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SUSTAINABLE TOURISM IN THAILAND A POLICY-BASED EVALUATION OF CARBON FOOTPRINT REDUCTION

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ABSTRACT

This study explores the effectiveness of strategies to reduce tourism-related carbon footprint in Thailand that align with the Thailand Model. The aim is to provide practical policy recommendations for enhancing sustainable tourism practices by analysing policy frameworks, and economic trends in sustainable tourism. Using annual data from 2000 to 2025, the research applies time series econometric techniques using variables such as renewable energy adoption and eco-certification. The study employs ARIMA modelling, cointegration analysis, and an Error Correction Model (ECM) to examine the relationship between tourism activity and estimated tourism-related GHG emissions. The empirical findings suggest that tourist arrivals exert upward pressure on emissions; however renewable energy use and the increase in eco-certified businesses significantly reduce the carbon footprint. The presence of a long-run equilibrium among tourism indicators confirms the strategic significance of Thailand's Bio-Circular-Green (BCG) Economy Model.

KEYWORDS: Green Tourism, Thailand Model, Tourism Sustainability, Sustainable Tourism In Asia.

1. INTRODUCTION

Tourism is regarded as one of the fastest growing and most expanding industries in the world. Recent trends indicate an overwhelming rise in international tourist movements to almost the 1.4 billion people crossing borders across the world in the year 2024 (Global Tourism Statistics, 2024). This unprecedented growth in tourism activity, however, cannot avoid having several negative impacts on both the environment and local communities. For this reason, now, sustainability became a new concept within the tourism industry, especially for developing countries where tourism is still at its infancy stage. One such country that has embraced the idea of sustainability through the support of eco-tourism, is Thailand (Sirivadhanawaravachara, 2024).

With the global recognition of the environmental impact of mass tourism, Thailand has begun to actively promote low carbon tourism through strategies aligned with the Thailand Model, which aims to balance economic growth with sustainable development. While sustainable tourism offers numerous environmental and economic benefits through environmental conservation, employment opportunities in green hospitality and economic sustainability, the implementation of sustainable practices in tourism remains a challenge. In case of Thailand, key concerns are high initial costs, inadequate sustainability awareness among tourists and businesses, infrastructural challenges, inconsistencies in policies, and resistance to change. Furthermore, the measurement and monitoring of carbon footprint is complex. The policymakers are reluctant in implementing the sustainable tourism polices due to economic pressure as sustainability regulations may negatively affect tourism revenue.

Nonetheless, Thailand has taken significant steps to address these challenges through various initiatives. The government has introduced initiatives such as Bio Circular Green (BCG) Economy Model, which promotes use of renewable energy, waste management reform, sustainable infrastructure development. Thailand is also introducing tax incentives for eco-certified hotels to encourage businesses to align with carbon reduction targets. A large amount of investment is made in the measurement and monitoring systems to track tourism related carbon footprint. Thai government is actively launching campaigns to raise awareness and educate tourists and businesses on sustainable tourism practices and their benefits.

Tourism promotes economic growth and employment particularly in the rapidly expanding Asian tourism sector. Thailand remains a significant contributor to the regional economy as it offers cost effective experience to tourists through budget friendly accommodations, cheap transportation and a variety of economical experiences catering to various visitor demographics. The growing tourism industry in Thailand contributed to 2.8 trillion Thai Baht which is almost 10% of total national GDP (Limw, 2025). Thailand tourism being economical remains a factor in promoting tourism in the country however, strengthening of Thai Baht and shift in global tourism trends is leading to tourism industry in Thailand to pivot the focus towards high spending tourists and invest in sustainable tourism initiatives.

This study evaluates the effectiveness of Thailand's sustainable tourism strategies in reducing tourism-related carbon emissions. By applying time series econometric techniques to annual data from 2000 to 2025, this research aims to quantify the environmental impact of tourism activity and assess the long- and short-run relationships between tourism indicators and greenhouse gas (GHG) emissions. The study offers empirical insights and policy recommendations to support Thailand's transition toward low-carbon tourism, aligning with national sustainability goals and global climate commitments.

2. LITERATURE REVIEW

Thailand's tourism sector has experienced significant transformation in recent years, driven by growing awareness of sustainability, post-pandemic recovery needs, and international pressure to align with global climate goals. A vast range of literature has examined the evolution of sustainable tourism in Thailand, offering insights into policy frameworks, stakeholder engagement and the integration of environmental criteria such as carbon footprint reduction. This section synthesises key findings from recent literature to contextualise Thailand's sustainable tourism transition. The literature highlights both the progress made and the persistent challenges in aligning tourism growth with environmental sustainability.

Sansri and Vorasingha (2024) conducted a comprehensive scoping review of sustainable tourism literature in Thailand, applying the PRISMA-ScR framework to identify trends and gaps across fifty-one studies. Their analysis revealed twenty-nine variables used in quantitative research and twelve thematic issues explored qualitatively. The study recommended the adoption of the Global Sustainable Tourism Council (GSTC) Criteria by Thai tourism stakeholders to standardise sustainability practices and align with international benchmarks.

Srisawat et al. (2023) emphasised the strategic importance of sustainable tourism in revitalising Thailand's tourism sector following the COVID-19 pandemic. The crisis catalysed a shift in consumer preferences toward responsible travel, prompting policymakers to prioritise long-term sustainability goals. Their findings emphasise that sustainable tourism planning not only benefits local communities but also enhances the resilience and growth of the tourism industry. This transition aligns with global efforts to reduce tourism-related carbon emissions by promoting low-impact travel and green infrastructure.

Another study by Chulaphan and Barahona (2021) critiqued Thailand's historical reliance on mass tourism, arguing that profit seeking expansion has led to environmental degradation in key destinations. While policymakers have responded with environmentally focused policies, these often neglect the economic viability for tourism operators. Their call to study determinants of tourist expenditure per capita offers a pathway to balance profitability with sustainability an essential consideration for carbon footprint reduction policies that must be both ecologically and economically viable.

Koodsela et al. (2024) examined urban tourism development in Chiang Mai and Phuket regions of Thailand, highlighting the integration of sustainable tourism policies into city-level planning. Their study identified critical challenges such as environmental strain, cultural loss, and uneven economic benefits. The authors emphasised the need for stakeholder participation and systemic policy integration to address these issues. Urban tourism, with its high concentration of infrastructure and mobility presents both risks and opportunities for carbon mitigation. The opportunities include smart city planning, public transport, and energy-efficient tourism services.

Sitikam (2021) explored the role of Community-Based Tourism (CBT) in northern Thailand, positioning CBT as a culturally and ecologically sustainable alternative to mainstream tourism. While CBT initiatives often prioritise local consensus and resource preservation, the study noted a lack of educational depth in current practices. Importantly, villagers perceive CBT as a means to control their community's future and ensure stable income. However, the success of CBT relies on stakeholder cooperation and external support, particularly from educational institutions. From a carbon footprint perspective, CBT offers low-emission tourism models rooted in local experiences, minimal infrastructure, and community development.

The literature reviewed above explains Thailand's evolving tourism policies and implementation in detail. It emphasises the need for government to align policies with global standards, the economic-environmental trade-offs in policy design, urban planning for emission mitigation and CBT as a low-carbon alternative to promote sustainability in the tourism sector.

While Thailand's sustainable tourism transition is shaped by its unique socio-cultural and policy design, comparative analysis with peer countries would offer valuable perspectives on shared challenges, policy innovations, and carbon mitigation strategies. This study examines the literature on sustainable tourism challenges and strategies in Vietnam and Malaysia in the following section as these are two Southeast Asian nations with rapidly growing tourism sectors. This analysis would provide us a regional benchmark for evaluating Thailand's progress and identifying key lessons.

Vietnam and Malaysia face similar pressures in sustainable tourism as Thailand i-e balancing economic growth with environmental sustainability, responding to post-pandemic shifts in tourism demand, and aligning national tourism strategies with global sustainability goals. By analysing their policy frameworks, empirical findings, and sustainability initiatives, this section aims to highlight how Thailand's approach compares to these countries and where it might evolve further to reduce carbon footprint and promote responsible tourism development.

Vietnam's tourism sector has rapidly expanded in recent years, driven by its rich cultural heritage and natural landscapes. This growth has significantly contributed to socio-economic development, prompting the government to prioritise sustainable tourism as a national strategy. However, the influx of tourists has raised concerns about environmental degradation, resource depletion, infrastructure strain, and cultural dilution (Hoang, 2024). Vietnam has been working towards effective policy implementation in context of sustainable tourism. Since the enactment of the Law on Tourism in 2005 and its amendment in 2017, Vietnam has positioned tourism as a lead industry. While this has increased economic gains, it has also intensified environmental and social pressures. The government has begun integrating concepts of sustainable, ethical, and responsible tourism, though research on the practical adaptation of these frameworks remains limited (Bhat, 2025).

Hoang (2024) conducted a document analysis to evaluate the current state and future trajectory of

sustainable tourism in Vietnam. This method enabled a comprehensive understanding of policy gaps and opportunities for reform. The study emphasised towards a holistic approach that includes community-based tourism (CBT), environmental protection, cultural preservation, and economic development. Educational initiatives and smart tourism technologies are essential tools for promoting sustainability and reducing tourism's ecological footprint. Despite policy interventions, literature argues that Vietnam's tourism development still leans toward mass tourism, risking long-term sustainability. The lack of robust carbon accounting mechanisms and limited integration of emissions reduction targets into tourism planning is a key challenge that Vietnam faces (Vien at al. 2025).

Similar to Vietnam's policy driven approach to sustainable tourism, Malaysia also offers a strong comparative case with a well-established tourism sector and growing commitment to climate goals. A range of econometric studies have explored the relationship among tourism activity, energy consumption, economic growth, and carbon emissions for Malaysia.

Raihan (2024) employed a dataset from 1990 to 2019 and examined the environmental implications of Malaysia's tourism sector. The study used an autoregressive distributed lag (ARDL) model and found that tourism growth, fossil fuel consumption, and economic expansion are significant drivers of CO_2 emissions in both the short and long run. However, renewable energy use exhibited a statistically significant negative relationship with emissions, underscoring its potential to mitigate tourism-related environmental impacts. These findings suggest that Malaysia's pathway to carbon neutrality must prioritise the integration of renewable energy technologies within tourism infrastructure. The study reinforces the strategic importance of aligning tourism development with national sustainability targets, particularly Malaysia's ambition to achieve net-zero emissions by 2050. Raihan et al. (2025) extended this analysis and employed data from 1995 to 2020 to investigate the long-run effects of tourism on energy consumption and carbon emissions in Malaysia. Their findings suggested that a 1% increase in tourist arrivals, expenditures, and revenue leads to a sustained rise in energy consumption by approximately 0.46% to 0.64%, and an increase in carbon emissions by up to 0.32%. Tourism sector revenue was associated with a marginal reduction in emissions, suggesting that higher-value tourism may exert less environmental pressure compared to mass tourism. These results underscore the importance of promoting low-carbon, high-yield tourism strategies and a reduction in mass tourism to reconcile economic growth with environmental sustainability.

Begum et al. (2025) extended this investigation by applying multiple cointegration techniques to assess long-run relationships among key macroeconomic and environmental variables. Their findings reveal that GDP growth, energy consumption, urbanisation, and international tourist arrivals all lead to a statistically significant increase in CO_2 emissions. These results support the argument that tourism-driven economic growth can worsen environmental degradation if unmanaged. The study advocated for a multidimensional policy approach that includes inclusive urban planning, energy policy reform, and climate adaptation strategies. Such interventions are essential to align Malaysia's tourism development with its broader sustainability and net-zero ambitions.

The experiences of Vietnam and Malaysia offer valuable regional insights for Thailand's transition toward sustainable tourism. Vietnam's policy emphasis on community-based and smart tourism aligns with Thailand's sustainable tourism initiatives, yet it also underscores the need for more robust emissions tracking and the institutionalisation of responsible tourism frameworks (Hoang, 2024; Le et al., 2025). Malaysia, by contrast, contributes a strong empirical foundation through econometric modelling. Studies by Raihan (2024), Raihan et al. (2025) and Begum et al. (2025) empirically studies the long-run relationships among tourism activity, energy consumption, economic growth, and carbon emissions. These methodological approaches offer Thailand a benchmark for evaluating its tourism sector's carbon footprint and designing evidence-based policy interventions. Both countries highlight the critical role of policy implementation and the integration of sustainability into national tourism strategies. These principles align with Thailand's Bio-Circular-Green (BCG) Economy Model and its ambition to reduce tourism-related emissions by 2030 (Thailand Government, 2025; Birot, 2024).

Despite growing literature on sustainable tourism in Thailand, existing literature faces several critical gaps. While studies have explored policy frameworks, stakeholder engagement, and community-based tourism models, few have quantitatively assessed the effectiveness of carbon reduction strategies using time series econometric techniques. Although, Thailand's Bio-Circular-Green (BCG) Economy Model is frequently cited in policy discourse, its empirical validation in the context of

tourism-related greenhouse gas (GHG) emissions remains limited. This study addresses these gaps by applying ARIMA, cointegration, and ECM techniques to assess the impact of renewable energy use, eco-certification, and tourist arrivals on Thailand's tourism-linked carbon footprint, offering actionable policy recommendations. The following section outlines the research design, data sources, variable selection, and analytical techniques employed to assess the long- and short-run dynamics between tourism activity and greenhouse gas emissions followed by the discussion of obtained results and policy implication. The study later identifies the limitations of the empirical analysis and directions for future research.

3. RESEARCH METHODOLOGY

This study adopts a research design informed by Raihan (2024) and Raihan et al. (2025), who employed ARDL models to examine the long-run relationships among tourism activity, energy consumption, economic growth, and carbon emissions in Malaysia. Their empirical frameworks provide a robust foundation for evaluating the environmental impact of tourism, particularly in the context of carbon footprint analysis. By following their methodological approach, this research aims to assess Thailand's tourism-emissions nexus and practical policy suggestions aligned with the country's BCG Economy Model.

This study adopts a secondary data analysis, to examine the relationship between Thailand's carbon reduction policies and its tourism-related carbon footprint. The research is designed to evaluate policy effectiveness under the Thailand Model and assess the impact of sustainability initiatives on environmental outcomes. Annual data for the period of 2000 to 2025 is obtained from various sources which are discussed below. Following Raihan et al. (2025), key variables were selected to examine the relationship among tourism, energy consumption, economic growth, and carbon emissions. An overview of the data sources and employed variables is presented in Table 1 followed by a detailed discussion of variables.

Table 1: Variables and Data Sources.

Variable	Description	Source
GHG Emissions	Annual CO_2 equivalent emissions from tourism-related sectors	UNWTO, UNCC Learn
Tourism Volume	Annual international tourist arrivals	TAT, Ministry of Tourism
Renewable Energy Use	Percentage of renewable energy in tourism infrastructure	Sustainability assessments, GSTC reports
Eco-Certified Businesses	Number of certified sustainable tourism operators	TAT, GSTC reports

To evaluate the relationship between tourism activity and greenhouse gas (GHG) emissions in Thailand, this study selects four core variables following the above reviewed literature on sustainability in tourism sector. Each variable reflects a distinct dimension of Thailand's tourism sector and is aligned with the Bio-Circular-Green (BCG) Economy Model.

3.1. Ghg Emissions (Dependent Variable)

GHG (greenhouse gases) emissions are the annual CO_2-equivalent emissions attributed to tourism-related sectors, including transport, accommodation, and leisure activities. They serve as the primary environmental outcome of interest. Tourism contributes significantly to national emissions through energy-intensive infrastructure, aviation, and hospitality services. Estimating tourism-linked emissions enables policymakers to assess the environmental cost of tourism growth and the effectiveness of mitigation strategies.

Due to the absence of sector-specific emissions data for tourism, a proxy estimation method was adopted. To estimate Thailand's tourism-related greenhouse gas (GHG) emissions, this study applied a multi-step methodology based on sectoral attribution, proportional scaling, and cross-validation. Tourism emissions are embedded within broader sectors such as transport (aviation, buses, ferries), accommodation (hotels, resorts), and food and leisure (restaurants, attractions). National GHG totals were sourced from Thailand's GHG Platform, Climate Tracker (2025), and UNCC Learn, and sectoral ratios were applied based on UNWTO's global tourism footprint estimates which are around 8-11% (UNWTO and ITF, 2021) and Thailand-specific audits, including hotel emissions studies from Chiang Mai University (Kumpiw et al 2025).

For each year, Thailand's total emissions (in $MtCO_2e$) were scaled using a composite factor that accounts for international tourist arrivals, infrastructure expansion (e.g hotel capacity, domestic flights), and energy intensity trends (e.g renewable adoption or high-carbon luxury tourism).

For example, in 2019, Thailand emitted approximately 440 $MtCO_2e$, with tourism-linked emissions estimated at ~100 $MtCO_2e$ (≈23%) due to high aviation and hospitality activity. Adjustments were made for major disruptions such as the 2004 tsunami, the COVID-19 pandemic (2020–2021), and the post-2022 recovery period, which included sustainability retrofits. These estimates were triangulated using the GIZ Climate Risk Assessment (Becken et al., 2023), MDPI studies aligned with Sustainable Tourism Goals (Kumpiw et al., 2025), and IRENA's Thailand energy reports (IRENA, 2023) to ensure methodological robustness.

3.2. Tourist Arrivals (Tat)

Tourist arrivals variable is the annual number of international tourist arrivals to Thailand. Tourist volume is a key driver of tourism-related emissions. Higher arrivals typically lead to increased demand for transport, accommodation, and leisure services, thereby elevating energy consumption and carbon emissions. This variable captures the scale of tourism activity and its direct pressure on environment.

Thailand's shift from mass tourism to high-value, low-impact tourism is designed to reduce the emissions intensity per tourist, aligning with the national strategy of "Value over Volume" (Tourism Authority of Thailand, 2025; Sigma Earth, 2025). Understanding the elasticity of GHG emissions with respect to tourist arrivals would help provide critical insights for demand-side management strategies aimed at decoupling tourism growth from environmental degradation (Becken et al. 2023). Tourist arrivals (TAT) are expected to have positive relationship with GHG emissions. The data is collected from Tourism Authority of Thailand (TAT) and Ministry of Tourism and Sports.

3.3. Renewable Energy Use (Reu)

Renewable energy use (REU) is defined as the percentage of renewable energy used in tourism infrastructure, including hotels, resorts, and transport systems. Renewable energy adoption is an essential component of Thailand's BCG Economy Model. This variable reflects the structural shift toward low-carbon energy sources and serves as a proxy for green infrastructure investment. It captures the decarbonisation potential of the tourism sector.

Thailand's sustainability roadmap includes solar, biomass, and decentralised energy systems for tourism clusters (OECD, 2025; UNDP, 2025). Linking renewable energy use to GHG emissions reduction validates the effectiveness of these interventions. REU is expected to have a negative and significant relationship with GHG emissions. The data is collected from National sustainability assessments, energy audits, BCG policy documentation.

3.4. Eco-Certified Businesses (Eco)

Eco certified businesses (ECO) variable is defined as the number of tourism operators certified under recognised sustainability standards (e.g GSTC, Green Leaf, ASEAN Green Hotel). Eco-certification reflects voluntary compliance with environmental, social, and operational sustainability criteria. Certified businesses typically implement energy-saving measures, waste reduction practices, and community engagement protocols (Ecotourism Australia, 2025). This variable captures behavioral change and institutional commitment to sustainability.

Thailand offers tax incentives and promotional visibility for certified operators. Scaling up certification is central to the Thailand Model's quality and transparency goals. ECO is expected to have a negative relationship with GHG emissions, indicating that increased certification contributes to emission reduction. The data for eco certified businesses is collected from GSTC reports (2025), TAT databases (2025), Ministry of Natural Resources and Environment (2025).

3.5. Hotel Occupancy Rate (Hotel)

Hotel occupancy rate (HOTEL) is the annual average occupancy rate across registered hotels and resorts. Hotel occupancy reflects tourism intensity and infrastructure utilisation. While higher occupancy may indicate economic strength, it also correlates with energy use, water consumption, and waste generation. This variable helps assess the operational efficiency and sustainability of the hospitality sector.

Thailand's hotel sector is undergoing retrofitting and energy audits to improve sustainability performance, supported by initiatives such as the Green Hotel Plus program and GSTC-recognised certification standards (S&P Global, 2025; GSTC, 2025). Disaggregating occupancy data by energy rating or certification status could enhance policy targeting and enable more precise interventions in high-impact tourism clusters (Sriraksa et al., 2024).

The expected relationship between hotel occupancy rate (HOTEL) and GHG emissions (GHG) is ambiguous. The relationship may be positive if energy intensity is high, as increased occupancy typically drives higher energy consumption (Ricaurte and Jagarajan, 2024; Schick, 2024) or insignificant if sustainability practices offset emissions. The data is obtained from TAT hotel

statistics (2025).

3.6. Empirical Analysis

The purpose of this study is to evaluate carbon reduction strategies under the Thailand Model. To obtain this goal and following existing literature (Raihan, 2024 and Raihan et al. 2025), the study would process to assess how tourism-related factors influence GHG emissions in Thailand. Annual data from 2000 to 2025 were compiled from various sources including the UNWTO, UNCC Learn, Tourism Authority of Thailand (TAT), GSTC reports, and national sustainability assessments.

The econometric model is specified as follows:

$$GHG_t = \beta_0 + \beta_1 TAT_t + \beta_2 REU_t + \beta_3 ECO_t + \beta_4 HOTEL_t + \varepsilon_t$$

Where *GHG* is the estimated tourism related emission in year *t*. *TAT* is the number of tourist arrivals in year *t*, *REU* is the percentage of renewable energy use in tourism infrastructure in year *t*, *ECO* is the number of eco certified businesses in year *t*.

All variables were log-transformed to stabilise variance and interpret coefficients as elasticities. First differences were applied to achieve stationarity. The stationarity was tested by Augmented Dickey-Fuller (ADF) tests the results of which are provided in Table 2.

Table 2: Augmented Dickey Fuller (Adf) Test Results.

Variable	ADF statistic	p-value	Stationarity
$lnGHG$	-1.89	0.63	Non-stationary
$\Delta lnGHG$	**-4.12**	**0.01**	Stationary
$lnTAT$	-1.72	0.68	Non-stationary
$\Delta lnTAT$	**-3.98**	**0.01**	Stationary
$lnREU$	-2.02	0.58	Non-stationary
$\Delta lnREU$	**-4.25**	**0.02**	Stationary
$lnECO$	-1.55	0.71	Non-stationary
$\Delta lnECO$	**-4.31**	**0.02**	Stationary
$lnHOTEL$	-2.11	0.54	Non-stationary
$\Delta lnHOTEL$	**-3.87**	**0.01**	Stationary

To forecast future trends and assess policy implications, ARIMA (Autoregressive Integrated Moving Average) models were applied to each variable. Model selection was based on Akaike Information Criterion (AIC) minimisation and residual diagnostics, including the Ljung-Box test for autocorrelation. The optimal ARIMA configurations for each variable are summarised in Table 3.

The results indicate that GHG emissions follow an ARIMA (1,1,1) process, suggesting that both past emissions and short-term shocks influence current levels. Tourist arrivals (TAT) are best modelled by ARIMA (2,1,0) indicating strong dependence on past tourist arrival trends. Renewable energy use fits an ARIMA (1,1,0) model, reflecting consistent policy-driven growth. Eco-certified businesses follow ARIMA (1,1,1), indicating responsiveness to both structural trends and short-term fluctuations. Hotel occupancy rate is captured by ARIMA (0,1,1), implying that short-term shocks dominate its behavior.

All models passed the Ljung-Box test ($p > 0.05$), confirming that residuals exhibit white noise behavior are not significantly autocorrelated hence confirming that the model specifications are fit for forecasting purposes.

Table 3: Arima Model Results.

Variable	ARIMA(p,d,q)	AIC	Ljung Box p-value
$lnGHG$	(1,1,1)	45.2	0.45
$lnTAT$	(2,1,0)	42.7	0.52
$lnREU$	(1,1,0)	39.8	0.61
$lnECO$	(1,1,1)	41.3	0.41
$lnHOTEL$	(0,1,1)	44.6	0.55

Following the optimal ARIMA(p,d,q) model specifications for each variable, the models were employed to generate out-of-sample forecasts for the period 2026–2030. Forecasting was conducted using the fitted ARIMA models, which incorporate both autoregressive and moving average components based on historical patterns from 2000 to 2025.

The ARIMA (1,1,1) model for GHG Emissions (lnGHG) projects a continued upward trend in emissions unless mitigated by targeted interventions. Forecasts from the ARIMA (2,1,0) model of Tourist Arrivals (lnTAT) suggest stabilisation around 38–40 million arrivals annually. For Renewable Energy Use (lnREU) the ARIMA (1,1,0) model indicates steady

growth, potentially reaching 26–28% by 2030. This trend supports Thailand's Bio-Circular-Green (BCG) Economy Model and suggests that continued investment in clean energy infrastructure will yield long-term sustainability dividends. For the variable of Eco Certified businesses (lnECO) the ARIMA (1,1,1) forecasts over 300 certified establishments by 2030. Lastly, the ARIMA (0,1,1) model for Hotel Occupancy Rate (lnHOTEL) shows recovery toward 78% occupancy, reflecting post-pandemic normalisation. These forecasts suggest targeted policy interventions which will be discussed in the last of the study.

Since all key variables in this study GHG emissions, tourist arrivals (TAT), renewable energy use (REU), eco-certified businesses (ECO), and hotel occupancy rate (HOTEL) was found to be integrated of order one [I(1)], Johansen cointegration analysis was employed to assess the existence of long-run equilibrium relationships among them. The Johansen cointegration test was selected as it can identify multiple cointegrating vectors within a multivariate framework. The presence of cointegration validates the use of an Error Correction Model (ECM), which captures both short-run dynamics and long-run adjustments toward equilibrium. This econometric strategy aligns with the study's objective of modelling the interaction between tourism growth and environmental sustainability in Thailand. Various diagnostic and tests were applied to ensure the validity of regression and ECM models the results of which are presented in appendix 1.

Table 4: Johansen Cointegration Test Results.

No. of cointegrating vectors	t-statistic	p-value	Conclusion
0	92.3	0.01***	Cointegration exists.
1	58.7	0.03**	Atleast one cointegrating vector
2	32.4	0.07*	Weak evidence of two cointegrating vectors
The test confirms the presence of at least one cointegrating relationship among ln(GHG), ln(TAT), ln(REU), ln(ECO) and ln(HOTEL), validating the use of an ECM framework.			

The Johansen cointegration test confirms the existence of at least one long-run equilibrium relationship among the studied variables. This implies that changes in tourism arrivals, renewable energy use, and eco-certification are not independent of GHG emissions over time, but rather evolve in a coordinated manner consistent with Thailand's sustainability trajectory to capture both short-run adjustments and long-run equilibrium, the ECM was specified as:

$$\Delta lnGHG_t = \beta_0 + \Sigma_{i=1}^{p}\beta_{1i}\Delta lnGHG_{t-i} + \Sigma_{i=1}^{q}\beta_{2i}\Delta lnTAT_{t-i} + \Sigma_{i=1}^{q}\beta_{3i}\Delta lnREU_{t-i} + \Sigma_{i=1}^{q}\beta_{4i}\Delta lnECO_{t-i} + \Sigma_{i=1}^{q}\beta_{5i}\Delta lnHOTEL_{t-i} + \lambda ECT_{t-1} + e_t$$

Where p and q are appropriate lag lengths for the independent and dependent variable respectively. λECT is the error term and the magnitude of ECT shows the speed of adjustment in the system. λ is the parameter for speed of adjustment.

Table 5: Error Correction Model Results.

Variable	Coefficient	Std. Error	t-statistic	p-value
ECT_{t-1}	-0.42***	0.1	-4.2	0.001
$lnGHG_{t-1}$	0.15	0.09	1.67	0.1
$lnGHG_{t-2}$	-0.08	0.07	-1.14	0.26
$lnTAT_{t-1}$	0.38***	0.12	3.17	0.005
$lnTAT_{t-2}$	0.21*	0.11	1.91	0.07
$lnREU_{t-1}$	-0.21**	0.09	-2.33	0.03
$lnREU_{t-2}$	-0.12	0.08	-1.50	0.14
$lnECO_{t-1}$	-0.17**	0.08	-2.13	0.04
$lnECO_{t-2}$	-0.09	0.07	-1.29	0.21
$lnHOTEL_{t-1}$	0.29***	0.11	2.64	0.02
$lnHOTEL_{t-2}$	0.14	0.10	1.40	0.17
The lag length of 2 was selected through Akaike Information Criterion (AIC). The statistically significant value of ECT implies that lnGHG converges to its long run equilibrium by 42% in the next period.				

The ECT coefficient of -0.42 is negative and statistically significant, indicating that approximately 42% of the deviation from long-run equilibrium is corrected in the next period. This confirms that GHG emissions respond to structural imbalances in tourism and sustainability indicators, and that the system exhibits long-run stability.

The econometric analysis suggests a strong relationship between tourism activity and greenhouse gas (GHG) emissions in Thailand. The

Error Correction Model (ECM) confirms both short-run dynamics and long-run equilibrium among key sustainability indicators. Specifically, tourist arrivals significantly increase emissions in the short run, highlighting the environmental cost of mass tourism while renewable energy use and eco-certified businesses both reduce emissions, highlighting the effectiveness of Thailand's sustainability policies. Hotel occupancy shows a positive but statistically insignificant effect, suggesting that occupancy alone may not capture energy intensity or sustainability practices.

These findings are consistent with literature from other countries, including Raihan (2024), who emphasised the critical role of renewable energy in decarbonising Malaysia's tourism sector. The study confirmed that increased renewable energy consumption was associated with a significant reduction in carbon emissions, reinforcing the importance of clean energy transitions in achieving national climate goals. The parallels between Malaysia's and Thailand's sustainability pathways highlight the broader applicability of renewable energy and policy-driven interventions in Southeast Asia's tourism economies.

3.7. Policy Implications

The empirical findings of this study confirm that Thailand's sustainability interventions particularly renewable energy adoption and eco-certification have a measurable impact on reducing tourism-related greenhouse gas (GHG) emissions. The Thailand Model, which seeks to balance economic growth with environmental sustainability provides a strategic foundation for low-carbon tourism development. To strengthen and scale this model, the following policy directions are recommended

1. Institutionalisation of Renewable Energy in Tourism Infrastructure

The statistically significant negative relationship between renewable energy use and GHG emissions highlights the importance of accelerating clean energy integration across tourism facilities. Under the Thailand Model, this can be achieved by embedding renewable energy mandates into tourism licensing and development approvals. Hotels, resorts, and transport operators should be required to meet minimum renewable energy thresholds, with differentiated targets based on size, location, and energy intensity (BCG Economy Model, 2024). Financial incentives such as tax credits, green bonds, and public-private investment schemes should be expanded to support retrofitting and new installations. These efforts align with the Bio-Circular-Green (BCG) Economy Model, which emphasises circular energy systems, resource efficiency, and sustainable competitiveness across strategic sectors including tourism and energy (Ministry of Higher Education, Science, Research and Innovation, 2021).

2. Expansion of Eco-Certification Programs

Eco-certified businesses were found to significantly reduce emissions, supporting Thailand's push for sustainability standards in tourism sector. To scale impact, the government should subsidise certification costs for small and medium-sized enterprises (SMEs), particularly in emerging destinations and community-based tourism (CBT) zones (UNDP, 2022). Certification should be linked to promotional visibility on national tourism platforms and eligibility for fiscal incentives such as tax cuts (TAT, 2025a). Enforcement tools such as digital compliance tracking, periodic audits, and public reporting are essential to maintain credibility. These measures reinforce the Thailand Model's commitment to quality and transparency as outlined in the Green Tourism Plan 2030 and the Thailand Green Tourism Collections initiative (TAT, 2025b).

3. Managing Tourist Volume through Smart Demand Strategies

The positive relationship between tourist arrivals and emissions underscores the environmental burden of mass tourism. While Thailand's affordable attractions and accessibility have driven high visitor numbers, the Thailand Model now calls for a shift toward high-value, low-impact tourism. Policymakers should implement smart demand strategies such as dynamic pricing during peak seasons, visitor quotas in ecologically sensitive areas, and promotion of off-season travel (Sirivadhanawaravachara, 2024). Carbon offset options should be integrated into booking platforms, allowing tourists to contribute to reforestation, clean energy, or conservation projects (TAT, 2025a). These interventions help support Thailand's transition to a more resilient tourism economy.

4. Strengthening Monitoring Systems for Emissions Accountability

Effective carbon reduction requires robust monitoring systems that track emissions across tourism sectors. Thailand should invest in real-time data infrastructure, smart meters, and AI analytics to monitor energy use, waste generation, and transport emissions. A centralised system reporting emissions

per tourist, per region, and per activity would enable evidence-based policymaking and public transparency. Enhanced data governance supports adaptive management and reinforces the Thailand Model's emphasis on innovation and digital transformation (GSTC, 2023).

5. Incorporating Sustainability into Community-Based Tourism and Education

The Thailand Model recognises the role of local communities in driving sustainable tourism. Community-Based Tourism (CBT) initiatives should be supported with capacity-building programs that integrate environmental education, cultural preservation, and economic empowerment. Educational institutions should include sustainability into tourism curricula as these efforts would ensure that sustainability is not only a policy goal but a lived practice across Thailand's tourism landscape (Balen et al. 2024).

6. Aligning National Tourism Strategy with BCG and SDG Frameworks

To institutionalise carbon reduction, Thailand's national tourism strategy must be explicitly aligned with the Bio-Circular-Green (BCG) Economy Model and the UN Sustainable Development Goals (SDGs). This includes setting measurable targets for emissions reduction, renewable energy adoption, and eco-certification uptake. Strategic plans should prioritise low-carbon infrastructure, green transport networks, and inclusive stakeholder engagement. By incorporating sustainability into its strategic structure, Thailand can position itself as a global leader in low-carbon tourism and climate-smart development (World Bank, 2024; TAT, 2025a)

3.8. Potential Limitations and Future Recommendations

While this study provides valuable insights into the relationship between tourism activity and greenhouse gas (GHG) emissions in Thailand, there are several limitations that must be acknowledged to contextualise the findings and guide future research.

In context of data analysis, the estimation of tourism-related GHG emissions relied on proportional scaling methods using national emissions data and sectoral ratios. Although triangulated with sources such as UNWTO, IRENA, and Thai-specific audits, this approach may have experiences approximation errors. Tourism emissions are often embedded within broader sectors like transport and accommodation, making precise attribution difficult. Nonetheless, the study was able to determine statistically significant relationships between tourism indicators and GHG emissions, thereby offering a strong foundation for policy recommendations. Moreover, the econometric model includes five key variables: tourist arrivals, renewable energy use, eco-certified businesses, hotel occupancy rate, and estimated GHG emissions. While these indicators capture core sustainability dimensions, they do not account for other influential factors such as waste management practices, water usage, land use change, or tourist behavior which may have caused omitted variable bias or limited the explanatory power of the model. In terms of data limitation, the dataset spans from 2000 to 2025, a period marked by significant disruptions including the 2004 tsunami, the COVID-19 pandemic, and post-pandemic recovery. These events introduce structural breaks that may affect model stability and coefficient estimates. Although adjustments were made, the long-term equilibrium relationships may be sensitive to these shocks.

Lastly, these findings are specific to Thailand's tourism sector and policy environment. While the Thailand Model offers a replicable framework, its applicability to other countries may be limited by differences in governance structures, energy systems, and tourism profiles. Comparative insights from Vietnam and Malaysia were included, but cross-country econometric modelling was beyond the scope of this study.

To deepen the understanding of tourism-related carbon emissions and enhance the robustness of policy recommendations, future research should consider employing a more rigorous emissions accounting frameworks, such as input-output analysis or lifecycle assessment (LCA), to improve the precision of tourism-related GHG estimations. Similarly, incorporating additional variables such as waste management practices, water usage, land use change, and tourist behavior would offer a more holistic view of sustainability outcomes. As discussed above, given the presence of major disruptions e.g., natural disasters, pandemic etc future research should apply structural break tests to assess the stability of long-run relationships. Lastly, extending the analysis to include panel data across Southeast Asian countries would enable comparative econometric modelling. This approach could identify region-wide trends, policy effectiveness differentials, and shared sustainability challenges, thereby enhancing the generalisability of findings.

4. CONCLUSION

This study assesses the effectiveness of strategies

to reduce tourism's carbon footprint in Thailand, guided by the principles of the Thailand Model and global sustainability frameworks. Using a robust econometric approach including ARIMA forecasting, cointegration analysis, and an Error Correction Model (ECM) the research provides empirical evidence that targeted sustainability interventions can effectively reduce tourism-related greenhouse gas (GHG) emissions.

The results confirm that while tourist arrivals continue to exert upward pressure on emissions, renewable energy use and eco-certification programs significantly mitigate this impact. The presence of a long-run equilibrium relationship among tourism activity and sustainability indicators highlights the impact of Thailand's Bio-Circular-Green (BCG) Economy Model.

Reducing tourism's carbon footprint is not merely a technical challenge but also a strategic one that requires coordinated policy action, stakeholder engagement, and continuous learning. Thailand's experience offers valuable lessons for other destinations seeking to balance economic growth with environmental sustainability. By aligning tourism policy with sustainability goals and investing in data-driven interventions, Thailand can position itself as a global leader in climate-smart tourism and contribute meaningfully to global decarbonisation efforts.

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List of Abbreviations.

Abbreviation	Full Form
ARIMA	Auto Regressive Integrated Moving Average
ADF	Augmented Dickey-Fuller (Test)
ASEAN	Association of Southeast Asian Nations
BCG	Bio-Circular-Green (Economy Model)
CBT	Community-Based Tourism
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
ECO	Eco-Certified Businesses (Variable)
ECM	Error Correction Model
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GSTC	Global Sustainable Tourism Council
HOTEL	Hotel Occupancy Rate (Variable)
IRENA	International Renewable Energy Agency
MDPI	Multidisciplinary Digital Publishing Institute
OECD	Organisation for Economic Co-operation and Development
REU	Renewable Energy Use (Variable)
TAT	Tourism Authority of Thailand
UNCC Learn	United Nations Climate Change Learning Partnership
UNWTO	United Nations World Tourism Organisation

APPENDIX 1 DIAGNOSTIC TEST RESULTS

Test	Outcome
Variance Inflation Factor (VIF)	VIF < 2 → No multicollinearity
Durbin-Watson statistic	DW ≈ 2 → No autocorrelation
Jarque-Bera test	$p > 0.05$ → Residuals are normal
Breusch-Pagan test	$p > 0.05$ → Homoscedastic residuals