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Toward green tourism: the role of renewable energy for sustainable development in developing nations

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Sustainable tourism (TOR) practices are essential for balancing economic growth and environmental conservation, enabling economies to protect natural resources while fostering socio-economic development. In the BIMSTEC region, where tourism is a significant economic driver, understanding the interplay between tourism and renewable energy (RE) is critical for achieving sustainable development. This study examines the influence of TOR and RE on environmental quality, measured through the load capacity factor (LCF), in BIMSTEC countries. It also explores the interaction between TOR and RE to evaluate their combined impact on environmental sustainability. Using panel data from 2000 to 2022, the study employs advanced econometric techniques, including the cross-sectional autoregressive distributed lag (CS-ARDL) and augmented mean group (AMG) methodologies, to assess long-term relationships and robustness. Wavelet coherence analysis further examines time-frequency correlations between TOR and environmental quality. The results reveal that while TOR alone negatively impacts environmental quality, RE significantly enhances it, with a 1% increase in RE leading to a 0.04% improvement in LCF. The interaction term TOR*RE demonstrates a positive synergy, mitigating the adverse effects of tourism on the environment. The wavelet analysis highlights an inverse relationship between TOR and environmental quality over time, reinforcing the need for sustainable practices in the tourism sector. The findings emphasize the importance of integrating renewable energy into tourism policies to reduce air pollution and climate change impacts. Policymakers in BIMSTEC countries should focus on financial development and establishing sustainable tourism-related industries to address socio-economic and environmental challenges. This study provides actionable insights to promote environmentally sustainable tourism while supporting economic growth in the BIMSTEC region.

KEYWORDS

sustainable tourism, developing nations, renewable energy, CS-ARDL, AMG

1 Introduction

Sustainable Development Objective 8 (Decent Work and Economic Growth) includes the sustainable development objective of tourism. This goal specifically strives to develop and implement policies by 2030 to support sustainable tourism that supports local products and culture while also creating jobs. To reduce environmental effects, promote conservation activities, and guarantee that tourism development helps local communities while advancing global sustainability goals, this goal places a strong emphasis on responsible travel behaviors. Tourism has grown over time as a phenomenon and has been observed as one of the major drivers of economic development. According to the United Nations World Tourism Organization (UNWTO, 2020), it creates 319 million employment and accounts for 10.5% of the world GDP, or more than $7.6 trillion. Sustainable tourism is essential for environmental sustainability, biodiversity protection, socioeconomic development, economic wellbeing, and ecological development. The potential significance of international tourism has made it imperative to investigate the fundamental aspects of tourism relevant to various industries (Baloch et al., 2023).

A tourist's fundamental right is to have access to renewable energy use (RE), a healthy environment, and activities based on their preferences (Naseer et al., 2024). The purpose of tourism (TOR) and sustainable development goals (SDGs) centers on the achievement of equal, general, and sufficient TOR resources for visitors. The SDGs include several goals aimed at minimizing carbon emissions, environmental degradation, and the availability of safe water at global TOR locations (Naseer et al., 2024; Voumik et al., 2024). Despite substantial advancements in tourism development in the most visited nations, the world's poorer or less visited countries require aid to present basic services to travelers and preserve a balance between the climate, economy, and cultural components of TOR. People must live without access to necessities, such as clean water and jobs while visiting tourist destinations (Naseer et al., 2024; Voumik et al., 2024).

As a result, local populations must encourage tourism more in their areas, which could lead to an abrupt drop in the number of visitors, their money, and the number of job chances that arise. This could have a negative impact on the local economy and the environment (Gupta et al., 2021). As a result, local populations must encourage tourism more in their areas, which could lead to an abrupt drop in the number of visitors, their money, and the number of job chances that arise. Subsequently, this could have detrimental effects on the local economy and environment. As the COVID-19 pandemic has shown, locals lost their employment, and millions of tourist destinations closed (Rasheed et al., 2021; WHO, 2020). Moreover, environmental problems such as inadequate sanitation and unsafe water in tourist destinations cost the US economy 7% of GDP, or around 250 billion dollars, annually. Thus, it is imperative to manage a healthy environment and fundamental tourist amenities to promote sustainable tourism development (Robinson, 2019). Figure 1 shows the trend of tourism in BIMSTEC nations.

In addition, concerns about the environment, human health, and safety are very important in foreign travel. Research such as those conducted by Torabian and Mair (2022) supports the idea that, despite the attractions and financial benefits, travelers do not choose to visit places that have health and environmental problems (Ahmad et al., 2024). Therefore, factors such as the environment, top health, and quality tourist attractions are important while making trip options. Before making any vacation plans, travelers always consider several critical concerns, including ecology, sanitation, and hygiene (Ahmad and Sheikh, 2024; Naumov et al., 2021).

While significant advancements have been made in tourism development within frequently visited nations (Igoumenakis et al., 2024), there remains a critical gap in understanding how sustainable tourism and renewable energy intersect within the BIMSTEC countries. The Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) includes seven countries: Bangladesh, Sri Lanka, Bhutan, Myanmar, Thailand, India, and Nepal. These nations are strategically located at the intersection of South and Southeast Asia, encompassing diverse ecological landscapes, ranging from the Himalayas to coastal regions, making them uniquely suited for tourism activities. However, the region also faces substantial environmental and socio-economic challenges (BIMSTEC, 2023; SAIS Review, 2024). BIMSTEC countries are among the most vulnerable to climate change, grappling with rising sea levels, deforestation, and extreme weather events that threaten both natural ecosystems and tourism-dependent economies (Roy, 2017). Moreover, these nations exhibit varying degrees of economic development, infrastructure quality, and renewable energy adoption, which further complicate efforts to balance tourism growth with sustainability objectives (Ridwan et al., 2024).

Despite tourism's economic potential, BIMSTEC nations face challenges such as inadequate renewable energy infrastructure, poor waste management, and limited access to clean water and sanitation, exacerbating ecological degradation (Chaudhary and Paudel, 2024; Yin and Qamruzzaman, 2024). While sustainable tourism is vital for the BIMSTEC region, existing research has largely overlooked the synergistic role of renewable energy in mitigating tourism's environmental impacts and promoting sustainability (Yin and Qamruzzaman, 2024). Most prior studies have independently examined either the economic benefits of tourism or the environmental advantages of renewable energy, without adequately exploring their combined influence on environmental sustainability within this unique regional context (Baloch et al., 2023).

For instance, Naveed et al. (2023) examined the association between economic development, transportation, tourism, renewable energy, and ecological footprint in the BIMSTEC region. Although their findings underscored the positive contributions of tourism and renewable energy to ecological integrity, the study did not delve into the long-term impacts of these factors on overall environmental quality or provide a comprehensive framework for their integration. Similarly, Bano et al. (2021) examined the nexus between tourism, renewable energy, income, and environmental quality in Pakistan. However, their focus was confined to a single country, limiting the applicability of their findings to the broader BIMSTEC region. Moreover, Gupta et al. (2021) study focuses on tourism and stakeholder satisfaction within the Pushkar region of Rajasthan, examining sustainability. While this provides valuable localized insights, it is limited to a single destination and does not address broader regional dynamics or the interplay between tourism and renewable energy.

This study seeks to bridge these gaps by investigating the long-term impacts of tourism and renewable energy on environmental quality across BIMSTEC economies. It adopts a holistic approach, integrating economic, technological, and environmental perspectives to capture the complex interplay between these sectors. By incorporating an interaction term for tourism and renewable energy, this research provides novel insights into how their combined effects drive environmental

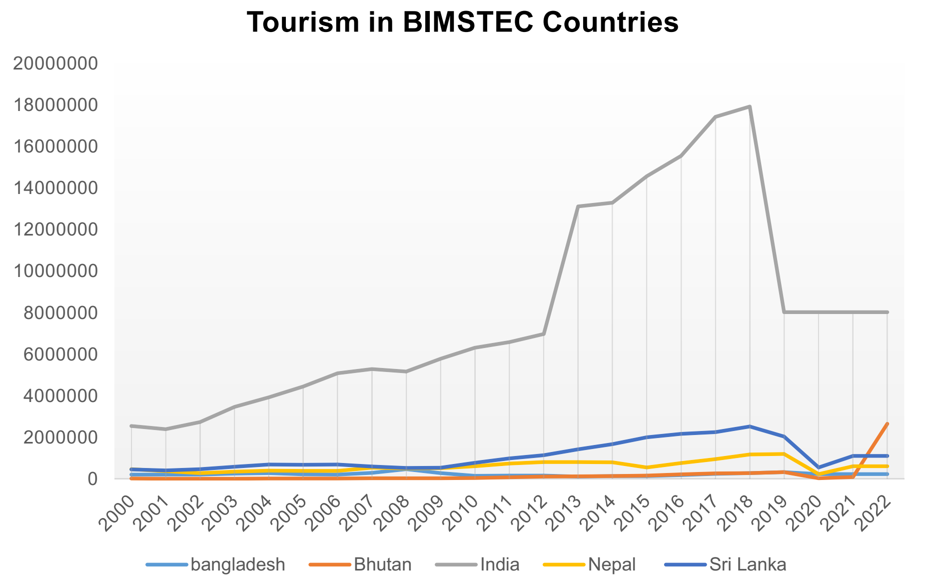

FIGURE 1
Tourism in BIMSTEC nations.

sustainability (Li et al., 2024)—an area overlooked in previous studies. This comprehensive analysis offers a valuable contribution to understanding and promoting sustainable development in the BIMSTEC region.

Furthermore, the application of second-generation panel regression and wavelet analysis allows for a nuanced understanding of cross-sectional dependence and policy implications, offering practical recommendations for sustainable tourism development in the BIMSTEC region.

Therefore, by comparing the ecological footprint (EF) per capita and bio-capacity, the current study investigates the LCC hypothesis considering TOR and RE on environmental quality (LCF). We use the CS-ARDL approach on data from the BIMSTEC economies from 2000 to 2022. To achieve this goal, a model for TOR is built that includes eco-advancements, per capita income, and access to green energy as variables.

This work adds to the body of knowledge on the financial and ecological factors driving international tourism in several ways. This study investigates the long-run effects of TOR on the environment in the economies of the BIMSTEC region. Second, raising the standard of RE and technological advancements can also raise income, promote the growth of sustainable tourism, and boost traveler demand. The economies of the BIMSTEC region are dealing with decreased levels of ecological footprint and green energy consumption, and previous research has not considered the influence of high-quality institutions on tourism. Moreover, this work includes an interactional term of TOR*RE to check its impacts on environmental quality. Third, a second generation of panel regression was used in this work to address cross-sectional dependence because these economies consist of various countries and behavioral patterns. Fourth, the results show that technical advancements, ecological footprints, and green energy use can all significantly boost foreign travel. Fifth, the application of wavelet analysis provides important policy options to promote sustainable tourism in the BIMSTEC region. Ultimately, the study's conclusions offer several policy recommendations that support the SDGs and help the region's tourist industry grow.

The Environmental Kuznets Curve (EKC) hypothesis and Load Capacity Curve (LCC) theories examine economic growth (GDP) and environmental effects from different angles. According to the EKC hypothesis, environmental degradation increases with economic development, but after a certain level of income per capita, technology, and more stringent laws to improve the environment. In contrast, the LCC hypothesis compares GDP to the load capacity factor, which is the greatest environmental strain an ecosystem can tolerate without degrading. The LCC theory emphasizes keeping economic activity within ecological limitations to avoid exceeding the environment's load capacity, unlike the EKC, which focuses on economic development to lessen environmental effects. The EKC holds that economic success will automatically improve the environment, whereas the LCC theory emphasizes the necessity for deliberate management to achieve sustainable growth within Earth's ecological constraints.

Second Section will address the review of literature, 3rd Section will address the methodology and materials, 4th Section will record the anticipated outcomes, and 5th Section will end the study with the conclusion and policy suggestions.

2 Literature review

2.1 Economic activities and tourism

According to earlier studies by Ulrich (2010), GDP has a greater impact on sustainable growth than TOR financial matters. Financially progressed nations are giving large social costs for GDP because of widening socioeconomic disparities, which have a detrimental impact on social cohesiveness (Komlos, 2018).

Mainstream economic science must reflect and address societal issues to generate a wider conversation on sustainable growth and TOR (Foxon et al., 2013; Ulrich, 2010). For example, Nowlin (2017) contended that sustainable development requires both social and GDP. Economic progress and social wellbeing are insufficient to achieve the collective, all-encompassing, and exclusive policy aim and sustained prosperity. Thus, rather than adopting a limited growth-oriented viewpoint, they support and concentrate on a multidimensional viewpoint on the financial, social, and political proportions (Bhatia and Dawar, 2023). Policy implications and objectives must be considered while making changes to natural and social settings to promote sustainable TOR (Baloch et al., 2023). In a similar vein, Soderbaum's (2007) one-dimensional analysis paradigm, or "economic reductionism," needs constant revision to comprehend sustained socio-economic development.

Furthermore, most issues about the availability of clean water and sanitary facilities are linked to the socioeconomic advancement of societies; unfortunately, nations worldwide are paying little attention to these matters, even though most of them face formidable obstacles to the supply of clean water and sanitary facilities. The financial impact of tourism has been researched extensively and is still a topic worth exploring (Jennings, 2009). As evidenced by current financial impact research on TOR (Comerio and Strozzi, 2019), most studies measure the primary and secondary effects of tourism activities to determine the economic relevance of the business.

To analyze the net changes in economic variables caused by TOR, several multipliers are used (Dwyer et al., 2004). However, economic activities need to be examined considering economic, social, environmental, and institutional factors to fully understand sustainable tourism development (Pulido-Fernandez et al., 2015). Socioeconomic sustainability is defined as the socioeconomic success and wellbeing of an individual. Nevertheless, the classic financial impact models have only yielded limited insights into socio-economic sustainability (Lee, 2009). As a result, one of the current study's objectives is to investigate the socioeconomic effects on TOR in the BIMSTEC nations, since these nations' and societies' socioeconomic development is essential to reaching Sustainable Development Goal No. 6. Sustainable tourism development is crucial to reduce carbon emissions (CO_2) and use of energy without affecting visitor arrivals or GDP. This requires measures to reduce CO_2 and GHG emissions from tourism destinations and achieve sustainable development objectives by 2030.

2.2 Environment and tourism

Environmental pollution caused by economic activity is becoming a substantial problem and worldwide trouble for achieving sustainable tourist growth. Previous researchers have extensively employed theories such as the Environmental Kuznets Curve (EKC) and Load Capacity Curve (LCC) to explore the relationships among economic growth, energy consumption, and environmental sustainability.

The EKC hypothesis posits an inverted U-shaped relationship between environmental degradation and income per capita, suggesting that environmental damage initially increases with economic growth but declines after a certain income threshold due to improved technologies and stricter environmental regulations. This framework provides insights into how economic development can transition from being a driver of environmental harm to a facilitator of sustainability. In contrast, the LCC hypothesis focuses on maintaining economic activities within ecological limits, emphasizing the maximum environmental load an ecosystem can bear without irreversible damage. This theory underscores the importance of proactive management and sustainable practices, particularly relevant to sectors like tourism and renewable energy (RE), which directly interact with ecological systems.

Empirical studies using these frameworks provide a nuanced understanding of the tourism-environment-energy nexus. For instance, Güngör et al. (2021) found reciprocal relationships between energy use, CO_2 emissions, and GDP in Chile, validating the EKC hypothesis. Similarly, Dogan and Turkekul (2015) demonstrated that urbanization and energy consumption contribute to environmental degradation, highlighting the complexities of managing sustainability. Additionally, a bidirectional causal relationship was shown between GDP and CO_2, urbanization and emissions of CO_2, and energy use and CO_2. Studies by Pata and Ertugrul (2023) and Pata and Yurtkuran (2023) applied the LCC hypothesis, showing that urbanization and globalization negatively impact the load capacity factor, requiring strategic interventions to mitigate environmental stress.

In tourism research, using the wavelet transform methodology (Raza et al., 2016) revealed that tourism growth has significant short-, medium-, and long-term impacts on greenhouse gas emissions and climate fragility. Katircioglu (2014) similarly examined the effects of tourism and energy use on environmental degradation in Turkey, demonstrating long-term linkages that align with both EKC and LCC frameworks. In contrast, Mehmood et al. (2021) supported the EKC hypothesis, finding that globalization accelerates environmental pollution but aligns with long-term improvements in environmental quality after surpassing a specific economic threshold.

Several studies explore regional variations in the application of these theories. For example, Sghaier et al. (2019) identified an inverted U-shaped EKC relationship in Morocco and Egypt, highlighting how economic affluence impacts carbon emissions differently across countries. Kongbuamai et al. (2020) found evidence of an EKC in ASEAN countries, with natural resources and tourism growth enhancing ecological footprints. Meanwhile, studies by Balsalobre-Lorente et al. (2019), Dogan and Pata (2022), and Pata and Tanriover (2023) further corroborated the LCC hypothesis, suggesting that environmental improvements are achievable when economic activities remain within sustainable limits. Gamage et al. (2017) examine the relationship between energy use, tourism development, and environmental degradation in Sri Lanka between 1974 and 2013. They discover that energy use affects the supply of clean water, sanitation, and environmental degradation in both the short and long term. Over time, tourism development exacerbates environmental degradation.

Comparable outcomes are seen in multiple economies. Principal component analysis (PCA) is used by Zaman et al. (2016) in non-OECD economies, the European Union, the high-income nations, and to assess the viability of the LCC and EKC hypotheses. The findings of their study support the U-shaped correlation between CO_2 and per capita income. The empirical results also support the causal links between growth-led TOR, and health-related growth in TOR, in the regions.

Despite this growing body of literature, existing research has not fully examined how tourism and renewable energy interact to influence environmental sustainability, particularly in the BIMSTEC region. This study seeks to address these gaps by integrating EKC and LCC perspectives to evaluate the socioeconomic and ecological drivers of tourism (Pata and Tanriover, 2023). Using the CS-ARDL approach, we analyze the interplay of GDP, tourism, renewable energy, and load capacity factors in BIMSTEC countries between 2000 and 2022. By bridging theoretical insights with empirical data, this work aims to enhance the understanding of sustainable tourism in the context of renewable energy integration and environmental management.

3 Materials and methods

This research investigates the effects of renewable energy, international tourism, environmental assessment computations, and GDP on the LCF in the BIMSTEC nations (Bhutan, Bangladesh, India, Myanmar, Nepal, Sri Lanka, and Thailand). For the requirements, data were gathered between 2000 and 2022. This paper measured the amount of RE consumed as 1 kW of power. World Development Indicators were used to obtain this variable. This study has chosen GDP in US dollars that were also obtained from the World Bank's World Development Indicators (WDI). This study has chosen to focus on foreign tourism, as indicated by the number of arrivals (Tiwari et al., 2021). The UNWTO tourism monitor is the source of this information. The ecological footprint, expressed in metric gha per capita, is used to determine the load capacity factor (LCF) or environmental quality, which is derived from data collected from the Footprint network. Table 1 lists the definitions, measuring units, and data sources.

The following is a possible formulation for the study's base model:

$$LCF = f(GDP, GDP2, RE, TOR) \quad (1)$$

TABLE 1 Data description and sources.

Variables	Abbreviation	Measurements	Sources
Environmental quality	LCF	Load capacity factor is measured by the ratio of biocapacity per capita to ecological footprints per capita	Global footprint network (GFN)
Economic development	GDP	GDP per capita	WDI
Tourism	TOR	International tourism number of arrivals	UNWTO tourism data
Renewable energy use	RE	Renewable energy consumption (kWh)	WDI

Another way to express Equation 1 is as follows:

$$LCP_{it} = \gamma_0 + \gamma_1 GDP_{it} + \gamma_2 GDP_{it}^2 + \gamma_3 TRA_{it} + \gamma_4 GEU_{it} + \vartheta_{it} \quad (2)$$

The LCC theory states that GDP2 and GDP coefficient are expected to have positive values (γ_2 = GDP2 > 0) and negative signs (GDP < 0), respectively, Pata and Samour (2022). The hold LCC theory might be disproved if the signs of the coefficients were switched. According to the coefficient of TOR and RE, we predict that, in the panel nations, renewable energy will have a positive impact on LCF (Dogan and Pata, 2022), whereas tourism will have a negative impact (Mohanty et al., 2021).

3.1 Methodology

The study employs a structured approach to analyze the relationship between tourism (TOR), renewable energy (RE), and environmental quality, measured through the load capacity factor (LCF), in BIMSTEC countries. The methodological framework ensures that the econometric analysis is robust, comprehensive, and suitable for the regional and variable-specific context.

The research framework is designed to assess both the individual and interactive impacts of TOR and RE on environmental quality. Drawing on the Environmental Kuznets Curve (EKC) and Load Capacity Curve (LCC) theories, the study aims to evaluate whether the observed relationships conform to these theoretical constructs while addressing the socio-economic and environmental dynamics of BIMSTEC nations.

The following procedures are used in the empirical investigation. Data is first gathered from the data sources. Second, the variables' descriptive statistics, normalcy, and correlation coefficient are looked at. Third, testing is done on cross-sectional dependence (CD) and slope homogeneity (SH). Fourth, the variables' unit roots are under control. Fifth, a cointegration test is run on the panel and individual nations. Sixth, estimates of the short- and long-term coefficients are made. Seventh, using different panel data techniques, the results are validated for robustness. Finally, based on the acquired empirical data, a discussion, implications, limitations, and future directions are offered.

The econometric analysis's main goal is to determine whether CD exists. To prevent biased stationarity and co-integration outcomes, inefficient information must be detected in CD (Salim et al., 2017). Externalities, interdependence between nations, and economic and financial activity all contribute to the CD. Pesaran (2015) test is used to verify the CD problem since, despite its limitations, this test is useful for scrutinizing the entire stationarity checking process. Then this work checks the stationarity problems by adopting the CIPS test and for the co-integration test, Westerlund (2005) test is applied.

3.1.1 Cross-sectional autoregressive distributed lag (CS-ARDL) approach

The statistical approach CS-ARDL is particularly well-suited for examining the long-term impacts of tourism and renewable energy on environmental quality in BIMSTEC countries due to its ability to address key econometric challenges such as slope heterogeneity and cross-sectional dependence (CD) (Wang et al., 2019). Equation 3 is provided to initiate this procedure.

$$U_{it} = \sum_{I=0}^{p_U} \gamma_{I,i}, U_{i,t-I} + \sum_{I=0}^{p_W} \beta_{I,i}, W_{i,t-I} + \varepsilon_{i,t} \quad (3)$$

Additionally, the expanded Equation 3, which addresses the inconsistencies and misleading parameters brought about by the occurrence of CD, is mentioned below as its cross-section averaged of each factor to describe the ARDL model (Chudik and Pesaran, 2015). However, if Equation 3 to the current procedure, the cross-sectional problem persists.

$$U_{it} = \sum_{I=0}^{p_U} \gamma_{I,i}, U_{i,t-I} + \sum_{I=0}^{p_W} \beta_{I,i}, W_{i,t-I} + \sum_{I=0}^{p_V} \alpha'_{i,I} \overline{V}_{i,t-I} + \varepsilon_{i,t} \quad (4)$$

The delays of each factor are indicated by the regressors of the dependent and independent variables in Equation 3, which are written as $\overline{V}_{i,t-I} = \left(U_{i,t-1}, W_{i,t-I}\right)$ and p_U, p_W, p_V. While Wit shows the factors like RE, GDP, and TOR, Uit provides the dependent variable (LCF). Lastly, V identifies the CD averages that have an impact on the data. Following this, the long-run numbers are taken out of the short-run value; as a result, the mean estimator is provided in Equation 5.

$$\pi_{CS-ARDL,i} = \frac{\sum_{I=0}^{pW} \hat{\beta}_{I,i}^{PU}}{1 - \sum I = 0} \gamma_{I,i} \quad (5)$$

Additionally, the mean group is described in Equation 6.

$$\pi_{MG} = \frac{1}{N} \sum_{i=0}^{N} \hat{\pi}_i \quad (6)$$

Additionally, the short-run coefficient is given as in Equations 7–10.

$$U_{i,t} = \vartheta_i \left[U_{i,t-1} - \pi_i W_{i,t}\right] - \sum_{I=1}^{PU-1} \gamma_{I,i}, \Delta_I U_{i,t-1} + \sum_{I=0}^{PW} \beta_{I,i}, \Delta_I W_{i,t} + \sum_{I=0}^{p_V} \alpha'_{i,I} \overline{V}_{i,t} + \varepsilon_{i,t} \quad (7)$$

Where, $\Delta_I = t - (t-1)$

$$\hat{\tau}_i = -\left(1 - \sum_{I=1}^{pU} \widehat{\gamma_{I,i}}\right) \quad (8)$$

$$\widehat{\pi i} = \frac{\sum_{I=0}^{PW} \hat{\beta}_{I,i}}{\hat{\tau}_i} \quad (9)$$

$$\bar{\hat{\pi}} MG = \frac{1}{N} \sum_{i=0}^{N} \hat{\pi}_i \quad (10)$$

Like the pooled group mean handled for the CS-ARDL approach, the equation is used to modify the mechanism for error correction [ECM (−1)] to the equilibrium point.

3.1.2 Robustness method

The augmented mean group (AMG) method is highly suited for examining long-term impacts on environmental quality in BIMSTEC countries due to its robust handling of non-stationary variables and cross-sectional dependence (CD). AMG is particularly advantageous as it accounts for slope heterogeneity (SH) and structural variations across countries, which are critical given the diverse socio-economic and environmental conditions in the BIMSTEC region. By averaging the coefficients across cross-sections, the AMG method effectively addresses the spillover effects caused by CD while excluding trends that could distort the analysis (Liddle, 2018).

Moreover, AMG incorporates structural breaks and variability, providing a robust framework for accommodating year-to-year fluctuations and cross-sectional dependencies without compromising the reliability of parameter estimates. This flexibility makes it a powerful tool for analyzing heterogeneous panels, ensuring that unobservable elements and temporal variations are effectively managed (Teal and Eberhardt, 2010). By leveraging AMG, this study achieves reliable and consistent estimates of long-term dynamics, providing nuanced insights into the relationship between tourism, renewable energy, and environmental quality in the BIMSTEC region.

3.1.3 Wavelet coherence analysis

Wavelet coherence analysis is used to explore the time-frequency relationships between TOR and environmental quality (LCF). The wavelet graphs visualize the correlations across different periods, highlighting lead-lag relationships and their implications for sustainability over time.

4 Results and discussion

All variables' summary statistics are displayed in Table 2. For LCP, the mean is 0.492, while the remainder of the series shows positive values. It is evident that the TOR standard deviation is greater than the GDP change than the LCF.

A non-symmetric series was also revealed by the skewness aspect deviating from 0 and the kurtosis displaying surplus

TABLE 2 Descriptive statistics.

	LCF	GDP	TOR	RE
Mean	0.492	4.016	1,922,643	62.133
Median	0.433	4.545	500,000	60.080
Maximum	0.980	14.681	17,914,000	93.460
Minimum	0.247	−10.804	5600.000	25.790
Std. Dev.	0.193	3.273	3,666,910	22.299
Skewness	1.160	−1.523	2.882	0.061
Kurtosis	3.300	8.666	11.005	1.470
Jarque-Bera	25.776	194.921	458.191	11.087
Probability	0.000	0.000	0.000	0.003

values; Table 2 exhibits significant values and significant leads for the Jarque-Bera test, proving that the data is not normal. The correlation statistic among the panel countries is shown in Table 3.

0.607% is the correlation coefficient between LCF and TOR. in a similar vein, there is a minimum connection of roughly −0.175 between TOR and RE and a moderate link of roughly 0.560 between TOR and RE. ultimately, there is a moderate relationship between LCF and RE, with a 0.666 correlation. the CD test enables us to assess whether to apply the first method and how dependent certain nations are on one another. Table 4 displays the test results from the tests.

TABLE 3 Pairwise correlations.

Variables	LCF	GDP	GDP2	TOR	RE
LCF	1.000				
GDP	−0.175*	1.000			
	(0.073)				
GDP2	0.069	0.728***	1.000		
	(0.465)	(0.000)			
TOR	−0.607***	0.121	−0.081	1.000	
	(0.000)	(0.218)	(0.389)		
RE	0.666***	−0.199**	−0.018	−0.560***	1.000
	(0.000)	(0.041)	(0.850)	(0.000)	

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

TABLE 4 Cross-sectional dependence test.

	CD
LCF	4.19**
	(0.048)
GDP	6.12***
	(0.000)
TOR	3.80***
	(0.000)
RE	9.10***
	(0.000)

***$p < 0.01$, **$p < 0.05$.

TABLE 5 CIPS unit root test.

	CIPS		
	I(0)		I(1)
LCF	−3.150***		−6.028***
GDP	−3.557***		−5.240***
TOR	−3.827***		−4.432***
RE	−0.524		−2.904**
	10%	5%	1%
Critical values at	−2.730	−2.860	−3.100

***$p < 0.01$, ** $p < 0.05$.

The findings disprove the null hypothesis, which states that the residual has no cross-section or association. They provide credence to the data showing a relationship between energy and tourism and environmental quality. The cross-sectoral dependency results in the panel data among BIMSTEC nations, however, support the applicability of the 2nd-generation stationarity test. Table 5 displays the results of the CIPS unit root test.

The results show that LCF, GDP, and TOR are stationary at level and first difference, rejecting the alternative hypothesis and accepting the null hypothesis at the level. The Westerlund (2005) in Table 6 shows a strong correlation among the variables of BIMSTEC countries.

The results obtained using the sophisticated CS-ARDL technique, which effectively addresses cross-sectional dependence and heterogeneity in panel data, are presented in Table 7.

Environmental quality (LCF) is negatively impacted by GDP at the 1% significance. A standard deviation of the GDP method is an ∼0.017 drop in the LCF change. The GDP^2 is favorable, though, and this results in a roughly 0.021 decrease in LCF, supporting the validity of the LCC hypothesis. These outcomes corroborate with Awan and Azam (2021) study examines the validity of the Environmental Kuznets Curve (EKC) hypothesis for G-20 economies and finds an N-shaped relationship between CO_2 emissions and GDP per capita. It suggests that while GDP growth initially leads to environmental degradation, higher levels

TABLE 6 Westerlund cointegration test.

Statistic	Value	Z-value	P-value
Gt	−6.954***	−10.557	0.000
Ga	−19.448**	−1.895	0.029
Pt	−20.227***	−14.237	0.000
Pa	−25.484***	−4.771	0.000

***$p < 0.01$, **$p < 0.05$.

TABLE 7 CS-ARDL test results.

LCF	Coef.	Std. Err.	P-value
Short run			
ΔlGDP	−0.017***	0.006	0.008
ΔlGDP2	0.021**	0.001	0.054
ΔlTOR	−0.003**	0.020	0.066
ΔlRE	0.004***	0.001	0.000
ΔlTOR*lRE	0.041***	0.005	0.000
ECM-1	−0.696***	0.142	0.000
Long run est.			
lGDP	−0.011***	0.004	0.006
lGDP2	0.010**	0.002	0.010
lTOR	−0.021**	0.001	0.048
lRE	0.002***	0.006	0.000
lTOR*lRE	0.927***	0.005	0.000

***$p < 0.01$, **$p < 0.05$.

of GDP can mitigate these impacts and promote sustainability. The findings also show that, for every 1% increase in RE, the amount of renewable energy per person considerably increases LCF by around 0.04%. It's interesting how our findings relate to the task. A 1% increase in TOR due to tourism causes a 0.003% increase in environmental degradation in the chosen countries. Villanthenkodath et al. (2022) investigated the impact of tourism development on environmental degradation in India using the autoregressive distributed lag (ARDL) approach and wavelet coherence analysis. Their findings also indicate that tourism development significantly contributes to environmental degradation, with changes in tourism development leading to variations in pollution levels at different frequencies and periods. It is worth noting that the interactional term TOR*RE enhances the environmental quality. This means that the interaction of TOR with clean energy is vital for these nations. This result is consistent with that of Zhang et al. (2023). Using the Q-ARDL model, their findings highlight the positive contributions of renewable energy and tourism to sustainability in OECD economies from 2000 to 2021. The CS-ARDL model in the current study seems to be occurring well, with furthermore, to extract true figures, the ECT (−1) signifies the equilibrium's adjustment speed. Finally, Table 8 presents the empirical results of the AMG models, which are utilized to ensure robustness by effectively addressing cross-sectional dependence, slope heterogeneity, and structural breaks in the data.

Table 8 shows the findings of AMG results while checking the impacts of tourism, RE, and GDP on LCF in BIMSTEC countries. The results indicate the existence of LCC hypotheses because GDP is lowering environmental quality, but its squared term is increasing it. This means that in the future, after achieving more economic prosperity, BIMSTEC countries will start to experience better environmental quality due to strict environmental regulations and better awareness. This result is consistent with the findings of Laghari et al. (2022), who demonstrated that while GDP growth can lead to environmental degradation, the square of GDP (indicating higher economic resilience) can mitigate environmental impacts and promote sustainability in 124 nations. Tourism is not good for environmental quality, and green energy is contributing to the development of LCF. These results are validated by Baloch et al. (2023). Their study investigated the relationship between tourism development and environmental sustainability, revealing that tourism activities lead to environmental degradation through land overutilization, pollution, and social vulnerability in Pakistan. When TOR interacts with RE, the impacts of TOR

TABLE 8 AMG test results.

lLCF	Coefficient	Std. error	*P*-value
lGDP	−0.034**	0.013	0.010
lGDP2	0.011**	0.001	0.055
lTOR	−0.018***	0.030	0.000
lRE	0.675**	0.074	0.040
lTOR*lRE	0.530***	0.004	0.003

***$p < 0.01$, **$p < 0.05$.

become good for environmental quality in BIMSTEC nations. The findings of the UNEP (2023) study align with the results of the current research, emphasizing the critical role of renewable energy in promoting sustainable tourism. UNEP (2023) also highlights how clean energy sources such as solar, wind, hydro, geothermal, and biomass can power the tourism industry sustainably, reducing environmental impacts, supporting local communities, and often lowering operational costs. These AMG results are validating the findings of CS-ARDL test.

The findings, supported by both CS-ARDL and AMG methodologies, provide a robust basis for policy recommendations. BIMSTEC countries must prioritize renewable energy integration, enforce stringent environmental regulations, and promote green tourism initiatives to achieve sustainable development. This aligns with global perspectives, such as Zhang et al. (2023) and UNEP (2023), which advocate for renewable energy's role in reducing ecological pressure and supporting sustainability. By situating these findings within the unique environmental and socio-economic contexts of BIMSTEC, this study offers actionable insights to policymakers aiming to balance economic growth with environmental preservation.

The outcomes of this study make significant contributions to both theoretical and practical frameworks, particularly the Environmental Kuznets Curve (EKC) and Load Capacity Curve (LCC). The EKC hypothesis suggests that environmental degradation initially increases with economic growth but eventually decreases after reaching a certain level of income due to improved regulations and technology. The results of the current study confirm this progression in BIMSTEC countries, where GDP growth initially lowers environmental quality but its squared term indicates future improvements, validating the EKC. This supports the view that strict environmental regulations and better awareness at higher income levels can mitigate ecological impacts, adding empirical evidence to the EKC's applicability in developing regions.

Similarly, the findings align with the LCC theory, which posits that economic activities must remain within an ecosystem's load capacity to avoid environmental degradation. This is evident from the positive impact of renewable energy on environmental quality, demonstrating that clean energy can reduce the strain on ecological systems caused by tourism and economic activities. Moreover, the interaction term between tourism and renewable energy highlights how integrating green energy with tourism can transform the sector into a driver of environmental sustainability, extending the practical applications of the LCC framework.

The study also challenges some assumptions by showing that tourism alone, without renewable energy integration, contributes to environmental degradation, a nuance that complicates simplistic EKC models. These findings enhance our understanding of both theories by illustrating how sustainable energy and tourism policies interact within diverse economies like BIMSTEC. Practically, the results underline the importance of targeted policy interventions, including renewable energy adoption and sustainable tourism practices, to balance economic growth with environmental conservation in the region. This dual theoretical and practical contribution advances both academic discourse and policy development for sustainable development in BIMSTEC countries.

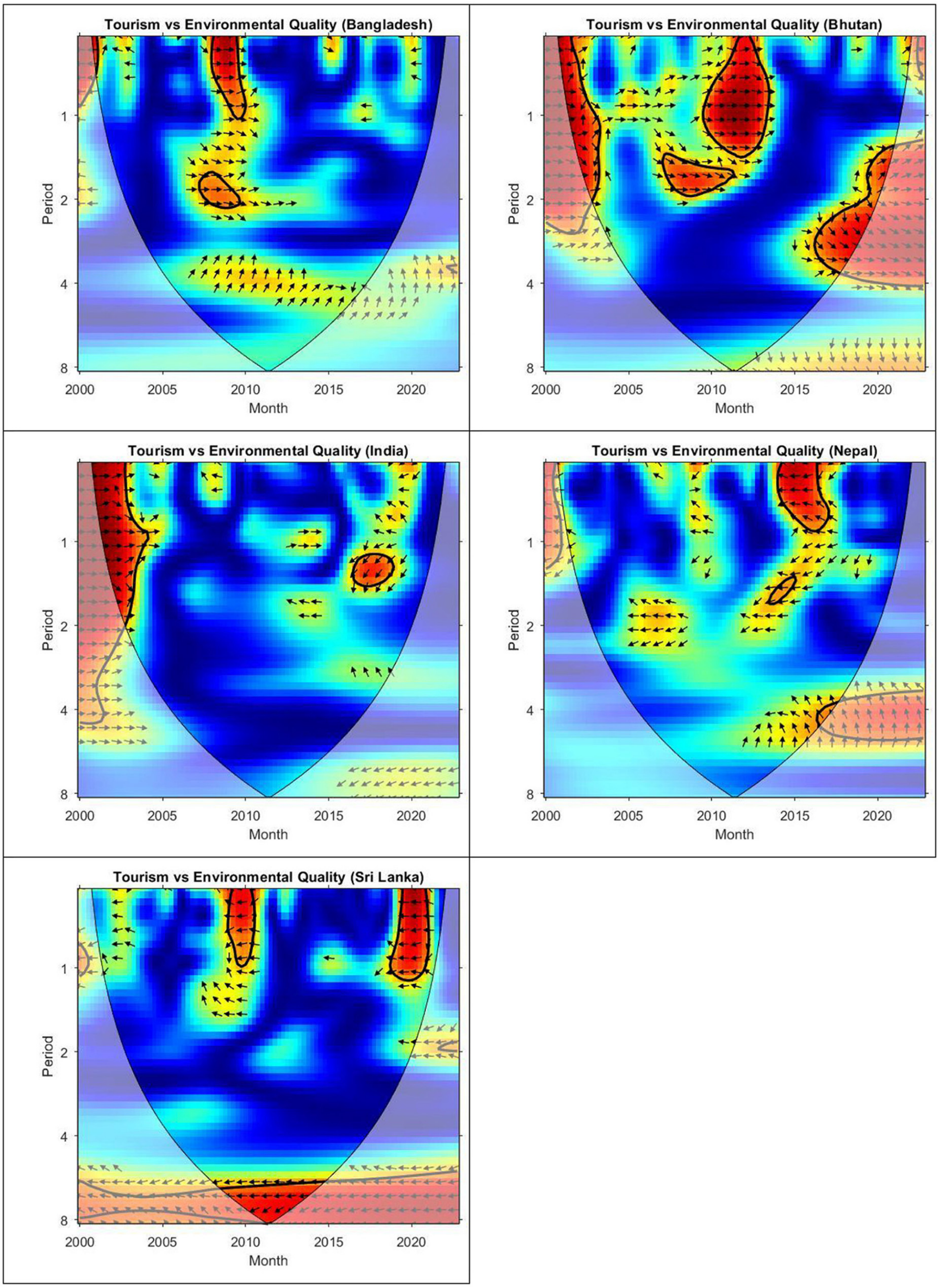

FIGURE 2
Wavelet analysis of tourism and environmental quality in BIMSTEC nations.

4.1 Wavelet analysis

The wavelet coherence graphs for the BIMSTEC countries' tourism and environmental quality from 2000 to 2022 are shown in Figure 2. Determining the degree of correlation between the two components in a time-frequency space is made easier by the wavelet coherence picture results. The period from 2000 to 2022 is shown on the x-axis in years, while the y-axis shows the time span in years, frequency, or magnitude. The color bar displays the consistency (highest) from dark blue (lowest) to dark red (highest). The areas denoted by black lines represent a 5% confidence level for the null hypothesis of the power spectrum, which is generated using Monte Carlo simulation. The found picture of the facts in the cone of influence (the region from the cone shape to the axis) should be analyzed carefully since it shows regions that could be affected by edge effects (i.e., outcomes from wavelets overextended outside of the constraints of the observed time). Arrows pointing left and right, respectively, represent the important associations that are positive and negative between the two parameters. Arrows pointing up and down reflect the lag-lead relationships between the variables (e.g., uncertainty). The first variable leading is negatively correlated with the rightward-down and leftward-up directions, whereas the additional vector heading to lead (the second independent variable causes the initial variable) is positively correlated with both directions.

These wavelet coherence graphs for BIMSTEC countries illustrate the dynamic relationship between tourism (TOR) and environmental quality (LCF) across time and frequency. The analysis shows statistically significant correlations, represented by regions within the black lines at a 5% confidence level, confirming the robustness of the observed patterns. The color intensity indicates varying correlation strengths, with dark red representing high coherence ($R^2 = 0.9–1$) and blue indicating weak or no coherence. The direction of the arrows further reveals the nature of these relationships, with rightward arrows indicating positive correlations, leftward arrows showing negative correlations, and vertical directions highlighting lead-lag relationships where one variable influences the other.

Country-specific analysis reveals distinct patterns. In Bangladesh, a strong negative correlation is observed from 2008 to 2015, particularly at medium frequencies (4–8 years), suggesting that increased tourism activity negatively impacts environmental quality during these periods. Bhutan exhibits consistent high coherence across short and medium time scales, with periods of both positive and negative correlations, indicating that tourism impacts environmental quality in mixed ways, potentially depending on the implementation of sustainable practices. India shows significant negative correlations in medium frequencies during 2005–2010 and post-2015, reflecting the strain of tourism on environmental resources, likely exacerbated by urbanization and insufficient environmental controls. Nepal's results highlight periodic high coherence from 2005 to 2020, with mixed lead-lag relationships, indicating that while tourism has negatively impacted environmental quality, eco-tourism efforts may have contributed positively during certain intervals. Sri Lanka shows high coherence from 2008 to 2015, with variable impacts of tourism on environmental quality, reflecting the country's reliance on tourism and the effectiveness of its environmental policies.

These findings align with the results from CS-ARDL and AMG methodologies, confirming the dual impact of tourism on environmental quality. Tourism's negative effects are evident when activities are unmanaged, but its positive influence is observed when coupled with renewable energy or sustainable tourism practices. This analysis underscores the importance of targeted interventions to mitigate tourism's adverse impacts. The lead-lag relationships, particularly in Bangladesh, India, and Nepal, highlight the urgency for proactive policy measures to address tourism-driven environmental challenges. Conversely, the positive correlations in Bhutan and periods of improvement in Nepal suggest that integrating renewable energy and sustainable practices into tourism policies can enhance environmental quality. These findings provide critical insights for policymakers, emphasizing the need to focus on eco-tourism, renewable energy adoption, and temporal patterns of tourism activity to ensure environmental sustainability in the BIMSTEC region. The statistical significance and consistency across methods validate the reliability of the results and their potential to inform sustainable development strategies.

As, Figure 2 shows, from 2000 to 2022, there was a significant correlation ($R^2 = 0.9–1$) between tourism and environmental quality at the time scale 4–16. In every country, the lines from 2000 to 2022 demonstrate a strong relationship with both tourism and environmental quality. This suggests that in the BIMSTEC countries, environmental quality has grown while tourism has decreased.

The wavelet coherence analysis emphasizes the need for policies that balance tourism growth with sustainability. Promoting low-impact tourism practices like eco-tourism and regulating activities in sensitive areas are crucial. Mandating renewable energy use in tourism infrastructure, supported by public-private partnerships, can reduce environmental impacts. Real-time monitoring tools, such as GIS and wavelet-based decision systems, should guide proactive strategies. Educating tourists and training stakeholders on sustainable practices can foster environmentally responsible behavior, while off-peak tourism and diversified attractions can reduce ecological strain. Aligning tourism policies with SDGs and requiring environmental impact assessments for major projects will ensure sustainability goals are met. Additionally, providing incentives for eco-friendly practices and engaging local communities in planning can enhance both ecological protection and economic benefits, ensuring balanced growth in BIMSTEC countries.

5 Conclusion and policy suggestions

The sustainable development goal of tourism is included in the eighth sustainable development goal (Decent Work and Economic Growth). Specifically, this target aims to create and execute policies by 2030 to promote sustainable tourism that creates jobs and supports regional goods and culture. This objective emphasizes ethical travel practices heavily to minimize environmental effects, support conservation efforts, and ensure that tourism development benefits local communities while furthering global sustainability goals. The phenomena of tourism have expanded over time, and it has been noted as one of the main forces behind economic development. Even though the BIMSTEC economies are home to the most stunning areas due to their scenic beauty, rich cultural legacy, mountains, oceans, and lakes, as well as diversified biodiversity, these economies see comparatively less international tourism than other regions. The foreign exchange needed for the GDP of the region can be supplied by the tourism industry's revenue. Previous empirical research examined terrorist and economic factors to explain international traveler behavior. This study is an initial assessment that combines environmental and socioeconomic elements to explain why international tourism is behaving so slowly. Cross-sectional dependence and heterogeneous order of integration are shown by the post-estimation test. To estimate the long and short-run impacts of independent factors with the rate of ECM, this study used the CS-ARDL approach. According to the estimated results, improvements in GDP have a long-term negative influence on foreign travel to the economies of the BIMSTEC region. According to the findings, to promote international tourism, these nations must increase the approach to cleaner energy and better rules, environmental impact, and green technologies. The primary cause of unsustainable tourist development in the region is the fossil fuel energy use and the adverse ecological effects of TOR.

5.1 Policy recommendations

Enhancing the quality of renewable energy, tourism infrastructure, and environmental management has the potential to significantly boost global tourism and improve public health. To achieve this, BIMSTEC countries must earnestly implement Sustainable Development Goal (SDG) 13 (Climate Action) and SDG 7 (Affordable and Clean Energy) by integrating renewable energy solutions into tourism infrastructure. The findings of this study, rooted in the Load Capacity Curve (LCC) theory, underscore the critical relationship between renewable energy, tourism expansion, and environmental sustainability. Policymakers should prioritize the adoption of clean energy technologies, such as solar and wind power, in tourist destinations to minimize ecological footprints and enhance the appeal of these locations.

To make tourist destinations safer, more attractive, and economically prosperous, implementing SDG 6 (Clean Water and Sanitation) is imperative. This requires coordinated efforts to ensure access to affordable and safe drinking water, improve wastewater treatment systems, and enhance water quality and efficiency at tourism sites. Integrated water resource management should be a key priority, focusing on restoring and protecting water-related ecosystems while increasing freshwater supply for both tourists and local communities. Policymakers should engage local stakeholders in managing water and sanitation services at tourist attractions, promoting awareness and acceptance of sustainable practices. This can include initiatives to eliminate open defecation, improve access to clean water, and foster a shared responsibility among local populations and tourism operators.

Tourism authorities should mandate the use of environmentally friendly technologies and eco-innovations for water purification, wastewater treatment, recycling, and repurposing tourism-related materials. Renewable energy planners and stakeholders can collaborate to develop infrastructure that not only supports tourism growth but also aligns with environmental conservation goals. By integrating these practical recommendations, BIMSTEC countries can achieve sustainable tourism development while addressing key environmental and social challenges.

5.2 Research limitations and future directions

The study has several limits that support the importance of the findings, but it also offers an agenda for further investigation. Initially, the BIMSTEC economies are the main subject of this research. By incorporating additional regions into the sample size and conducting cross-country analysis, future research can broaden the study's scope. Secondly, this study aimed to incorporate significant socio-economic and environmental factors that had been disregarded in earlier research. Additional factors including relative prices, the cost of transportation, and other destination-specific factors may be included in future studies.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://databank.worldbank.org/source/worldwide-governance-indicators.

Author contributions

YG: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. YC: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsut.2025.1512922/full#supplementary-material

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