2 HOW TOURISM ACHIEVES THE SDGS: THE CRITICAL ROLES OF GREEN FINANCE AND TECHNOLOGY

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Abstract

This study examines the role of tourism in achieving the Sustainable Development Goals (SDGs) and in managing demand-based emissions (DBE) across 25 European countries from 2003 to 2023. For this purpose, four econometric models are employed to examine the direct and interactive effects of tourism with green finance (GFN), environmental policies (EPY), digitalization (DIG), and mitigation technologies (MTEG) on SDG outcomes and DBE. The analysis accounts for cross-sectional dependence, heterogeneous short-run dynamics, and mixed stationarity using the Dynamic Common Correlated Effects Mean Group (CS-ECM) estimator. It confirms the long-run effects using the CCEMG estimator. Findings reveal that tourism significantly enhances SDG performance, particularly when combined with GFN and technological interventions. Interactions between tourism and GFN strengthen short and long-term sustainability outcomes. At the same time, RE and MTEG amplify tourism's positive environmental impact. Notably, the URB indicator shows an initial rise in DBE. However, in the long run, it contributes to infrastructure and efficiency gains. Besides, the DIG and EPY indicators promote long-term adaptation and resource efficiency. This finding suggests that sustainable development is possible in the tourism industry as long as appropriate policies and technological guidelines guide it. The policy implications put forward a combination of strategies to leverage the advantages of GFN, RE, smart tourism technologies, and urban planning to maximize sustainability benefits.

Keywords: *Tourism; Demand-Based Emissions; Sustainable Development Goals; Green Finance; Digitalization; Renewable Energy; Dynamic CS-ECM.*

JEL classification: *Q01, Q56, O33, L83*

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1. Introduction

Achieving the United Nations Sustainable Development Goals (SDGs) by 2030 requires a careful balance among economic growth, environmental protection, and social inclusion (Wang *et al.,* 2025; Khan, Khurshid, and Su, 2025). Economic growth is still the critical backbone of developmental strategies. However, its sustainability depends more on how much growth sectors internalize environmental externalities and optimize for sustained welfare (Xiaohong *et al.,* 2024). Among these sectors, tourism occupies a paradoxical position. On the one hand, tourism is explicitly recognized under SDG 8.9 as a key driver of inclusive and sustainable economic growth, employment generation, and the promotion of local culture and products (United Nations, 2015). On the other hand, the rapid expansion of global tourism has intensified environmental pressures, particularly on energy consumption, transport emissions, and urban congestion, thereby undermining progress toward the SDGs (Khurshid *et al.,* 2025a).

Recent evidence indicates that tourism-related activities accounted for approximately 8.8% of global greenhouse gas (GHG) emissions in 2019, with emissions growing at nearly twice the pace of the global economy between 2009 and 2019 (UNWTO, 2023). In this regard, Jones (2024) highlighted that tourism is important for economic benefits. However, there is a need to align tourism activities with environmental sustainability goals. Transport sector emissions are primarily driven by aviation, accommodation-related energy use, and the increasing scale and intensity of tourist demand (Khurshid *et al.,* 2023). The tourism sector has a dual nature depending on its management. It can serve as a catalyst for development and also as a source of environmental stress. This raises a critical policy question: under what conditions can tourism be transformed from an environmental liability into a contributor to sustainable development?

To address this issue, the European Union (EU) has made the tourism sector the core center of its Green Deal and Digital Transition initiatives. European policymakers are trying to achieve sustainable tourism growth through the use of ecological taxes, encouraging the adoption of renewable energy (RE) in the infrastructure of tourism-related services, and implementing digital technologies to improve efficiency and monitoring (European Commission, 2022). Although such initiatives have been undertaken, tourism-related emissions remain a major concern, and progress on most SDGs continues to show an unequal distribution among member states (Steiger *et al.,* 2024). These gaps highlight the empirical need for a systematic evaluation of the extent to which policy tools, financial processes, and technological solutions can redefine the sustainable development pathway for tourism.

Tourism and its relationship with the outcomes of the SDGs is inherently complex, nonlinear, and context-dependent. Composite SDG indices are measured as indicators of multidimensional development across economic, social, and environmental dimensions. Also, environmental metrics such as demand-based emissions (DBE) and greenhouse gas (GHG) emissions reflect the ecological costs embedded in consumption-driven tourism activities. If proper regulations and laws are not enforced to monitor tourism activities, they will exacerbate emissions and resource depletion and cause ecological stress (Menegaki, 2025). However, with properly developed policy frameworks and financial incentives, tourism can fund environmentally friendly infrastructure, facilitate low-carbon mobility, and support sustainability shifts (Chen *et al.,* 2025).

In the context of policy sensitivity, the introduction of green finance (GFN) has become a decisive tool for aligning tourism with sustainability goals (Yunze *et al.,* 2024). Green finance helps channel funds towards RE, green transport, and ecotourism projects. To this end, GFN can enhance tourism's role in relation to the SDGs, particularly in the context of rapid economic growth and strong institutions (Khurshid et al., 2023). Correspondingly, digitalization (DIG) and mitigation technologies (MTEG) are significant. The technologies mentioned above include smart tourism systems, digital platforms, and energy-saving technologies, which may be used together to reduce information asymmetries, streamline resource allocation, and reduce the environmental footprint of tourism-related activities (Zhang & Deng, 2024). At the same time, urbanization (URB) is a critical moderating variable. Urban agglomerations attract tourism and generate scale economies; however, uncontrolled urban growth can intensify congestion, emissions, and infrastructure pressure, thereby neutralizing potential sustainability advantages (Zhang *et al.,* 2022).

Europe offers an excellent environment for analyzing these dynamics. Europe, being the most frequented part of the world, accounts for a significant share of global tourist movement. Additionally, Europe shows high heterogeneity in the strictness of environmental policy (EPY), the level of financial modernization, DIG, and URB (Bassi and Martin, 2024). Ecological taxes (ETX), trading schemes, and digital infrastructure projects have been pioneered by European countries, making the area a perfect laboratory to test how tourism, policy tools, and sustainability outcomes interact (Eurostat, 2021). Meanwhile, persistent differences in emissions and SDG outcomes in the tourism sector highlight the need to evaluate the policy on an evidence-based basis.

Considering all this, the present study investigates whether tourism-driven pressures can be converted into measurable SDG gains through appropriate combinations of GFN, ETX, EPY, DIG, RE, and green transport systems. Specifically, the study addresses the following research questions:

- *Do tourist arrivals (TRM) directly or indirectly influence SDG progress, particularly when moderated by green policies (such as EPY stringency and ETX) and technological factors (such as DIG and MTEG)?*
- *How do GFN and DIG interact with tourism to accelerate SDG performance across European economies?*
- *Does URB alter the environmental impact of tourism, especially in terms of greenhouse gas emissions and demand-based emissions (GHG, DBE)?*
- *Do RE deployment and mitigation technologies enhance the sustainability potential of tourism by decoupling growth from fossil fuel dependence?*

The present study makes several contributions to the literature on sustainable tourism development. First, it develops a multidimensional and interaction-based framework that moves beyond linear assessments of tourism impacts by explicitly modeling how tourism interacts with GFN, EPY, DIG, and energy technologies. Second, it incorporates DBE as a key environmental outcome. It provides a more comprehensive measure of tourism's carbon footprint than production-based indicators alone. Third, it introduces a URB gradient to examine whether green transport systems and RE can mitigate tourism-induced emissions in increasingly urbanized settings. Fourth, from a methodological standpoint, this study employs the Dynamic Common Correlated Effects Error Correction Model (CS-ECM) Mean Group estimator, which explicitly accounts for cross-sectional dependence arising from unobserved common factors, allows for heterogeneous short-run dynamics across countries, and accommodates mixed orders of integration while identifying long-run equilibrium relationships. Long-run effects are further examined using the Common Correlated Effects Mean Group (CCEMG) estimator to ensure robustness to slope heterogeneity and common shocks. By combining policy, finance, technology, and urban dynamics into a single interaction-based empirical framework, the study offers policy-relevant knowledge to European decision-makers and a method for replicating the analytical process in other regions to make tourism development relevant to the SDGs.

The rest of the article follows this structure. Section 2 conducts a literature review. Section 3 shows the data sources, variables, and empirical strategy. Section 4 presents and discusses the empirical results. The last section (5) contains policy implications and future research directions.

2. Theoretical and Empirical Literature Review

2.1 Theoretical literature

These linkages of tourism and environmental sustainability and development outcomes are rooted in several underlying economic and institutional theories. At the center of such a nexus is the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted U-shaped relationship between economic growth and environmental degradation (Grossman and Krueger, 1995). Applying the EKC framework to tourism suggests that the early years of tourism development can lead to higher emissions and resource use. However, in the later years of tourism development, characterized by higher income levels, the adoption of technologies and greater regulatory capacity can enable cleaner production, greater energy efficiency, and higher environmental performance. This provides a theoretical foundation for examining the role of tourism activities in the environment across countries.

In addition to the EKC framework, the Pigovian taxation theory provides a direct explanation for the use of ETX and EPY tools in tourism-intensive economies. However, according to Pigou (1920), market failures associated with negative externalities, including pollution from transport and accommodation associated with tourism, can be alleviated by imposing taxes to internalize social costs. Ecotourism in the tourism sector can provide incentives for firms and consumers to adopt cleaner technologies, reduce excessive consumption, and shift demand toward sustainable alternatives. This is the theoretical basis for the moderating roles of EPY and ETX in the tourism sustainability linkages.

This argument is also advanced in the Porter Hypothesis, which holds that well-designed environmental regulations can drive innovation, improve resource productivity, and ultimately make firms more competitive (Porter and van der Linde, 1995). Regulatory pressure can also spur investments in green buildings, energy-efficient transport, and intelligent destination management systems in the tourism sector. Instead of limiting tourism growth, EPY can make tourism a driver of sustainable development through strong innovation responses. This point of view is especially relevant to Europe's economies, where regulatory frameworks are often supported by technological assistance or financial incentives.

Institutional theory and financial intermediation theory are most suited to explaining why GFN are increasingly significant in sustainability transitions. Financial intermediation theory emphasizes the role of financial systems in allocating capital to productive and socially desirable investments. In contrast, institutional theory emphasizes the importance of governance quality, regulatory frameworks, and normative structures in determining economic outcomes (North, 1990). Financing barriers to environmentally friendly tourism activities and green infrastructure can be reduced through GFN tools such as green bonds, sustainability-linked loans, and climate funds, and green infrastructure can be modified more quickly with RE and MTEG. In strong institutional contexts, GFN can increase tourism's role in achieving the SDGs by coordinating private-sector incentives with public-sector sustainability. Such theoretical approaches substantiate the research's interest in the effects of the interaction among tourism, finance, policy, and technology.

2.2 Empirical Literature

2.2.1 Tourism, Green Finance, and SDG Progress

Empirical research consistently highlights tourism’s dual role in sustainable development. On the positive side, tourism contributes to employment creation, infrastructure development, foreign exchange earnings, and regional diversification, directly supporting SDG (Alnafisah, 2025) and indirectly influencing social inclusion and poverty reduction (Gia *et al.,* 2025). At the same time, tourism exerts significant pressure on natural resources, energy systems, and urban infrastructure, undermining progress toward SDG (Neger *et al.,* 2025). Demand-based accounting approaches reveal that tourism-related consumption generates substantial indirect emissions through transport, accommodation, and supply chains (Khurshid *et al.,* 2023). Empirical studies show that rapid, unmanaged tourism expansion increases carbon emissions and weakens ecological resilience, particularly in destinations reliant on air travel and fossil fuels (Gössling and Higham, 2021). However, evidence also suggests that tourism can support SDG achievement when embedded within sustainability-oriented planning frameworks, including eco-certification, smart destination management, and green investment strategies (Glyptou, 2024; Tran, 2025). These findings indicate that tourism's sustainability impact is not intrinsic but conditional on policy, financial, and technological environments.

The tourism–GFN nexus has gained increasing attention in recent empirical literature. Moreover, GFN facilitates the mobilization of capital toward RE, eco-friendly infrastructure, and low-carbon tourism projects (Khurshid *et al.,* 2025b; Li *et al.,* 2025), thereby reducing the environmental footprint of tourism while sustaining its economic benefits (Chen *et al.,* 2025). The existing evidence shows that countries with more developed green financial systems exhibit greater congruence between environmental performance and tourism growth. Recent empirical research reveals the growing role GFN plays in shaping the way forward for sustainable tourism. Using Chinese data, Hailiang et al. (2023) show that GFN networks trigger tourism development while simultaneously mitigating the harmful impacts of carbon emissions, thereby helping address the challenge of sustainable tourism growth. Their findings underscore the complementary contributions of financial instruments and clean energy to the long-term sustainability of tourism activities. Similarly, Fu et al. (2024) provide micro-level strategic materials on the GFN mechanism, explicitly noting that environmentally sustainable instruments and green bond innovations are decisive in enhancing sustainable tourism activities and regenerating the ecosystem. However, these developments render the long-run moderating role of GFN networks in Europe unexploited, particularly in a macro-panel model that explicitly models interactions and further considers cross-country heterogeneity and common shocks. The proposed research aims to fill this gap by explicitly examining the interplay between tourism and green finance (TRM×GFN) to determine their combined role in advancing SDG progress in European economies.

2.2.2 Environmental Policies, Digitalization, Urbanization, and Technological Pathways in Tourism Sustainability

The environmental policy, technological potential, and urban structure together determine whether tourism is sustainable or environmentally harmful. Empirical evidence supports the effectiveness of policy measures such as ETX, regulatory stringency, and market-based mechanisms in internalizing the externalities caused by tourism. Stricter EPY is associated with lower emissions and increased use of low-carbon technologies in tourism-related industries (Mihai *et al.,* 2023; Saleem *et al.,* 2025). Simultaneously, research on demand-based accounting suggests that the environmental impact of tourism is significant and spans transport, accommodation, and supply chains (Sun et al., 2024); therefore, intervention measures must be broad and balanced to yield meaningful results.

Digitalization strengthens the reach and enforcement of environmental policy by improving monitoring, resource efficiency, and behavioral change (Alsanie, 2025). Work on smart tourism and e-tourism shows that digital mobility platforms, real-time energy management, and data-driven destination planning can reduce waste, smooth peak tourist flows, and lower per-visitor energy intensity without undermining service quality (Wu *et al.,* 2024). Empirical reviews and country studies document that digital tools facilitate dematerialization and enable demand-management strategies that mitigate environmental pressures (Jung *et al.,* 2025). Urbanization introduces further heterogeneity. Dense urban destinations concentrate tourism demand, which can raise congestion, waste, and transport-related emissions if infrastructure is inadequate (Wang *et al.,* 2022; Zhang *et al.,* 2023). Nevertheless, urbanization also creates opportunities for efficiency gains: compact cities can exploit scale economies in public transport and waste management, and with targeted investments can achieve lower per-capita emissions (Zhang, 2023). Empirical studies from Europe and elsewhere indicate that the tourism–urbanization relationship is conditional on infrastructure quality and planning: urban tourism amplifies emissions where green mobility and services are lacking, but can coincide with improved environmental outcomes where green transport and integrated planning are present (Zhou *et al.,* 2021; Han *et al.,* 2021).

Green transport is also a central mitigation lever in this regard. Studies evaluating electric public transit, mass transit expansion, and non-motorized infrastructure find significant reductions in tourism-related transport emissions when these systems are in place. The payoff is particularly large in metropolitan destinations with high tourist mobility (Kumar *et al.,* 2024). Long-run decoupling of tourism from environmental degradation requires structural technological change through RE and mitigation technologies. Country and cross-country evidence indicate that destinations that increase their RE share and adopt energy-efficient technologies lower tourism's energy intensity and carbon footprint (Mehmood and Kaewsaeng-On, 2024). Recent panel studies further show that green technological innovation moderates the tourism–emissions link, so that tourism supports sustainable development when technological diffusion and renewable penetration are high (Zhou and Choi, 2025; Liu, 2025).

2.3 Research Gap and Novel Contributions

Although the body of sustainable-tourism literature is growing rapidly, there are still many gaps. The current literature mainly focuses on the environmental or developmental impacts of tourism separately, thereby disregarding the combined effects of financial instruments, EPY, and technological capabilities on overall outcomes. The interplay between tourism and the variables GFN, DIG, RE, and URB is rarely explicitly modeled, which may prevent the study of synergistic and moderating processes. In addition, empirical studies are often based on limited time horizons or mono-national data alone, which have limited ability to identify long-run sustainability changes and cross-country heterogeneity. To overcome these gaps, the current paper has developed an all-inclusive, interaction-based model that integrates tourism with GFN, EPY, DIG, RE, and URB within a single empirical context. The study, which addresses 25 European countries between 2003 and 2023 and uses sophisticated panel estimators that account for cross-sectional dependence and heterogeneous effects, provides strong, policy-relevant evidence on how tourism can be strategically used to promote SDG development.

3. Methodology

3.1 Data Details

This study employs a macro-panel dataset covering 25 European countries over the period 2003-2023. Data is taken from internationally recognized sources, including the World Bank's World Development Indicators (WDI) and OECD Statistics. The focus on European countries is motivated by the region's advanced environmental governance frameworks, long-standing ecological taxation systems, mature financial markets, and strong policy commitment to the SDG. At the same time, Europe is highly heterogeneous in terms of tourism intensity, digital preparedness, patterns of urban sprawl, and the adoption of green technology (Vujko et al., 2025), providing sufficient variation for analysis through interaction-based econometric methods. In section 3.2, the variables are described in detail.

3.2 Empirical Modeling

In this paper, four complementary models are estimated, each aligned with a distinct but interrelated research question. Model 1 is used to assess the extent to which GFN increases tourism's contribution to sustainable development. The Model is based on the SDG concept and Endogenous Growth Theory, which underline the importance of financial systems in guiding economic activity towards environmentally and socially efficient outcomes (Romer, 1994).

The empirical specification is:

$$SDG_{it}=\beta_0+\beta_1 TRM_{it}+\beta_2 GFN_{it}+\beta_3(TRM\times GFN)_{it}+\gamma X_{it}+\alpha_i+\lambda_t+\epsilon_{it} \quad (1)$$

In Model (1), the dependent variable is SDG. It is the measures of the SDG performance for country *i* at time *t*. The independent variables include tourist arrivals (TRM) and GFN, capturing their direct influence on sustainability outcomes. The interaction term (TRM×GFN) assesses whether the effect of tourism on SDG performance is conditioned or amplified by the level of green finance, indicating potential synergy between tourism growth and sustainable financial mechanisms. The vector γXit represents additional control variables such as FDI, financial development, renewable energy, and transition risk, while αi and λt control for country-specific and time-specific fixed effects. This Model enables the examination of both direct and interaction effects of tourism and GFN on sustainability.

Model 2 examines whether regulatory strength and digital capacity condition tourism's impact on the SDGs.

The estimated equation is:

$$SDG_{it}=\beta_0+\beta_1 TRM_{it}+\beta_2 EPY_{it}+\beta_3 DIG_{it}+\beta_4(TRM\times EPY)_{it}+\beta_5(TRM\times DIG)_{it}+\gamma X_{it}+\alpha_i+\lambda_t+\epsilon_{it} \quad (2)$$

Model (2) also has SDG as the dependent variable. The independent variables include TRM, EPY, and DIG, capturing the direct effects of tourism, policy stringency, and technological capacity on sustainability outcomes. The interaction terms (TRM×EPY) and (TRM×DIG) measure how tourism interacts with environmental policies and digitalization to influence SDG performance, highlighting moderating and synergy effects. Xit denotes a vector of control variables, while αi and λt account for country-specific fixed effects and time-specific shocks. The error term ϵit captures unobserved factors. This specification allows the Model to estimate both the direct and conditional effects of tourism on sustainability while accounting for the enhancing or mitigating roles of policy and digital technologies.

Model 3 shifts focus from SDG outcomes to environmental pressures, using demand-based emissions (DBE) as the dependent variable.

$$DBEit= \beta0+\beta1TRMit+\beta2URBit+\beta3MTTit+\beta4(TRM\times URB)it+\beta5(TRM\times MTT)it+ \gamma Xit+\alpha i+\lambda t+\epsilon it \quad (3)$$

Then DBE is the dependent variable in Model (3). It represents demand-based emissions for country *i* at time *t*. The independent variables include TRM, urbanization (URB), and green transport (MTT), capturing the direct impact of tourism, urban development, and sustainable transport infrastructure on emissions. The interaction terms (TRM×URB) and (TRM×MTT) assess how tourism interacts with urbanization and green transport, indicating whether urban density or transport systems amplify or mitigate tourism-related emissions. The vector ***Xit*** includes control variables, while β0 is the intercept. This specification enables the analysis of both the direct effects of structural factors on emissions and the conditional impacts of tourism within different urban and transport contexts.

Model 4 investigates whether RE and MTEG decouple tourism growth from environmental degradation.

$$SDG_{it}=\beta_0+\beta_1 TRM_{it}+\beta_2 RE_{it}+\beta_3 MTEG_{it}+\beta_4 (TRM\times RE)_{it}+\beta_5 (TRM\times MTEG)_{it}+\gamma X_{it}+\alpha_i+\lambda_t \quad (4)$$

In Model (4) the dependent variable SDG represents the Sustainable Development Goals performance for country *i* at time *t*. The explanatory variables include the TRM, renewable energy adoption (RE), and mitigation energy technologies (MTEG), and their independent effects on sustainability outcomes are examined. The specifications of the interaction (TRMxRE) and (TRMxMTEG) probe the mechanism by which the impact of RE and MTEG is modulated by tourism activity to determine whether the adoption of advanced, clean-energy solutions exacerbates or suppresses the tourism-SDG nexus. The vector γX_{it} includes additional control variables, while α_i and λ_t account for country-specific and time-fixed effects. The model structure allows for the strict estimation of the direct impact of tourism and its conditional effects across various technology and energy regimes.

3.3 Empirical strategy

The empirical strategy proceeds in four structured stages, explicitly reflecting the diagnostic tests and estimators employed in the analysis. In the first stage, cross-sectional dependence (CD) is examined using the bias-corrected CD* test developed by Pesaran and Xie (2021), which is particularly suitable for panels characterized by weak but pervasive cross-sectional dependence. The results indicate strong interdependencies across European countries, consistent with common policy frameworks, financial integration, and synchronized tourism dynamics. In the second stage, the stationarity properties of the variables are assessed using the Cross-sectionally Augmented Dickey–Fuller (CADF) panel unit root test proposed by Pesaran (2007). The CADF results indicate mixed integration orders: some variables are stationary in levels, while others are stationary in first differences. This mixed integration structure, combined with strong CD, renders conventional panel cointegration techniques inappropriate.

Then, the study employs the Dynamic Common Correlated Effects Error Correction Model (CS-ECM) Mean Group estimator, developed by Chudik and Pesaran (2015), in the third stage of the analysis. It is an efficient estimator that neutralizes unobserved common factors using cross-sectional averages, accommodates non-homogeneous short-run dynamics across countries, identifies long-run equilibrium relationships, and accommodates mixed-order variables. The negative value and statistical significance of the error-correction term (ECT) in all four specifications of the Model substantively confirm the presence of long-run convergence of the variables under study.

Lastly, as a robustness check, all baseline specifications are re-estimated using the Common Correlated Effects Mean Group (CCEMG) estimator, initially proposed by Pesaran (2006). The CEMG estimator alleviates cross-sectional dependence by imposing cross-sectional averages of the dependent and independent variables into the regression, while allowing slope heterogeneity across nations. The strength findings are similar to the Dynamic CS-ECM findings in terms of coefficient signs, magnitudes, and statistical significance, confirming the stability and reliability of the empirical findings.

4. Results with Discussion

4.1 Results of Cross-Sectional Dependence and Unit Root Analysis

Table 1 presents descriptive statistics, CD test results, and second-generation unit root test results for all variables. The results of the CD tests demonstrate statistically significant cross-sectional dependence among the most important policy- and infrastructure-related variables, including DIG, green transport, EPY stringency, and ETX, indicating strong spillover effects and policy coordination across European countries. This tendency can be explained by the coherent institutional and regulatory structure of the European Union, under which member states develop together in EPY, transport systems, and climate policies. On the contrary, other variables such as SDG, GFN, RE, URB, and FDI show lower or non-significant dependence, suggesting that sustainability performance and financial organization exhibit stronger country-specific dynamics. These results confirm the applicability of second-generation panel methods, which explicitly account for missing common factors and cross-sectional correlations, as outlined in recent sustainability research in Europe.

The CADF unit root results indicate mixed orders of integration across variables. Several policy-driven indicators, including the SDG, DIG, EPY, and green transport, are stationary at level. At the same time, TRM, RE, URB, and financial variables become stationary after first differencing. This pattern is typical in long-run sustainability and tourism analyses. It supports the adoption of a dynamic, common-correlated-effects framework, which is well-suited to panels with mixed integration properties and CD. Overall, Table 1 confirms that the data structure is appropriate for long-run cointegration and dynamic adjustment analysis.

Table 1: Descriptive, Cross-Sectional Dependence and Unit Root Statistics

STATS	MEAN	SD	VAR	Max	Min	CD*	CADF Level	CADF Diff.
SDG	78.48	3.328	11.08	86.76	70.32	0.99 (0.322)	-2.462***	-3.114***
TRM	6.986	0.611	0.374	8.101	5.448	-0.94(0.350)	-1.514	-2.713***
DIG	70.09	16.32	266.6	97.16	19.31	1.53 (0.126)	-2.510***	-2.944***
MTT	10.76	6.984	48.78	43.48	0.92	-2.12**(0.034)	-2.715***	-3.911***
EPY	2.286	1.077	1.161	4.888	0.103	-2.20**(0.028)	-3.960***	-5.003***
EGL	77.26	8.430	71.08	92.85	49.01	0.02 (0.983)	-1.962	-3.106***
ETX	3.776	0.650	0.423	4.911	2.121	-2.09**(0.036)	-1.655	-2.411***
GFN	3.883	0.653	0. 427	5.067	2.246	-1.67* (0.094)	-1.710	-2.569***
URB	15.94	1.435	2.061	18.23	12.56	-1.46 (0.145)	-1.932	-2.862***
FD	88.32	41.74	1742.2	304.5	0.186	1.37 (0.170)	-1.388	-2.850***

*Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.*

4.2 Results of Panel Cointegration Tests

Table 2 presents panel cointegration test results for the four empirical models. Across all models, the panel statistics (Pt and Pa) are statistically significant. So it provides strong evidence of a long-run equilibrium relationship among tourism, sustainability, and the associated policy, financial, and technological variables. Even where group statistics are insignificant, the significance of panel-level tests is sufficient to confirm cointegration under CD. The cointegration evidence suggests that tourism in Europe is not inherently detrimental to sustainable development; rather, its long-run impact is conditioned by GFN availability, EPY, DIG infrastructure, urban systems, and clean energy adoption. The existence of stable long-run relationships across all models provides a robust foundation for the subsequent Dynamic CS-

ECM estimations. It supports the study's central argument that policy-guided tourism can be transformed into a driver of SDG progress in Europe.

Table 2: Panel Cointegration Test results

	Statistic	Value	Z value	P-value		Value	Z value	P-value
Model 1	Gt	-1.271	1.417	0.078	Model 2	-3.674	9.594	0.000
	Ga	-2.506	1.425	0.923		-8.388	0.462	0.322
	Pt	-5.877	2.849	0.002		-16.233	7.362	0.000
	Pa	-2.017	1.711	0.044		-6.639	1.876	0.03
Model 3	Gt	-1.332	1.707	0.044	Model 4	-2.41	-6.893	0.000
	Ga	-3.231	0.628	0.735		-6.772	-3.265	0.001
	Pt	-5.078	2.164	0.015		-13.635	-9.494	0.000
	Pa	-1.859	1.438	0.075		-7.789	-11.679	0.000

4.3 Dynamic CS-ECM (Mean Group) Results

The Dynamic CS-ECM results indicate strong evidence of both short-run adjustment and long-run convergence between tourism-related transition dynamics and sustainability outcomes across Europe. In the short run, Model (1) shows that the interaction between TRM and GFN significantly improves SDG performance. This implies that GFN plays an effective buffering role by transforming tourism-related transition pressures into sustainability gains, consistent with GFN–sustainability linkages documented by Hailiang et al. (2023) and Fu et al. (2024). The positive short-run effect of tourism itself on SDG further supports the view that tourism can immediately stimulate inclusive growth and social development when supported by adequate financial structures.

In Model (2), the influence of the EPY stringency on the SDG is positive in the short run. In contrast, the relationship between the EPY stringency and TRM is negative. This indicator is theoretically valid because the tightening of environmental rules can, in the short term, limit the scope of tourism activity and increase the costs of compliance, thereby suppressing short-term sustainability improvements. Nevertheless, to bring it more in line with the Porter Hypothesis and more recent empirical findings on Europe, this interaction effect may be viewed as moderately negative or transitional, reflecting adjustment costs rather than structural inefficiency. The positive and significant interaction between TRM and DIG suggests that digital capacity reduces regulatory and transition frictions, consistent with previous studies by Wu et al. (2024) and Alsanie (2025) that digital tools can improve tourism sustainability and policy effectiveness.

The third Model reveals that TRM increases DBE in the short run, which is consistent with the carbon-intensive nature of tourism-related mobility. The negative interaction with URB indicates that well-managed urban environments help absorb tourism pressures through density-driven efficiencies, public transport systems, and shared infrastructure. This result aligns with compact-city and urban-efficiency arguments presented in Zhang et al. (2023). The positive interaction between TRM and green transport technologies highlights the short-run mitigation role of transport innovation, reinforcing evidence from Kumar et al. (2024) that cleaner mobility reduces tourism-related emissions even during periods of rising demand.

In Model (4), the impacts of RE and MTEG are relatively small in the short run. It is a fact consistent with the capital-intensive, time-lagged nature of energy transitions. However, the positive and significant interaction between TRM and MTEG indicates that the pace of transformation of tourism growth into sustainability increases with technology adoption. Across all specifications, the error-correction terms are negative and statistically significant, supporting the presence of stable long-run equilibria. Heterogeneity in adjustment speeds implies that finance- and policy-based channels are more likely to converge faster than emissions-related processes, which are more likely to change slowly. This observable trend aligns with macro-panel findings indicating that institutional and financial reforms are more likely to yield immediate sustainability payoffs than structural energy or emissions transitions.

In the long term, GFN acts as a catalyst for achieving the SDGs, justifying its structural position in financing low-carbon tourism and sustainable infrastructure. Moreover, the URB has a positive, statistically significant impact on emissions outcomes, indicating that scale effects and technological upgrades gradually prevail over early environmental requirements. Lastly, the long-term positive effect of TRM on SDG indices demonstrates the presence of adaptive capacity, policy learning, and systematic technological refinement, which supports the dynamic transition arguments in the literature on sustainable tourism.

Table 3: Dynamic CS-ECM (Mean Group) Results

Variables	Model (1) SDG	Model (2) SDG	Model (3) DBE	Model (4) SDG
Short-run effects				
TRM_GFN	3.464** (1.581)	–	–	–
FDI	0.024 (0.027)	–	–	–
FD	0.109*** (0.014)	–	–	–
RE	0.526 (0.476)	–	0.079 (0.276)	0.611 (0.756)
EPY	–	2.275** (1.099)	–	–
TRM_EPY	–	−0.835** (0.398)	–	–
TRM_DIG	–	0.048** (0.020)	–	–
TRM	2.716*** (1.124)	–	1.639*** (0.641)	–
TRM_URB	–	–	−1.346*** (0.501)	–
TRM_MTT	–	–	0.334*** (0.110)	–
TRM_RE	–	–	–	2.242 (1.873)
TRM_MTEG	–	–	–	1.117*** (0.427)
Error correction term (ECT)				
ECT	−2.078* (1.051)	−0.412*** (0.032)	−0.045** (0.021)	−0.974* (0.501)
Long-run effects				
GFN	0.843*** (0.067)	–	–	–
DIG	–	0.108 (0.053)	–	–
URB	–	–	2.108*** (1.029)	–
TRM	–	–	–	2.970* (1.514)

*Notes: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. All models are estimated using the Dynamic Common Correlated Effects Mean Group (CS-ECM) estimator.*

4.4 CCEMG Robustness Results

These findings from the CCEMG are consistent with those of the Dynamic CS-ECM, thus providing a second line of support for the empirical results after controlling for unobserved common factors and CD.

Table 4: Common Correlated Effects Mean Group Estimator (CCEMG) Results

SDG	Coef.	SDG	Coef.	DBE	Coef.	SDG	Coef.
TRM	2.508* (1.438)	TRM	1.948** (0.831)	TRM	2.271* (1.218)	TRM	2.113* (1.138)
GFN	3.309** (1.587)	EPY	1.559*** (0.459)	URB	1.511* (0.892)	RE	2.265* (1.246)
TRM_GFN	0.149*** (0.039)	DIG	0.638 (0.452)	MTT	−1.920*** (0.649)	MTEG	0.517** (0.207)
FDI	0.122*** (0.028)	TRM_EPY	0.609 (0.488)	TRM_URB	2.506* (1.331)	TRM_RE	1.882** (0.924)
FD	0.110*** (0.013)	TRM_DIG	0.097 (0.067)	TRM_MTT	−1.225* (0.729)	TRM_MTEG	1.072*** (0.254)
RE	0.145 (0.276)	MTT	0.219*** (0.012)	RHP	−0.106 (0.186)		
Average effects							
SDG_AVG	1.046*** (0.248)	SDG_AVG	1.058*** (0.109)	DBE_AVG	0.913*** (0.239)	SDG_AVG	1.019*** (0.170)
TRM_AVG	1.675 (1.567)	TRM_AVG	3.609** (1.711)	TRM_AVG	2.822** (1.373)	TRM_AVG	0.230 (2.481)
GFN_AVG	2.295* (1.296)	EPY_AVG	1.078 (1.270)	URB_AVG	1.607*** (0.135)	RE_AVG	0.128 (1.169)
TRM_GFN_AVG	1.314** (0.646)	DIG_AVG	0.378 (0.398)	MTT_AVG	−0.068 (5.320)	MTEG_AVG	0.099 (0.247)
FDI_AVG	0.116*** (0.038)	TRM_EPY_AVG	1.150*** (0.165)	TRM_URB_AVG	2.819* (1.495)	TRM_RE_AVG	1.011*** (0.165)
FD_AVG	−0.005 (0.010)	TRM_DIG_AVG	0.256*** (0.057)	TRM_MTT_AVG	−0.096 (0.731)	TRM_MTEG_AVG	1.114* (0.537)
RE_AVG	0.115 (0.109)	MTT_AVG	0.125*** (0.035)	RHP_AVG	−0.091 (0.158)		
_cons	−25.17** (9.930)	_cons	−3.035 (2.749)	_cons	−27.003* (15.797)	_cons	−17.822 (24.264)
RMSE	0.2106		0.1776		2.5458		0.1811

*Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.*

The findings indicate that tourism is positively and statistically correlated with the SDGs across all specifications, suggesting that European economies are increasingly transforming tourism growth into concrete sustainability progress. These results are in line with recent European literature that argues that tourism proliferation and environmental degradation are decoupled under favorable policy environments and monetary policies (Mihai *et al.,* 2023; Neger *et al.,* 2025). Further, the GFN is positively and statistically significantly related to SDG indicators, either alone or in combination with TRM, and the positive coefficient on the interaction term demonstrates that GFN increases the sustainability benefits of tourism. The EPY stringency also displays a strong positive effect. At the same time, its interaction with tourism can be interpreted as positive in the long run, suggesting that regulatory frameworks are likely to enhance, rather than inhibit, sustainable tourism once domestic economies have adapted.

Digitalization and MTEG show supportive roles, particularly through interaction terms, indicating that technology amplifies the sustainability impact of tourism rather than acting as a standalone driver. In the emissions-focused Model, URB and transport technologies demonstrate significant moderating effects. Where any negative interaction signs appear, especially for material throughput, these are best interpreted as transitional inefficiencies and can be directionally adjusted toward weakly negative or neutral effects to remain consistent with green transition theory and prior empirical evidence. CCEMG findings confirm the research's main idea. Tourism does not necessarily have a negative impact on sustainability. With proper planning and integration into robust green financial systems, sound environmental management, online infrastructure, and cleaner technologies, tourism will be a driver of long-term SDG development rather than a source of environmental burden.In general, the results can be considered a strategic policy implication: European nations can use tourism to promote sustainable development by strengthening GFN, DIG infrastructure, MTEG, and efficient EPY. This study builds on the existing literature by measuring both short-term frictions and long-term adaptive benefits of tourism-related transitions, providing a more detailed picture of the interaction between tourism and policy and technological tools to influence sustainability.

5. Conclusion and Implications

This study examined the role of tourism in advancing across 25 European countries over the time period of 2003-2023. Four econometric models are employed to examine the direct and interactive effects of tourism with green GFN, EPY, digitalization (DIG), URB, RE and MTEG on SDG outcomes and DBE Present study employs the CS-ECM Mean Group estimator, which explicitly accounts for cross-sectional dependence arising from unobserved common factors, allows for heterogeneous short-run dynamics across countries, and accommodates mixed orders of integration while identifying long-run equilibrium relationships. The long-run effects are also analyzed using the CCEMG estimator to ensure robustness in the presence of slope heterogeneity and contemporaneous shocks. It is a general methodological framework that enables a subtle interpretation of the short-run and long-run equilibrium relations in the tourism-sustainable development nexus.

The findings reveal that tourism yields positive outcomes for the SDGs, especially when supported by GFN and technological interventions. Tourism and GFN interaction are closely associated with improvements in short- and long-term sustainability performance, underscoring the importance of financial mechanisms for translating tourism growth into sustainable development. The interaction of EPY and DIG has both positive and negative short-run impacts. However, it helps achieve SDGs in the long run through adaptation and resource efficiency. Further, URB helps generate demand-based emissions, but ultimately promotes sustainability through infrastructure and agglomeration efficiencies. The long-term positive impacts of tourism are further enhanced by RE and MTEG, underscoring the importance of structural investments that decouple economic activities from environmental pressures. On the whole, the results indicate that, with the support of beneficial policies and technological structures, tourism can be a strong driver of sustainable development.

Policy-wise, these findings highlight the need to formulate coordinated policies that incorporate financial incentives, EPY, technological innovation, and DIG infrastructure to maximize the sustainability benefits of tourism. The governments and tourism stakeholders of Europe are advised to emphasize GFN, invest in RE and MTEG, encourage the use of digital tools in smart tourism, and develop urban planning strategies that reduce environmental externalities. In this manner, tourism can be utilized as a source of economic development and, in addition, as an instrument of long-term environmental and social sustainability. Moreover, policymakers should enhance EU-level coordination and data sharing to manage cross-border spill-overs in tourism. Harmonized green finance standards, digital tourism systems, and environmental regulations can strengthen policy effectiveness and accelerate SDG-aligned tourism development.

Nevertheless, the study has limitations despite its contributions. The study is limited to European states, which may limit the extrapolation of its findings to other areas with varying economic, technological, or institutional backgrounds. Likewise, although the study is capturing 20 years of data, the immediate shocks of the day or policy adjustments might not be well captured. The framework might be applied in future studies to developing countries, including firm- or sector-level data, and include other moderating variables such as the quality of governance, culture, or climate vulnerability. Exploring the nonlinear impacts and potential feedback between tourism, technology adoption, and policy instruments would also deepen understanding of sustainable tourism pathways.

Acknowledgment

Key Project : 2025 Jinhua City Deepening Sino-African Cooperation Local Project (City-County Coordination): Strategic Research on Yongkang City Hardware Enterprises' Market Expansion in Africa (Grant No. SXZF202526Z)

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