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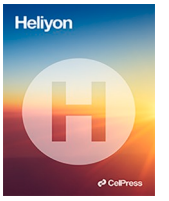

Research article

# Evaluating the mitigating potential of tourism on economic growth-induced ecological footprint: Insights from Asian countries

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ABSTRACT

Over the past three decades, Asian countries have experienced rapid economic growth, leading to a substantial increase in ecological footprint and posing significant challenges to sustainability. This study investigates the potential of tourism as a sustainable development strategy to mitigate the ecological footprint induced by economic growth. Utilizing data from 1990 to 2022 across 28 Asian countries, rigorous econometric methods including panel cointegration tests were employed to detect co-integration relationships. The results not only confirm the existence of co-integration but also reveal that tourism plays a crucial role in reducing the ecological footprint associated with economic growth in Asian countries. Furthermore, the study identifies specific mechanisms through which tourism contributes to mitigating environmental impact, such as promoting sustainable practices, conservation efforts, and eco-friendly infrastructure development. These findings underscore the importance of integrating tourism into sustainable development strategies and highlight its potential to balance economic growth with environmental conservation in Asian nations. This research provides actionable insights for policymakers and stakeholders, emphasizing the need for sustainable tourism initiatives to address the challenges of economic growth-induced ecological footprint in Asia.

## 1. Introduction

The economic development trajectory of Asian countries has been characterized by remarkable growth over the years, driving substantial increases in industrialization, urbanization, and consumerism. However, this rapid economic expansion has also brought about significant environmental challenges, particularly in terms of escalating ecological footprints. The ecological footprint represents the amount of natural resources and ecosystem services required to support human activities and consumption patterns, including energy use, land occupation, and waste generation. As Asian economies surged forward, their ecological footprints expanded, exerting pressure on fragile ecosystems, biodiversity, and natural resources. Economic growth is essential for improving living standards, reducing poverty, and fostering technological advancements. On the other hand, unchecked economic growth often comes at the expense of environmental degradation, resource depletion, and ecosystem disruption. This dilemma underscores the urgent need to explore sustainable development pathways that can reconcile economic prosperity with environmental conservation and resilience. Tourism emerges as a potential mitigating factor [1]. Tourism, when managed sustainably, can contribute positively to environmental protection, conservation of natural areas, and promotion of eco-friendly practices. By channeling economic resources into conservation efforts, supporting local communities, and raising awareness about environmental issues, tourism has the potential to mitigate the adverse ecological impacts of economic growth. However, the effectiveness of tourism as a sustainable development

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strategy varies across different contexts and requires empirical evaluation. The tourism industry has experienced the highest growth of the sector—doubling every ten years since 1991 and expanding significantly in emerging economies effects on community infrastructure require special consideration [2]. The tourism industry's financial, societal, and ecological effects are measured in this work using a comprehensive method of local resources. The opening of a new cruising terminal in Honduras allowed researchers to test these effects on nearby indigenous people using a scientific study. This novel multi-method testable theory enables more flexibility and precision compared to other investigations [3].

Problems concerning cruise travel in our environment go beyond academia, as is the case for most potential impacts. Afro-indigenous residents of Trujillo, Honduras, alleged exclusion from the procedure and its advantages as the start of cruise travel in the area in November 2014 pitted them with wealthy Honduran and international people in business. The trial of Randy Jorgensen, the site's Canadian builder, who was charged with stealing property from the Garifuna to build his industry's cruise ship terminal and other visitor attractions, marked the height of these conflicts. The entrepreneurs' representatives repeated that the town would profit from cruise tourism's revenues and that the protesters ignored its straightforward job and financial advantages [4,5]. These issues relate to significant fundamental discussions in global trade on the potential benefits of locally supported economic schemes. On one side of this argument, proponents of free-market growth contend that the regional poor will profit from capital funding since financial expansion helps all stakeholders. Others [6,7] argue that early disparities distort economies and subvert government in the service of the strong, a claim frequently made in connection with dependence and world-systems theory. Between these two views, some contend that the magnitude of economic inefficiencies caused by the supply of government commodities or perfectly competitive limits the extent to that free enterprise capital helps societies. Additionally, certain scholars emphasize that progress should be assessed by financial impacts and the assessment of multifaceted local resources, which are frequently connected with the capabilities approach.

Different issues (For instance, the earth's climate, weather, water, polluted air, wildlife mortality, loss, and the depletion of essential commodities) represent a significant danger to the stability of the ecosystem. The issues primarily relate to ecologically negligent human conduct. Studies agreed that by changing human behavior to be environmentally friendly, troublesome concerns might be handled and remedied [8]. Ecological viability is primarily dependent on changes in people's consumption habits (such as buying and using things in an environmentally friendly way). As a result, over the past few years, academics and the public sector have increasingly emphasized the critical problem of evoking ecologically friendly consumer behavior. It is challenging to define eco-friendly consumer behavior, but the term is widely used and used as an overarching framework to showcase a person's different behavior that conserve natural resources (such as water and energy), reduce ecological damage (such as waste reduction), fulfill the requirements of community, and enhance his or her standard of living further states that "ecological conduct is such activity which is typically (or based on understanding of ecological research) assessed in the framework of the examined community as a defensive manner of ecological behavior or a homage to the peaceful ecosystem". Thus, phrases like "ecologically sound behaviors", "ecologically viable behaviors", and "environment-protecting/preserving behaviors" are all used to describe such Environmental behaviors and environmental behaviors are frequently used as synonyms for pro-environmental behavior. Pro-social consuming practices, which ultimately help the ecosystem and the general public, include ecologically responsible consumption behavior [9].

In the tourism industry and service, economic sustainability is growing more and more of a problem. The issue of environmental usage and greener growth is more crucial than ever in the modern tourist industry and accommodation business sector as a growing number of individuals in the market realize that many severe ecological types of defects are deeply embedded in the tourist industry extracurricular. Consumers in this industry are increasingly prepared to engage in social sustainability and expect sustainable goods (such as ecologically friendly accommodations, cafes, voyages, airplanes, locations, resorts, conferences, and gambling). Many tourist and hotel businesses are progressively demonstrating a propensity to become active in developing green processes and goods due to this need and the environmental and economic climate [10]. Consumers in the tourism and hotel industries are simultaneously learning that ecologically friendly practices are inevitable in both the settings where they purchase products and in their daily lives [11]. There is no consensus on what constitutes ecologically responsible behavior of customers at this time. The words "green behavior" and "pro-environment behavior" are frequently used in ecological and psychological research to describe ecologically friendly conduct. In other words, eco-friendly behavior promotes sustainable development. Gave one of the most concise explanations, stating that ecologically friendly behavior is any conduct that does not harm the ecosystem (or even good). A person's conduct that scarcely hurts the ecosystem or benefits it in a retail setting of a good or service is considered ecologically sound customer behavior in the current work. Ecologically responsible actions are typically referred to as "pro-environmental activity" in the research on consumer behavior [12].

This study makes a significant contribution to the existing literature on sustainable development and environmental economics, particularly in the context of Asian countries. By employing a comprehensive analytical framework that integrates co-integration tests, dynamic modeling techniques such as the Augmented Mean Group, dynamic system generalized method of moments (GMM), and Fully changed OLS, this research advances our understanding of the relationship between tourism, economic growth, and ecological footprint. The inclusion of rigorous econometric methods enhances the robustness and reliability of the findings, providing nuanced insights into the dynamics of these interrelated factors. Furthermore, the study's focus on a diverse range of Asian countries spanning multiple decades (1990–2022) enriches the empirical evidence base and offers a broader perspective on the effectiveness of tourism as a sustainable development strategy across different socio-economic contexts and geographical regions within Asia. By considering variations in policy frameworks, environmental regulations, tourism practices, and economic structures across these countries, the study sheds light on the contextual factors that influence the mitigating potential of tourism on economic growth-induced ecological footprint. Moreover, the research contributes methodologically by utilizing a combination of co-integration tests and dynamic modeling approaches, which allows for a more nuanced analysis of long-term relationships and causal mechanisms. This methodological contribution not only enhances the robustness of the empirical findings but also offers insights into the complex interactions

between economic, environmental, and social variables over time. Overall, this study's contribution to the literature lies in its comprehensive analysis, methodological rigor, longitudinal perspective, and focus on a diverse set of Asian countries. By bridging theoretical insights with empirical evidence, the research advances knowledge in the field of sustainable development and provides actionable recommendations for policymakers, practitioners, and stakeholders seeking to promote environmentally sustainable economic growth in Asian regions.

## 2. Related literature

The relationship between economic growth and ecological footprint has been a subject of extensive research, particularly in the context of developing regions such as Asia. This study investigates the potential of tourism as a mitigating factor for the ecological footprint induced by economic growth. The conceptual framework of this research is based on the premise that while economic growth often exacerbates environmental degradation, sustainable tourism practices can potentially counterbalance these adverse effects by promoting conservation efforts, sustainable practices, and eco-friendly infrastructure development.

Numerous studies have explored the dynamics between economic growth and environmental sustainability. For instance Ref. [13], provides a comprehensive analysis of the Environmental Kuznets Curve (EKC) hypothesis, suggesting that environmental degradation initially increases with economic growth but eventually decreases as income reaches higher levels. This hypothesis forms a foundational element of our conceptual framework, indicating the potential for economic growth to eventually support environmental sustainability under certain conditions.In the context of Asian countries, studies such as those by Ref. [14] highlight the rapid economic growth and its consequent environmental impacts [15]. emphasizes the significant increase in ecological footprint due to industrialization and urbanization in Asian economies [16]. extend this by analyzing the correlation between energy consumption, economic growth, and CO2 emissions, revealing a positive relationship that underscores the environmental costs of economic advancement.The role of tourism in mitigating environmental impacts has been examined by various scholars [17].argue that tourism can contribute to environmental conservation through the promotion of eco-friendly practices and the generation of revenue for conservation projects. Their work is critical in understanding how tourism can be leveraged as a tool for sustainable development. Similarly [18], find that tourism development can lead to better environmental quality in the long run, as increased awareness and funding for environmental protection become available. Furthermore, studies by Ref. [19] provide empirical evidence supporting the positive impact of tourism on environmental sustainability [20]. explores the tourism-led growth hypothesis, demonstrating that tourism not only stimulates economic growth but also fosters environmental sustainability through investments in green infrastructure and conservation activities [20]. build on this by showing that countries with well-developed tourism sectors tend to have lower ecological footprints relative to their GDP, indicating that sustainable tourism practices can indeed mitigate the environmental impact of economic growth.

According to a study of the research, several empirical research on the tourist industry have examined how the sector affects neighborhood growth, but these works are rare, and even fewer make use of comprehensive local resource ratings. According to a current meta, only 14 studies published since 1999 have focused on reducing local poverty. Those that collected data sets employed regional and travel industry views of effects to evaluate the effects [21]. Semi-structured questionnaires conducted over a short period were the most popular data collection method in these studies; no test subjects were included, and the majority were solely financial. The most alarming result is that there hasn't been enough study to truly comprehend the connection between the tourist industry and social inclusion, despite the researchers of the meta-study finding proof that alleviating poverty or growth in any aspect is unusual without significant public control of initiatives. Makes a case for local-level effect research employing multiple economic indicators and primary data collection techniques [22].

Studies [23], particularly on cruise visitors, have been less thorough than general tourist research, and none have incorporated multiple growth metrics or accurately examined local effects. Some studies use passenger questionnaires to quantify cruise visitor spending relative to land visitors. According to this research, financial coefficients for cruise travel are often modest because most cruises are tied to tax-haven ports, and guests frequently dine, eat, rest, and pay money on the ship using debit cards. The detailed requirements for commercial vessels have been used to evaluate the ecological effects by contrasting the production requirements of the ships for pollutants with the capacity of terminals and the ecosystem to take such outputs [24]. Under voluntary Corporate Social Responsibility (CSR) reporting requirements, cruise ship owners voluntarily publish various environmental metrics; nevertheless, the study has shown gaps in these statements. The fact that business statements often only cover topics that are "marginal to the heart of the company and have a beneficial effect or preempt sector regulation" demonstrates how insensitive market analysts are to local member requirements and requests for indications These results are backed by, while emphasize that studies frequently lack verifiability and exclude crucial topics like financial well-being and job standards. Underline the necessity of outside public effect assessments, citing related studies, to prevent relying on unreliable and unsubstantiated corporate self-reports. This supports prior claims made by and that research of effects or outcomes conducted independently of the cruise lines must be included when evaluating cruising travel [25].

Second, studies of demographic, financial, and environmental data are frequently used in research on travel and its impact on indigenous citizens. Qualitative methods are also commonly used in studies conducted after the start of tourist programming. While not directly targeting the cruises industry, some empirical research has been done to examine how Honduran Garifuna tribes interact with various forms of the tourist industry. These researchers have reported local assertions that the tourist industry has caused separation, displacement, property seizure, traditional eroding, carbon pollution, and marginalization, but these concerns have not been empirically evaluated.Visitors' ecofriendly choosing behavior towards ecological goods for nature conservation is referred to as "ecological buying" as one fundamental kind of ecologically responsible customer behavior in the travel and tourist industry. Such

ecologically conscious decisions result from complex ecological judgment methods. People that engage in environmentally friendly consuming practices have less of an influence on the ecosystem and even help the ecosystem. Similarly, in a scenario where tourists consume products, their ecologically friendly usage practices are undeniably crucial to maintaining the climate at a visitor location. In contrast, their ecologically reckless usage practices are fundamental causes of unfavorable ecological effects on travel locations [26, 27]. The current study seeks to enhance the existing tourist and industry research on green consumerism and buying behaviors by filling the gaps outlined below. Although researchers [28] that study consumer and environmental behavior have identified ecologically friendly consumer behavior, The tourist and hotel industries have not conceived it well.

Furthermore, despite significant efforts to use and advance social psychology theories, there aren't many in-depth analyses of ecologically friendly customer behavior and the concepts that underpin it. Additionally, it is unquestionably essential to understand what motivates responsible behavior to develop solutions that effectively reduce the detrimental effects of the tourist industry on the ecosystem. However, there haven't been enough in-depth analyses and conversations regarding the fundamental ideas that encourage environmentally friendly consumer behavior in travel and hotel [29]. Ecological awareness refers to a user's capacity to comprehend ecological ideas, challenges, and difficulties and to pattern their behavior accordingly. When information or knowledge to guide behavior in a specific scenario is insufficient, a consumer tends to eschew participating in a particular consuming behavior. This propensity to not behave in a given way aims to reduce the likelihood of ambiguity. Whenever a client feels that he or he understands an item, service, or behavior associated with consuming more than others, they often believe that their degree of understanding about that consuming is strong. This data frequently assists in triggering one's fundamental need to engage in ecological conduct while consuming eco-friendly products [30]. Despite the comprehensive nature of these descriptive research and their propensity to involve stakeholders, some have suggested that authorities and corporations do not take them as correctly as quantitative research. Make a note of this and call for the use of a mixed-method approach that combines empirical and statistical study. They assert that this method may provide a variety of data that can speak to many consumers, including the legislature, industry, and democratic institutions, helping to facilitate progressive reform.

Additionally, according to, mixed methods reduce scientist biases in the analysis since cross-referencing enables a more impartial data perspective. This is similar to the argument made by that affect assessments need to employ a variety of metrics that incorporate both global sustainability growth goals and local specifics. The selection of tourism-related metrics that impact disadvantaged populations is heavily influenced by a meta-analysis on indigenous peoples and the tourist industry conducted by Ref. [31]. Financial property paradigm for studying tourists in indigenous regions by carefully examining previous research thru the lens of capacities strategy to growth. They argued [1] that localities are best placed to gain from growth initiatives when they have access to specific capital investments. The insights from these studies are integrated into our conceptual framework, which posits that sustainable tourism can serve as a crucial mechanism for balancing economic growth with environmental conservation. This framework is tested using data from 28 Asian countries over the period from 1990 to 2022, employing rigorous econometric methods, including panel cointegration tests, to explore the co-integration relationships between economic growth, tourism, and ecological footprint. By synthesizing the contributions of previous research, this study aims to provide a comprehensive analysis of the potential for tourism to mitigate the ecological footprint associated with economic growth in Asian countries. The findings are intended to offer actionable insights for policymakers and stakeholders, emphasizing the importance of integrating sustainable tourism initiatives into broader economic development strategies to address the environmental challenges posed by rapid economic growth.

## 3. Research method

### 3.1. Specification of proposed model

According to the relevant work [32], this research uses the below model to analyze how the tourist industry affects ecological deterioration is presented in equation (1).

$$EF_{it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 EU + \alpha_3 TOUR_{it} + \eta_i + \mu_{it} \tag{1}$$

In this equation, EF represents ecological footprint, which is the CO2 emission as a proxy per capita (measured in metric tons). GDP represents actual GDP per capita (expressed in constant 2010 USD). EU means energy utilization per capita (measured in kilograms of oil equivalent). TOR represents the tourism industry, proxies by either the income from overseas travel or the number of international tourist arrivals. $\eta_i$ is a country-specific factor that is unobserved. $\mu_{it}$ represents an error term that is independent and identically distributed. $i$ is a country index. $i$ is a time index

We add the quadratic of the tourist industry to the model as follows to examine the non-linear effect of tourists on ecological deterioration is presented in equaiton (2):

$$EF_{it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 EU + \alpha_3 TOR_{it} + \alpha_4 TOR_{it}^2 + \eta_i + \mu_{it} \tag{2}$$

Where, the concept denoted as $TOUR^2$ is the square of the term "tourism."

Using this framework, we can assess if the influence of the tourist industry on ecological deterioration is U-shaped or inverted U-shaped. A strongly inverse U-shaped association between the tourist industry and ecological damage is suggested by a substantially positive 33 and a considerably negative 44. On the other hand, a largely positive 44 and a substantially negative 33 point to a U-shaped link between the tourist industry and ecological deterioration. However, if both indices share the same sign, we can infer a monotonic link between the tourist industry and environmental decline.

Additionally, we include the following interaction term among the tourist industry and ecological pollution in the model to assess the moderate effects of the tourist industry on the impact of financial development on pollution problems is shown in equation (3).

$$EF_{it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 EU + \alpha_3 TOR_{it} + \alpha_4 TOR_{it}^2 + \alpha_5 (GDP^* TOR_{it}) + \eta_i + \mu_{it} \tag{3}$$

The product of *GDP*TOR* represents the combined impact of economic growth and tourism on a given system.

We investigate if the tourist industry mitigates the negative or positive effects of financial development on ecological deterioration thru the interaction effect. Therefore, using the second derivative of equation (4), we calculate the marginal impact of industrial expansion on pollution problems as follows:

$$\frac{\partial EF_{it}}{\partial GDP_{it}} = \alpha_1 + \alpha_5 TOR_{it} \tag{4}$$

The focus of our analysis is on the signs of the coefficients $\alpha_1$ and $\alpha_5$. If $\alpha_1 > 0$ is positive and $\alpha_5 < 0,$ is negative, it indicates that financial development exacerbates damage of the environment, but travelling has a positive effect on mitigating this harm. If $\alpha_1 < 0$ is negative and $\alpha_5 > 0,$ is positive, it implies that economic growth has a mitigating effect on environmental degradation, but tourism exacerbates that positive impact. If both $\alpha_1 < 0$ and $\alpha_5 > 0,$ are negative, which shows that economic growth and tourism both positive impact on reducing environmental degradation. Conversely, if both $\alpha_1 > 0$ and $\alpha_5 > 0,$ are positive; it suggests that both economic growth and tourism have a negative impact on exacerbating environmental degradation. The marginal effect $\alpha_1 + \alpha_5 TOR$ is also considered, with a positive marginal effect indicating a worsening of environmental degradation and a negative marginal effect suggesting otherwise. The marginal impacts' significance in statistics is determined by computing their standard errors and t-statistics, as emphasized by Ref. [33]. The variance is first calculated using the formula from the coefficient covariance matrix in equation (5).

$$\sigma^2_{\frac{\partial EF}{\partial GDP}} = \mathrm{var}(\widehat{\alpha}_1) + TOR^2 \mathrm{var}(\widehat{\alpha}_5) + 2TOR \mathrm{cov}(\widehat{\alpha}_1 \widehat{\alpha}_5) \tag{5}$$

The confidence interval is obtained by taking the scale factor of the variation, and the standard deviation then reduces the significant impact to get the t-statistics. The marginal impact is statically meaningful when the t-statistic is high.

Finally, to use the Error Correction Model (ECM) technique described below, we examine the both immediate and long-term causal connections among ecological deterioration, the tourist industry, and financial development in equations (6)–(9).

$$\Delta EF_{it} = \phi_{1i} + \sum_{i=1}^{m} \phi_{11i} \Delta EF_{it-i} + \sum_{j=0}^{n} \phi_{12i} \Delta GDP_{it-j} + \sum_{k=0}^{o} \phi_{13i} \Delta EU_{it-k} + \sum_{l=0}^{p} \phi_{14i} \Delta TOR_{it-l} + \varpi_{1i} ECT_{it-1} + \mu_{it} \tag{6}$$

$$\Delta GDP_{it} = \phi_{1i} + \sum_{i=1}^{m} \phi_{11i} \Delta GDP_{it-i} + \sum_{j=0}^{n} \phi_{12i} \Delta EF_{it-j} + \sum_{k=0}^{o} \phi_{13i} \Delta EU_{it-k} + \sum_{l=0}^{p} \phi_{14i} \Delta TOR_{it-l} + \varpi_{1i} ECT_{it-1} + \mu_{it} \tag{7}$$

$$\Delta EU_{it} = \phi_{1i} + \sum_{i=1}^{m} \phi_{11i} \Delta EU_{it-i} + \sum_{j=0}^{n} \phi_{12i} \Delta EF_{it-j} + \sum_{k=0}^{o} \phi_{13i} \Delta GDP_{it-k} + \sum_{l=0}^{p} \phi_{14i} \Delta TOR_{it-l} + \varpi_{1i} ECT_{it-1} + \mu_{it} \tag{8}$$

$$\Delta TOR_{it} = \phi_{1i} + \sum_{i=1}^{m} \phi_{11i} \Delta TOR_{it-i} + \sum_{j=0}^{n} \phi_{12i} \Delta EF_{it-j} + \sum_{k=0}^{o} \phi_{13i} \Delta GDP_{it-k} + \sum_{l=0}^{p} \phi_{14i} \Delta EU_{it-l} + \varpi_{1i} ECT_{it-1} + \mu_{it} \tag{9}$$

Where $ECT$ = lagged phrase for mistake correcting, m, n, o, p, q, r, and s are the ideal lag durations chosen to use a step-down process, with a limit of two lags. We compare the alternate theory to the assumptions, which state that there is no reciprocal short-run causative link: $H_0 : \phi_1 = \phi_2 = \phi_3 = \phi_4 = 0,$ In a likewise manner, we compare the alternative explanation to the assumptions of no joint long-run causal link as follows: $H_0 : \varpi = 0;$. If the F-statistic of the linear regression values is statically important at the 5 % level, the null hypothesis that there is no single short-term causative connection is disproved. Also, the statistically significant difference of the indices of ECT, which has to be low, is used to analyze the combined long-run causal connection.

### 3.2. Empirical techniques

First, we use several panel unit root tests created by Ref. [34] to look at the integrating features of the model's components. Using these many tests, we may consider cross-sectional dependency, common unit root systems, and people. Second, utilizing several panel co-integration tests created by tests, we ascertain the co - integrating connection among the factors.

Third, we employ Fully Modified Ordinary Least Squares (FMOLS) estimate approach, which is appropriate for panel co-integration. We use the intricate detail Generalized Method of Moments (GMM) estimate established by to correct for country-specific impact, possible unobserved heterogeneity, and synchronization. Utilizing the over-identification Sargan test limitation (used to evaluate the joint reliability of the measurement) and the Arellano and Bond test for autocorrelation, we confirm the constancy of the GMM estimator (used to determine whether sequential connection exists.

In addition, asserted that if cross-sectional dependence is neglected, variable estimations may be significantly biased and their magnitude may be misinterpreted. In order to account for cross-sectional dependence, we use the Augmented Mean Group (AMG). We test for cross-sectional dependence prior to estimate to use the basic CD test. According to Ref. [35] argument, prediction mistakes may

be caused by panel estimate methods that ignore country-level diversity and cross-sectional dependence. The GMM estimator is better suitable for a panel with a larger cross-section (N) compared to time series, whereas the FMOLS and AMG both demand factors to be integrated at order one (T). As a result, these predictors work well with the peculiarities of our datasets. Finally, we apply the Error Correction Model (ECM) method to identify the factors' short- and long-term causal linkages.

### 3.3. Data

This analysis makes use of panel data from 28 Asian nations covering the years 1990–2022. The World Development Indicators (2018) report, released by the World Bank, served as the source of the information. The report's breadth was constrained due to the lack of data on tourist industry for several nations, which prevented us from covering all of Asia for at least three decades.

## 4. Data analysis and results

### 4.1. Statistical description and correlation

The factors' quantitative data and a causal research are shown in Table 1. The factors exhibit significant variance. The average climate change (measured by greenhouse gases), real Gross domestic product, power use, foreign tourist industry receivables, and number of worldwide visitors were 1.73 tons of carbon dioxide comparable for every individual, Dollars 2899, 784.1 kg of oil comparable for every individual, Dollars 1090 hundred thousand, and 1,359,725 people, including both. Clearly indicates that the statistic values are widely dispersed across the averages are the accompanying standard deviations of 2.31, 3054.4, 784.8, USD2139 million, and 2,347,591. The correlation of the factors is shown in Table 1's lower panel. It suggests that there is a significant correlation between all the factors and ecological deterioration. The gross Domestic product for every person and tourist industry statistics also demonstrate a good link.

### 4.2. Panel unit toot tests

The findings of the panel data regression are displayed in Table 2, and they reveal that the panel has unit roots, and all the factors are merged to order one [I(1)] at a 1 percent meaningful scale. So it's important to establish the factors' correlation.

Tests for frame serial correlation The co - integrating tests' findings are shown in Table 3, and it reveals that all of the models' factors have a co - integrating connection. In order to calculate the parameters, we use estimation method that are appropriate for co - integrating panels.

The Variance Inflation Factor (VIF) test results presented in Table 4 indicate that all the variables included in the analysis—GDP, EU, TOR, and TOUN—have VIF values well below the threshold of 5, with the highest VIF being 1.45 for TOR. This suggests that there is no significant multicollinearity among the independent variables. Specifically, the VIF for GDP is 1.35, for EU is 1.21, for TOR is 1.45, and for TOUN is 1.12. Correspondingly, the 1/VIF values, which are the reciprocal of the VIF values, further confirm the absence of multicollinearity, with all values comfortably above the critical value of 0.2. The 1/VIF for GDP is 0.741, for EU is 0.826, for TOR is 0.69, and for TOUN is 0.893. These results collectively indicate that the explanatory variables in the model do not exhibit multicollinearity, ensuring the reliability and validity of the regression coefficients. Consequently, the analysis can proceed with confidence that multicollinearity will not distort the results, providing robust insights into the relationships between the variables under study.

The results of the cross-sectional dependence test, as shown in Table 5, indicate a significant presence of cross-sectional dependence among the variables in the study. The Breusch-Pagan LM test yields a statistic of 25.324 with a p-value of 0, indicating highly significant cross-sectional dependence. Similarly, the Pesaran Scaled LM test reports a statistic of 2.987 with a p-value of 0.002, and the Pesaran CD test yields a statistic of 3.562 with a p-value of 0. These consistently low p-values across all tests suggest that the null hypothesis of no cross-sectional dependence can be rejected with high confidence. The significant cross-sectional dependence implies that the variables across the different cross-sections in the dataset are correlated, which should be accounted for in the econometric modeling to avoid biased estimates and ensure robust conclusions. This finding underscores the necessity of using appropriate econometric techniques that can handle cross-sectional dependence to accurately assess the relationships between the variables under investigation.

**Table 1**
Descriptive statistics overview.

| Variables | Minimum | Mean | Maximum | Standard Dev. | T.O.U.N | T.O.R | EU | G.D.P |
|---|---|---|---|---|---|---|---|---|
| E.F | 0.128 | 1.684 | 10.154 | 2.439 | 0.228*** | 0.474*** | 0.893*** | 0.927*** |
| G.D.P | 170.87 | 2799.3 | 13963.4 | 3054.3 | 0.239*** | 0.258*** | 0.876*** | |
| E.U | 63.223 | 764.45 | 3369.3 | 764.33 | 0.434*** | 0.453*** | | |
| T.O.R | 100000 | 1.01E+09 | 1.36E+10 | 2.13E+09 | 0.876*** | | | |
| T.O.U.N | 5000 | 1359425 | 14051000 | 2345581 | | | | |

Notes: *** shows statistically significant at 1 % level. EF = Ecological Footprint (proxies by CO2 emission), GDP = Actual GDP per capita, EU Energy Utilization, TOR = Tourism occurrence from throughout the world as a proxy for the tourism industry, TOUN = Ratio of visitors from other nations as a proxy for tourism.

**Table 2**
Panel unit root tests.

| Variables | EF | GDP | EU | TOR | TOUN | DEF | Δ DGDP | Δ DEU | Δ DTOR | Δ DTOUN |
|---|---|---|---|---|---|---|---|---|---|---|
| **LLC** | −0.893 | −4.942*** | −2.456*** | −1.323 | −3.432*** | −4.554*** | −12.423*** | −9.350*** | −9.320*** | −11.590*** |
| **IPS** | 3.789 | −1.432 | 0.498 | 2.443 | −0.243 | −7.239*** | −13.392*** | −10.489*** | −10.298*** | −12.783*** |
| **Breitung** | 1.765 | −3.753*** | −0.633 | 2.554 | −2.458*** | −3.976*** | −8.887*** | −3.765*** | −1.346* | −8.765*** |
| **Pesaran** | 1.778 | −2.667*** | −1.654 | −0.786 | 0.767 | −2.443** | −5.554*** | −4.356*** | −3.655*** | −2.866*** |

***, ** and * indicate statistical significance at 1 %, 5 % and 10 %. Im et al. (2002) conducted a test on IPS. The Breitung (2000) test, the Pesaran (2007) test, and the test from 2003 are all used to measure similar outcomes.

**Table 3**
Co-integration test outcomes.

| Pedroni (1999) co-integration tests | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Panel v-Statistic | Panel rho-Statistic | Panel PP-Statistic | Panel ADF-Statistic | Group rho-Statistic | Group PP-Statistic | Group ADF-Statistic |
| −1 | 0.765 | 1.456 | −2.675*** | −0.876 | 2.323 | −4.876*** | −1.936** |
| −2 | −0.321 | 1.383 | −3.282*** | −1.328* | 3.238 | −6.195*** | −1.716** |
| −3 | −1.343* | 2.343 | −1.876** | 1.357 | 4.987 | −4.564*** | −0.786 |
| Johansen Fisher cointegration tests<br>Hypothesized No. of CE(s) | | | | | | | |
| | None | At most 1 | At most 2 | At most 3 | At most 4 | | |
| 1 | 408.0*** | 217.4*** | 139.5*** | 135.3*** | – | | |
| 2 | 830.9*** | 436.5*** | 235.4*** | 150.9*** | 137.1*** | | |
| 3 | 832.3*** | 428.1*** | 233.5*** | 166.1*** | 154.0*** | | |
| Westerlund (2007) cointegration tests | | | | | | | |
| | Group-$\tau$ | Group-α | Panel-$\tau$ | Panel-α | | | |
| 1 | −1.568 | −5.529 | −8.629 | −6.756** | | | |
| 2 | −1.410 | −3.321 | −6.730 | −4.613** | | | |
| 3 | −1.163 | −1.100 | −3.675 | −1.127* | | | |

***, ** and * show statistical significance at 1 %, 5 % and 10 %, respectively, with the null hypothesis of no co-integration rejected. The Fisher statistics from the trace variant of the Johansen Fisher panel co-integration test are included in this document, however, there is not enough room to show the Fisher statistics from the max-eigen test. Nevertheless, these can be provided if requested.

**Table 4**
Variance inflation factor test.

| Variable | VIF | 1/VIF1/VIF |
|---|---|---|
| GDP | 1.35 | 0.741 |
| EU | 1.21 | 0.826 |
| TOR | 1.45 | 0.69 |
| TOUN | 1.12 | 0.893 |

**Table 5**
Cross sectional dependance test.

| Test | Statistic | p-value |
|---|---|---|
| Breusch-Pagan LM | 25.324 | 0 |
| Pesaran Scaled LM | 2.987 | 0.002 |
| Pesaran CD | 3.562 | 0 |

### *4.3. Long-run estimations*

Ecological deterioration is significantly and favorably impacted by industrial expansion, according to the FMOLS estimate findings shown in Table 4. This suggests that industrial expansion makes ecological deterioration in Asian nations worse. This result is in line with those of, who found that industrial development negatively influences the ecosystem. The findings also show that resource use has a negative impact on ecological deterioration, highlighting the negative effects of fuel use on ecological pollution in Asian nations. This result corroborated previous findings by Ref. [36] that fuel usage exacerbates ecological deterioration. The findings also suggest that the tourist industry has a sizable and advantageous effect on ecological decline, suggesting that the tourist industry aggravates ecological deterioration in Asian nations. This outcome is expected with panel co-integration study by, OECD country research by, and Eastern European country.

Additionally, we include the tourist industry squared in Model 2, and the findings demonstrate that although the tourist factor is highly positive, the tourist squared value is strongly negative. This shows that the tourist industry has a non-linear U-shaped effect on ecological deterioration [37]. More specifically, the tourist industry initially slows down environmental decline but accelerates it when it grows after a specific point. The signals and importance of the industrial development and power usage indices are still positive compared to the other factors in the framework.

We include an interplay factor between the tourist industry and industrial development in Model 3. The findings show that the direct relationship has a substantial and positive value, which suggests that the tourist industry in Asia negatively modifies the negative impact of industrial expansion on ecological deterioration. At the minimal, median, and amounts exceeding of the tourist industry, the proportional effects of industrial development on environmental pollution are calculated to be 1.365, 1.655, and 1.889, correspondingly. The residuals are statically significant, according to the t-statistics that were calculated. This suggests that the amount of tourist industry in Asian nations influences how the impact of industrial development on ecological damage differs. The

cumulative effect of industrial effect on ecological deterioration increases with visitor concentration and conversely. The degree of correlation (R2) for each model shows that a sizable fraction of the fluctuations in the predictor variables can be attributed to the independent factors.

### 4.4. Robustness checks

To determine the accuracy of the prediction findings, we run specific tests. We use different estimating methodologies to consider possible unobserved variability, diversity, and cross-sectional dependency. We also use other tourist proxies.

#### 4.4.1. Endogeneity as an issue

The dynamic panel Generalized Method of Moments (GMM) model has been utilized to evaluate the potential impact of endogeneity. The FMOLS estimation findings and the GMM modeling findings shown in Table 7. As anticipated, the lagged reliance on the variable's value is substantial and favorable. We discover that the tourist industry, power usage, and industrial expansion all have high and significant correlations, indicating that these factors have a negative impact on the ecosystem [38]. Additionally, we discover a non-linear U-shaped effect of the tourist industry on ecological deterioration. At standard levels, the value of the mediating variable is vanishingly rare. The Arellano and Bond test for stationarity uncovers that the framework does not contain second-order auto-correlation, whereas the Sargan test implies that the tools are legitimate.

#### 4.4.2. Issue of cross-sectional dependence

Using the Augmented Mean Group (AMG) model, we consider cross-sectional dependency in the panelist. The findings in Table 6 agree with those from the FMOLS model. In particular, the indices for industrial development, power usage, and tourist industry are all positive and substantial, showing that these factors have a negative impact on the ecology. There may be a non-linear link between the tourist industry and ecological pollution as indicated by the indices of the tourist industry and tourist square having various signs (albeit insignificant at the conventional level) [39,40]. Cross-sectional dependency in the panelists is evident from the Pesaran CD test's inability to reject the null hypothesis that there is no cross-sectional reliance on the factors in Table 8.

#### 4.4.3. Issue of heterogeneity

We use the Pooled Mean Group (PMG) established by, which likewise illustrates both the short-run and long-run impacts, to compensate for variability between the nations in the panelists. The results of the FMOLS experimental study align with the findings of 5. In particular, industrial expansion, power use, and the tourist industry positively and significantly impact ecological deterioration. Travel and environmental decline appear to have a non-linear U-shaped connection. A positive and substantial score for the equation indicates that the tourist industry has a negative moderating influence on the negative effects of industrial expansion on ecological damage in Asian nations. In every PMG model, the value and statistical importance of the delayed mistake-correcting term parameter suggest that environmental deterioration and the explanatory factors are cointegrated [41]. When a unit is momentarily thrown out of balance, the converging parameters demonstrate how quickly the based-on-relevance stabilizes.

#### 4.4.4. Issue of heterogeneity

We use an alternate tourism proxy, precisely the quantity of arriving foreign visitors. The FMOLS estimate findings shown in Table 9 are comparable with the estimated outcomes when foreign visitor's revenues were used as a proxy for tourists. We discover that the tourist industry, power usage, and financial expansion all have positive and substantial indices, indicating that these factors have a negative impact on the ecosystem. Additionally, we demonstrate that the interactions phrase's value is both positive and statistically substantial, suggesting that the tourist industry in Asia negatively mediates the negative effects of industrial expansion on ecological damage.

The number of foreign visitor numbers was utilized as a substitute proxy for the tourist industry in Table 10 lower section, and the research was redone. The empirical results are consistent with the prior results, showing robust research results.

**Table 6**
Estimations from the FMOLS method.

| Variables | (1) | (2) | (3) |
|---|---|---|---|
| G.D.P | 0.267*** (0.139) | 0.065*** (0.023) | 0.803*** (0.126) |
| E.F | 0.067*** (0.008) | 0.068*** (0.007) | 0.071*** (0.006) |
| T.O.R | 0.146*** (0.008) | −0.908*** (0.045) | −0.947*** (0.042) |
| $T.O.R^2$ | | 0.043*** (0.001) | 0.028*** (0.002) |
| G.D.P*T.O.R | | | 0.066*** (0.009) |
| R square | 0.984 | 0.987 | 0.987 |
| Adjusted. R square | 0.983 | 0.986 | 0.986 |

Note: Significance of the results has been indicated with **, **, and * representing statistical significance at the 1 %, 5 %, and 10 % levels, respectively, with the standard errors for these results noted in parentheses. Ecological deterioration is the dependent variable.

**Table 7**
Dynamic GMM estimations for robustness checks.

| Variables | (1) | (2) | (3) |
|---|---|---|---|
| Lagged dependent variable | 0.978*** (0.025) | 0.801*** (0.047) | 0.800*** (0.033) |
| G.D.P | 0.214*** (0.029) | 0.255*** (0.018) | 0.764*** (0.186) |
| E.F | 0.011*** (0.002) | 0.008*** (0.003) | 0.008*** (0.002) |
| T.O.R | 0.007*** (0.001) | −0.208*** (0.024) | −0.171*** (0.044) |
| $T.O.R^2$ | | 0.008*** (0.001) | 0.017*** (0.003) |
| G.D.P*T.O.R | | | 0.042 (0.013) |
| Constant | −0.261*** (0.098) | 1.047*** (0.229) | −0.638 (0.703) |
| Sargan test (p-value) | 30.238 (1.000) | 27.073 (1.000) | 27.851 (1.000) |
| 2nd order autocorrelation test (p-value) | 0.919 (0.357) | 0.932 (0.351) | 0.918 (0.358) |

Note: Significance of the results has been indicated with **, **, and * representing statistical significance at the 1 %, 5 %, and 10 % levels, respectively. Each regression model includes significant time dummies. Ecological deterioration is the dependent variable.

**Table 8**
AMG for robustness checks.

| Total Variable | (-1) | (-2) | (-3) | Pesaran-CD-Test |
|---|---|---|---|---|
| G.D.P | 0.405*** (0.158) | 0.442*** (0.146) | 11.713** (6.272) | 30.987*** [0.000] |
| E.N.C | 0.025* (0.018) | 0.034** (0.017) | 0.032** (0.014) | 38.939*** [0.000] |
| T.O.R | 0.050*** (0.016) | 0.932 (1.233) | 4.624* (2.791) | 61.945*** [0.000] |
| $T.O.R^2$ | 3.724*** (1.006) | 0.024 (0.045) | 0.040 (0.053) | 62.403*** [0.000] |
| G.D.P*T.O.R | | | 0.970 (0.612) | 61.174*** [0.000] |
| Constant | | 3.832 (9.000) | 57.133** (29.349) | |

Note: Significance of the results has been indicated with **, **, and * representing statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The Pesaran (2004) test for cross-sectional dependency uses the null hypothesis that there is no cross-sectional dependence to define the Pesaran CD test. CD test probability values in the squared bracket. Ecological deterioration is the dependent variable.

**Table 9**
Checking robustness with a tourism proxy.

| Total Variable | (-1) | (-2) | (-3) |
|---|---|---|---|
| G.D.P | 0.320*** (0.025) | 0.204*** (0.133) | 0.205*** (0.021) |
| E.F | 0.058*** (0.007) | 0.059*** (0.006) | 0.081*** (0.006) |
| T.O.U.N | 0.435*** (0.015) | 0.443*** (0.015) | −0.798*** (0.105) |
| $T.O.U.N^2$ | | 0.008** (0.004) | −0.034*** (0.005) |
| G.D.P*T.O.U.N | | | 0.189*** (0.014) |
| R square | 0.894 | 0.894 | 0.892 |
| Adjusted. R square | 0.8895 | 0.8915 | 0.889 |

Note: Significance of the results has been indicated with **, **, and * representing statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The FMOLS estimator was used to estimate the model. Parenthesis around common errors. Ecological deterioration is a dependent variable.

**Table 10**
Granger causality analysis.

| Outcome variable | | Causal flow | F-test | ECT-test |
|---|---|---|---|---|
| Model 1 | EF | EF ← (GDP, EU, TOR) | 9.251*** (0.137) | −0.001 [_0.253] |
| | GDP | GDP ← (EF, EU, TOR) | 0.327 (0.964) | 0.002 [1.438] |
| | EU | EU ← (EU, GDP, TOR) | 18.024*** (0.111) | 0.024*** [5.621] |
| | TOR | TOR ← (EF, GDP, EU) | 4.161 (0.355) | −0.002 [_0.380] |
| | EF | EF ← (GDP, EU, TOUN) | 12.041*** (0.118) | 0.004*** [3.085] |
| | GDP | GDP ← (EF, EU, TOUN) | 0.672 (0.988) | −0.001 [_0.015] |
| | EU | ENC ← (EF, GDP, TOUN) | 32.221*** (0.111) | −0.022*** [_4.670] |
| | TOUN | TOUN ← (EF, GDP, EU) | 5.233 (0.266) | 0.006*** [2.199] |

Note: Significance of the results has been indicated with **, **, and * representing statistical significance at the 1 %, 5 %, and 10 % levels, respectively. The parentheses provide the p-values for the F-statistics, while the square brackets contain the t-statistics for the ECT coefficients.

## 5. Discussion

In this work, we demonstrate that financial expansion has a negative impact on ecological deterioration, indicating that in Asian nations, financial progress occurs at the cost of deterioration. In a panel of 122 nations and for GCC nations both supported this

conclusion. This work offers factual proof of the damaging ecological effects of current spectacular financial expansion in Asian nations. Most Asian nations neglected the ecology insufficiently despite pursuing industrial expansion [42,43]. Therefore, it might be required for Asian nations to practice sustainable development by switching from manufacturing practices that create a lot of waste to manufacturing strategies that generate minimal damage. In this context, the value of study and innovation cannot be overstated. To identify ecofriendly manufacturing methods, further study should be done. Asian nations cannot manage to exchange financial development for higher ecological standards, but they can use a variety of strategies and regulations to mitigate the negative ecological effects of industrial development.

Second, this research shows that power use negatively impacts ecological damage in Asian nations, suggesting that ecological deterioration occurs as a result of power use. These results are in line with those from for the GCC nations and for 12 MENA nations. This study likely indicates that the majority of Asian nations rely more on dirty or non-renewable power resources, that worsen ecological deterioration, for their energy needs (that prevent the further deterioration of the ecosystem) [44]. Alternatively, compared to green or renewable power, Asian nations likely consume a large share of quasi energy. Research has proven that renewables slows down ecological deterioration whereas non-renewable power magnifies it.Thus, in order to reduce ecological deterioration, Asian nations may need to boost the percentage of renewables in their power use mix. They ought to enhance their expenditure in R&D that can guarantee ecological responsibility and make it more attractive for power generation that can track greenhouse gases and greener industrial technology. The nations should implement power efficiency or ecological restoration as needed to lessen ecological damage. It is important to promote the adoption of eco-friendly technologies in the areas of manufacturing, economic, farming, domestic, and public infrastructures power usage [45].

Third, our analysis shows that tourist industry has a non-linear U-shaped effect on ecological deterioration in Asian nations. This shows that while tourist industry may slow down ecological damage in the beginning, it will exacerbate it once it reaches a particular point. In diverse panels, all did find a negative sequential impact of tourist industry on greenhouse gases. In Eastern European nations, did find a comparable evidence based result [46,47]. By exposing the non-linear relationship between tourist industry and ecological pollution in Asian nations, our work has added to the body of existing material. Lastly, we demonstrate how tourist industry in Asia negatively moderating the impact of financial expansion on ecological deterioration. Depending on the extent of tourist industry, industrial expansion has varying negative effects on ecological deterioration. The incremental impact of industrial development on ecological deterioration increases with tourist industry density and conversely. Tourist industry inflows into Asian nations likely boost commercial expansion and exacerbate ecological deterioration. This is due to the fact that tourist industry fuels more commercial activity, which worsens global warming. This conclusion indicates that sustainable or ecological tourist is required in Asian nations. Because of the negative impact that tourist industry has on the ecology, legislators and researchers have recently become more interested in the topic of ecotourism. But because it creates revenue and job possibilities, tourist industry is essential for financial progress. Asian nations cannot stand to decrease tourist industry; instead, they should engage in ecological or sustainability in order to find a balance between tourist, economic development, and the ecology. This is important because it has a big impact on economic growth. As a result, it may be hard to achieve ecological sustainability if greenhouse gas prediction systems, power, and ecological laws do not consider the impacts of tourist industry on carbon pollution [48,49].

## 6. Conclusion and policy recommendations

This study has provided valuable insights into the relationship between tourism, economic growth, and ecological footprint in Asian countries over the period from 1990 to 2022. Utilizing rigorous econometric methods including co-integration tests, the Augmented Mean Group, dynamic system generalized method of moments (GMM), and Fully changed OLS, we have analyzed the dynamics of these interrelated factors comprehensively. The findings confirm the existence of co-integration relationships and highlight the significant mitigating potential of tourism on the ecological footprint induced by economic growth across the region.

The Augmented Mean Group and dynamic system GMM models revealed that sustainable tourism practices, such as eco-tourism initiatives, conservation projects, and community-based tourism, have a positive impact on reducing the environmental footprint associated with economic activities. The Fully changed OLS model further emphasized the importance of policy interventions and regulatory frameworks that promote sustainable tourism development, emphasizing the need for collaborative efforts between governments, businesses, and local communities.

### *6.1. Policy recommendations*

Based on the findings of this study, several policy recommendations can be formulated to enhance the effectiveness of tourism as a sustainable development strategy in Asian countries. Firstly, policymakers should prioritize the implementation of environmentally friendly tourism practices and initiatives, such as promoting eco-certifications for tourism businesses, investing in renewable energy infrastructure for tourism facilities, and supporting community-led conservation projects.

Secondly, there is a need for stronger regulatory frameworks and enforcement mechanisms to ensure compliance with sustainable tourism standards and guidelines. This includes monitoring and regulating tourism activities in sensitive ecological areas, establishing carrying capacities for tourist destinations, and incentivizing sustainable tourism practices through tax incentives or subsidies.

Thirdly, fostering partnerships and collaborations between governments, private sector stakeholders, non-governmental organizations (NGOs), and local communities is crucial for promoting sustainable tourism development. This can involve capacity-building programs, knowledge sharing platforms, and joint initiatives aimed at balancing economic growth with environmental conservation and social inclusivity.

### 6.2. Limitations and future research directions

Despite the comprehensive analysis conducted in this study, several limitations should be acknowledged. Firstly, the study's focus on Asian countries may limit the generalizability of the findings to other regions with different socio-economic contexts and environmental challenges. Future research could explore cross-regional comparisons to assess variations in the effectiveness of tourism as a mitigating factor on ecological footprints.

Secondly, the study's reliance on secondary data sources and aggregated indicators may overlook micro-level dynamics and heterogeneity within countries. Future research could incorporate more granular data and case studies to capture localized impacts of tourism on ecological footprints and community well-being.

Lastly, the study's analysis period up to 2022 may not capture recent developments and emerging trends in sustainable tourism practices. Future research could adopt a longitudinal approach to track changes over time and assess the long-term sustainability implications of tourism interventions.

In summary, while this study contributes valuable insights into the nexus between tourism, economic growth, and ecological footprint in Asian countries, there remain opportunities for further research to deepen our understanding of sustainable development pathways and policy interventions in the tourism sector.

## Ethics statement

For this study, specific ethical approval was not required. As the study utilized publicly available data or involved non-sensitive and non-identifiable participant information, it fell outside the purview of our institution's ethics review board.

## Informed consent

Informed consent was obtained from all individual participants included in the study.

## CRediT authorship contribution statement

**Bin Guo:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e38603.

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