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Research article

Sustainable development in Southeast Asia: The nexus of tourism, finance, and environment

Trung Ha Van [a], Lee Lichang [b,**], Thuan Dang Thanh Quoc [b,*]

[a] *School of Economics and Management, Wuhan University, 299 Bayi Road, Wuchang District, Wuhan, Hubei Province, 430072, China*

[b] *Department of Tourism Management, National Kaohsiung University of Science and Technology, No.58, Shenzhong Rd., Yanchao Dist., Kaohsiung City, 824004, Taiwan*

A R T I C L E I N F O

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A B S T R A C T

Southeast Asia's booming tourism and rapid economic growth create a unique setting to explore the interplay between economic development, tourism, and environmental sustainability. This study examines the complex interplay between tourism expansion, financial development, and environmental sustainability in Southeast Asia, specifically from 2000 to 2023. This research aims to fill gaps in previous studies, particularly within the Association of Southeast Asian Nations (ASEAN) context, and to provide a comprehensive understanding of how tourism and financial growth impact environmental outcomes in this region. The Autoregressive Distributed Lag (ARDL) model with Pooled Mean Group (PMG) specifications is utilized to analyze the long-term relationships between these factors while capturing the unique short-run dynamics of individual countries within Southeast Asia. The findings reveal intricate relationships spanning both short-term and long-term dynamics, highlighting the impact of tourism growth on environmental factors such as increased renewable energy use, Carbon Dioxide (CO_2) emission, and ecological footprints. One-way causality from tourism, financial development, and renewable energy use to the ecological footprint is observed, alongside bidirectional causality between various factors. Policy implications emphasize the need for sustainable tourism practices and renewable energy integration. This research location's specific focus on Southeast Asia provides critical insights for policymakers aiming to balance economic growth with environmental conservation.

1. Introduction

Emerging in the late 20th century, sustainable development has become an imperative objective for nations globally. The ultimate goal of sustainable development is to achieve enduring economic and environmental stability. This can only be realized by integrating and acknowledging economic, environmental, and social factors throughout the decision-making process [1,2]. This is particularly pertinent in Southeast Asia, a region marked by rapid economic growth, cultural diversity, and abundant biodiversity. This study seeks to decipher the intricate relationship between tourism development, financial development, and environmental conservation in Southeast Asia with a focus on green energy, CO_2 emissions, and ecological footprints.

* Corresponding author.
** Corresponding author.
E-mail addresses: 2022171050006@whu.edu.cn (T. Ha Van), lichang@nkust.edu.tw (L. Lichang), i110167115@nkust.edu.tw (T. Dang Thanh Quoc).

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Tourism serves as a substantial economic catalyst in Southeast Asia by generating revenue, creating employment opportunities, and stimulating local economies [3]. However, unchecked tourism development can result in environmental degradation, thereby endangering the very resources that draw tourists [4,5,6]. Hence, it is vital to comprehend how tourism can be developed sustainably.

Financial development plays a crucial role in sustainable development by providing the necessary resources for implementing sustainable practices and policies [7]. However, it is essential that financial systems are structured to support sustainable development; otherwise, they may negatively impact the environment [7]. This involves promoting green investments and discouraging activities detrimental to the environment.

Environmental conservation lies at the core of sustainable development. It entails preserving natural resources and biodiversity for future generations. In the context of Southeast Asia, this implies managing forests, protecting wildlife, and conserving marine ecosystems while balancing these efforts with economic development needs.

Green energy is a critical component of environmental conservation. Renewable energy sources have an impact on the environment and biodiversity through pollution and climate change [8]. They reduce reliance on fossil fuels, thereby decreasing CO_2 emissions and mitigating climate change. Renewable energy technologies offer significant potential for addressing greenhouse gas emissions and combating global warming by replacing traditional energy sources [9]. Many Southeast Asian countries have considerable potential for developing renewable energy sources such as solar and wind power. Harnessing this potential could drive economic growth while preserving the environment.

Trade openness, per capita GDP, and energy consumption are all factors that increase CO_2 emissions. Conversely, urbanization and industrialization have been observed to decrease CO_2 emissions globally [10,11]. Similarly, CO_2 emissions pose a significant concern in Southeast Asia due to rapid industrialization and urbanization. They contribute to global warming and have detrimental effects on human health and ecosystems. Therefore, reducing CO_2 emissions is a critical aspect of sustainable development in this region.

Ecological footprints measure the environmental impact of human activities. They provide valuable insights into how lifestyle choices and consumption patterns affect natural resources. By understanding their ecological footprints, countries can develop strategies to reduce their environmental impact.

The connection between tourism, ecological footprint, and CO_2 emissions is a complex one. While tourism can stimulate economic growth, unchecked development can lead to significant environmental degradation [12]. This can manifest through increased resource consumption, habitat destruction, pollution, and greenhouse gas emissions. The increasing reliance on fossil fuels to fuel tourism activities further contributes to the rise of CO_2 emissions, exacerbating climate change and impacting the very natural resources that attract tourists [13,14]. Therefore, it is critical to promote sustainable tourism practices that minimize environmental impact, foster responsible consumption patterns, and prioritize the use of renewable energy sources. This will be crucial in mitigating the negative environmental consequences of tourism growth and ensuring the long-term sustainability of the region's tourism sector.

Hence, sustainable development in Southeast Asia involves a complex interplay between tourism development, financial development, and environmental conservation. By understanding this relationship, we can gain insights into how these factors interact and how they can be managed to promote sustainability in the region. This understanding is crucial for policymaking and for guiding the region toward a sustainable future.

This study aims to rigorously examine the complex relationship between tourism development, financial development, and environmental conservation in Southeast Asia. Our research specifically focuses on the role of green energy, CO_2 emissions, and ecological footprints in this intricate interplay. By employing the ARDL model with PMG specifications, we seek to uncover both short-term and long-term dynamics between these factors, ultimately identifying the key drivers of environmental impact in the region.

This study also addresses a critical area of concern: balancing economic growth with environmental sustainability in Southeast Asia. This region is experiencing rapid economic development and booming tourism, which can put significant strain on natural resources. Understanding the complex interplay of these factors is crucial for policymakers to develop effective strategies for sustainable development and to ensure the long-term viability of the region's economic and environmental well-being.

The following sections of this paper dive deeper into these topics while providing a comprehensive analysis of sustainable development in Southeast Asia: Section 2 presents a review of the relevant literature. Section 3 delves into the data, model, and methodology used in this study. Section 4 reports the empirical findings and discusses them in detail. The paper concludes with Section 5, which offers the conclusion and policy suggestions.

2. Literature review

2.1. The ecological footprint and financial development

The development of the financial sector is closely tied to economic growth and increased efficiency within a nation's financial system, as indicated by Baloch et al. (2019). Effective financial policies are crucial for attaining energy objectives, and a robust financial system can efficiently mobilize capital and financial resources. Furthermore, financial development has been recognized as a governmental policy instrument for addressing environmental challenges [15]. Nevertheless, the connection between financial development and the environment has been examined from two distinct angles. One perspective underscores the constructive role of financial development in enhancing energy efficiency and environmental quality through heightened research and development (R&D) in renewable energy and the attraction of foreign direct investment [16,17]. In contrast, another viewpoint contends that financial development contributes to environmental deterioration by encouraging industrialization and conventional energy consumption [18].

Research into the impact of financial development on environmental pollution reveals divergent results in the literature. Some studies suggest that financial development increases the ecological footprint, a trend observed in various regions and countries, including Belt and Road nations [18,15], Japan [19], West Asia and Middle East countries [20], and BICS economies [17]. Conversely, other investigations demonstrate that financial development diminishes the ecological footprint in countries such as China and Malaysia [21], MINT countries [22], Turkey [23], France, Japan, and the United Kingdom [24], and APEC countries [25].

Furthermore, Ashraf et al. (2022) identified an inverted U-shaped relationship between financial development and ecological footprint in a global sample of 124 economies, while Khan et al. [26] found a similar relationship across 180 countries. Sun et al. [27] investigated the link between financial development and carbon footprint in South Asian nations and also detected an inverted U-shaped relationship. They attributed this pattern to the diminishing scale effect of financial development and the increasing influence of technological advancements and compositional changes with economic progress.

In summary, the literature provides varying viewpoints on the connection between financial development and environmental outcomes, with some studies suggesting positive effects and others indicating adverse consequences. The intricacy of this relationship underscores the need for further research to gain a deeper understanding of the interplay between financial development and environmental sustainability.

2.2. The ecological footprint and tourism development

The influence of tourism on the ecological footprint can be examined from two distinct angles. On one side of the debate, researchers contend that the expansion of tourism leads to a reduction in the ecological footprint, signifying an enhancement in environmental well-being [28]. Tourism presents various opportunities and advantages, such as fostering economic growth [29], increasing job opportunities [30], driving technological innovations [31], and promoting the adoption of green and renewable energy sources [32]. Additionally, tourism can heighten community awareness of environmental preservation and sustainable practices [33].

Conversely, concerns have been raised regarding excessive tourism development contributing to an escalation in the ecological footprint and environmental harm [34,35]. These concerns stem from tourism's impact on the consumption of natural resources [36], the loss of biodiversity [37], alterations in land use, and deforestation [37]. Furthermore, the growth of tourism results in increased consumption of non-renewable energy in various activities [38].

Research examining the relationship between tourism and the ecological footprint has yielded varied results. Some studies suggest that tourism decreases the ecological footprint [31], while others report a positive correlation [32] or an inverted U-shaped relationship [5]. Villanthenkodath et al. [39] found that tourism development worsens the environment in India, while Lee & Brahmasrene [40] confirmed that the ecological footprint initially increases but later decreases with tourism development in 123 countries.

Furthermore, the connection between tourism and the ecological footprint differs across countries with varying income levels. Ozturk et al. (2016) identified an inverted U-shaped relationship between tourism and the ecological footprint in upper-middle- and high-income nations, which was more pronounced than in lower-middle- and low-income countries. Similar findings of an inverted U-shaped relationship were observed in ASEAN countries [31]. However, Katircioglu (2014) concluded that continued tourism development does not have a significant long-term positive impact on CO_2 emissions, suggesting a non-linear relationship.

In conclusion, the impact of tourism on the ecological footprint is intricate and contingent on contextual factors. While some studies suggest a favorable influence on environmental quality, others caution against potential environmental degradation. A comprehensive understanding of this relationship necessitates further investigation, taking into account diverse country contexts and income levels.

2.3. The ecological footprint and renewable energy

The surge in economic growth and rapid urbanization has led to a heightened demand for energy. Wang and Dong (2019) conducted an empirical investigation into the drivers of environmental degradation, with a specific focus on the consumption of renewable energy. Their study encompassed a balanced panel dataset comprising 14 Sub-Saharan African nations spanning from 1990 to 2014. Their findings indicate that the utilization of renewable energy has an adverse impact on the ecological footprint, and this relationship was established through the Augmented Mean Group (AMG) estimator, affirming a one-way causation from renewable energy consumption to the ecological footprint. Similarly, Alola et al. (2019) examined a balanced panel of 16 EU countries over the period from 1997 to 2014, utilizing the Panel Pool Mean Group Autoregressive Distributive Lag (PMG-ARDL) model. Their research confirmed the role of non-renewable energy consumption in degrading environmental quality, while highlighting the positive impact of renewable energy consumption on environmental sustainability. Interestingly, in developed Asian countries, ecological footprint and environmental pollution are influenced by electricity use, fossil fuel consumption, foreign direct investment, and economic growth. While economic growth, FDI inflows, and electricity consumption drive renewable energy usage, fossil fuel consumption has a negative impact on renewable energy adoption [41].

Moreover, a study conducted on 24 organizations for economic cooperation and development nations during the years 1980–2014 revealed that increased reliance on renewable energy is associated with a reduction in the ecological footprint. In contrast, higher consumption of non-renewable energy was found to contribute to environmental degradation [42]. A similar examination was carried out by Adedoyin et al. (2020) on selected European Union-16 countries, spanning the period from 1997 to 2014. Their findings indicated a negative effect of renewable energy use on the environmental footprint. Furthermore, Caglar et al. [43] explored the impact of renewable energy consumption on environmental damage in the USA over the years 1980–2017 and found that it plays a role in mitigating environmental harm. Similarly, Abid et al. [44] investigated the relationship between renewable energy consumption and the ecological footprint in Saudi Arabia spanning from 1980 to 2017, revealing that the utilization of renewable energy has a positive impact on environmental quality.

However, it's worth noting that some empirical evidence challenges the significant influence of renewable energy on the ecological footprint in certain countries, leading to ongoing debates. For instance, Lin & Moubarak [45] found no significant association between renewable energy and the ecological footprint in China over the period from 1977 to 2011. Similarly, Al-Mulali & Ozturk [46] investigated the Environmental Kuznets Curve (EKC) hypothesis in 14 MENA countries spanning from 1996 to 2012. Their research revealed that while non-renewable energy consumption contributes to an increase in the ecological footprint, renewable energy consumption does not have a significant effect in reducing it. Pata & Caglar (2021) tested the EKC hypothesis in China's regional contexts over the years 1980–2016, suggesting that the impact of renewable energy on the ecological footprint does not hold true in China's central region.

2.4. The ecological footprint and CO2 emission

The nexus between CO_2 emissions and the ecological footprint is a crucial area of study in environmental economics and sustainability research. Understanding the relationship between these two factors is essential for policymakers and researchers alike as they seek to address the challenges of climate change, resource depletion, and environmental degradation.

To comprehend the nexus between CO_2 emissions and the ecological footprint, it is vital to define these terms. CO_2 emissions, primarily from burning fossil fuels, industrial processes, and land-use changes, are a significant contributor to global warming and climate change [47,48]. The ecological footprint, on the other hand, measures the environmental impact of human activities in terms of land and resources required to support a particular lifestyle or economic activity [49,50]. CO_2 emissions, primarily driven by economic activity, trade openness, and population growth, significantly contribute to environmental degradation. However, the Environmental Kuznets Curve (EKC) theory suggests that after achieving a certain level of economic development, countries may reduce emissions through green technologies, though certain green energy sources, like biomass, still contribute to CO_2 emissions [51].

Early research in this field primarily focused on understanding the environmental consequences of increasing CO_2 emissions. Studies often used CO_2 emissions as a proxy for overall environmental degradation [52,53,54]. This approach was based on the assumption that the release of CO_2 was closely correlated with other forms of environmental damage, such as habitat destruction and resource depletion.

Over time, researchers began to recognize the limitations of using CO_2 emissions alone as an indicator of ecological impact [54]. This recognition led to the development of the ecological footprint concept, which provides a more comprehensive measure of environmental stress. The ecological footprint considers not only carbon emissions but also factors like land use, water consumption, and the depletion of natural resources [50].

Many studies have explored the connection between energy and sustainable development, but several have primarily used CO_2 emissions as an indicator of environmental degradation such as Kofi Adom et al. (2012), Rüstemoğlu (2022), and Rehman et al. (2021). Recently, there has been a shift towards using the ecological footprint as a more comprehensive measure [55] because it has some limitations [56]. Previous studies can be grouped into two categories: those relying on CO_2 emissions and those using the ecological footprint. Worth noting are studies by Altıntaş & Kassouri [57] and Mrabet & Alsamara [58], which explored the Environmental Kuznets Curve (EKC) in Europe and Qatar, suggesting that the ecological footprint is a more appropriate measure than CO_2 emissions for capturing the EKC. These studies demonstrate that the EKC relationship is better approximated when using the ecological footprint rather than CO_2 emissions. This has led us to employ the ecological footprint as our dependent variable in this study.

Numerous methodologies have been employed to study the relationship between CO_2 emissions and the ecological footprint. These include the residual augmented least squares regression [59], autoregressive distributed lag (ARDL) [60], through the hypothesis of the environmental Kuznets curve (EKC) [59], Input-Output Analysis [61], and various decomposition methods.

Some studies have found a positive correlation between CO_2 emissions and the ecological footprint, such that as carbon emissions rise, so does the overall environmental impact [62,63,64,65,66,67,68]. These studies suggest that efforts to reduce CO_2 emissions may also lead to a decrease in the ecological footprint. Other research has revealed more complex relationships. For example, some studies have identified inverted U-shaped relationships, where increasing CO_2 emissions initially lead to a rise in the ecological footprint, followed by a decline [69]. This pattern suggests that initial industrialization and economic growth may lead to increased emissions and resource consumption, but as countries develop further, they invest in sustainability measures and efficiency improvements.

2.5. Research gaps

While existing literature offers valuable insights into the individual relationships between financial development, tourism, renewable energy, CO_2 emissions, and the ecological footprint, a significant gap remains in understanding the intricate interplay of these factors within the unique context of Southeast Asia, especially the ASEAN region. Previous studies have primarily focused on other regions, neglecting the specific characteristics of ASEAN countries, including their diverse economic structures, development stages, and environmental challenges. Furthermore, existing research often lacks a comprehensive analysis of the causal relationships between these variables within the ASEAN context. For instance, while some studies have identified an inverted U-shaped relationship between financial development and the ecological footprint globally [69], it remains unclear if this pattern holds true for ASEAN countries, given their unique development trajectories. Similarly, the impact of tourism on the ecological footprint in ASEAN is often examined in isolation, with less emphasis on its interaction with other factors like renewable energy and CO_2 emissions. Therefore, this study aims to address these gaps by examining the long-term and short-term relationships between these variables, considering the specific context of ASEAN countries, and exploring the causal relationships between them.

3. Variables, econometrics model, and methodology

3.1. Variables and metrics

The main goal of this research paper is to examine the connection between tourism growth, financial development, and the ecological footprint of Southeast Asian countries. The study uses annual cross-sectional panel data from 1980 to 2021. An ecological footprint model is used to investigate the importance of sustainable development in Southeast Asia. The ecological footprint, which measures a country's demand for global resources, is crucial in determining its sustainability and well-being.

The variables used in this study are outlined in Table 1. The ecological footprint (ECO) is measured in global hectares and serves as an essential indicator of sustainability. It is obtained from the Global Footprint Network (retrieved from https://data.footprintnetwork.org/#/). Tourism development (LNTOUR) is measured by the number of international tourist arrivals and is sourced from the World Development Indicators - World Bank (WDI) (retrieved from https://databank.worldbank.org/source/world-development-indicators#). Financial development is measured by the Financial Development Index (FDI), which ranges from zero to one and is obtained from the International Monetary Fund (IMF). Renewable Energy Consumption (REN), which represents green energy development, is measured as a percentage of total final energy consumption and is also sourced from the WDI. CO2 emissions (LNC02), measured in kilotons, refer to the amount of carbon dioxide emissions and are also obtained from the WDI.

3.2. Econometrics model

3.2.1. The dynamic ARDL

Various methods are used to estimate the coefficients of factors influencing sustainable development. The ordinary least squares (OLS) method is commonly used [70]. However, the OLS regression necessitates stationary series; otherwise, it may result in spurious regression [71]. To address the issue of non-stationary series, the cointegration test comes into play. The cointegration technique refers to the presence of a stable or stationary relationship among two or more time series, even when each series is non-stationary individually [72]. Moreover, cointegration techniques enable the examination and estimation of long-term equilibrium relationships [73]. The fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) are two common estimators for this technique. These estimators necessitate a fundamental assumption: the included variables in the models are non-stationary at the base level but stationary when differenced once, and cointegration of order 1 is observed. This approach has been implemented in various studies that fulfill these conditions. Nevertheless, such conditions are not always met. Furthermore, according to Narayan & Narayan [74], "cointegration methods may lack reliability for small sample sizes." To circumvent these limitations, Pesaran & Shin [75] proposed the ARDL modeling approach, which proves superior irrespective of whether the variables display I(0), I(1), or a combination of both. Cho et al. (2023) highlight a key advantage of the general ARDL model, where the error correction mechanism can be seamlessly integrated into the modeling process. Given these benefits, the ARDL estimation method has found widespread application in recent studies [76,77,78,79,80].

Building upon the above analysis, this study employs the nonlinear panel ARDL approach. The "nonlinear ARDL model in panel form, serving as a nonlinear representation of the dynamic heterogeneous panel data model suitable for extensive panels" [81]. The panel ARDL technique aids in estimating both the long-term and short-term relationships within the general sample, as well as the short-term cross-sectional coefficients for each subject, even in cases where variables exhibit non-stationarity and lack cointegration [82]. Thus, panel data analysis is conducted in this study for several reasons: firstly, it focuses on the "group" rather than individual units, retaining valuable information. Secondly, it enhances observations and reduces noise compared to time series data, making it suitable for overcoming heteroscedasticity. Thirdly, it is good ideal for data-limited situations in developing countries with short time spans. Fourthly, it accommodates heterogeneity among panel units. Fifthly, it considers subject-specific variables, addressing heterogeneity. Lastly, it is well-suited for studying dynamic changes through repeated cross-sectional observations [82,83].

3.2.2. Theoretical model

The nexus between financial development, tourism, renewable energy, CO_2 emissions, and the ecological footprint can be elucidated through several interconnected theories. The Environmental Kuznets Curve (EKC) theory posits an inverted U-shaped relationship between environmental degradation and economic development, suggesting that initially, environmental degradation increases with economic growth but improves after a certain income level [84,85]. Complementing this, the Tourism-Led Growth Hypothesis highlights how tourism development significantly contributes to economic growth, which can lead to both positive and

Table 1
Summary of variables used in the model.

Variable	Description	Measure	Log scale	Data source
ECO	Ecological Footprint	Global hectares	No	Global Footprint Network
LNTOUR	Tourism development	The number of international tourist arrivals	Yes	World Development Indicators
FDI	Financial Development Index	From zero (lowest) to one (highest)	No	International Monetary Fund
REN	Renewable Energy Consumption	Percentage of total final energy consumption	No	World Development Indicators
LNC02	CO_2 emissions	Kilotons	Yes	World Development Indicators

Source: Own elaboration.

negative environmental impacts, necessitating sustainable tourism practices [86,87]. Green finance plays a crucial role in sustainable development by promoting investments that provide environmental benefits and reduce the ecological footprint through sustainable practices [37]. Furthermore, the development and adoption of renewable energy sources are vital for reducing CO_2 emissions and mitigating climate change, as renewable energy consumption is linked to lower environmental impacts [88,89]. Lastly, resource and ecological footprint analysis measures the environmental impact of human activities by accounting for the demand on natural resources and the ecosystems' capacity to regenerate these resources, providing a framework for assessing the sustainability of economic activities, including tourism and financial development [90,91]. These theories collectively offer a robust foundation for understanding and addressing the challenges of sustainable development in Southeast Asia.

3.2.3. *Cross-sectional dependence*

To address cross-sectional dependence in the panel data, the study employs Pesaran's (1999b) cross-sectional dependence (CD) test. This test is appropriate for panels with large numbers of cross-sectional units (N) and time periods (T), providing a robust method to detect the presence of cross-sectional dependence. The CD test statistic is based on the average of pairwise correlation coefficients of the residuals from individual OLS regressions [92,93]. The null hypothesis is cross-sectional independence. Using the STATA application with the syntax "xtcsd", including the abs option in the xtcsd command, we can get the average absolute correlation of the residuals. Here, the average absolute correlation is 0.430, which is a very high value. Hence, there is enough evidence suggesting the presence of cross-sectional dependence.

xtcsd, pesaran abs.

Pesaran's test of cross-sectional independence = 31.538, Pr = 0.0000.

The average absolute value of the off-diagonal elements = 0.430.

3.2.4. *The panel ARDL model*

The panel ARDL model employed in this study is expressed in equations (1) and (2). A general form of ARDL model for t = 1, 2, …, T periods and i = 1, 2, …, N groups is given in (1):

$$\text{ARDL}\,(\text{p},\text{q},\text{q},..,\text{q}):Y_{\text{i,t}}=\sum_{k=1}^{p}\lambda_{ik}Y_{i,t-k}+\sum_{k=0}^{q}\delta_{ik}\text{X}_{i,t-k}+\omega_i+\varepsilon_{\text{i,t}} \tag{1}$$

Where Xit is vector of explanatory variables for group i, λik is coefficient of lagged dependent variable, δik is coefficient vectors, ωi is group-specific fixed effects error term, and εit is error term.

From the equation above, we have the panel ARDL VEC model, including long run and short run, as follows:

$$Y_{\text{i,t}}=\sum_{k=1}^{p-1}\lambda_{ik}\Delta Y_{i,t-k}+\sum_{k=0}^{q-1}\delta_{ik}\Delta\text{X}_{i,t-k}+\varphi_i\left(Y_{i,t-1}+\beta_iX_{i,t}\right)\omega_i+\varepsilon_{\text{i,t}} \tag{2}$$

Where λik, δik is the short run, φ is group specific error-correction coefficient and βi is the vector of long run coefficients.

For a comprehensive analysis, model (3) is used to determine the effect of time series on the environment. The model is converted into a logarithmic form of tourism growth (TOUR) and CO_2 emission in equation (4). The logarithmic form is used for several reasons, including capturing non-linear relationships, normalizing skewed data, addressing heteroscedasticity issues, and simplifying result interpretation by expressing coefficients as elasticities [94].

$$\text{ECO} = \text{f (LNTOUR, FDI, REN, LNC02)} \tag{3}$$

$$\text{ECO}_{\text{i,t}}=\delta 0+\delta 1 LNTOUR_{\text{i,t}}+\delta 2 FDI_{\text{i,t}}+\delta 3 REN_{\text{i,t}}+\delta 4 LNCO2_{\text{i,t}}+\varepsilon_{\text{i,t}} \tag{4}$$

Equation (4) explains the econometric model of variable relationships, where LN denotes the natural logarithm of tourism growth (TOUR) and CO_2 emissions (CO2). ECO represents ecological footprint consumption, FDI is the financial development index, and REC represents renewable energy consumption. The subscript ti of each variable indicates the time dimension and country of the respective variable. $\delta 0$ represents the intercept terms of the functions, $\delta 1$ to $\delta 4$ indicate the regressors' elasticity, and εt indicates the stochastic error term.

To apply the model to this study on sustainable development, we employ a system of panel ARD-VEC models involving the ecological footprint (5) as the dependent variable. Additionally, Xi denotes the independent variables as listed below:

$$ECO_{\text{i,t}}=\sum_{k=1}^{p-1}\lambda_{ik}\Delta ECO_{i,t-k}+\sum_{k=0}^{q-1}\delta_{ik}\Delta\text{X}_{i,t-k}+\varphi_i\left(ECO_{i,t-1}+\beta_iX_{i,t}\right)\omega_i+\varepsilon_{\text{i,t}} \tag{5}$$

3.3. *Empirical methodology*

Panel Auto Regressive Distributed Lag (ARDL) estimation is a powerful tool for analyzing relationships between variables in panel data. The process involves 8 steps: (1) Model specification, (2) Data description, (3) Correlation analysis, (4) Unit root testing, (5) Hausman Test, (6) Cointegration testing, (7) Model estimation, and (8) Causality testing. These steps involve selecting dependent and independent variables and their lags, describing the panel dataset, analyzing correlation coefficients, performing unit root tests, choosing between fixed or random effects models, performing cointegration tests, estimating the model using appropriate panel data methods, and performing causality tests to determine directional influences between variables.

4. Result and discussion

The study on sustainable development in Southeast Asia, focusing on the interconnected relationships between tourism development, financial development, green energy, carbon dioxide emissions, and environmental conservation, faces a significant challenge known as multicollinearity. Multicollinearity occurs when there is a high degree of correlation among the independent variables in a regression model. In this context, the study aims to understand the complex interplay between various factors influencing sustainable development in the region. However, the presence of multicollinearity can complicate the interpretation of the relationships between these variables, potentially leading to unreliable and imprecise estimates of their individual effects.

To assess the extent of multicollinearity in the study, Variance Inflation Factors (VIFs) have been calculated for each independent variable. The VIF measures the inflation in the variances of the regression coefficients due to multicollinearity. Looking at the results in Table 2, all variables exhibit centered VIF values below 5, indicating having no multicollinearity.

4.1. Descriptive statistics

The descriptive statistics in Table 3 reveal insights into five variables: Ecological Footprint (ECO), Tourism Development (LNTOUR), Financial Development Index (FDI), Renewable Energy Consumption (REN), and CO_2 emissions (LNC02). ECO shows significant variation with a positively skewed distribution and heavy tails. LNTOUR has a higher mean, potentially indicating concentrated development in tourist destinations but lacks significant outliers. FDI is skewed towards lower values, suggesting uneven financial development. REN has a substantial mean with a symmetric distribution. LNC02 has a moderately high mean, with a negatively skewed distribution and heavy-tailed outliers. In summary, these statistics highlight the diversity and distribution of these variables. Further analysis is needed to understand their relationships and patterns, considering potential outliers and correlations, and accounting for departures from normality in statistical methods.

4.2. Correlation analysis

The correlation analysis among tourism development (LNTOUR), financial development index (FDI), renewable energy consumption (REN), CO_2 emissions (LNC02), and ecological footprint (ECO) provides valuable insights into their interactions within the context of ecological sustainability. LNTOUR demonstrates a positive correlation with ECO (0.351), indicating that a 1 % increase in tourism development is associated with a 0.35 % higher ecological footprint. The results of this study are consistent with those of Acar et al. (2015), Ansari & Villanthenkodath (2021), Ozturk et al. (2016), Qureshi et al. (2019), and Mikayilov et al. (2019) mentioned in section 2. Tourism in ASEAN, while driving economic growth, poses environmental challenges and leaves behind significant ecological footprints. The influx of tourists generates substantial amounts of solid waste, including plastic packaging, food scraps, and non-biodegradable materials, leading to the pollution of waterways, landfills, and fragile natural habitats. Additionally, tourism development often entails the construction of infrastructure, including roads, resorts, and hotels, which fragment natural habitats and disrupt ecosystems, resulting in biodiversity loss. Furthermore, tourism activities contribute significantly to energy consumption, leading to increased greenhouse gas emissions and exacerbating climate change. This suggests that the expansion of tourism in certain regions may exert environmental pressure, possibly due to increased resource consumption and emissions linked to tourism activities.

FDI exhibits a stronger positive correlation with ECO (0.648), implying that countries with higher financial development tend to have larger ecological footprints. Specifically, a 1 % increase in FDI corresponds to a 0.648 % increase in ECO. Our findings are in line with the results obtained by Baloch et al. (2019) and Saud et al. (2020) in Belt and Road nations, Ahmed et al. (2021) in Japan,

Table 2
Variance inflation factors.

Variable	Coefficient	Std. Error	t-Statistic	Prob.	Centered VIF
LNTOUR	0.018123	0.005665	3.198912	0.0015	**1.256889**
FDI	2.505339	0.315148	7.949724	0.0000	**3.696813**
REN	−0.012045	0.001623	−7.419832	0.0000	**2.030591**
LNC02	−0.051081	0.019309	−2.645510	0.0084	**2.388240**
C	1.291504	0.135122	9.558068	0.0000	**NA**
Root MSE	0.776834	R-squared		**0.536168**	
Mean dependent var	1.232418	Adjusted R-squared		**0.532108**	
S.D. dependent var	1.141874	S.E. of regression		0.781072	
Akaike info criterion	2.354465	Sum squared resid		278.8037	
Schwarz criterion	2.399222	Log likelihood		−538.8814	
Hannan-Quinn criter.	2.372086	F-statistic		132.0675	
Durbin-Watson stat	0.076080	Prob(F-statistic)		0.000000	

Note: Dependent variable: ECO.
Note: Dependent variable: ECO.
Source: Own elaboration.

Table 3
Descriptive statistics.

Elements	ECO	LNTOUR	FDI	REN	LNC02
Mean	1.232418	9.443687	0.283307	38.10651	9.416914
Median	0.717372	13.59789	0.297972	33.78500	10.13002
Maximum	5.236752	17.50229	0.831252	94.53600	13.31346
Minimum	0.158569	0.000000	0.000000	0.000000	0.000000
Std. Dev.	1.141874	7.198914	0.221942	31.93324	2.911595
Skewness	1.583243	−0.480187	0.581183	0.250294	−1.531846
Kurtosis	4.507777	1.352724	2.432870	1.645072	5.755005
Jarque-Bera	236.7755	69.98979	32.20005	40.16355	326.7930
Probability	0.000000	0.000000	0.000000	0.000000	0.000000
Sum	569.3770	4362.983	130.8879	17605.21	4350.614
Sum Sq. Dev.	601.0873	23891.03	22.70811	470096.2	3908.075
Observations	462	462	462	462	462

Source: Own elaboration.

Kihombo et al. (2021a) in West Asia and Middle East countries and Ngoc & Awan (2022) in BICS economies. The larger ecological footprints associated with higher financial development stem from several factors. First, increased wealth and income levels fuel elevated consumption patterns, driving up the demand for resource-intensive goods and services with significant environmental impacts. Second, the growth of resource-intensive industries, characteristic of developing economies, exacerbates the ecological impact due to their high resource consumption, energy demands, and waste generation. Third, as economies progress, the reliance on fossil fuels for energy intensifies, contributing to environmental degradation and greenhouse gas emissions. Fourth, rapid urbanization and infrastructure development, hallmarks of economic growth, lead to habitat destruction, deforestation, and alterations in natural landscapes. Fifth, technological advancements, while driving economic growth, may not always be environmentally friendly, with some contributing to pollution and resource depletion. Sixth, globalization, a feature of financially developed economies, increases the ecological footprint through the transportation of goods over long distances. Finally, in some cases, higher financial development may be associated with weaker environmental regulations or lax enforcement, allowing businesses to operate with fewer constraints on their ecological impact. This finding raises concerns about the environmental impact of economic activities in financially developed nations, emphasizing the importance of sustainable practices in these contexts.

Conversely, REN reveals a substantial negative correlation with ECO (−0.636), indicating that a 1 % greater adoption of renewable energy sources is associated with a 0.636 % reduction in ecological footprint. This research yields similar results to the study conducted by Wang & Dong [95], Alola et al. (2019), Destek & Sinha (2020) and Adedoyin et al. (2020). Renewable energy consumption significantly diminishes the ecological footprint by mitigating reliance on fossil fuels and curbing environmental degradation. Unlike non-renewable sources, renewable energy, derived from sunlight, wind, and hydropower, generates power without emitting harmful greenhouse gases. This transition fosters a sustainable energy paradigm, minimizing air and water pollution while mitigating climate change impacts. Additionally, renewable technologies often have lower ecological impacts throughout their life cycles compared to conventional energy sources. This is an encouraging result, highlighting the potential for renewable energy to mitigate the environmental consequences of energy consumption and contribute to sustainable development.

LNC02 (CO2 emissions) displays a relatively weak positive correlation with ECO (0.260), suggesting that a 1 % increase in CO_2 emissions is associated with a 0.26 % higher ecological footprint. The results of this study are consistent with those of Anser et al. (2021), Awosusi et al. (2023), Bhowmik et al. (2022), Boontome et al. (2017), Dissanayake et al. (2023), Syed et al. (2022) and Syed &

Table 4
Correlation analysis.

Variable	ECO	LNTOUR	FDI	REN	LNC02
ECO	1.000000				
	–				
	–				
LNTOUR	0.350974	1.000000			
	[8.038956]	–			
	(0.0000)	–			
FDI	0.648296	0.437388	1.000000		
	[18.26192]	[10.43169]	–		
	(0.0000)	(0.0000)	–		
REN	−0.636018	−0.215024	−0.585248	1.000000	
	[-17.67725]	[-4.722208]	[-15.48019]	–	
	(0.0000)	(0.0000)	(0.0000)	–	
LNC02	0.259978	0.373885	0.658501	−0.079705	1.000000
	[5.774464]	[8.645987]	[18.76647]	[-1.714935]	–
	(0.0000)	(0.0000)	(0.0000)	(0.0870)	–

Note: The value in [.] and (.) denote t-statistic and probability, respectively.
Source: Own elaboration.

Bouri (2022). In the ASEAN region, CO_2 emissions exhibit a relatively weak positive correlation with the ecological footprint due to a combination of factors. The diverse economic structures within ASEAN member states, ranging from heavily industrialized nations to those with primarily agrarian economies, contribute to variations in emissions per capita. Additionally, some ASEAN countries prioritize sustainable practices and renewable energy sources, mitigating the environmental impact of economic activities. The region's reliance on carbon-neutral sectors, such as agriculture and forestry, further influences the disconnect between CO_2 emissions and ecological footprints. Disparities in regulatory frameworks, coupled with efforts to balance economic growth and environmental sustainability, result in a nuanced relationship between CO_2 emissions and ecological footprints across the diverse landscape of ASEAN nations. Although this connection is not as pronounced as others, it underscores the need to address emissions as a critical factor in ecological sustainability.

In conclusion, the correlation analysis reveals complex relationships among these variables, making the achievement of ecological sustainability a multifaceted challenge. While tourism and financial development may present environmental challenges, the adoption of renewable energy holds promise for reducing ecological footprints. Nonetheless, these findings emphasize the importance of integrated policies and sustainable practices to balance economic growth with environmental conservation and to mitigate the impact on ecological footprints. The results of correlation analysis are presented in Table 4.

4.3. Unit root tests

Prior to investigating the enduring and immediate connections among the ecological footprint and other factors that explain it, it is imperative to conduct a stationarity assessment on the variables within the panel data. This process is vital to assure the credibility of outcomes derived from panel data analysis. Stationarity tests are devised to detect whether variables exhibit stationarity, a condition in which variables demonstrate trends or patterns that might lead to false associations, thus jeopardizing causal connections and statistical conclusions. By confirming stationarity, we can prevent spurious regression, assure precise interpretation, establish causation, and enhance the stability of the model. Ultimately, this safeguards the legitimacy and resilience of findings in studies employing panel data [96,97].

There are several panel unit root tests available, such as Augmented Dickey-Fuller (ADF) test [98], Phillip Perron (PP) test [99], Levin, Lin & Chu (LLC) test [100], and Im, Pesaran and Shin [101] (IPS) test [102]. The assessment of stationarity or the existence of unit roots is based on a comparison between the absolute *p*-value obtained from these tests and a significance threshold of either 0.01 or 0.05. When the absolute *p*-value resulting from the LLC, IPS, ADF, or PP test is lower than this specified threshold, it indicates that the variable under examination is deemed stationary or devoid of unit roots. Conversely, if the absolute *p*-value surpasses the 0.05 critical level, it signifies that the variable being tested is regarded as non-stationary or possessing unit roots.

As depicted in Table 5, the ecological footprint, renewable energy consumption, financial development, CO_2 emissions, and tourism growth all exhibit stationarity when assessed at the first difference, signifying statistical significance at the 0.01 confidence level. Additionally, the ecological footprint, CO_2 emissions, and tourism growth are also stationary at a fundamental level. Consequently, the majority of these series demonstrate stationarity at the first difference. Given these findings, it is advisable to proceed with additional

Table 5
Unit root test results.

Series in level	ECO		LNTOUR		FDI		REN		LNCO2	
	In	Tr	In	Tr	In	Tr	In	Tr	In	Tr
LLC	2.93	−3.00	−1.45	3.11	0.03	−0.21	0.54	−0.03	−2.93	−0.73
Prob	0.998	0.001	0.073	0.999	0.515	0.413	0.707	0.485	0.001	0.232
IPS	4.39	−0.84	0.68	2.47	1.24	−0.40	2.83	1.39	0.07	0.64
Prob	1.000	0.200	0.752	0.993	0.894	0.342	0.997	0.918	0.530	0.742
ADF	7.60	27.44	11.13	5.21	16.99	24.28	20.40	19.44	56.16	20.72
Prob	0.998	0.194	0.972	0.999	0.763	0.332	0.557	0.617	0.000	0.538
PP	9.43	32.73	10.59	5.84	17.18	29.65	19.62	11.11	109.77	98.72
Prob	0.990	0.065	0.980	0.999	0.753	0.127	0.606	0.973	0.000	0.000
Series in first difference	ECO		LNTOUR		FDI		REN		LNCO2	
	In	Tr	In	Tr	In	Tr	In	Tr	In	Tr
LLC	−9.69	−8.81	−13.45	−12.83	−12.74	−11.47	−7.82	−8.16	−4.17	−3.57
Prob	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IPS	−12.54	−12.71	−10.55	−8.87	−13.60	−12.48	−8.10	−7.70	−7.16	−7.76
Prob	0.000	0.000	0.000	0.000	0.000	0.0000	0.000	0.000	0.000	0.000
ADF	184.11	174.86	147.11	112.0	200.42	168.54	111.83	99.53	96.58	103.04
Prob	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PP	350.40	185.80	268.65	224.96	338.47	792.21	224.88	224.29	201.26	435.35
Prob	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: In: Intercept; Tr: Trend; P: Probability; LLC: Levin, Lin & Chu statistic; IPS: Im, Pesaran and Shin W-stat; ADF: ADF - Fisher Chi-square; PP: Phillips-Perron - Fisher Chi-square.
Source: Own elaboration.

testing to explore the enduring connections between these variables in the long term.

4.4. Cointegration test

Once we've ensured that all variables have undergone differencing to achieve first-order integration, the subsequent step involves examining the presence of cointegration, which signifies enduring relationships among these variables. To do this, we utilize the Panel ARDL bound test, designed to detect cointegration within panel data that encompasses multiple variables across various time periods and entities. This test serves several pivotal purposes: it determines the appropriate lag structure, validates the existence of long-term equilibrium relationships, aligns with established economic theories, confirms the validity of the econometric models in use, and enhances our understanding of complex economic interactions. We employ two widely recognized panel cointegration tests, originally introduced by Pedroni [103] and Kao [104], due to their comprehensive and widely applicable nature. The Pedroni Residual cointegration test is conducted both within and between groups, and the resulting findings are elaborated in the table for reference.

Based on the outcomes of our analysis, we need to evaluate the null hypothesis associated with each statistic, which posits the absence of cointegration, to determine whether we should reject this null hypothesis. Among the array of statistics considered, panel rho-statistic, panel PP-statistic and panel ADF-statistic are considered reliable indicators.

In our findings related to the intercept, we reject the null hypothesis of no cointegration at a 1 % significance level using the panel rho-statistic, panel PP-statistic, and panel ADF-statistic for both within and between groups. Additionally, we reject the null hypothesis of no cointegration at a 5 % significance level based on the Panel v-Statistic within the between-group model. When considering both the intercept and trend, both the panel PP-statistic and panel ADF-statistic reject the null hypothesis at a 1 % significance level within and between groups. Furthermore, we can reject the null hypothesis within the between-group model based on the panel v-statistic at a 1 % significance level and within the within-group model using the panel rho-statistic at a 5 % significance level. Consequently, we can confidently affirm the presence of cointegration and a long-term relationship among the variables in the ecological footprint model. Cointegration test is illustrated in Table 6.

4.5. The mean group estimator (MG), Pooled Mean Group (PMG) estimator, dynamic fixed effect estimator (DFE) and Hausman test

The Pooled Mean Group Estimator (PMG): PMG is a method that keeps the long-term slope coefficients the same for all countries but allows short-term coefficients and error variations to be different across countries [93]. It is useful when we assume that long-term relationships between variables are consistent across countries or a subgroup of them. However, there are specific conditions that must be met to ensure the reliability, consistency, and effectiveness of this methodology. First, for the existence of a long-term relationship among the variables of interest, it is essential that the coefficient on the error-correction term is negative and not lower than −2. Second, for the ARDL model to be consistent, it is crucial that the resulting residuals of the error-correction model are serially uncorrelated and the explanatory variables can be considered exogenous. These conditions can be satisfied by including ARDL (p,q) lags for both the dependent (p) and independent (q) variables in the error correction form. Third, the relative sizes of T (time periods) and N (number of entities or countries) are crucial. When both T and N are large, it allows the use of dynamic panel techniques, which helps mitigate bias in the average estimators and addresses the issue of heterogeneity. Eberhardt [105] and Eberhardt & Teal [106] emphasize that dealing with heterogeneity is fundamental to understanding the growth process. Failing to meet these conditions can lead to inconsistent estimates in PMG.

The Mean Group Estimator (MG): The MG method, introduced by Pesaran & Smith (1995), involves estimating separate regressions for each country and then averaging the coefficients from these regressions. This approach does not impose any restrictions, allowing for variability and differences in all coefficients, both in the long-run and short-run. However, to ensure the consistency and validity of

Table 6
Cointegration test results.

	Intercept		Intercept and trend	
	Statistic	Prob.	Statistic	Prob.
Pedroni Residual cointegration test				
Within group				
Panel v-Statistic	0.020741	0.4917	−1.605849	0.9458
Panel rho-Statistic	−4.034947	0.0000	−1.886273	0.0296
Panel PP-Statistic	−7.409142	0.0000	−6.822903	0.0000
Panel ADF-Statistic	−7.754156	0.0000	−7.874324	0.0000
Between group				
Panel v-Statistic	1.456236	0.0402	−0.538769	0.0000
Group rho-Statistic	−1.716012	0.0031	−0.516223	0.3028
Group PP-Statistic	−5.531145	0.0000	−4.997727	0.0000
Group ADF-Statistic	−5.537983	0.0000	−5.412288	0.0000
Kao test	−0.272997	0.3924		

Note: Null hypothesis: no cointegration; ***, ** and * indicate that the estimated parameters reject the null hypothesis of no cointegration at 1 %, 5 % and 10 %.
Source: Own elaboration.

this approach, it is crucial to have a sufficiently large time-series dimension in the data. The cross-country dimension should also be substantial, ideally including around 20 to 30 countries. Additionally, for smaller N, the average estimators (MG) in this approach can be sensitive to outliers and small variations in the model [107].

The Dynamic Fixed Effect Estimator (DFE): The DFE estimator closely resembles the PMG estimator, as both require uniformity in slope coefficients and error variances across all countries in the long-run. In the DFE model, there is an additional requirement that the speed of adjustment coefficient and the short-run coefficient must be identical. Despite the inclusion of country-specific intercepts, this model remains effective. Additionally, Blackburne & Frank [108] introduced a cluster option for DFE, allowing researchers to estimate intra-group correlation along with standard errors, making it a valuable research tool. However, it is worth noting that Baltagi et al. [109] point out that this model may be subject to a simultaneous equation bias in the case of small sample sizes due to endogeneity between the error term and the lagged dependent variable.

When examining a sample of ASEAN countries, we initially expect these countries to have a similar ecological footprint consumption pattern. However, in the short term, variations may occur due to the influence of local laws and regulations specific to each country. The PMG estimator is preferred over MG estimators, assuming long-term homogeneity, as it provides more efficient estimates. Additionally, given that our study spans 41 years, the MG estimator may suffer from limited degrees of freedom. Therefore, PMG estimation is more suitable for this analysis. To determine the choice among MG, PMG, and DFE methods, we employ the Hausman test as proposed by Hausman in 1978 and updated in 2015 [110], which assesses whether there is a significant difference between these estimators. The null hypothesis of this test is that the difference between PMG and MG or PMG and DFE estimation is not significant. If we fail to reject the null hypothesis, we recommend using the PMG estimator for its efficiency [111]. Conversely, if the null hypothesis is rejected, indicating a significant difference, we consider using MG or DFE estimators. It is important to note that if there are outliers, the average estimator may have a high variance, potentially reducing the power of the Hausman test. Therefore, we choose PMG when the *p*-value is not significant at the 5 % level and opt for MG or DFE if the *p*-value is significant. Based on the results presented in Table 7, it is recommended to use the PMG estimator for our panel ARDL model.

4.6. Estimated model - PMG results

In order to identify the impact of the variables of interest, error correction based on autoregressive distributed lag ARDL (p,q) model has been used, with focus on the exclusive feature of PMG model over the other error-correction based estimations, MG and DFE. Table 8 reports the results of PMG estimation in the long run and short run and Table 9 illustrate for individual country.

According to the PMG estimator as presented in Table 8, financial development has no long-term impact and a significant negative short-term impact on the ecological footprint. This is consistent with the finding of Baloch et al. (2019), who discovered that financial development increases the ecological footprint in BRI countries. Kihombo et al. (2021) also found that financial development increases the level of the ecological footprint, suggesting that financial development contributes to ecological degradation in West Asia and Middle East nations. In contrast, Sabir et al. [112] discovered an inverted U relationship between financial development and the ecological footprint of Asia-Pacific Economic Cooperation countries. Ashraf [113] noted that there is a significant difference in the impact of the development of financial institutions and financial markets on the ecological footprints of different countries worldwide. From the perspective of ASEAN countries, this can be explained by the fact that most ASEAN countries are developing countries, and FDI worsens environmental quality by increasing CO_2 emissions [114]. On the other hand, financial development in ASEAN often leads to increased consumption, urbanization, and industrialization, which raises the ecological footprint. As incomes rise, people consume more resource-intensive products, driving resource extraction and waste. Infrastructure and industrial expansion, if not managed sustainably, can harm the environment. As a result, balancing economic growth with ecological sustainability is a major challenge for ASEAN countries.

Tourism initially shows no immediate impact but has a slightly negative long-term effect on the ecological footprint in ASEAN. An increasing 1 % in tourism growth is associated with a 0.3 % decrease in the ecological footprint, as supported by studies like Kongbuamai et al. (2020) and Hoang Ngoc [115]. However, on a global scale, this finding contrasts with Lee & Chen (2021), who suggest that tourism has shifted towards promoting environmentally harmful behaviors, such as reducing forest and grazing land. Tourism in the ASEAN region is a complex issue with both short-term and long-term ecological implications. It is essential to understand that these impacts can vary widely depending on specific circumstances and a range of factors. While the long-term effect of tourism on the ecological footprint in ASEAN may not seem strongly significant at first glance, it is crucial to recognize the potential negative consequences that can accumulate over time. Continuous tourism development can result in habitat destruction, increased resource consumption, and pollution. However, these impacts may not be immediately obvious, as other, larger-scale environmental factors like industrialization and urbanization can overshadow them. Nevertheless, it is encouraging to note that some ASEAN countries are taking proactive measures to encourage sustainable tourism practices, promote conservation efforts, and implement environmental

Table 7
PMG hausman specification test.

PMG Hausman Specification Test			
Null hypothesis: Estimator is statistically similar to the PMG estimator			
Estimator	Stat.	DOF	p-Value
Mean Group	5.0582	5	0.40881

Source: Own elaboration.

Table 8
ARDL-PMG long run and short run estimates.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Long-run (Pooled) Coefficients				
LNTOUR	−0.003**	0.001	−1.953	0.050
FDI	0.487	0.418	1.165	0.244
REN	−0.003**	0.001	−1.985	0.047
LNC02	0.090***	0.024	3.739	0.000
C	0.142	0.255	0.559	0.575
Short-run (Mean-Group) Coefficients				
COINTEQ	−0.063**	0.044	−1.446	0.014
D(ECO(-1))	−0.134**	0.068	−1.964	0.050
D(FDI)	0.897**	0.608	1.475	0.014
D(LNC02)	0.676**	0.305	2.217	0.027

Log-Likelihood: 637.0704; Estimator: Pool Mean Group; Dependent Variable: D(ECO); Model selection method: Akaike info criterion (AIC); Selected model: MG (2,0,1,0,1).
Note: ***, **, and * represent 1 %, 5 % and 10 % level of significance, respectively; prob. indicates probability value.
Source: Own elaboration.

Table 9
ARDL-PMG short run estimates, individual country.

Country	COINTEQ	D(ECO (−1))	D(FDI)	D(LNC02)
Brunei	0.003	−0.421**	1.853	1.815**
	(0.909)	(0.015)	(0.188)	(0.023)
Vietnam	0.028**	0.027	−0.125	0.516***
	(0.036)	(0.804)	(0.188)	(0.000)
Malaysia	−0.032	−0.613***	0.725	1.460***
	(0.422)	(0.005)	(0.310)	(0.001)
Indonesia	−0.002	−0.129	−0.115	0.234***
	(0.879)	(0.397)	(0.434)	(0.009)
Thailand	−0.086*	0.024	−0.392	−0.007
	(0.093)	(0.872)	(0.179)	(0.958)
Philippines	−0.004	0.065	0.134	0.158*
	(0.674)	(0.686)	(0.531)	(0.076)
Singapore	−0.007	−0.121	1.681	3.076**
	(0.776)	(0.412)	(0.241)	(0.005)
Laos	−0.036	−0.093	−0.285	0.152**
	(0.553)	(0.603)	(0.439)	(0.014)
Timor-Leste	−0.039	−0.325**	6.493***	−0.091***
	(0.343)	(0.039)	(0.009)	(0.010)
Cambodia	−0.494***	0.024	−0.465*	0.095***
	(0.000)	(0.712)	(0.096)	(0.006)
Myanmar	−0.029**	0.084	0.373	0.033
	(0.039)	(0.588)	(0.196)	(0.179)

Note: The value in (.) denotes probability; ***, **, * represent 1 %, 5 %, and 10 % level of significance, respectively.
Source: Own elaboration.

regulations to address and mitigate the long-term ecological footprint.

By analyzing the impact of renewable/alternative energy use on the ecological footprint in the ASEAN countries, our results verify that renewable energy is an important factor in increasing environmental quality. Particularly, it is observed that with a positive 1 % boost in renewable energy consumption, the ecological footprint abates by 0.3 % in the long run. However, there is insignificant change in the short term. Renewable energy consumption in ASEAN initially has no immediate impact due to the need for infrastructure investments and the coexistence of fossil fuel sources. However, in the long term, it exhibits a weakly significant negative impact on the ecological footprint. As renewable technologies mature and replace fossil fuels, they contribute to reduced greenhouse gas emissions and pollution, mitigating environmental harm over time. Nevertheless, the pace of this transition varies across ASEAN countries, and the overall ecological footprint is influenced by multiple factors beyond energy consumption, including agriculture and land use. The outcomes of this study align with and corroborate the previous findings of Sahoo & Sethi [116], Sun et al. [117], Li et al. [118], and Alper et al. [119].

CO_2 emissions play a pivotal role in elevating the ecological footprint, a finding corroborated by Rüstemoğlu (2022) in both the short and long term. Specifically, a 1 % increase in CO_2 emissions corresponds to a 0.9 % increase in the ecological footprint over the long run and a more substantial 6.76 % increase in the short term. Non-renewable energy consumption exacerbates this environmental impact by generating CO_2 emissions, as noted by Alola et al. [120]. The globalization-driven surge in CO_2 emissions, as highlighted by Pata [121], significantly diminishes environmental quality. Consequently, the rise in CO_2 emissions within the ASEAN region yields short-term consequences like air and water pollution, deforestation, and land use changes that collectively amplify the ecological footprint. Over the long haul, heightened CO_2 levels lead to climate change, biodiversity depletion, resource depletion, health challenges, and economic repercussions, further exacerbating the ecological footprint.

Table 9 illustrates ARDL-PMG short run estimates in individual country. Obviously, tourism has no distribution to the raise of ecological footprint in every country in ASEAN.

The results indicate that tourism development (LNTOUR) and financial development (FDI) both have positive and significant impacts on the ecological footprint (ECO), highlighting the environmental costs associated with increased tourism activities and economic growth facilitated by improved access to capital. This aligns with economic theories suggesting that higher resource consumption and industrial activities strain environmental resources, supported by previous studies such as Katircioglu [122]. Conversely, renewable energy consumption (REN) demonstrates a negative and significant impact on the ecological footprint, consistent with the hypothesis that renewable energy sources reduce environmental degradation by lowering reliance on fossil fuels and greenhouse gas emissions, as corroborated by Sadorsky (2009).

Furthermore, the positive relationship between CO_2 emissions (LNC02) and the ecological footprint reinforces the direct link between carbon-intensive activities and environmental degradation, aligning with the Environmental Kuznets Curve (EKC) theory [84]. These findings underscore the critical balance between economic development and environmental sustainability in Southeast Asia. Efforts should focus on enhancing renewable energy adoption and mitigating the environmental impacts of tourism and financial development to ensure sustainable growth in the region. This comprehensive view of the dynamic interactions between tourism, financial development, renewable energy consumption, CO_2 emissions, and the ecological footprint highlights the importance of integrating environmental considerations into economic planning and development strategies.

4.7. Pairwise Dumitrescu Hurlin panel causality tests

In the final phase of our research, we examined the directional relationship between variables using the panel Granger causality analysis. Traditionally, Granger causality tests were conducted based on a uniform panel assumption with consistent intercepts and slopes, which was standard for analyzing panel data [123]. However, recent studies in the context of ecological footprint [114,124] have transitioned towards the Dumitrescu-Hurlin heterogeneous panel causality test introduced by Dumitrescu & Hurlin (2012). This method is more adaptable to the heterogeneity commonly observed in ecological footprint trends across various countries. It modifies both the regression model and the causality relationship to account for this heterogeneity, as outlined by Dumitrescu & Hurlin (2012).

$$Y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_{ik} Y_{i,t-k} + \sum_{k=1}^{K} \beta_{ik} X_{i,t-k} + \varepsilon_{i,t} \tag{6}$$

where X and Y represent two stationary variables for country i in year t, αi is the individual fixed effect, βi = (βi1, …, βiK) are slope parameters, and γi = (γi1, …, γiK) are lag parameters. The model allows βik and γik to vary across cross sections while remaining constant over time.

The Dumitrescu-Hurlin panel causality test is a method used to determine if a causal relationship exists across different sections within a panel. The null hypothesis, also referred to as the homogeneous noncausality hypothesis (H0: βi = 0 for i = 1, 2, …, N), posits that there is no causality across the panel. On the other hand, the alternative hypothesis (H1: βi = 0 for i = 1, …, N1 and i = N1 + 1, …,

Table 10
Pairwise Dumitrescu hurlin panel causality tests.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
LNTOUR does not homogeneously cause ECO	3.248*	1.658	0.097
ECO does not homogeneously cause LNTOUR	2.622	0.737	0.461
FDI does not homogeneously cause ECO	7.685***	8.187	0.000
ECO does not homogeneously cause FDI	2.791	0.986	0.324
REN does not homogeneously cause ECO	11.239***	13.416	0.000
ECO does not homogeneously cause REN	3.135	1.491	0.136
LNC02 does not homogeneously cause ECO	10.026***	11.632	0.000
ECO does not homogeneously cause LNC02	3.323*	1.768	0.077
FDI does not homogeneously cause LNTOUR	33.152***	45.662	0.000
LNTOUR does not homogeneously cause FDI	4.416***	3.378	0.001
REN does not homogeneously cause LNTOUR	4.175***	3.022	0.003
LNTOUR does not homogeneously cause REN	1.895	−0.333	0.739
LNC02 does not homogeneously cause LNTOUR	2.917	1.171	0.242
LNTOUR does not homogeneously cause LNC02	1.541	−0.854	0.393
REN does not homogeneously cause FDI	3.327*	1.774	0.076
FDI does not homogeneously cause REN	2.476	0.523	0.601
LNC02 does not homogeneously cause FDI	5.442***	4.886	0.000
FDI does not homogeneously cause LNC02	2.157	0.053	0.958
LNC02 does not homogeneously cause REN	3.907***	2.628	0.009
REN does not homogeneously cause LNC02	3.308*	1.746	0.081

Note: ***, ** and * denote 1 %, 5 % and 10 % level of significance, respectively.
Source: Own elaboration.

N) proposes that there is causality in at least one section. To evaluate the null hypothesis, Dumitrescu and Hurlin [125] compute individual Wald statistics and Zbar-statistics for each section. They then calculate the Wald test statistic and Zbar-statistics for the entire panel by averaging all individual values. The findings of the causality test are then tabulated.

The Granger causality test results reveal significant relationships between variables, presented in Table 10. There is unidirectional causality from tourism development, financial development, and renewable energy consumption to ecological footprint. Similarly, unidirectional causality is observed from renewable energy to tourism development and financial development, with one-way causality from CO_2 emissions to financial development. Bidirectional causality exists between CO_2 emissions and ecological footprint, between tourism development and financial development, and between CO_2 emissions and renewable energy consumption. In summary, financial development influences ecological footprint and tourism, while renewable energy affects ecological footprint, tourism, and financial development. Carbon dioxide emissions impact environmental degradation, financial development, and renewable energy consumption. Finally, tourism growth influences ecological footprint and finance. This study again confirms the findings that tourism development is associated with ecological footprint by Acar et al. (2015), Ansari & Villanthenkodath (2021a), Ozturk et al. (2016), Qureshi et al. (2019), and Mikayilov et al. (2019); financial development corresponds to increase in ecological footprint by Baloch et al. (2019a), Saud et al. (2020), Ahmed et al. (2021), Kihombo et al. (2021a) and Ngoc & Awan (2022); greater consumption of renewable energy sources will decrease ecological footprint by Wang & Dong [126], Destek & Sinha (2020) and Adedoyin et al. (2020); and greater CO_2 emissions are associated with higher ecological footprints by those of Anser et al. (2021), Awosusi et al. (2023), Bhowmik et al. (2022), Boontome et al. (2017), Dissanayake et al. (2023), Syed et al. (2022), and Syed & Bouri (2022).

Thus, this research corroborates existing literature that highlights tourism's dual nature as an economic catalyst and potential environmental threat. In line with Acar et al. (2015) and Ozturk et al. (2016), the study reveals a positive correlation (0.351) between tourism expansion and ecological footprint growth, reflecting increased resource use and waste generation. This relationship is particularly evident in ASEAN countries, where rapid tourism growth has led to higher energy consumption and greenhouse gas emissions, echoing concerns raised by Mikayilov et al. (2019) about tourism sustainability.

Moreover, the study's results regarding the unidirectional causality from renewable energy to tourism growth and financial development highlight the critical role of sustainable energy practices in mitigating the environmental impacts of tourism. This finding resonates with the work of Majeed et al. (2019), who argue that financial development can facilitate investments in renewable energy, thereby promoting sustainable tourism. By integrating renewable energy solutions into tourism infrastructure, Southeast Asian nations can not only reduce their ecological footprints but also enhance the resilience of their tourism sectors against climate change impacts.

The observed bidirectional causality between CO2 emissions and the ecological footprint further underscores the complexity of these relationships. This finding is consistent with the inverted U-shaped relationship identified in previous studies, where initial economic growth and industrialization lead to increased emissions, followed by a transition towards sustainability as countries mature [60,69]. In the context of ASEAN, this suggests that while the region may currently be experiencing the negative externalities of tourism and financial growth, there is potential for a shift towards more sustainable practices as awareness and investment in environmental initiatives increase.

Finally, the study's emphasis on the unique contexts and environmental challenges faced by individual Southeast Asian nations aligns with the call for more localized research in the literature. As highlighted by Saud et al. (2020), understanding the specific socio-economic and cultural dimensions of each country is crucial for developing effective policy interventions. Future research should continue to explore these localized factors, as well as the effectiveness of existing environmental policies, to inform a more nuanced approach to sustainable development in the region.

5. Conclusion, policy implications, contributions and limitations

5.1. Conclusion

The objective of this study is to explore the interplay between the expansion of tourism, financial growth, and environmental health in Southeast Asian nations. Utilizing the Panel Auto Regressive Distributed Lag (ARDL) model, the research examines the immediate and long-term impacts of tourism growth, financial development indices, renewable energy usage, and CO_2 emissions on the ecological footprint, covering the period from 1980 to 2021. This comprehensive analysis fills notable gaps in previous studies, particularly within the specific context of ASEAN countries.

The findings affirm a significant long-term correlation between tourism growth, renewable energy usage, CO_2 emissions, and the ecological footprint. The immediate impacts of these factors on the ecological footprint are evidenced by the negative and statistically significant adjustment coefficient (error correction parameter). Notably, the short-term estimates from the ARDL-PMG model vary across individual countries, highlighting the unique contexts and environmental challenges each nation faces. The study also reveals a one-way causality from tourism growth, financial development, and renewable energy usage to the ecological footprint. Additionally, there is a unidirectional causality from renewable energy to both tourism growth and financial development, and from CO_2 emissions to financial development. Furthermore, a bidirectional causality is observed between CO_2 emissions and the ecological footprint, between tourism growth and financial development, and between CO_2 emissions and renewable energy consumption.

These findings underscore the complex and interconnected nature of tourism, financial development, renewable energy usage, and environmental health in Southeast Asia. They highlight the need for tailored policy interventions that consider both immediate and long-term impacts on the ecological footprint, thereby contributing valuable insights to the existing body of literature on sustainable development in the region.

5.2. Policy implications

The results of this study hold significant implications for policymakers and stakeholders in Southeast Asia. Given the positive impact of tourism development on the ecological footprint, it is imperative to implement sustainable tourism practices. Governments and tourism authorities should promote eco-friendly tourism initiatives, such as eco-tourism, and enforce regulations that minimize the environmental impact of tourism activities. This includes managing tourism product development at destinations and investing in providing knowledge on the principles of sustainability [127].

The relationship between financial development and the ecological footprint underscores the need for green financing mechanisms. Financial institutions should be encouraged to support environmentally sustainable projects through green bonds, sustainable investment funds, and other financial instruments that incentivize businesses to adopt eco-friendly practices. Financial policies should play a significant role in environmental health by providing incentives for businesses to adopt sustainable practices.

The negative impact of renewable energy consumption on the ecological footprint highlights the importance of accelerating the transition to renewable energy sources. Policymakers should invest in renewable energy infrastructure, provide subsidies and incentives for renewable energy projects, and promote research and development in green technologies to reduce reliance on fossil fuels and lower greenhouse gas emissions. Investment in renewable energy infrastructure is crucial, as the study reveals a one-way causality from renewable energy usage to the ecological footprint.

Furthermore, the direct link between CO_2 emissions and the ecological footprint calls for stringent environmental regulations and policies aimed at reducing carbon emissions. This includes implementing carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, to internalize the environmental costs of carbon emissions and encourage businesses to adopt cleaner technologies. Given the bidirectional causality between CO_2 emissions and the ecological footprint, it is recommended that CO_2 emissions be closely monitored and regulated, with a push towards cleaner energy sources.

Collaboration among various stakeholders, including government agencies, financial institutions, tourism operators, and the private sector, is crucial to achieving these policy goals. Environmental NGOs and community organizations should also be actively involved in raising awareness and advocating for sustainable practices. Each Southeast Asian country should develop its own strategies based on its specific context and needs, as the short-term estimates from the ARDL-PMG model vary across individual countries. By integrating environmental considerations into economic planning and development strategies, Southeast Asia can achieve a balance between economic growth and environmental sustainability, ensuring a better quality of life for future generations. Further research is encouraged to continue exploring these relationships and their implications, especially in the context of ASEAN countries.

5.3. Contributions and limitations

This study makes several noteworthy contributions to our understanding of the intricate dynamics between tourism expansion, financial growth, and environmental well-being in Southeast Asian nations. Notably, it fills critical research gaps by delving into the unique context of ASEAN countries, shedding light on previously overlooked nuances. The identification of a robust long-term correlation between tourism growth, renewable energy utilization, CO_2 emissions, and the ecological footprint underscores the imperative of sustained environmental planning and sustainable development. Furthermore, the recognition of immediate impacts, substantiated by statistically significant negative adjustment coefficients, emphasizes the urgency of environmental policy action. The study's insights into causal relationships, including unidirectional and bidirectional causality patterns, provide valuable guidance for crafting targeted strategies to mitigate environmental impact. However, the study does have limitations, including data quality and generalizability concerns, short-term variability across countries, and the complexity of causality in such multifaceted systems. Despite these limitations, the study's findings constitute a valuable foundation for informed policymaking and sustainable development efforts in Southeast Asia.

5.4. Directions for future research

Given the findings and limitations of this study, several directions for future research emerge. First, future studies should improve data quality and generalizability by incorporating comprehensive datasets, potentially from additional sources or using advanced collection techniques. Second, researchers should dive deeper into short-term variability across countries, exploring the unique contexts and environmental challenges faced by individual Southeast Asian nations. Comparative studies within the region could provide valuable insights into localized factors influencing the ecological footprint. Third, the complexity of causality in multifaceted systems warrants further investigation. Advanced econometric methods and analytical frameworks should be employed to dissect the intricate causal relationships between tourism growth, financial development, renewable energy usage, CO_2 emissions, and the ecological footprint. Longitudinal studies tracking these variables over extended periods could offer a more nuanced understanding of their interactions. Fourth, examining the role of policy interventions is crucial. Researchers should evaluate existing environmental policies' effectiveness and identify best practices adaptable across different contexts, with case studies on successful policy implementations in specific Southeast Asian countries providing practical insights. Lastly, future research should consider the socio-economic and cultural dimensions of sustainable development. Understanding how societal values, cultural practices, and economic structures influence environmental outcomes can inform the design of holistic and inclusive sustainable development strategies. Interdisciplinary approaches integrating perspectives from economics, sociology, and environmental science can enrich our understanding of sustainable development pathways in Southeast Asia. Addressing these research directions can build on this study's insights, contributing to more effective, context-specific strategies for promoting sustainable development in the region.

CRediT authorship contribution statement

Trung Ha Van: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Lee Lichang:** Supervision, Project administration, Funding acquisition. **Thuan Dang Thanh Quoc:** Writing – review & editing, Writing – original draft, Visualization, Validation, Conceptualization.

Ethical statements

Review and/or approval by an ethics committee was not needed for this study and informed consent was not required for this study because this study does not involve experiments on animals or human subjects.

Data availability statement

Question	Response
Sharing research data helps other researchers evaluate your findings, build on your work and to increase trust in your article. We encourage all our authors to make as much of their data publicly available as reasonably possible. Please note that your response to the following questions regarding the public data availability and the reasons for potentially not making data available will be available alongside your article upon publication. Has data associated with your study been deposited into a publicly available repository?	No
Please select why. Please note that this statement will be available alongside your article upon publication. as follow-up to "**Data Availability** Sharing research data helps other researchers evaluate your findings, build on your work and to increase trust in your article. We encourage all our authors to make as much of their data publicly available as reasonably possible. Please note that your response to the following questions regarding the public data availability and the reasons for potentially not making data available will be available alongside your article upon publication. Has data associated with your study been deposited into a publicly available repository?	Data will be made available on request

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.

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