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Climate Mitigation Pathways in E-7 Countries: The Interplay of Technology Exports, Renewable Energy Consumption, and Resource Productivity under Digitalization

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Abstract

This study investigates the determinants of environmental sustainability in E7 economies, emphasizing the novel role of digitalization as a moderating factor in the nexus between Technology Exports (TE), renewable energy consumption, Resource Productivity (RP), and ecological quality. Given the rising environmental pressures associated with rapid industrialization, this research contributes to the literature by integrating these variables within a unified framework using the load capacity factor as a comprehensive sustainability indicator. The analysis covers Brazil, China, India, Indonesia, Mexico, Russia, and Turkey over the period 2005-2024, employing the Dynamic Common Correlated Effects (DCCE) estimator to address Cross-Sectional Dependence (CSD) and heterogeneity. The findings reveal that TE negatively affect environmental quality, whereas renewable energy consumption, RP, and digitalization improve sustainability. Importantly, digitalization mitigates the adverse impact of TE, strengthens the positive effect of renewable energy, and enhances the environmental benefits of RP. Policymakers should align digital transformation with green industrial strategies. Expanding renewable energy and promoting resource efficiency remain essential for sustainable development.

Keywords: Ecological sustainability, Renewable energy consumption, Technology exports, Resource productivity, Digitalization.

1 | Introduction

Achieving a balance between environmental sustainability and economic expansion remains one of the most pressing challenges for emerging economies, particularly the E-7 countries, including Brazil, China, India,

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Indonesia, Mexico, Russia, and Turkey. These economies have experienced rapid industrialization and urbanization, which have significantly increased their contribution to global carbon emissions while simultaneously driving global economic growth [1]. Their economic structures are heavily reliant on energy-intensive industries and resource exploitation, making them highly vulnerable to environmental degradation. Previous studies indicate that economic growth, when not accompanied by sustainable practices, exacerbates ecological pressure through increased energy demand and emissions [2], [3]. Given their demographic weight and economic influence, the environmental trajectory of E-7 countries plays a decisive role in achieving global climate targets. Therefore, understanding the drivers of environmental quality in these economies is essential for designing effective climate mitigation strategies.

Technology Exports (TE) are increasingly recognized as a key determinant of environmental performance, particularly in emerging economies undergoing structural transformation. High-Technology Exports can facilitate the diffusion of cleaner production processes and enhance energy efficiency, thereby reducing emissions [4], [5]. However, the environmental implications of TE are not unidirectional. While advanced technologies can support decarbonization, they may also stimulate industrial expansion and energy consumption if not accompanied by strong environmental regulations [6]. Evidence from emerging economies suggests that the environmental impact of TE depends on institutional quality and the nature of technological innovation [7]. In the context of E-7 countries, where industrial growth remains a priority, analyzing the environmental consequences of TE becomes crucial for achieving sustainable development.

Renewable energy consumption has been widely identified as a fundamental mechanism for improving environmental quality and achieving carbon neutrality. The transition from fossil fuels to renewable sources such as wind, solar, and hydropower reduces greenhouse gas emissions and mitigates ecological degradation [3], [8]. Empirical evidence consistently shows that increased reliance on renewable energy leads to lower carbon emissions, particularly in developing and emerging economies [9], [10]. In E-7 countries, renewable energy plays a dual role by supporting economic growth while simultaneously reducing environmental pressure. However, the effectiveness of renewable energy policies depends on complementary factors such as technological innovation, institutional frameworks, and energy infrastructure [11]. Thus, examining the role of renewable energy consumption is essential for understanding environmental sustainability in these economies. Resource productivity (RP), which reflects the efficiency of converting natural resources into economic output, is another critical factor influencing environmental sustainability. Higher RP reduces material consumption and environmental pressure, contributing to lower emissions [12], [7]. Nevertheless, the relationship between RP and environmental quality can be complex. In some cases, efficiency gains may lead to increased production and energy use, resulting in rebound effects that offset environmental benefits [13]. Empirical studies highlight that the impact of RP varies across countries depending on their level of industrialization and technological advancement [14]. In E-7 economies, where resource-intensive industries dominate, understanding this dynamic is vital for designing policies that enhance sustainability without compromising economic growth.

Digitalization has emerged as a pivotal factor shaping environmental quality in emerging economies, particularly within the E-7 countries (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey), where rapid technological adoption accompanies economic expansion. On the one hand, digitalization exerts a direct effect on environmental quality by enhancing energy efficiency, optimizing production processes, and enabling smart resource management systems. These improvements can contribute to reducing environmental degradation and supporting sustainable development pathways [1]. On the other hand, digitalization plays a crucial indirect (moderating) role by influencing how key economic and environmental determinants affect ecological outcomes. Specifically, digital technologies can enhance the environmental benefits of TE by facilitating cleaner and more efficient production systems, strengthen the impact of Renewable Energy Consumption through smart grids and improved energy integration, and improve RP by enabling efficient allocation and reduced waste. However, the environmental implications of digitalization are not entirely unidirectional, as increased digital infrastructure may also raise energy demand in the short run

[15], [16]. Therefore, examining both the direct and moderating roles of digitalization is essential for understanding its overall contribution to environmental quality in E-7 economies.

The selection of E-7 countries is grounded in their growing influence on both the global economy and environmental sustainability. These economies collectively represent a substantial share of global population, industrial output, and energy consumption, making them central to climate change mitigation efforts [1]. Rapid industrialization and economic growth in these countries have significantly increased carbon emissions, positioning them among the largest contributors to global environmental challenges. At the same time, their development pathways offer a unique opportunity to adopt sustainable technologies and transition toward cleaner energy systems. Previous studies emphasize that policy decisions in emerging economies have far-reaching implications for global sustainability [17], [18]. Moreover, the heterogeneity among E-7 countries in terms of institutional quality, technological capabilities, and energy structures provides a valuable context for empirical analysis. Therefore, focusing on E-7 countries allows for a comprehensive examination of how economic growth can be aligned with environmental sustainability.

This study offers several key contributions to the existing literature. First, it provides an integrated framework that simultaneously examines the effects of TE, renewable energy consumption, and RP on environmental quality. Second, it introduces load capacity factor as a more comprehensive indicator of environmental sustainability, moving beyond traditional emission-based measures. Third, the study investigates the moderating role of digitalization, analyzing how it influences the impact of TE, renewable energy consumption, and RP on environmental quality. This moderating effect represents a novel contribution, as prior studies have largely focused on direct relationships. Finally, by focusing on E-7 countries, the research addresses a gap in the literature, providing new insights into climate mitigation pathways in emerging economies. 1) To examine the impact of TE, renewable energy consumption, and RP on Load Capacity Factor (LCF), and 2) To analyze the direct and moderating role of digitalization in shaping environmental quality. To this end, we proposed an innovative study to address the following research questions (RQ): (RQ1) How does TE affect environmental quality?; (RQ2) What is the impact of renewable energy consumption on LCF?; (RQ3) How does RP influence environmental sustainability?; (RQ4) What is the direct effect of digitalization on LCF?; (RQ5) Does digitalization moderate the effects of TE, renewable energy consumption, and RP on LCF?

2 | Literature Review, Research Gap, and Hypotheses Development

2.1 | Technology Exports and Environmental Quality

The relationship between TE and environmental quality remains a subject of ongoing debate in the empirical literature. TE are often associated with the transfer of advanced and cleaner production techniques, which can contribute to improved environmental outcomes. Studies such as Su et al. [4] suggest that high-technology exports may reduce emissions by promoting energy-efficient and environmentally friendly industrial processes. Similarly, Irfan et al. [5] argue that technology-driven trade can enhance environmental sustainability through innovation diffusion. However, this relationship is not always beneficial, particularly in emerging economies where increased export-oriented industrialization may intensify energy consumption and environmental degradation [6]. The net effect of TE thus depends on factors such as regulatory quality, technological absorption capacity, and the structure of exports. Given these mixed findings, further investigation is necessary to understand how TE influence environmental quality in rapidly growing economies.

2.2 | Renewable Energy Consumption and Environmental Quality

Renewable energy consumption has been widely identified as a key driver of environmental sustainability. The transition from fossil fuels to renewable energy sources plays a significant role in reducing greenhouse gas emissions and mitigating environmental degradation. Empirical evidence indicates that increased renewable energy use contributes to improved environmental quality, particularly in developing and emerging economies [3], [8]. Furthermore, renewable energy supports sustainable development by reducing reliance on non-renewable energy sources and enhancing energy security [9], [19]. However, the environmental benefits of renewable energy may vary depending on the level of technological development, infrastructure, and institutional support. Some studies also highlight that the impact of renewable energy is influenced by the broader energy mix and economic conditions. Therefore, understanding the role of renewable energy consumption is essential for assessing environmental sustainability in emerging economies.

2.3 | Resource Productivity and Environmental Quality

RP plays a critical role in determining environmental outcomes by influencing how efficiently natural resources are utilized in economic activities. Higher RP is generally associated with reduced environmental pressure, as it implies lower resource consumption and waste generation per unit of output [12]. Similarly, Alola and Adebayo [7] emphasize that improvements in resource efficiency can contribute to environmental sustainability by reducing emissions and promoting cleaner production practices. However, the relationship between RP and environmental quality is not always linear. The rebound effect suggests that efficiency gains may lead to increased production and energy use, potentially offsetting environmental benefits [13]. This complexity is particularly relevant in emerging economies, where industrial expansion often accompanies efficiency improvements. Consequently, the net impact of RP on environmental quality remains an empirical question that requires further investigation.

2.4 | Digitalization and Environmental Quality

Digitalization has emerged as a crucial factor influencing environmental sustainability through both direct and indirect channels. On the one hand, digital technologies improve energy efficiency, enhance resource management, and support cleaner production processes, thereby contributing to improved environmental quality [1]. On the other hand, the expansion of digital infrastructure and increased use of information and communication technologies may lead to higher energy consumption and emissions, particularly in the short term [15], [16]. Empirical studies also indicate that the impact of digitalization may follow a nonlinear pattern, where initial increases in emissions are followed by long-term environmental improvements as efficiency gains materialize [20], [21]. Moreover, digitalization acts as a moderating factor by influencing how TE, renewable energy consumption, and RP affect environmental quality. This dual role makes digitalization a key variable in understanding sustainable development pathways in emerging economies.

2.5 | Research Gap

Despite the growing body of literature examining the determinants of environmental sustainability, several important gaps remain, particularly in the context of emerging economies. First, existing studies have largely focused on the individual effects of variables such as TE, renewable energy consumption, and RP on environmental quality, often overlooking their simultaneous and integrated impacts. This fragmented approach limits a comprehensive understanding of how these factors jointly shape environmental outcomes. Second, while prior research has extensively examined environmental degradation using traditional indicators such as CO2 emissions, there is still limited attention given to more comprehensive measures of environmental sustainability, such as the LCF, which captures both ecological demand and supply. This creates a methodological gap in accurately assessing environmental quality. Third, although digitalization has been recognized as an important determinant of environmental performance, most studies have primarily focused on its direct effects, neglecting its potential moderating role. In particular, there is insufficient empirical evidence on how digitalization influences the effectiveness of TE, renewable energy consumption, and RP in improving environmental quality. Finally, the majority of empirical studies have concentrated on developed or specific regional economies, with limited attention given to E-7 countries, despite their increasing contribution to global emissions and economic growth. Given the structural differences and rapid development patterns of these economies, findings from developed countries may not be directly applicable. Therefore, this study addresses these gaps by providing an integrated analysis of TE, REC, and RP on environmental quality LCF, while also incorporating the moderating role of digitalization within the E-7 context.

2.6 | Research Hypotheses

Building upon the above explanations, the Research Hypotheses (RH) are as follows: (RH1) TE are increasingly viewed as a mechanism for transferring advanced production techniques and environmentally friendly innovations across borders. In theory, the diffusion of cleaner technologies through exports enhances energy efficiency and reduces environmental degradation. Empirical studies suggest that high-technology exports can lower emissions by promoting cleaner industrial processes and reducing reliance on carbon-intensive production systems [4], [5]. However, in emerging economies, increased export-oriented industrial activity may also lead to higher energy consumption and environmental pressure if environmental regulations are weak [6]. In the context of E-7 countries, where industrial expansion is a key growth driver, the net environmental impact of TE remains ambiguous and requires empirical validation. Based on the above discussion, it is hypothesized that TE have a significant impact on environmental quality LCF.

(RH2) Renewable energy consumption is widely recognized as a key driver of environmental sustainability. The transition toward renewable energy sources reduces greenhouse gas emissions and mitigates environmental degradation by replacing fossil fuel-based energy systems [3], [8]. In emerging economies such as the E-7, increasing renewable energy adoption is crucial for achieving sustainable growth, given their heavy dependence on fossil fuels. Empirical evidence generally supports a negative relationship between renewable energy consumption and environmental degradation, indicating improved environmental quality [9]. In light of the theoretical and empirical arguments, it can be proposed that renewable energy consumption positively affects environmental quality LCF.

(RH3) RP reflects how efficiently natural resources are utilized in generating economic output. Higher RP implies reduced material use and waste generation, which can improve environmental quality [12]. However, the relationship is not always straightforward. Efficiency gains may trigger a rebound effect, where increased productivity leads to higher production levels and energy consumption, potentially offsetting environmental benefits [13]. In E-7 economies, characterized by resource-intensive industries, examining the role of RP is essential to determine whether efficiency improvements translate into environmental sustainability. Drawing on prior studies, it can be expected that RP has a significant impact on environmental quality LCF.

(RH4) Digitalization influences environmental sustainability through multiple channels. On one hand, digital technologies improve energy efficiency, optimize resource use, and support cleaner production processes. On the other hand, increased digital infrastructure may raise energy consumption and emissions [15], [16]. Recent studies indicate that digitalization may initially increase emissions but contributes to environmental improvement in the long run [20], [21]. Accordingly, this study posits that digitalization has a significant direct effect on environmental quality LCF.

(RH5) Digitalization enhances the efficiency and environmental performance of exported technologies by facilitating innovation, smart manufacturing, and cleaner production systems. Thus, it is expected to strengthen the positive environmental effects of TE. Therefore, it is reasonable to assume that digitalization moderates the relationship between TE and LCF. (RH6) Digitalization improves energy management systems, smart grids, and renewable energy integration, thereby amplifying the environmental benefits of renewable energy consumption. Accordingly, this study proposes that digitalization positively moderates the effect of renewable energy consumption on LCF. (RH7) Digitalization enable efficient resource allocation, waste reduction, and circular economy practices. Therefore, digitalization is expected to strengthen the positive impact of RP on environmental quality. From a theoretical standpoint, digitalization moderates the relationship between RP and LCF. In alignment with the preceding literature review and RH, the conceptual framework of the study is depicted in *Fig. 1* illustrating the direct effects of TE, Renewable Energy

Consumption (REC), and RP on environmental quality, proxied by LCF. In addition, Digitalization (DIG) is incorporated as a moderating variable influencing the relationships between TE, REC, and RP and LCF.

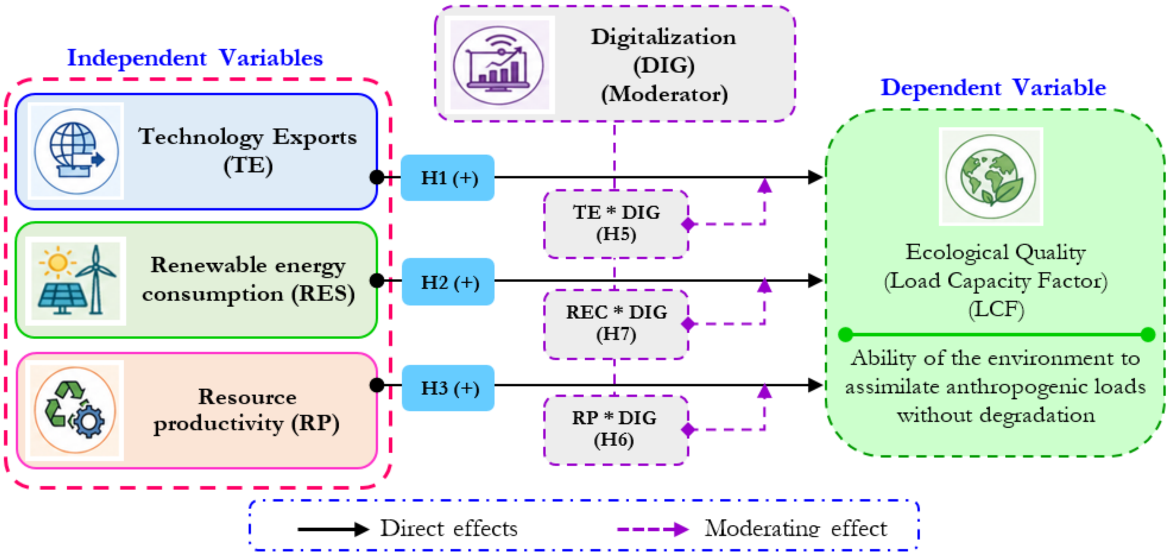

Fig. 1. Conceptual framework depicting the direct impacts of study variables on ecological sustainability, along with the moderating role of digitalization.

3 | Data and Methodology

3.1 | Data

Based on data availability, the paper utilizes a panel dataset spanning the period 2005-2024 from the E-7 economies, including Brazil, China, India, Indonesia, Mexico, Russia, and Turkey countries to investigate the impact of TE, RP, renewable energy consumption, and digitalization on LCF, with the aim of advancing carbon neutrality. The dependent variable, LCF, are measured as biocapacity/ecological footprint. the independent variables consist of TE, renewable energy consumption (REC), and RP, and digitalization (DIG).

Table 1. Variable description, sources and summary statistics.

Variable	Measure	Mean	Min	Max	Obs	Source
LCF	Biocapacity/Ecological Footprint	0.58	0.08	0.79	140	GFN (2025)
TE	High-technology exports (% of manufactured exports)	12.88	2.97	41.88	140	WDI (2025)
REC	Share of renewable energy (% of final energy consumption)	18.61	0.19	53.81	140	OECD (2025)
RP	RP (Purchasing power standard (PPS) per kilogram)	1.236	0.453	4.66	140	OECD (2025)
DIG	Digitalization	1.21	-8.09	3.96	140	WDI (2025)

Table 1 shows that the average LCF is 0.58, indicating that the E7 economies generally operate under ecological pressure, since their ecological demand remains high relative to available biocapacity. This is consistent with the economic structure of Brazil, China, India, Indonesia, Mexico, Russia, and Turkey, where rapid industrialization, fossil-fuel dependence, urban expansion, and resource-intensive production systems continue to place pressure on environmental sustainability. TE have a relatively high mean value, but the wide range suggests strong heterogeneity among E7 countries. China, for example, has a much stronger high-technology manufacturing base than several other E7 members. This implies that TE may not automatically generate environmental gains unless they are linked to clean production, energy efficiency, and green

innovation. REC also varies considerably across the sample. This reflects the uneven renewable energy transition in the E7 group: some countries have substantial hydropower or bioenergy potential, while others remain heavily dependent on coal, oil, and gas. Therefore, renewable energy can support environmental sustainability, but its effectiveness depends on the national energy mix and infrastructure. RP has a modest mean value, suggesting that E7 economies still rely heavily on material- and energy-intensive growth models. Since these countries are major producers and consumers of natural resources, improving RP is essential for reducing ecological pressure without slowing economic development. DIG also shows substantial variation, which indicates different levels of digital infrastructure, ICT penetration, and technological readiness across E7 economies. This matters because digitalization can improve environmental quality through smart energy systems, efficient logistics, and cleaner production, but it may also increase electricity demand if powered by fossil fuels. Overall, *Table 1* confirms that E7 economies are structurally diverse but share a common challenge: achieving environmental sustainability while maintaining industrial and economic growth.

3.2 | Methodology

In this study, given the potential presence of Cross-Sectional Dependence (CSD) among the E-7 countries, an advanced econometric technique known as the Dynamic Common Correlated Effects (DCCE) estimator, developed by Chudik and Pesaran [22], is employed. This approach is particularly suitable for panel data characterized by heterogeneity and interdependence across cross-sectional units. The DCCE framework builds upon earlier panel estimation techniques, including the Pooled Mean Group (PMG) estimator introduced by Pesaran et al. [23], the Mean Group (MG) estimator by Pesaran and Smith [23], and the Common Correlated Effects (CCE) approach proposed by Pesaran [24], while extending their capabilities to account for dynamic interactions and cross-sectional dependencies simultaneously. Although the PMG estimator is widely used for analyzing non-stationary heterogeneous panels, it assumes cross-sectional independence, which may lead to biased results when countries are interconnected, as is often the case in globalized economies. Similarly, the traditional CCE estimator accounts for CSD but does not incorporate dynamic structures or lagged dependent variables as regressors. To overcome these limitations, the DCCE approach integrates both dynamic specifications and cross-sectional averages, thereby capturing unobserved common factors and allowing for heterogeneous slope coefficients across countries. Another key advantage of the DCCE estimator is its flexibility in handling both small and large panel datasets [25]. Through the application of jackknife bias correction techniques, the estimator remains reliable even in samples with limited observations [25], [26]. Moreover, the method demonstrates strong robustness in the presence of structural breaks and is capable of producing consistent estimates in unbalanced panel settings. These properties make it particularly appropriate for analyzing the complex relationships between economic, technological, and environmental variables in E-7 economies. The dynamic specification of the DCCE model, as developed by Chudik and Pesaran [22], [26], can be expressed *Eq (1)*:

$$\mathrm{WR}_{it} = \alpha_i \mathrm{WR}_{it-1} + \delta_i X_{it} + \sum_{p=0}^{P_T} \gamma_{ip}^{x} X_{t-p} + \sum_{p=0}^{P_T} \gamma_{ip}^{y} Y_{t-p} + \mu_{it}. \tag{1}$$

By incorporating the study variables, including dependent and independent variables, the empirical model of this study is specified within the DCCE framework as *Eq. (2)*:

$$\mathrm{LCF}_{it} = \alpha_i \mathrm{LCF}_{it-1} + \beta_1 \mathrm{TE}_{it} + \beta_2 \mathrm{RE}_{it} + \beta_3 \mathrm{RP}_{it} + \beta_4 \mathrm{DIG}_{it} + \sum_{p=0}^{P_T} \gamma_{ip} \bar{X}_{t-p} + \sum_{p=0}^{P_T} \phi_{ip} \bar{Y}_{t-p} + \varepsilon_{it}. \tag{2}$$

where LCF_{it} represents environmental sustainability LCF for country *i* at time *t*, and LCF_{it-1}captures the dynamic persistence of environmental conditions. The variables TE_{it}, REC_{it}, RP_{it}, and DIG_{it} denote TE, renewable energy consumption, RP, and digitalization, respectively. The terms $\bar{X}_{t-p}$ and $\bar{Y}_{t-p}$ represent cross-sectional averages and their lagged values, which are included to control for unobserved common factors affecting all countries. Finally, ε_{it} denotes the error term. To incorporate this moderating mechanism, the *Eq. (3)* is employed:

$$\mathrm{LCF}_{it} = \alpha_i \mathrm{LCF}_{it-1} + \beta_1 \mathrm{TE}_{it} + \beta_2 \mathrm{RE}_{it} + \beta_3 \mathrm{RP}_{it} + \beta_4 \mathrm{DIG}_{it} + \beta_4 \mathrm{DIG}_{it} + \beta_5 (\mathrm{DEG}_{IT} * \mathrm{IVs}_{i,t}) + \sum_{p=0}^{P_T} \gamma_{ip} \bar{X}_{t-p} + \sum_{p=0}^{P_T} \phi_{ip} \bar{Y}_{t-p} + \varepsilon_{it}. \quad (3)$$

where $IV_{i,t}$ represents the set of explanatory variables (TE, REC, and RP), and β_5 captures the interaction effects between DIG and each of these variables. This specification allows for a more comprehensive understanding of how DIG conditions the impact of TE, REC, and RP factors on ecological sustainability. *Fig. 2* shows the flow chart of the econometric modelling process that this paper follows.

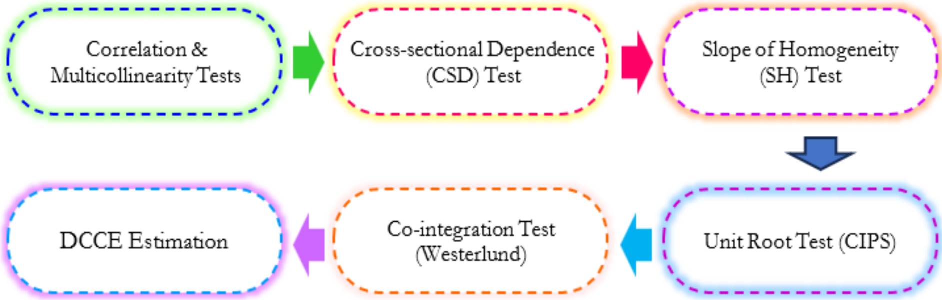

Fig. 2. Flow chart of econometric modelling process.

4 | Results and Discussion

This section describes some critical empirical tests necessary for data validation. At the very first step, *Table 2* describes correlation and multicollinearity tests outcomes. The results indicate that TE, renewable energy consumption, RP, and digitalization are all positively and significantly correlated with LCF. Since a higher LCF reflects better environmental sustainability, these initial correlations suggest that these variables are associated with improved ecological conditions in E7 economies. The strongest correlation with LCF belongs to digitalization, followed by TE and RP. This suggests that digital transformation may be particularly important in E7 countries, where smart infrastructure, digital monitoring, and data-driven production can help reduce inefficiencies in energy and resource use. The positive correlation between REC and LCF is weaker but still significant. This may reflect the fact that although renewable energy improves environmental quality, fossil fuels still dominate the energy structure of many E7 countries. Therefore, the environmental benefit of renewables may be constrained by the scale of conventional energy use. On the other hand, the VIF values are all below the conventional threshold of concern, and the mean VIF is 1.76. This confirms that multicollinearity is not a serious problem. In other words, the explanatory variables are sufficiently independent to be included together in the econometric model.

Table 2. Correlation and multicollinearity tests.

Variables	LCF	TE	REC	RP	DIG	VIF
LCF	1					-
TE	0.422***	1				2.03
REC	0.128***	0.088***	1			1.85
RP	0.288***	0.055***	0.389***	1		1.04
DIG	0.508***	0.431***	0.019***	0.265***	1	2.12
Mean/VIF						1.76

Note: The asterisk (***) indicates significance at %1 level.

Table 3 describes CSD test outcomes and provides the most reliable outcomes. Specifically, each study variable has CSD; therefore, running the Slope of Homogeneity (SH) test for further validation is essential. Similarly, *Table 3* describes the slope of homogeneity and validates prior expectations. Such strong outcomes allow this study to perform the data integration tests to investigate the data properties.

Table 3. CSD and SH tests results.

Variables	CD Test	P-Value
lnLCF	8.91***	0.0000
lnTE	14.55***	0.0000
lnREC	8.71***	0.0000
lnRP	6.89***	0.000
lnDIG	7.33***	0.000
Slope of Homogeneity		
	Delta	Adjusted
Statistics (p-value)	13.084*** (0.000)	17.060 *** (0.000)

Note: The asterisk (***) indicates significance at %1 level.

Table 4 reports the CIPS unit root test results. At level, the variables are not stationary, but after first differencing, all variables become stationary at the 1% significance level. This means that LCF, TE, renewable energy consumption, RP, and digitalization are integrated of order one. For E7 economies, this result is economically meaningful. Environmental quality, renewable energy use, TE, and digitalization usually evolve gradually over time rather than fluctuating randomly from year to year. These variables are shaped by long-term industrial policies, infrastructure investment, technological upgrading, and energy transition strategies. The finding that the variables become stationary after first differencing also justifies the use of cointegration analysis. Since the variables follow long-run trends, it is necessary to test whether they move together over time. This is particularly relevant for E7 economies, where structural transformation and environmental pressure develop simultaneously.

Table 4. CIPS unit root test results.

Variable	Level	First Differences
lnLCF	-2.588	-5.108***
lnTE	-2.498	-3.790***
lnREC	-3.119	-4.119***
lnRP	-2.557	-5.817***
lnDIG	-2.661	-5.661***

Note: *** indicates significance at %1 level.

Table 5 shows that all four Westerlund test statistics are significant at the 1% level. Therefore, the null hypothesis of no cointegration is rejected. This confirms the existence of a long-run relationship among LCF, TE, renewable energy consumption, RP, and digitalization. For E7 economies, this is an important result. It means that environmental sustainability is not only affected by temporary changes in energy use or technology, but is structurally linked to the long-term evolution of TE, renewable energy adoption, resource efficiency, and digital transformation. This finding supports the idea that climate mitigation in E7 countries requires integrated policy design. Technology upgrading alone is not enough; it must be combined with renewable energy expansion, resource-efficiency improvements, and digital infrastructure.

Table 5. Westerlund ECM panel co-integration tests.

H0: no cointegration	Value	Robust P-Value
Group-t	-5.83***	0.0000
Group-a	-22.18***	0.0000
Panel-t	-11.83***	0.0000
Panel-a	-21.87***	0.0000

Note: *** indicates significance at %1 level.

The results from DCCE estimator are presented in *Table 6*. The lagged LCF is positive and significant across the estimations, showing that environmental quality in E7 economies has a persistent dynamic pattern. In practical terms, current environmental sustainability depends partly on past environmental conditions. This reflects the path-dependent nature of ecological systems and industrial structures. In E7 countries, this persistence is expected because energy infrastructure, production systems, urbanization patterns, and resource-use behavior do not change quickly. Countries with historically high ecological pressure may continue to face environmental constraints unless strong policy reforms are introduced.

Table 6. DCCE estimation.

Exogenous Variable	Model 1	Model 2	Model 3	Model 4
lnLCF (-1)	0.138***	0.147***	0.156***	0.141***
lnTE	-0.032***	-0.037***	-0.035***	-0.036***
lnREC	0.013***	0.016***	0.017***	0.015***
lnRP	0.027**	0.024**	0.026**	0.025**
lnDIG	0.015***	0.013***	0.014***	0.016***
lnDIG*ln lnTE	-	0.003**	-	-
lnDIG*ln lnREC	-	-	0.008**	-
lnDIG*ln lnRP	-	-	-	0.006**

Note: The asterisks (***) and (**) indicate significance at %1 and 5% levels.

TE have a negative and significant effect on LCF. Since LCF represents environmental sustainability, this result suggests that TE reduce environmental quality in E7 economies. This may seem counterintuitive, but it is understandable in the E7 context. Many E7 countries are still expanding their manufacturing and export sectors. If TE are driven by energy-intensive industrial production rather than clean innovation, they can increase energy demand, material use, and emissions. In other words, TE may reflect industrial scale expansion more than green technological upgrading. This result suggests that TE in E7 economies have not yet fully translated into cleaner production. Without strict environmental standards, green innovation incentives, and low-carbon energy systems, export-oriented technological development may intensify ecological pressure. This finding contrasts with Su et al. [4] and Irfan et al. [5] who argue that TE can improve environmental quality through cleaner production and innovation diffusion. However, it is more consistent with Nathaniel et al. [6] who suggest that technology-related economic expansion may worsen environmental outcomes when institutional and regulatory conditions are insufficient.

Renewable energy consumption has a positive and significant impact on LCF. This means that increasing renewable energy use improves environmental sustainability in E7 economies. The result is economically reasonable because renewable energy reduces dependence on fossil fuels and helps lower ecological pressure. For E7 countries, this finding is especially important. These economies are among the world's largest energy consumers, and several of them still rely heavily on coal, oil, and natural gas. Expanding renewable energy can therefore play a major role in improving environmental quality. However, the coefficient is relatively small, which suggests that the renewable energy transition is still not strong enough to fully offset the environmental pressure caused by industrial growth. Renewable energy policies need to be supported by grid modernization, storage capacity, green finance, and industrial decarbonization. This outcome is in harmony with Ullah et al. [3], Li et al. [8], and Aydin et al. [9] who show that renewable energy consumption contributes to environmental improvement. It also supports Twum et al. [11] who argue that renewable energy strategies are essential for achieving climate-related sustainable development goals.

RP positively and significantly affects LCF. This indicates that more efficient use of natural resources improves environmental sustainability in E7 economies. When countries generate more economic output per unit of resource input, they reduce waste, material pressure, and ecological degradation. This result is highly relevant for E7 economies because many of them rely on resource-intensive industries such as mining, manufacturing, construction, heavy industry, and energy production. Improving RP allows these countries to maintain economic growth while reducing environmental pressure. The result also implies that circular economy policies, cleaner production technologies, recycling systems, and efficient industrial processes can strengthen environmental sustainability in E7 countries. This finding is consistent with Mushafiq and Prusak

[12] and Alola and Adebayo [7], who show that RP supports environmental quality. It differs from the rebound-effect argument discussed by Afolabi [13], where efficiency improvements may increase production and offset environmental benefits. In this study, the positive effect suggests that efficiency gains dominate the rebound effect in the E7 sample.

Digitalization has a positive and significant effect on LCF. This shows that digital transformation improves environmental sustainability in E7 economies. Digital technologies can reduce ecological pressure by improving energy management, optimizing production, reducing waste, and supporting smart infrastructure. In E7 countries, digitalization can be particularly useful because these economies face large-scale challenges in urban management, industrial efficiency, logistics, and energy distribution. Digital tools can improve monitoring, reduce inefficiencies, and support cleaner growth pathways. Nevertheless, the positive coefficient should be interpreted carefully. Digitalization improves sustainability only when digital infrastructure is supported by cleaner electricity, efficient data systems, and appropriate environmental regulation. Otherwise, the expansion of ICT infrastructure may increase energy demand. This result is consistent with Olanrewaju and Kirikkaleli [1], Ha et al. [16], Ren et al. [20], and Saqib et al. [21], who argue that digitalization can enhance environmental performance. It is less supportive of Bansal et al. [15] caution that digitalization may worsen environmental pressure in the short run through higher energy consumption.

The interaction between digitalization and TE is positive and significant. This means that digitalization weakens the negative environmental effect of TE and helps transform TE into a more sustainability-enhancing force. For E7 economies, this is a crucial finding. TE alone may increase ecological pressure because of industrial expansion, but when combined with digitalization, production can become more efficient, cleaner, and better monitored. Digital systems can improve supply-chain management, reduce waste, support smart manufacturing, and increase the environmental efficiency of export-oriented sectors. Thus, digitalization acts as a corrective mechanism. It does not eliminate the environmental risks of TE, but it helps redirect them toward cleaner industrial performance.

The interaction between digitalization and renewable energy consumption is positive and significant. This indicates that digitalization strengthens the positive environmental effect of renewable energy consumption. In the E7 context, this result is very important because renewable energy systems require advanced management, forecasting, storage coordination, and grid integration. Digital technologies such as smart grids, real-time monitoring, and AI-based demand management can make renewable energy more reliable and efficient. This means that renewable energy policies in E7 economies should not be designed separately from digital infrastructure policies. The environmental benefits of renewables become stronger when digital systems improve energy distribution and reduce technical losses.

The interaction between digitalization and RP is also positive and significant. This means that digitalization enhances the environmental benefit of RP. For E7 economies, this finding is highly relevant because resource-intensive industries dominate many parts of their economies. Digital technologies can improve resource tracking, reduce production waste, optimize material use, and support circular economy practices. As a result, RP becomes more effective in improving LCF when digitalization is higher. This suggests that digitalization helps E7 countries move from traditional resource-based growth toward smarter and more efficient production systems. It strengthens the ability of RP to reduce environmental pressure. Drawing upon the empirical findings obtained, a synthesized overview of the key results is visually presented in *Fig. 3* to provide a clearer and more integrated understanding of the relationships among the study variables.

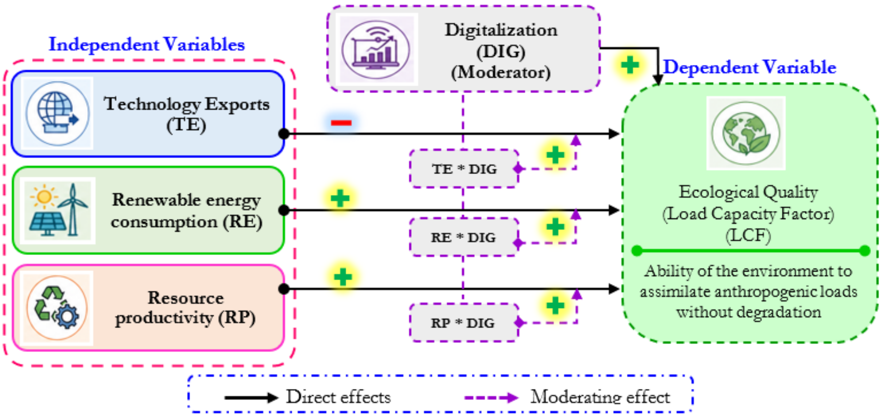

Fig. 3. Summary of empirical findings.

5 | Conclusion

This study examines the dynamic relationships between TE, renewable energy consumption, RP, and environmental sustainability within the context of E7 economies (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey) over the period 2005–2024. Given the increasing environmental pressure resulting from rapid industrialization and economic expansion in these emerging economies, understanding the drivers of ecological sustainability is of critical importance for achieving global climate targets. To address CSD and heterogeneity across countries, the study employs the DCCE estimator, which provides robust and reliable long-run estimates. Furthermore, the analysis incorporates digitalization not only as a direct determinant but also as a moderating factor, offering a more comprehensive perspective on how technological and structural transformations influence environmental outcomes in E7 countries.

The empirical findings reveal several important insights into the determinants of environmental sustainability in E7 economies. TE are found to exert a negative and statistically significant impact on environmental quality, suggesting that export-oriented industrial expansion remains largely energy-intensive and environmentally damaging in these countries. In contrast, renewable energy consumption significantly improves environmental sustainability, highlighting its critical role in reducing ecological pressure and supporting cleaner growth pathways. Similarly, RP positively contributes to environmental quality, indicating that more efficient use of natural resources can mitigate environmental degradation while sustaining economic activity. Furthermore, digitalization emerges as a key driver of environmental improvement, reflecting its capacity to enhance energy efficiency, optimize production processes, and support sustainable resource management. Overall, these findings underscore the importance of structural transformation, energy transition, and technological advancement in shaping sustainable development trajectories across E7 economies.

5.1 | Policy Recommendations

Based on the empirical findings, several policy implications can be derived for E7 economies. First, policymakers should promote green-oriented TE by encouraging environmentally friendly innovation and enforcing stricter environmental regulations in export-driven industries. This is essential to prevent the adverse environmental consequences associated with industrial expansion. Second, expanding renewable energy infrastructure should remain a top priority, particularly through investments in smart grids and energy storage systems, to maximize the environmental benefits of clean energy transitions. Third, improving RP requires the adoption of circular economy strategies, including efficient resource allocation, recycling systems, and cleaner production technologies. These measures can reduce environmental pressure while sustaining economic growth. Fourth, digitalization should be integrated into environmental and industrial policies, as it plays a critical role in enhancing the effectiveness of renewable energy systems, optimizing resource use, and improving production efficiency. Finally, given the significant moderating role of digitalization, governments should invest in digital infrastructure and promote the adoption of advanced technologies such as artificial intelligence, big data, and smart manufacturing. Aligning digital transformation with environmental objectives will be crucial for achieving sustainable development pathways in E7 economies.

Authors' Contributions

R. Y.: Writing-original draft, Methodology, Data Curation, Conceptualization, Software, and Visualization, Writing-Review & Editing, and Validation. S. K. S.: Writing-Review & Editing, Formal Analysis, and Investigation. M. R.: Validation, Writing-Review & Editing, and Formal Analysis. The authors have read and agreed to the published version of the manuscript.

Data Availability

The data is available on request from the corresponding author.

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There are no competing interests to declare.

Consent for Publication

The authors have given consent for the publication of this manuscript.

Ethics Approval and Consent to Participate

The authors confirm that this research did not involve human participants or animal subjects.

References

[1] Olanrewaju, V. O., & Kirikkaleli, D. (2026). How Do Green Technologies, Green Energy Consumption and Digitalization Influence Environmental Sustainability in E7 Economies? A Quantile-Based Analysis. *Politická ekonomie*, *74*(1), 66–91. https://polek.vse.cz/pdfs/pol/2026/01/03.pdf

[2] Meo, M. S., & Adebayo, T. S. (2025). Role of financial regulations and climate policy uncertainty in reducing CO2 emissions—an application of bootstrap subsample rolling-window Granger causality. *Clean technologies and environmental policy*, *27*(6), 2377–2393. https://doi.org/10.1007/s10098-024-02991-z

[3] 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

[4] Su, C.-W., Xie, Y., Shahab, S., Faisal, C. M. N., Hafeez, M., & Qamri, G. M. (2021). Towards achieving sustainable development: role of technology innovation, technology adoption and CO2 emission for BRICS. *International journal of environmental research and public health*, *18*(1), 277. https://doi.org/10.3390/ijerph18010277

[5] Irfan, M., Quddus, A., Shahzad, F., & Wang, Y. (2025). Do ICT trade balances and natural resources foster carbon emissions? The role of government effectiveness and green technology innovation. *Structural change and economic dynamics*, *72*, 320–329. https://doi.org/10.1016/j.strueco.2024.12.007

[6] Nathaniel, S. P., Solomon, C. J., Khudoykulov, K., & Fakher, H. A. (2026). Linking resource richness, digital economy, and clean energy to ecological footprint and load capacity factor in emerging markets. *Natural resources forum* (Vol. 50, No. 2, pp. 727-742). https://doi.org/10.1111/1477-8947.12590

[7] Alola, A. A., & Adebayo, T. S. (2023). Are green resource productivity and environmental technologies the face of environmental sustainability in the Nordic region? *Sustainable development*, *31*(2), 760–772. https://doi.org/10.1002/sd.2417

[8] Li, R., Wang, Q., & others. (2023). Does renewable energy reduce per capita carbon emissions and per capita ecological footprint? New evidence from 130 countries. *Energy strategy reviews*, *49*, 101121. https://doi.org/10.1016/j.esr.2023.101121

[9] Aydin, M., Degirmenci, T., & Yavuz, H. (2023). The influence of multifactor productivity, research and development expenditure, renewable energy consumption on ecological footprint in G7 countries: Testing the environmental Kuznets curve hypothesis. *Environmental modeling & assessment*, *28*(4), 693–708. https://doi.org/10.1007/s10666-023-09879-0

[10] Fakher, H.-A., Abedi, Z., Ahmadian, M., & Shaygani, B. (2018). Comparative examine the impact of financial development (based on money market and capital market) in the intensity of economic growth effects on the environmental performance. *Environmental researches*, *9*(17), 133–146. https://dor.isc.ac/dor/20.1001.1.20089597.1397.9.17.17.4

[11] Twum, A. K., Zhang, J., Ding, X., & Cobbinah, J. (2024). Advancing renewable energy strategies towards sustainable development goal 13: Insights from belt and road initiative (BRI) countries. *Environment, development and sustainability*, 1–32. https://doi.org/10.1007/s10668-024-05800-1

[12] Mushafiq, M., & Prusak, B. (2023). Resource productivity and environmental degradation in EU-27 countries: context of material footprint. *Environmental science and pollution research*, *30*(20), 58536–58552. https://doi.org/10.1007/s11356-023-26631-z

[13] Afolabi, J. A. (2025). Towards carbon neutrality in Europe: The role of technology exports, renewable energy consumption, and resource productivity. *Journal of environmental management*, *395*, 127862. https://doi.org/10.1016/j.jenvman.2025.127862

[14] Shobande, O. A., & Ogbeifun, L. (2024). Exploring the criticality of natural resources management and technological innovations for ecological footprint in the OECD countries. *The journal of developing areas*, *58*(1), 157–170. https://doi.org/10.1353/jda.2024.a924520

[15] Bansal, S., Singh, S., & Nangia, P. (2022). Assessing the role of natural resource utilization in attaining select sustainable development goals in the era of digitalization. *Resources policy*, *79*, 103040. https://doi.org/10.1016/j.resourpol.2022.103040

[16] Ha, L. T., Huong, T. T. L., & Thanh, T. T. (2022). Is digitalization a driver to enhance environmental performance? An empirical investigation of European countries. *Sustainable production and consumption*, *32*, 230–247. https://doi.org/10.1016/j.spc.2022.04.002

[17] Usman, O., Ozkan, O., Alola, A. A., & Ghardallou, W. (2024). Energy security-related risks and the quest to attain USA's net-zero emissions targets by 2050: A dynamic ARDL simulations modeling approach. *Environmental science and pollution research*, *31*(12), 18797–18812. https://doi.org/10.1007/s11356-024-32124-4

[18] Zambrano-Monserrate, M. A. (2024). Trust, corruption, and willingness to pay for improved environmental goods: An experimental analysis from a developing country. *Social science quarterly*, *105*(3), 709–725. https://doi.org/10.1111/ssqu.13381

[19] Fakher, H. A., & others. (2023). The impact of gross domestic product, financial development, energy consumption on environmental quality: with emphasis on six environmental indicators. *Journal of natural environment*, *76*(2), 345–363. http//doi.org/10.22059/jne.2023.346356.2469

[20] 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

[21] Saqib, N., Duran, I. A., & Ozturk, I. (2023). Unraveling the interrelationship of digitalization, renewable energy, and ecological footprints within the EKC framework: empirical insights from the United States. *Sustainability*, *15*(13), 10663. https://doi.org/10.3390/su151310663

[22] Chudik, A., & Pesaran, M. H. (2015). Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. *Journal of econometrics*, *188*(2), 393–420. https://doi.org/10.1016/j.jeconom.2015.03.007

[23] Pesaran, M. H., & Smith, R. (1995). Estimating long-run relationships from dynamic heterogeneous panels. *Journal of econometrics*, *68*(1), 79–113. https://doi.org/10.1016/0304-4076(94)01644-F

[24] Pesaran, M. H. (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica*, *74*(4), 967–1012. https://doi.org/10.1111/j.1468-0262.2006.00692.x

[25] Ditzen, J. (2018). Estimating dynamic common-correlated effects in Stata. *The stata journal*, *18*(3), 585–617. https://doi.org/10.1177/1536867X1801800306

[26] Chudik, A., & Pesaran, M. H. (2015). Large panel data models with cross-sectional dependence: A survey. In B. H. Baltagi (Ed.), *The oxford handbook of panel data* (pp. 3–45). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199940042.013.0001