucial roles in determining the environmental outcomes of digital and economic transformations (Ren et al., 2023; Pegkas, 2024). Effective governance fosters policy implementation, environmental regulation, and infrastructure planning, while high human capital supports technological diffusion and public awareness. Renewable energy consumption, enabled by strong institutions and skilled labor, is essential for transitioning to a green economy.

Preliminary trends in E-7 economies (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey) reveal considerable heterogeneity across CE, tourism (TR), NR, ECOM, RE, GOV, and HC. Tourism revenues fluctuate in response to global economic shocks and health crises, as seen during the COVID-19 pandemic. E-Commerce has rapidly expanded, particularly in India, China, and Brazil, with mixed environmental outcomes.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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Resource-rich countries such as Russia exhibit higher CE due to overreliance on extractive industries. These patterns highlight the complex relationship between development and sustainability.

The time series analysis presented in *Figure 1* reveals distinct and evolving trends across emerging economies in terms of carbon emissions, natural resource dependence, tourism activity, and renewable energy consumption between 2000 and 2022. Carbon emissions (CE) generally exhibit upward trajectories in several countries, though some show stabilization or decline in recent years, potentially reflecting shifts in energy policy or technological adoption. Natural resource rents (NR) display significant volatility, suggesting fluctuating reliance on extractive sectors and vulnerability to commodity price cycles. Tourism (TR) shows a steady increase across most nations, underscoring its growing economic importance but also its potential environmental burden. In contrast, renewable energy consumption (RE) demonstrates a gradual upward trend, with notable acceleration in later years for some countries, indicating progress toward cleaner energy systems. Together, these dynamics highlight the complex interplay between economic development, environmental pressures, and the transition to sustainable energy, thereby justifying the study's exploration of nonlinear and interaction effects within this context.

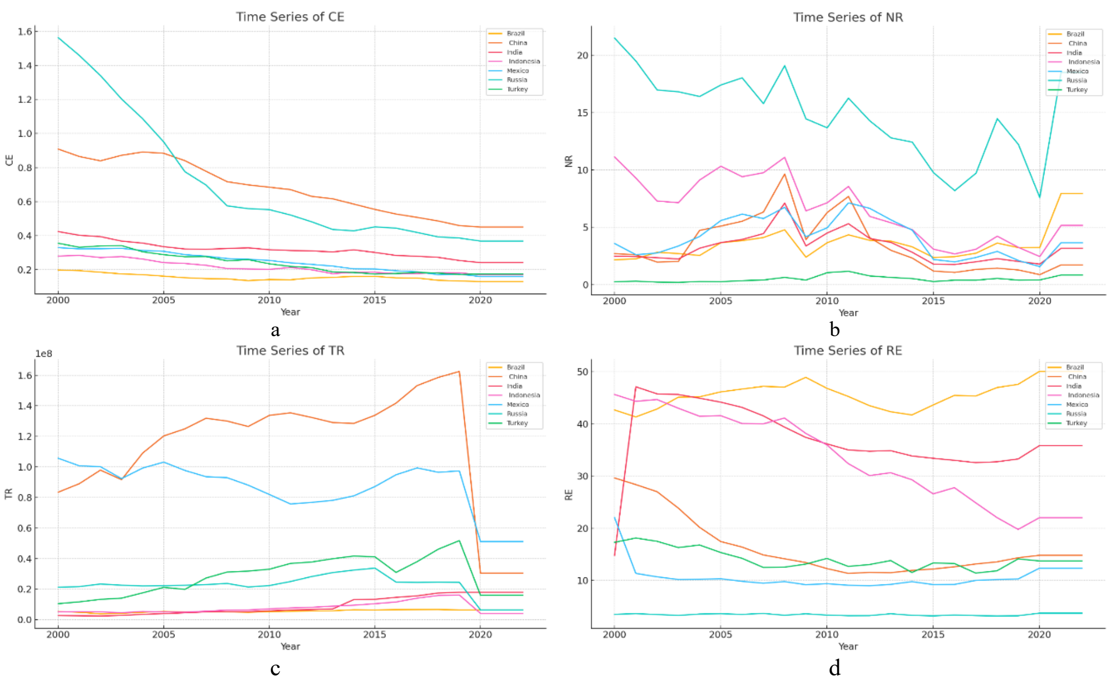

Figure 1a-d. *Time series trends of carbon emissions (CE, metric tons per capita), natural resource rents (NR, % of GDP), international tourist arrivals (TR, number of arrivals), and renewable energy consumption (RE, % of total final energy consumption) across emerging economies (2000–2022). The plots illustrate heterogeneous trajectories across countries, capturing nonlinear patterns in emissions and resource dynamics, as well as evolving tourism flows and renewable energy adoption. These visual trends support the empirical investigation of threshold effects and the role of renewable energy in mitigating environmental degradation. Trends for E-commerce activity (ECOM) and governance quality (GOV) are not included in the figure because these variables are composite indices constructed through Principal Component Analysis (PCA). Their scales are not directly comparable with raw indicators such as emissions, natural resource rents, tourism, and renewable energy. Instead, ECOM and GOV are fully incorporated into the econometric analysis, where their standardized values allow robust comparison across countries*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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By employing a comprehensive econometric framework, including Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), Method of Moments Quantile Regression (MMQR), and Dumitrescu-Hurlin panel causality tests, this study captures both average and distributional effects across varying levels of environmental stress, providing a robust understanding of these dynamics.

The specific objectives of this study are fivefold. First, to examine the relationship between tourism and carbon emissions in the E-7 economies, with particular attention to identifying threshold effects that may signal a turning point toward more sustainable tourism practices. Second, to investigate the environmental implications of E-commerce expansion, with a focus on the moderating role of governance quality in mitigating its carbon footprint. Third, to assess the impact of natural resource dependency on emissions, exploring the conditions under which resource exploitation either exacerbates or alleviates environmental pressures. Fourth, to evaluate the mitigating influence of renewable energy adoption, governance capacity, and human capital development in reducing carbon emissions. Finally, to derive actionable policy recommendations that integrate tourism management, digital economy governance, and sustainable resource utilization into comprehensive low-carbon development strategies.

This study advances the growing literature on digital transformation and environmental sustainability by providing new empirical evidence on the dual role of E-commerce as both a driver of emissions and a domain where effective governance can moderate environmental risks. By incorporating threshold analysis and governance interaction effects, the study offers novel insights into how emerging economies can navigate the trade-offs between economic growth and environmental sustainability.

Literature review

This section synthesizes existing research on the links between tourism (TR), natural resources (NR), E-commerce (ECOM), governance quality (GOV), renewable energy consumption (RE), human capital (HC), and carbon emissions (CE). It identifies prevailing findings, trends, and research gaps relevant to this study.

Tourism and carbon emissions

Tourism is a dual-edged contributor to both economic growth and environmental degradation. Bi and Zeng (2019) identify a U-shaped relationship between tourism and CE, where initial expansion increases emissions but later stabilizes with the adoption of sustainable practices. Empirical evidence from Turkey (Eyuboglu and Uzar, 2020), top global economies (Razzaq et al., 2023), and Asian nations (Wangzhou et al., 2022) confirms tourism's role in driving growth. However, tourism's environmental impact remains contested. Some studies report positive effects on CE mitigation through eco-tourism and carbon offset initiatives (Liu et al., 2022; Wei and Huang, 2022), while others emphasize tourism's contribution to rising emissions (Zhou et al., 2023). These mixed findings suggest that sustainable tourism policy is critical to balancing economic and environmental objectives.

Natural resources and carbon emissions

Natural resources are a central factor in the environmental performance of many economies. While some studies argue that NR exploitation leads to increased CE,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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particularly in resource-dependent regions such as the Middle East and North Africa (Ullah et al., 2021), others highlight the potential for NR to lower energy costs and support cleaner energy transitions if managed effectively (Khan et al., 2022; Akhayere et al., 2023). Conversely, Ibrahim et al. (2023) and Du and Wang (2023) caution that unchecked resource extraction tends to reinforce carbon-intensive economic structures. These conflicting perspectives underscore the importance of governance and technology in shaping the environmental outcomes of NR utilization.

E-commerce and carbon emissions

E-Commerce is increasingly recognized as a disruptive force in economic systems, with both positive and negative environmental implications. On the positive side, digital platforms can improve market efficiency, reduce reliance on physical retail spaces, and promote green product consumption (Cheng et al., 2024). However, E-Commerce can also elevate CE through increased packaging waste, transportation emissions, and energy use in data centers (Uddin et al., 2024). While digitalization may offer opportunities for sustainable consumption, its environmental footprint depends on supply chain management, consumer behavior, and digital infrastructure efficiency. Further research is needed to clarify these dynamics, particularly in emerging markets.

Governance and carbon emissions

Governance quality is a key enabler of environmental sustainability. Effective governance enhances regulatory enforcement, promotes institutional integrity, and supports the implementation of environmental policies (Khan and Hassan, 2024). Strong governance is essential for managing tourism growth, resource exploitation, and digital economy expansion in an environmentally responsible manner. Poor governance, by contrast, often results in regulatory gaps and weak policy enforcement, exacerbating CE and environmental degradation. Thus, institutional quality plays a decisive role in determining whether economic growth aligns with sustainability goals.

Renewable energy and carbon emissions

Renewable energy (RE) adoption is widely recognized as a cornerstone of carbon mitigation strategies. Transitioning from fossil fuels to renewable energy sources such as solar, wind, and bioenergy reduces CE while enhancing energy security (Binyamin et al., 2024). Empirical studies consistently show that increasing the share of renewable energy in total energy consumption leads to significant environmental benefits, particularly in emerging economies seeking to balance growth with sustainability (Xu et al., 2024a). However, the pace of renewable energy adoption varies across regions, often constrained by technological, financial, and institutional barriers.

Human capital and carbon emissions

Human capital (HC), measured through educational attainment and workforce skill levels, is critical for fostering technological innovation and environmental awareness. Higher HC enhances the capacity of economies to adopt green technologies, improve energy efficiency, and implement sustainable practices (Xu et al., 2024b). It also supports the development of governance structures capable of enforcing environmental regulations. Thus, investing in education and workforce development is essential for achieving long-term sustainability.

Identified research gaps and contributions

Although a growing body of literature has explored the relationships between tourism, natural resource dependency, E-commerce activity, governance quality, renewable energy consumption, human capital, and carbon emissions, several important research gaps remain unaddressed.

First, much of the existing evidence is region-specific, with limited cross-economy comparative analyses that account for the distinct economic structures, governance capacities, and environmental pressures faced by emerging economies such as those in the E-7 group. This lack of comparative research limits the generalizability of findings and the development of targeted policy recommendations.

Second, the mechanisms through which governance moderates the environmental impacts of economic activities, particularly E-commerce and tourism, remain insufficiently understood. While digitalization is often discussed in relation to environmental efficiency, few studies empirically test the interaction between institutional quality and digital economy expansion in shaping carbon outcomes.

Third, there is limited longitudinal evidence capturing long-term environmental dynamics, especially studies that integrate both average and distributional effects over multiple decades. This gap restricts understanding of how sectoral impacts evolve across different stages of economic development and emission intensity.

Addressing these gaps, this study investigates the long-run and distributional effects of tourism, natural resources, E-commerce, governance quality, renewable energy, and human capital on carbon emissions in E-7 economies over the period 2000 to 2022. By incorporating threshold analysis and governance interaction effects, the study offers new insights into how these factors jointly influence environmental performance across different levels of carbon emissions. The findings contribute to the advancement of integrated policy frameworks aimed at promoting sustainable economic growth, enhancing governance capacity, and managing digital and tourism transitions in emerging economies striving for carbon neutrality.

Theoretical framework

This study is grounded in multiple theoretical perspectives that explain the relationship between economic activities, institutional dynamics, and environmental outcomes. The Environmental Kuznets Curve (EKC) hypothesis provides the foundational framework, positing that environmental degradation initially increases with economic growth but eventually declines after reaching a certain income threshold. While traditionally applied to GDP-growth relationships, this study extends the EKC logic to sector-specific dynamics, particularly tourism and natural resource exploitation, to test whether similar threshold or inverted U-shaped patterns exist in their environmental impacts.

The Pollution Haven Hypothesis (PHH) and Pollution Halo Hypothesis (PHH) further contextualize the role of foreign investment, trade, and sectoral expansion—including tourism and E-commerce—in environmental degradation. While PHH suggests that weak regulatory environments in emerging economies attract pollution-intensive activities, the pollution halo perspective argues that such activities can improve environmental performance if supported by effective governance and clean technologies. This duality provides the theoretical justification for examining the moderating role of governance quality in shaping the environmental outcomes of tourism and E-commerce activities in the E-7 context.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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Additionally, the study draws on Institutional Theory, which emphasizes the role of governance structures, regulatory capacity, and institutional quality in shaping environmental performance. Effective governance is theorized to moderate the environmental risks associated with economic activities by enforcing environmental regulations, promoting cleaner technologies, and enhancing institutional accountability. This theoretical perspective underpins the inclusion of interaction terms between governance quality and E-commerce to empirically test governance's moderating influence on digital economy-driven emissions.

The role of Renewable Energy Transition Theory is also central to this framework, recognizing the shift from fossil fuel dependency to cleaner energy systems as a critical pathway toward carbon neutrality. Similarly, Human Capital Theory highlights the importance of education, skills development, and technological capacity in enabling economies to adopt sustainable practices and mitigate environmental degradation.

Integrating these theoretical perspectives, the proposed framework conceptualizes carbon emissions as a function of tourism, natural resources, E-commerce, renewable energy, governance quality, and human capital. It further posits that governance quality moderates the environmental effects of E-commerce, while tourism and natural resources may exhibit nonlinear threshold effects. This multi-dimensional framework enables a comprehensive examination of both direct effects and interaction dynamics, providing a robust foundation for empirical analysis and policy recommendations aimed at achieving sustainable development in E-7 economies.

Material and methods

Data description

This study investigates the effects of tourism (TR), natural resources (NR), E-commerce activity (ECOM), governance quality (GOV), renewable energy consumption (RE), and human capital (HC) on carbon emissions (CE) in E-7 economies (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey) over the period 2000–2022. *Table 1* shows the sources of the study variables. The analysis employs a balanced panel dataset compiled from reputable international sources to ensure reliability and cross-country comparability.

- Tourism (TR) is measured by the total number of international tourist arrivals, sourced from the World Bank's World Development Indicators (WDI).
- Carbon Emissions (CE) are measured in metric tons per capita, sourced from WDI.
- Natural Resources (NR) are measured as the percentage of total natural resource rents, including oil, gas, minerals, forests, and coal, sourced from WDI.
- E-Commerce Activity (ECOM) is constructed using Principal Component Analysis (PCA) of three indicators: internet usage, broadband subscriptions, and secure internet servers, sourced from the WDI.
- Governance Quality (GOV) is derived using PCA of six World Governance Indicators (rule of law, government effectiveness, regulatory quality, political stability, control of corruption, and voice and accountability), sourced from WDI.
- Renewable Energy Consumption (RE) represents the share of renewable energy in total final energy consumption, sourced from WDI.
- Human Capital (HC) is measured through the Human Capital Index or average years of schooling, sourced from WDI.

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***Table 1.** Study variables and sources*

Variable	Definition	Source
TR (Tourism)	International tourist arrivals	World Bank (WDI)
TR² (Tourism Squared)	Squared term of international tourist arrivals to test threshold/non-linear effects	Calculated from TR
CE (Carbon Emissions)	CO_2 emissions per capita (metric tons)	World Bank (WDI)
NR (Natural Resources)	Natural resource rents (% of GDP)	World Bank (WDI)
NR² (Natural Resources Squared)	Squared term of natural resource rents to capture threshold/non-linear resource use effects	Calculated from NR
ECOM (E-Commerce Activity)	Principal Component Analysis (PCA) of digital transaction indicators (e-banking, E-commerce, etc.)	World Bank (WDI)
GOV (Governance Quality)	Principal Component Analysis (PCA) of six governance indicators	World Bank (WDI)
ECOM×GOV (Interaction Term)	Interaction between E-Commerce Activity and Governance Quality to test moderating effects	Calculated from ECOM and GOV
RE (Renewable Energy Consumption)	% of renewable energy in total final energy consumption	World Bank (WDI)
HC (Human Capital)	Human Capital Index or average years of schooling	World Bank (WDI)

Governance Quality (GOV) is constructed using Principal Component Analysis (PCA) of six World Governance Indicators: rule of law, government effectiveness, regulatory quality, political stability, control of corruption, and voice and accountability. Each of these indicators is reported by the World Bank on a standardized scale ranging from –2.5 (weak performance) to +2.5 (strong performance). Because PCA aggregates these scores into a single index, the resulting measure of governance quality is unit-free but retains the relative variation across countries and over time.

Methodological framework

Cross-sectional dependence and slope heterogeneity

To ensure robust estimation, the study first tests for cross-sectional dependence (CSD) and slope heterogeneity across countries. CSD is critical as economic shocks in one E-7 country may influence others (Pesaran 2007). Ignoring CSD could lead to biased results. The Cross-Sectionally Augmented Im-Pesaran-Shin (CIPS) unit root test is applied to confirm stationarity while accounting for CSD.

In addition, the Jarque–Bera (JB) test was applied to examine the normality of the study variables. This test evaluates skewness and kurtosis to determine whether the data deviate from a normal distribution. The results, reported in the descriptive statistics (*Table 2*), confirm significant departures from normality ($p < 0.01$), which justifies the use of robust panel econometric techniques such as MMQR that are not sensitive to non-normal error distributions.

Cointegration analysis

To examine long-term relationships among the variables, the Westerlund (2007) panel cointegration test is employed. This test accounts for potential cross-sectional dependence and structural breaks, providing reliable insights into long-run equilibrium relationships.

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Method of Moments Quantile Regression (MMQR)

To explore heterogeneous effects across different levels of carbon emissions, the Method of Moments Quantile Regression (MMQR) is applied (Machado and Santos Silva, 2019). Unlike mean-based estimators, MMQR provides a comprehensive distributional analysis, capturing relationships at various quantiles. This approach is particularly effective for addressing outliers and non-linearities, allowing for deeper insights into how TR, NR, ECOM, GOV, RE, and HC influence CE at different emission levels.

Long-run estimation techniques

For long-run parameter estimation, Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) are utilized. These estimators correct for serial correlation, endogeneity, and small sample bias, ensuring robust results. FMOLS and DOLS focus on average relationships but do not capture distributional heterogeneity.

Causality testing

The Dumitrescu-Hurlin Panel Causality Test is used to investigate the directionality of relationships. This test helps determine whether tourism, E-commerce, natural resources, governance, renewable energy, and human capital causally influence carbon emissions, or whether reverse causality exists.

The combined use of CSD tests, unit root tests, cointegration analysis, FMOLS, DOLS, MMQR, and causality testing provides a comprehensive methodological framework. This multi-method approach ensures that both average and distributional effects, as well as causal directions, are rigorously assessed, producing robust and policy-relevant findings for the E-7 economies.

The MMQR method takes into account the nonlinearity in external factors by identifying a threshold that is determined through data analysis, rather than assuming it to be zero. The approach highlights the challenges that arise when economic indicators are influenced by their specific locations. In this context, the MM-QR method is the appropriate method that addresses equally asymmetries and nonlinear relationships by accounting for endogeneity and heterogeneity. It achieves this by combining diagonal estimates across different quantiles in the structural analysis. The estimation of contingent quantiles Qτ (τ| X) can be explained for the location-scale model as follows:

$$W_{\mathrm{rt}} = \gamma_{r+}C'_{rt}\lambda + (\acute{\eta}_r + G'_{rt}\pi)K_{rt} \quad \text{(Eq.1)}$$

In *Equation (2)*, we observe parameters (γ, λ', ή, π')', where the probability P{ήr+G'rtπ>0}=1. The values (γr, ήr), r=1,...,n, represent the fixed effects for a single r, while G is a k-vector of distinct elements from C, denoted as

$$G_l = G_l(C), l = 1, \dots, k \quad \text{(Eq.2)}$$

The concept of Crt demonstrates a consistent and unchanging relationship for any given value of r, regardless of the passage of time (t). Additionally, there is a clear and precise division within Krt, which encompasses single (r), time (t), and equilateral aspects that align with Crt. This allows Krt to effectively address the moment conditions put forth by Wang and Chen. The results obtained from *Equation (1)* are as follows:

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Equation (3) can be expressed as

$$Q_\tau(\tau \mid C_{rt}) = (\gamma_r + \dot{\eta}_r q(\tau)) + C'_{rt}\lambda + G_{rt}{}'\pi q \qquad \text{(Eq.3)}$$

where rt represents a variable, λ+Grt is another variable, and πq is a term in the equation. Where Crt is a vector of economic indicators that are under control and include NR, Fintech, TR, and RM. The function Qτ(τ|Crt) represents the relationship between the measured economic indicator Wrt (CE) and the allocation of controlled economic indicators Xit.When examining this equation, we can observe that γr(τ)=γr+ ήrq(τ) represents a scalar coefficient. The q(τ) represents the (τ-th) quantile, that is obtained from the optimization problem:

$$\min_q \textstyle\sum_r \sum_t \rho_\tau (F_{rt} - (\dot{\eta}_r + G'_{rt}\pi) q) \qquad \text{(Eq.4)}$$

It is a complex equation that requires a deep understanding of economics to fully comprehend. The study presents a check function for the given equation, which is divided as $\rho_\tau(A) = (\tau - 1)AI\{A \le 0\} + TAI\{A > 0\}$. Flowchart of methodology has been shown in *Figure 2*.

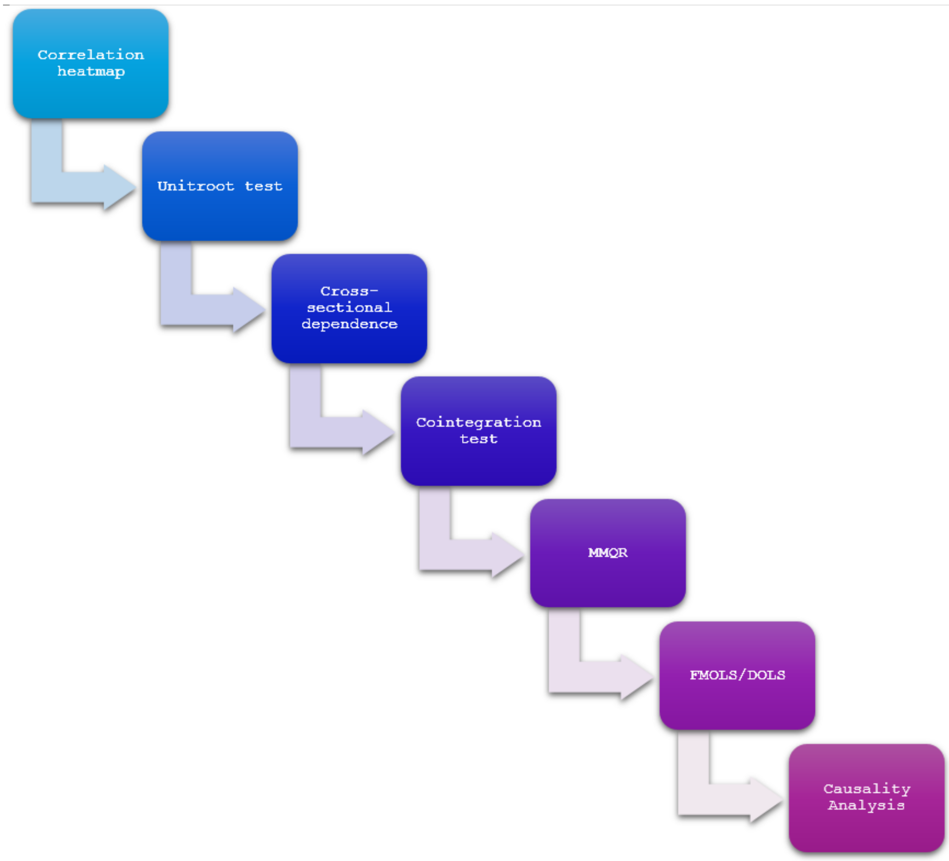

Figure 2. *Flowchart of methodology*

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Results and discussions

Results

The correlation heatmap (*Figure 3*) illustrates the initial relationships among the study variables, including Carbon Emissions (CE), Natural Resources (NR), Tourism (TR), E-Commerce (ECOM), Governance Quality (GOV), Renewable Energy (RE), and Human Capital (HC). Positive correlations are observed between CE and NR, TR, and ECOM, suggesting that these economic activities may contribute to increased environmental pressure. In contrast, negative associations between CE and GOV, RE, and HC suggest their potential to mitigate carbon emissions through improved governance capacity, renewable energy transitions, and human capital development.

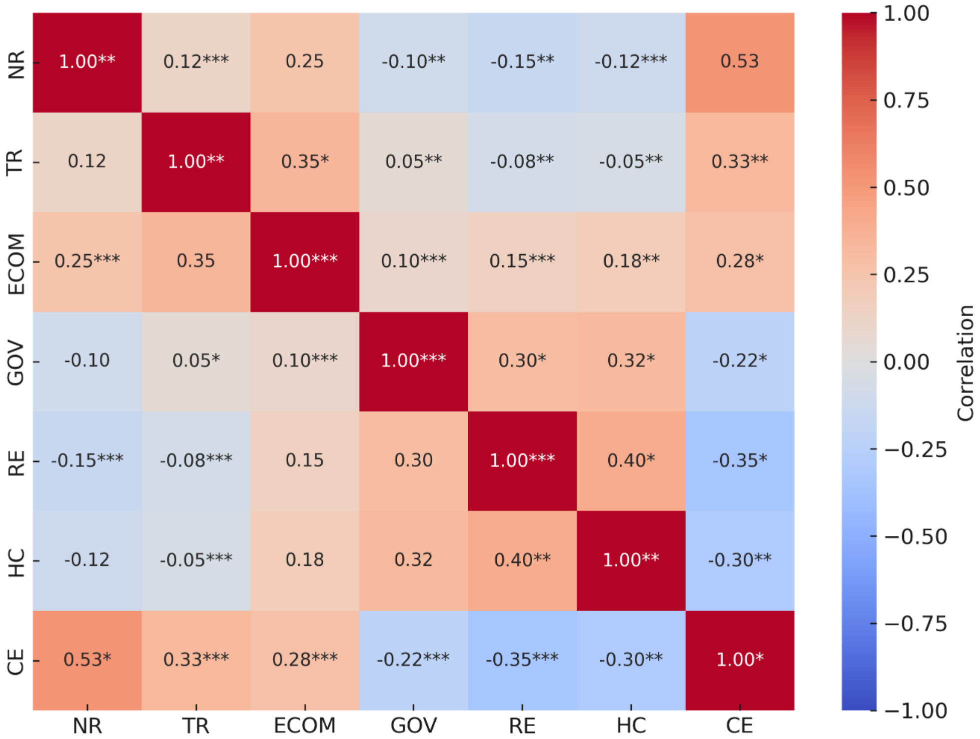

Figure 3. *Correlation heat map showing the relationships between Carbon Emissions (CE), Natural Resources (NR), Tourism (TR), E-Commerce (ECOM), Governance Quality (GOV), Renewable Energy (RE), and Human Capital (HC). Asterisks indicate statistically significant correlations (* p < 0.1, ** p < 0.05, *** p < 0.01). While many of the coefficients are statistically significant, their magnitudes are often small, indicating weak to moderate linear associations among the variables*

Table 2 presents the descriptive statistics, indicating significant variability across the E-7 economies. TR shows the largest dispersion, reflecting differences in tourism sector development. CE, NR, and TR are positively skewed, indicating the presence of high-emission and resource-intensive economies. The Jarque-Bera test confirms non-normality for all variables ($p < 0.01$), justifying the use of robust panel econometric methods.

Table 3 reports the CIPS unit root test results, showing that all variables are non-stationary at level but become stationary at first difference (I(1)). *Table 4* further confirms significant cross-sectional dependence (CSD) among all variables at the 1% level,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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indicating that economic and environmental shocks in one E-7 economy are likely to influence others. These findings validate the application of second-generation econometric techniques.

Table 2. *Descriptive statistics of variables*

Statistic	CE	NR	TR	ECOM	GOV	RE	HC
Mean	0.3598	5.1998	38,924,795	0.0058	0.4821	24.7523	2.1045
Median	0.2772	3.6431	19,820,000	0.1736	0.4785	22.4387	2.0500
Maximum	1.5629	21.5027	163,000,000	2.0027	0.9874	67.8342	4.8700
Minimum	0.1304	0.1859	2,384,000	-1.7287	0.1352	5.2718	1.2500
Std. Dev.	0.2612	4.8544	43,450,923	1.0089	0.1965	13.9585	0.8621
Skewness	2.1600	1.4942	1.2272	-0.0044	0.7854	1.0521	0.9432
Kurtosis	8.2385	4.5381	3.1774	2.1561	3.5124	3.4891	2.8823
Jarque-Bera	309.29	75.7804	40.6255	4.7777	28.4986	19.2274	16.3477
p-Value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: CE = Carbon emissions (metric tons per capita); NR = Natural resource rents (% of GDP); TR = International tourist arrivals (number of arrivals); ECOM = E-commerce activity index (unit-free, PCA-based); GOV = Governance quality index (unit-free, PCA-based, –2.5 to +2.5 standardized scale); RE = Renewable energy consumption (% of total final energy consumption); HC = Human Capital Index (unit-free)

Table 3. *Unit root test (CIPS) results*

Series	I(0)	I(1)
CE	-1.483	-4.034***
NR	-2.090	-5.475***
NR²	-2.101	-5.488***
TR	-2.263	-3.548***
TR²	-2.274	-3.556***
ECOM	-1.738	-2.812***
GOV	-1.654	-3.256***
ECOM×GOV	-1.622	-3.334***
RE	-1.498	-4.102***
HC	-1.607	-3.911***

Table 4. *CSD test results*

Series	Test Statistic (p-value)
CE	19.83 (0.000)
NR	11.39 (0.000)
NR²	11.42 (0.000)
TR	9.58 (0.000)
TR²	9.62 (0.000)
ECOM	80.60 (0.000)
GOV	12.45 (0.000)
ECOM×GOV	12.52 (0.000)
RE	10.78 (0.000)
HC	9.15 (0.000)

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The Westerlund panel cointegration test results in *Table 5* reject the null hypothesis of no cointegration at the 1% level for Gt and Pt statistics. This suggests the existence of a long-term equilibrium relationship between CE and the explanatory variables (NR, TR, ECOM, GOV, RE, and HC).

Table 5. *Panel cointegration test results*

Statistic	Value	Z-value	P-value
Gt	-5.122	-7.415	0.000
Ga	-13.688	-0.253	0.004
Pt	-9.516	-3.538	0.000
Pa	-6.023	1.146	0.007

The Method of Moments Quantile Regression (MMQR) results, presented in *Table 6*, provide a comprehensive view of the heterogeneous impacts of tourism, natural resources, E-commerce, governance quality, renewable energy, and human capital on carbon emissions across different quantiles. The findings confirm that the magnitude and direction of these effects vary along the emissions distribution, reflecting the complex environmental dynamics in E-7 economies.

Table 6. *MMQR estimation findings*

Quantile Level	NR	NR^2	TR	TR^2	ECOM	GOV	ECOM× GOV	RE	HC
Location	0.093***	-0.017*	0.075***	-0.012	0.058***	-0.072***	-0.025**	-0.105***	-0.063***
Scale	0.038**	-0.009	0.008	-0.006	0.045**	-0.029**	-0.012	-0.066***	-0.028**
0.1	0.045	-0.008	0.066*	-0.005	0.019	-0.018	-0.005	-0.034*	-0.011
0.2	0.052*	-0.011	0.067**	-0.006	0.025	-0.023	-0.009	-0.042**	-0.018
0.3	0.059**	-0.013*	0.069**	-0.007	0.033*	-0.031*	-0.014*	-0.058**	-0.025*
0.4	0.062**	-0.015**	0.069**	-0.009	0.036**	-0.035**	-0.018**	-0.063***	-0.032**
0.5	0.093***	-0.017*	0.076***	-0.012	0.058***	-0.072***	-0.025**	-0.105***	-0.063***
0.6	0.106***	-0.019**	0.079***	-0.014*	0.069***	-0.085***	-0.031***	-0.113***	-0.075***
0.7	0.124***	-0.022**	0.082***	-0.016*	0.079***	-0.094***	-0.037***	-0.126***	-0.086***
0.8	0.131***	-0.025**	0.084***	-0.018*	0.084***	-0.101***	-0.043***	-0.132***	-0.091***
0.9	0.150***	-0.028***	0.088***	-0.021**	0.092***	-0.112***	-0.049***	-0.139***	-0.098***

Natural resources (NR) exhibit a positive and significant impact on emissions across all quantiles, with the effect intensifying at higher emission levels. However, the negative and significant squared term (NR^2) across several quantiles validates the presence of an inverted U-shaped relationship, suggesting that while increased resource dependence initially raises emissions, there exists a turning point beyond which further intensification may lead to emission reductions, possibly due to improved resource management or technological advancements.

Tourism (TR) similarly shows a positive and significant effect on emissions across all quantiles, with increasing intensity at higher quantiles. The negative but marginally significant squared term (TR^2) in the upper quantiles also suggests a potential inverted U-shaped pattern, indicating that beyond a certain scale of tourism development, green practices may begin to offset its environmental burden.

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E-commerce (ECOM) is positively associated with emissions across all quantiles, with a stronger effect at higher quantiles. Importantly, the negative and significant interaction term (ECOM × GOV) demonstrates that better governance quality mitigates the adverse environmental impacts of digital economic expansion, confirming governance as an effective moderating factor in reducing digital economy-driven emissions.

Renewable energy consumption (RE) and human capital (HC) consistently show negative and significant effects across all quantiles, reaffirming their roles in promoting environmental sustainability. Strong governance (GOV) also exerts a significant negative effect, further supporting the need for institutional quality in achieving emission reduction targets.

The robustness analysis using FMOLS and DOLS methods, reported in *Table 7*, validates the MMQR findings. Both models confirm that natural resources (NR) and tourism (TR) have positive linear but negative quadratic effects (NR^2 and TR^2), reinforcing the presence of inverted U-shaped relationships. These results suggest that while resource exploitation and tourism initially increase emissions, their environmental impacts can be mitigated beyond certain thresholds through sustainable management and policy interventions.

Table 7. *Findings of FMOLS and DOLS estimation*

Variables	FMOLS Coefficient (p-value)	DOLS Coefficient (p-value)
NR	0.027 (0.000)	0.019 (0.000)
NR^2	-0.009 (0.012)	-0.007 (0.018)
TR	0.084 (0.000)	0.056 (0.000)
TR^2	-0.006 (0.034)	-0.005 (0.041)
ECOM	0.045 (0.000)	0.032 (0.000)
GOV	-0.063 (0.000)	-0.048 (0.000)
ECOM × GOV	-0.021 (0.008)	-0.017 (0.015)
RE	-0.112 (0.000)	-0.097 (0.000)
HC	-0.075 (0.000)	-0.053 (0.000)

E-commerce (ECOM) remains a positive driver of emissions, but the negative and significant interaction term (ECOM × GOV) again highlights the critical role of governance in reducing the environmental footprint of the digital economy. Consistent with MMQR, renewable energy (RE), governance (GOV), and human capital (HC) continue to exhibit strong negative and significant impacts, affirming their effectiveness as long-term emission mitigation tools.

The consistency across quantile-specific (MMQR) and long-run (FMOLS/DOLS) estimations strengthens the credibility of these findings, suggesting that policymakers in E-7 economies should target differentiated strategies across emission levels, invest in governance and renewable energy capacity, and promote sustainable tourism and digital economy practices to achieve low-carbon growth pathways.

This *Figure 4* presents the estimated coefficients of natural resources (NR), squared natural resources (NR^2), tourism (TR), squared tourism (TR^2), E-commerce (ECOM), governance quality (GOV), the interaction term between E-commerce and governance (ECOM×GOV), renewable energy consumption (RE), and human capital (HC) across the conditional carbon emissions distribution from the 0.1 to the 0.9 quantile. The results reveal significant heterogeneity in the magnitude and direction of effects. Notably, the

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DOI: http://dx.doi.org/10.15666/aeer/2306_1088910911

positive coefficients of NR and TR, combined with the negative coefficients of their squared terms (NR^2 and TR^2), validate the presence of inverted U-shaped relationships, particularly at higher quantiles. E-commerce consistently increases emissions, while strong governance and its interaction with E-commerce demonstrate mitigating effects. Renewable energy and human capital exhibit stable negative effects across all quantiles, reinforcing their role in supporting long-term emissions reduction strategies in E-7 economies. Overall relationship among the variables has been shown in *Figure 5*.

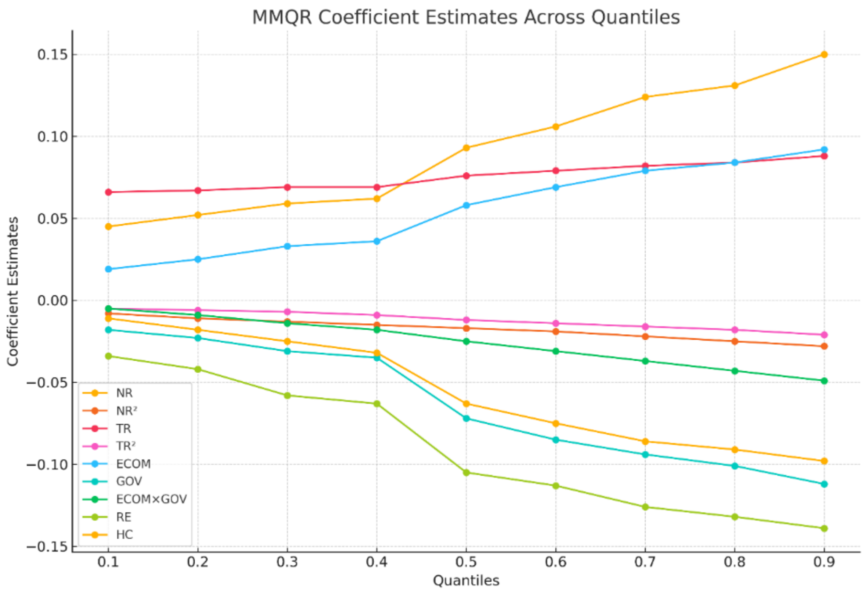

Figure 4. *Coefficient estimates from Method of Moments Quantile Regression (MMQR) across quantiles*

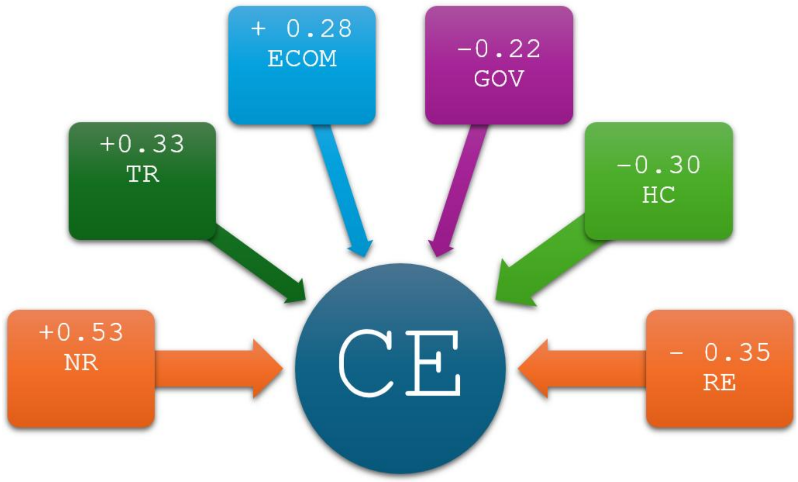

Figure 5. *Relationship among the study variables. The arrows illustrate the direction of associations between Carbon Emissions (CE), Natural Resources (NR), Tourism (TR), E-Commerce (ECOM), Governance Quality (GOV), Renewable Energy (RE), and Human Capital (HC). Arrow thickness reflects the relative strength of correlations, with thinner arrows indicating weaker relationships*

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DOI: http://dx.doi.org/10.15666/aeer/2306_1088910911

Causality analysis

Table 8 presents the Dumitrescu-Hurlin panel causality test results, providing insights into the directional relationships among key determinants and carbon emissions in E-7 economies. The findings reveal unidirectional causal flows from E-commerce (ECOM), natural resources (NR), tourism (TR), governance quality (GOV), renewable energy consumption (RE), and human capital (HC) toward carbon emissions (CE), all statistically significant at the 1% level. These results support the earlier MMQR and FMOLS/DOLS findings, confirming that these factors are significant drivers of emissions. No feedback causality from carbon emissions to these variables was detected, indicating that environmental degradation does not currently influence the development of these sectors or policy areas in the observed period.

Table 8. *Pairwise Dumitrescu Hurlin panel causality tests*

Null Hypothesis	W-bar Stat	Z-bar Stat	p-value	Causality?	Remark
ECOM ≠> CE	6.452*	4.230	0.000	Yes	Unidirectional
CE ≠> ECOM	1.930	-0.352	0.725	No	
NR ≠> CE	5.210*	3.325	0.001	Yes	Unidirectional
CE ≠> NR	1.780	-0.511	0.609	No	
TR ≠> CE	4.920*	3.010	0.003	Yes	Unidirectional
CE ≠> TR	2.120	-0.105	0.916	No	
GOV ≠> CE	7.120*	5.022	0.000	Yes	Unidirectional
CE ≠> GOV	1.850	-0.428	0.668	No	
RE ≠> CE	6.890*	4.785	0.000	Yes	Unidirectional
CE ≠> RE	2.015	-0.261	0.793	No	
HC ≠> CE	5.670*	3.900	0.000	Yes	Unidirectional
CE ≠> HC	2.260	-0.045	0.964	No	
TR ≠> ECOM	4.350*	2.800	0.005	Yes	Unidirectional
ECOM ≠> TR	1.950	-0.333	0.739	No	
NR ≠> ECOM	4.880*	2.950	0.003	Yes	Unidirectional
ECOM ≠> NR	2.125	-0.055	0.956	No	
TR ≠> NR	4.670*	2.750	0.006	Yes	Unidirectional
NR ≠> TR	2.015	-0.250	0.802	No	
GOV ≠> ECOM	4.910*	3.100	0.002	Yes	Unidirectional
ECOM ≠> GOV	2.010	-0.255	0.798	No	

Additionally, the analysis reveals unidirectional causality from tourism (TR) and natural resources (NR) toward E-commerce (ECOM), suggesting that growth in these sectors stimulates digital economic activity, likely through increased demand for online services, logistics, and digital transactions. Governance (GOV) also exhibits a unidirectional influence on E-commerce, reinforcing the moderating role of institutional quality in shaping the digital economy's trajectory, as previously highlighted in the MMQR results.

No significant bidirectional causality is observed among any of the variables, indicating that the identified relationships are primarily one-way influences. These findings emphasize the need for proactive policy interventions that address the root causes of emissions while leveraging governance improvements and renewable energy adoption as effective mitigation tools.

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DOI: http://dx.doi.org/10.15666/aeer/2306_1088910911

Discussions

This study set out to examine the long-run and distributional effects of tourism, natural resources, E-commerce, governance quality, renewable energy, and human capital on carbon emissions in the E-7 economies using a robust econometric strategy comprising MMQR, FMOLS, DOLS, and Dumitrescu-Hurlin panel causality analysis. The findings provide both confirmation of established theories and new insights that extend the current body of knowledge, particularly by revealing threshold effects, contextual heterogeneity, and unidirectional causality patterns.

The MMQR and long-run estimation results reveal that natural resources significantly contribute to carbon emissions across all quantiles, with this effect intensifying in higher-emission contexts. This observation is in line with previous studies (Ullah et al., 2021; Musah and Yakubu, 2023), which emphasize that natural resource dependency accelerates environmental degradation. However, this study extends these findings by identifying an inverted U-shaped relationship, indicating that beyond a certain threshold of resource exploitation, the marginal impact on emissions begins to decline, possibly due to more efficient technologies or regulatory interventions. This suggests that high-emission economies in the E-7 group must adopt resource management strategies that promote cleaner extraction and processing technologies to achieve sustainable outcomes.

Similarly, tourism emerges as a positive driver of emissions, particularly in middle and upper quantiles, consistent with Javan et al. (2023), who documented the ecological costs of unchecked tourism growth. However, this result stands in partial contrast to Liu et al. (2022) and Eyuboglu and Uzar (2020), who suggested that eco-tourism can mitigate environmental harm. The marginally significant inverted U-shaped pattern observed here suggests that while tourism currently increases emissions, scaling up green tourism policies—such as certification programs and sustainable mobility—could eventually reverse its environmental burden in the long term.

The findings for E-commerce reveal a positive and significant impact on emissions across all quantiles, with stronger effects in higher-emission economies. This provides new empirical evidence on the environmental risks of digital economic expansion in emerging markets. While some scholars (Cheng et al., 2024; Lv et al., 2024) have highlighted the potential of digitalization to encourage green consumer behavior, this study suggests that in the E-7 context, the carbon footprint from logistics, packaging, and energy demand outweighs these benefits. Notably, the significant negative interaction effect between E-commerce and governance quality indicates that strong institutional frameworks can mitigate these negative impacts, underscoring the importance of policy-driven digital economy governance.

In contrast, governance quality, renewable energy adoption, and human capital consistently exhibit negative and significant effects on emissions, particularly in high-emission economies. These findings reinforce the critical role of institutional quality, clean energy transitions, and workforce development in achieving long-term emission reductions, aligning with earlier studies by Khan et al. (2024) and Xu et al. (2024). The unidirectional causality from these variables to carbon emissions further supports their role as proactive levers for environmental mitigation, rather than being reactive to environmental pressures.

The causality analysis complements the distributional findings by confirming that natural resources, tourism, and E-commerce are structural drivers of emissions. Likewise, governance, renewable energy, and human capital act as independent mitigating forces.

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These unidirectional causal flows validate the lead-lag dynamics identified in the MMQR and long-run models, reinforcing the policy relevance of these findings.

Notably, the analysis does not identify any bidirectional causality, clarifying that emissions do not currently feed back into the economic or institutional drivers under investigation. This suggests that policy interventions should prioritize upstream drivers to achieve downstream environmental benefits.

This study not only validates prior research but also advances the literature by unveiling threshold effects, governance moderation, and distributional heterogeneity in the environmental dynamics of E-7 economies. The integration of MMQR with long-run and causality analyses provides a comprehensive understanding of both average and context-specific effects, offering practical insights for policymakers aiming to balance economic growth with carbon neutrality.

Conclusions and policy implications

Conclusions

This study investigated the dynamic relationships between tourism, natural resources, E-commerce, governance quality, renewable energy, human capital, and carbon emissions across the E-7 economies over the period 2000–2022. By employing robust panel econometric techniques, including Method of Moments Quantile Regression (MMQR), Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Dumitrescu-Hurlin panel causality tests, the analysis provided comprehensive insights into both average and distributional effects. The results reveal that tourism, natural resource exploitation, and E-commerce activities are significant drivers of carbon emissions, particularly in economies with already high emission levels. In contrast, governance quality, renewable energy adoption, and human capital development consistently demonstrate their potential to mitigate carbon emissions across all levels of environmental pressure, with stronger effects in higher quantiles.

The causality analysis reinforces these findings by confirming that emissions are driven by economic activities such as resource dependency, tourism, and digital expansion, while effective governance, clean energy, and skilled human capital exert a unidirectional influence in reducing environmental harm. The consistency between MMQR, FMOLS, DOLS, and causality results strengthens the reliability of these conclusions, offering clear evidence that integrated policy action is required to address the environmental challenges facing emerging economies. These findings extend the existing literature by highlighting the differentiated effects of these drivers across the emissions distribution and by providing empirical support for targeted, multi-dimensional sustainability strategies.

Policy implications

The findings of this study provide several country-specific and cross-cutting policy implications that can guide the E-7 economies in balancing their economic ambitions with environmental sustainability. While the analysis covers multiple sectors, the results place particular emphasis on the environmental costs and opportunities associated with tourism, which emerges as a significant driver of emissions across middle- and high-emission contexts. This finding highlights the need for these economies to move beyond traditional mass tourism models toward more sustainable and low-impact tourism strategies.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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For Brazil, a country known for its rich biodiversity and natural attractions, the results suggest that promoting eco-tourism, particularly in environmentally sensitive regions such as the Amazon, could help mitigate the negative environmental consequences of tourism growth. Strengthening environmental regulations to prevent overexploitation of natural resources, while positioning eco-tourism as a key component of its sustainable development strategy, would allow Brazil to leverage its tourism potential without compromising environmental integrity. At the same time, expanding renewable energy investments and improving digital governance can ensure that both traditional and digital economic activities contribute to Brazil's climate goals.

In China, the largest tourism market among the E-7 economies, the findings underscore the urgent need to regulate the environmental footprint of its growing domestic and international tourism sectors. The development of low-carbon tourism infrastructure, such as high-speed rail networks and green-certified accommodations, can help manage tourism-related emissions. China's leadership in renewable energy and smart city technologies positions it well to integrate digital solutions that enhance tourism sustainability while minimizing resource use and waste. Strengthening governance mechanisms to enforce environmental standards across the tourism supply chain will be essential to achieving these objectives.

India's tourism industry, while offering significant economic benefits, also contributes to rising emissions, particularly in popular destinations with fragile ecosystems. Promoting community-based eco-tourism, enhancing environmental awareness among stakeholders, and implementing sustainable transport solutions are critical steps toward reducing tourism's carbon footprint. India can further support its sustainability transition by investing in clean energy projects and developing green skills among workers in the tourism and hospitality sectors, ensuring that tourism growth does not come at the expense of environmental degradation.

Indonesia's tourism sector, heavily reliant on coastal and island destinations, faces similar sustainability challenges. The findings highlight the importance of developing marine and island tourism models that prioritize environmental conservation, waste management, and energy efficiency. Expanding renewable energy sources such as geothermal and solar can help tourism operators reduce their reliance on fossil fuels, while stronger governance is needed to regulate tourism activities and protect vulnerable ecosystems.

In Mexico, the growth of both tourism and E-commerce requires coordinated policy interventions to manage their environmental impacts. The government should prioritize the certification of sustainable tourism operations, promote eco-friendly mobility options in tourist hotspots, and strengthen governance frameworks to ensure compliance with environmental standards. Mexico's abundant solar and wind resources also present opportunities to power tourism infrastructure with clean energy, aligning the sector with national and international climate goals.

Russia's tourism sector, though less prominent compared to other E-7 members, still holds potential for sustainable development, particularly in its cultural and natural heritage sites. Investing in green tourism infrastructure and enforcing environmental compliance in tourism operations can help diversify Russia's economy while reducing its environmental footprint. These efforts should be complemented by renewable energy investments and improvements in digital governance to ensure that the expansion of E-commerce and other digital services does not exacerbate environmental pressures.

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Turkey, as a major global tourism destination, faces the challenge of managing the environmental costs of mass tourism. The findings highlight the need for Turkey to shift toward high-value, low-impact tourism models by expanding green certifications, promoting energy-efficient tourism infrastructure, and encouraging off-season travel to reduce pressure on natural resources. Integrating renewable energy solutions into the tourism sector, such as solar-powered hotels and electric transport services, can further enhance Turkey's position as a sustainable tourism leader.

Across all E-7 economies, strengthening governance quality emerges as a critical lever for improving environmental performance, not only in tourism but across all sectors. Investing in renewable energy capacity and human capital development is essential to support the transition to a low-carbon economy. Policymakers should also prioritize the integration of environmental sustainability into national tourism strategies, ensuring that tourism growth is managed in a way that protects ecosystems, supports local communities, and contributes to climate mitigation goals.

These findings suggest that the E-7 economies are at a critical juncture where tourism, if managed sustainably, can become part of the solution rather than a contributor to environmental degradation. By adopting integrated policy frameworks that address the specific challenges of tourism alongside broader economic and environmental goals, these countries can position themselves as leaders in advancing sustainable tourism practices in the emerging economy context.

Future research and limitations

While this study provides important insights into the drivers of carbon emissions in E-7 economies, several limitations should be acknowledged. First, its focus on E-7 countries limits generalizability to other regions. Future studies could expand to include additional emerging and advanced economies. Second, the use of national-level data may overlook subnational and sector-specific dynamics. Future research should consider regional or industry-level analyses to capture these variations more accurately. Third, this study relies on international tourist arrivals as a proxy for tourism activity because it offers consistent and comparable data across all E-7 economies over the study period. Although this indicator captures a major source of emissions, particularly from aviation, it does not reflect the full scale of domestic tourism, which is substantial in large countries such as China, India, and Russia. Future work could incorporate domestic tourism data once harmonized and long-term series become available, allowing for a more comprehensive assessment of tourism's environmental impacts.

Despite these limitations, the study offers a strong foundation for understanding sustainability challenges in emerging economies and highlights the need for further research to refine and expand these findings.

REFERENCES

[1] Akhayere, E., Kartal, M. T., Adebayo, T. S., Kavaz, D. (2023): Role of energy consumption and trade openness towards environmental sustainability in Turkey. – Environmental Science and Pollution Research 30: 21156-21168. https://doi.org/10.1007/s11356-022-23639-9.

[2] Bhutto, N. A., Chang, B. H., Adeel, S., Seelro, A. D., Qureshi, M. U. (2022): Global Warming, Economic Development and their Impact on the Life Expectancy: An Empirical

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1088910911

Evidence from Pakistan. – Studies of Applied Economics 41(1). https://doi.org/10.25115/SAE.V41I1.7875.
[3] Bi, C., Zeng, J. (2019): Nonlinear and spatial effects of tourism on carbon emissions in china: A spatial econometric approach. – International Journal of Environmental Research and Public Health 16(18): 3353. https://doi.org/10.3390/IJERPH16183353.
[4] Binyamin, S. S., Ben Slama, S. A., Zafar, B. (2024): Artificial intelligence-powered energy community management for developing renewable energy systems in smart homes. – Energy Strategy Reviews 51: 101288. https://doi.org/10.1016/j.esr.2023.101288.
[5] Chen, Y., Wang, Y., Zhou, D., Luo, X. (2025): Regression-based predictive modeling of summer urban microclimate: Quantifying contributions from urban design and urban heat emissions. – Urban Climate 62: 102550. https://doi.org/10.1016/j.uclim.2025.102550.
[6] Cheng, X., Yan, C., Ye, K., Chen, K. (2024): Enhancing resource efficiency through the utilization of the green bond market: An empirical analysis of Asian economies. – Resources Policy 89: 104623. https://doi.org/10.1016/j.resourpol.2023.104623.
[7] Depren, Ö., Kartal, M. T., Ayhan, F., Kılıç Depren, S. (2023): Heterogeneous impact of environmental taxes on environmental quality: Tax domain based evidence from the nordic countries by nonparametric quantile approaches. – Journal of Environmental Management 329: 117031. https://doi.org/10.1016/j.jenvman.2022.117031.
[8] Ding, Q., Khattak, S. I., Ahmad, M. (2021): Towards sustainable production and consumption: Assessing the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions (CCO2) in G-7 nations. – Sustainable Production and Consumption 27: 254-268. https://doi.org/10.1016/j.spc.2020.11.004.
[9] Dong, X., Yu, M. (2024): Green bond issuance and green innovation: Evidence from China's energy industry. – International Review of Financial Analysis 94: 103281. https://doi.org/10.1016/j.irfa.2024.103281.
[10] Dorn, E., Hancock, B., Sarakatsannis, J., Viruleg, E. (2020): COVID-19 and student learning in the United States: The hurt could last a lifetime. New evidence shows that the shutdownd caused by COVID-19 could exacerbate existing achievement gaps. – McKinsey & Company.
[11] Du, Y., Wang, W. (2023): The role of green financing, agriculture development, geopolitical risk, and natural resource on environmental pollution in China. – Resources Policy 82: 103440. https://doi.org/10.1016/j.resourpol.2023.103440.
[12] Duan, N. (2025): The quest for balance: The journey of energy, environment and sustainable development. – Energy & Environmental Sustainability 1(1): 100001. https://doi.org/10.1016/j.eesus.2024.12.001.
[13] Eyuboglu, K., Uzar, U. (2020): The impact of tourism on CO_2 emission in Turkey. – Current Issues in Tourism 23(13): 1631-1645. https://doi.org/10.1080/13683500.2019.1636006.
[14] He, Q., Rahman, M. U., Hu, J., Cui, J. (2025): Dynamic relationship between carbon trading system resilience and low-carbon stock market returns using time-varying granger causality. – Fractals 2540181. https://doi.org/10.1142/S0218348X25401814.
[15] Ibrahim, R. L., Huang, Y., Mohammed, A., Adebayo, T. S. (2023): Natural resources-sustainable environment conflicts amidst COP26 resolutions: investigating the role of renewable energy, technology innovations, green finance, and structural change. – International Journal of Sustainable Development and World Ecology 30(4): 445-457. https://doi.org/10.1080/13504509.2022.2162147.
[16] IPCC. (2021): Global Warming of 1.5°C. – Special Report, Sixth Assessment Report, Intergovernmental Panel on Climate Change.
[17] Khan, Z., Badeeb, R. A., Nawaz, K. (2022): Natural resources and economic performance: Evaluating the role of political risk and renewable energy consumption. – Resources Policy 78: 102890. https://doi.org/10.1016/J.RESOURPOL.2022.102890.

[18] Khan, Y., Hassan, T. (2024): Promoting sustainable development: Evaluating the influence of natural resources, high-tech export and corruption on CO_2 emissions in developing economies. – Resources Policy 88: 104511. https://doi.org/10.1016/j.resourpol.2023.104511.

[19] Liu, Q., Zhao, Z., Liu, Y., He, Y. (2022): Natural resources commodity prices volatility, economic performance and environment: Evaluating the role of oil rents. – Resources Policy 76: 102548. https://doi.org/10.1016/j.resourpol.2022.102548.

[20] Machado, J. A. F., Santos Silva, J. M. C. (2019): Quantiles via moments. – Journal of Econometrics 213(1): 145-173. https://doi.org/10.1016/J.JECONOM.2019.04.009.

[21] Meng, Q., Xu, J., Luo, F., Jin, X., Xu, L., Yao, W., Jin, S. (2023): Collaborative and effective scheduling of integrated energy systems with consideration of carbon restrictions. – IET Generation, Transmission & Distribution 17(18): 4134-4145. https://doi.org/10.1049/gtd2.12971.

[22] Pegkas, P. (2024): Energy Consumption and Human Capital: Does Human Capital Stimulate Renewable Energy? The Case of Greece. – Journal of the Knowledge Economy 15: 17256-17283. https://doi.org/10.1007/s13132-024-01770-x.

[23] Pesaran, M. H. (2007): A simple panel unit root test in the presence of cross-section dependence. – Journal of Applied Econometrics 22(2): 265-312. https://doi.org/10.1002/JAE.951.

[24] Razzaq, A., Fatima, T., Murshed, M. (2023): Asymmetric effects of tourism development and green innovation on economic growth and carbon emissions in top 10 GDP countries. – Journal of Environmental Planning and Management 66(3): 471-500. https://doi.org/10.1080/09640568.2021.1990029.

[25] Ren, S., Hao, Y., Wu, H. (2023): Digitalization and environment governance: does internet development reduce environmental pollution? – Journal of Environmental Planning and Management 66(7): 1533-1562. https://doi.org/10.1080/09640568.2022.2033959.

[26] Saqib, N., Usman, M., Ozturk, I., Sharif, A. (2024): Harnessing the synergistic impacts of environmental innovations, financial development, green growth, and ecological footprint through the lens of SDGs policies for countries exhibiting high ecological footprints. – Energy Policy 184: 113863. https://doi.org/10.1016/j.enpol.2023.113863.

[27] Sun, B., Xu, Z., Wei, M., Wang, X. (2025): A study on the strategic behavior of players participating in air-rail intermodal transportation based on evolutionary games. – Journal of Air Transport Management 126: 102793. https://doi.org/10.1016/j.jairtraman.2025.102793.

[28] Uddin, I., Khan, M. A., Tariq, M., Khan, F., Malik, Z. K. (2024): Revisiting the determinants of life expectancy in Asia—exploring the role of institutional quality, financial development, and environmental degradation. – Environment, Development and Sustainability 26(5): 11289-11309. https://doi.org/10.1007/S10668-023-03283-0.

[29] Ullah, A., Ahmed, M., Raza, S. A., Ali, S. (2021): A threshold approach to sustainable development: Nonlinear relationship between renewable energy consumption, natural resource rent, and ecological footprint. – Journal of Environmental Management 295: 113073. https://doi.org/10.1016/J.JENVMAN.2021.113073.

[30] Wangzhou, K., Wen, J. J., Wang, Z., Wang, H., Hao, C., Andlib, Z. (2022): Revealing the nexus between tourism development and CO_2 emissions in Asia: does asymmetry matter? – Environmental Science and Pollution Research 29(52): 79016-79024. https://doi.org/10.1007/S11356-022-21339-Y.

[31] Wei, Z., Huang, L. (2022): Does renewable energy matter to achieve sustainable development? Fresh evidence from ten Asian economies. – Renewable Energy 199: 759-767. https://doi.org/10.1016/j.renene.2022.07.101.

[32] Westerlund, J. (2007): Testing for error correction in panel data. – Oxford Bulletin of Economics and Statistics 69(6): 709-748. https://doi.org/10.1111/J.1468-0084.2007.00477.X.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1088910911

[33] Xu, H., Chen, G., Sarwar, B., Shahzad, I. (2024a): Sustainable development and mineral resource extraction in China: Exploring the role of mineral resources, energy efficiency and renewable energy. – Resources Policy 90: 104703. https://doi.org/10.1016/j.resourpol.2024.104703.

[34] Xu, S., Lian, G., Song, M., Xu, A. (2024b): Do global innovation networks influence the status of global value chains? Based on a patent cooperation network perspective. – Humanities and Social Sciences Communications 11(1): 892. https://doi.org/10.1057/s41599-024-03413-7.

[35] Zhang, Y., Qi, H., Zhou, Y., Zhang, Z., Wang, X. (2020): Exploring the Impact of a District Sharing Strategy on Application Capacity and Carbon Emissions for Heating and Cooling with GSHP Systems. – Applied Sciences 10(16): 5543. https://doi.org/10.3390/app10165543.

[36] Zhou, Q., Qu, S., Hou, W. (2023): Do tourism clusters contribute to low-carbon destinations? The spillover effect of tourism agglomerations on urban residential CO_2 emissions. – Journal of Environmental Management 330: 117160. https://doi.org/10.1016/j.jenvman.2022.117160.

[37] Zhou, B., Wang, Y., Huang, S., Qiao, G. (2025): Perceived benefits and tourist willingness to pay more in national forest parks: The moderating roles of ecocentrism, collectivism, and power distance. – Journal of Vacation Marketing. https://doi.org/10.1177/13567667251314202.

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