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Tourism Development and Environmental Kuznets Curve Hypothesis in ASEAN Countries: New Evidence From Panel Estimators Robust to Cross-Sectional Dependence

Abstract

Tourism development has become one of the key drivers of economic growth in many ASEAN countries, however, the adverse environmental impacts of tourism and economic growth have raised significant concerns among policymakers in the region. With that, this study examines the role of tourism development within the context of the environmental Kuznets curve (EKC) hypothesis across ten ASEAN countries over 25 years from 1995 to 2019, employing panel estimators robust to cross-sectional dependence. The results confirm that tourism development significantly contributes to environmental degradation, particularly in the baseline estimation and in robustness checks when population size is excluded. Notably, ASEAN countries are found to exhibit an economic growth-environment trajectory that follows an inverted N-shaped EKC. The computed threshold values of GDP per capita, whether in the baseline or robustness estimations, suggest that the current economic development in ASEAN is having an adverse impact on the environment. Still, renewable energy emerges as a crucial mitigating factor. Furthermore, population size plays a key role in driving both CO₂ and GHG emissions. These findings underscore the intricate relationships between tourism development, economic growth, and environmental quality in the ASEAN region. Subsequently, several policy implications are discussed.

Keywords: CO₂ emissions, environmental Kuznets curve, panel estimators, renewable energy, tourism development

1. Introduction and background

The Association of Southeast Asian Nations (ASEAN) is a 10-country regional organisation comprising Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam. ASEAN has experienced a substantial increase in economic activity and has demonstrated positive economic development over the years. According to the ASEAN Economic Integration Brief (Association of Southeast Asian Nations [ASEAN], 2023), this positive economic growth has made ASEAN the world's fifth-largest

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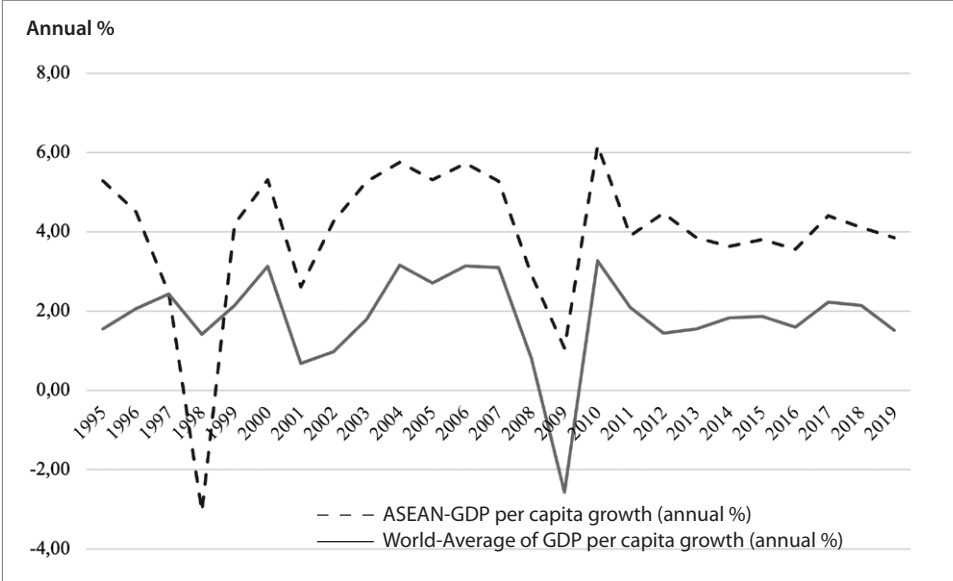
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economy, with a GDP of over USD 3.6 trillion in 2022. The region is expected to become the fourth-largest economy by 2030, following the United States, China, and India.

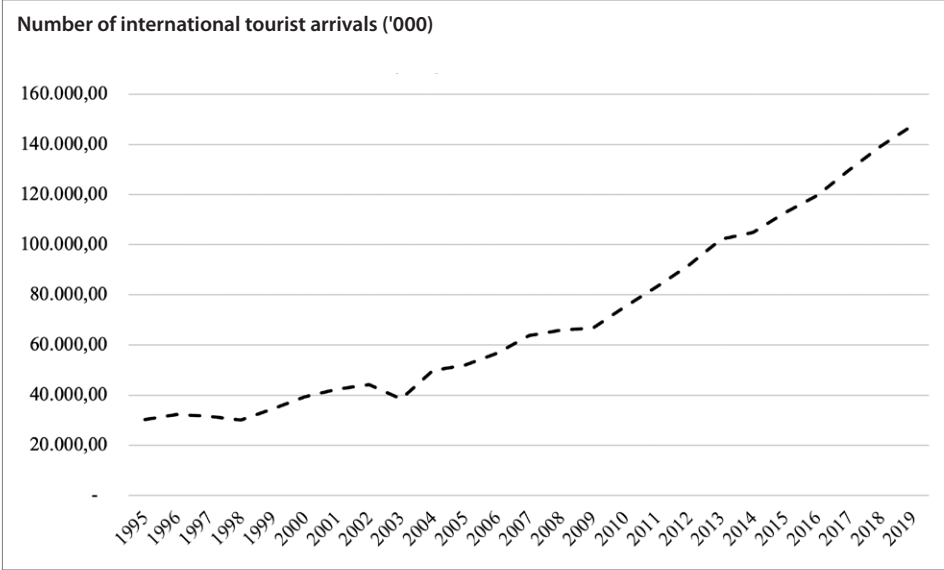
As shown in Figure 1, ASEAN has consistently outperformed the world's GDP per capita growth, achieving an average GDP per capita growth rate of 3.9% over the 25 years from 1995 to 2019, surpassing the global average of 1.8%. Undoubtedly, tourism development has become one of the key drivers of economic growth in many ASEAN countries, as tourist arrivals have expanded by approximately five times from 30 million in 1995 to 148 million in 2019 (see Figure 2). ASEAN's economic growth and tourism development indicate its vast potential and prospects that can no longer be overlooked.

Figure 1
GDP per capita growth of ASEAN and the world, 1995 - 2019



Source: World Development Indicators and authors' own computation based on the data collected from the World Development Indicators (The World Bank, 2024).

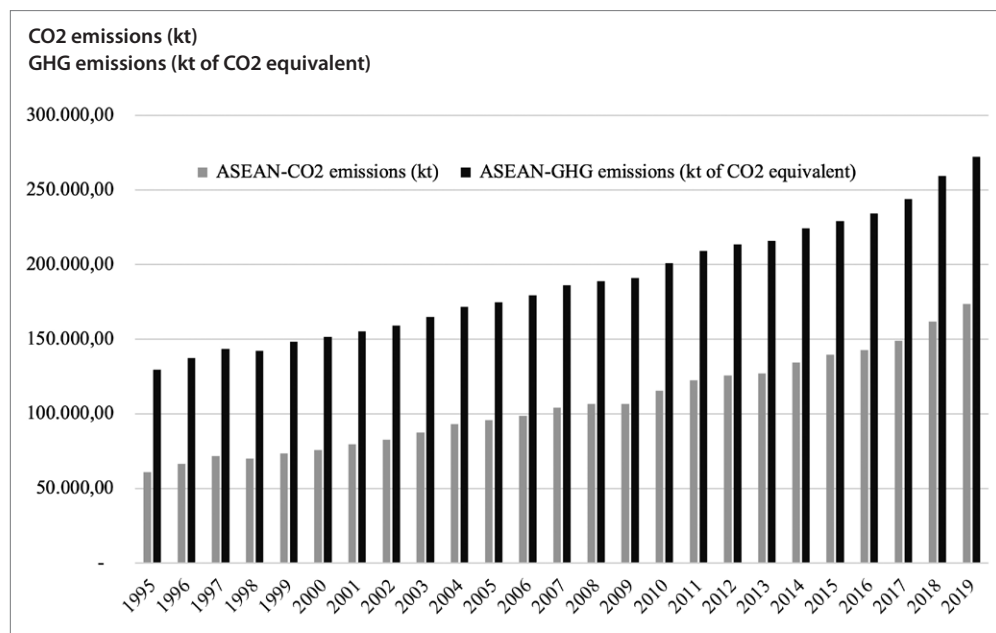
Figure 2
Total number of international tourist arrivals of ASEAN, 1995 - 2019



Source: World Development Indicators and authors' own computation based on the data collected from the World Development Indicators (The World Bank, 2024).

However, rapid development and mass tourism often lead to the overexploitation of natural resources and various forms of pollution, particularly through transportation, accommodation, and other tourism-related activities. As seen in Figure 3, the average CO₂ emissions in ASEAN rose significantly from 61,036 kt in 1995 to 173,571 kt in 2019. Similarly, average GHG emissions increased from 129,653 kt of CO₂ equivalent in 1995 to 272,073 kt of CO₂ equivalent in 2019. Both emissions are expected to continue to rise, coinciding with the significant expansion of the region's tourism activities and economic growth.

Figure 3
CO₂ and GHG emissions of ASEAN, 1995 - 2019



Source: World Development Indicators and authors' own computation based on the data collected from the World Development Indicators (The World Bank, 2024).

The environmental Kuznets curve (EKC) hypothesis posited that environmental degradation initially rises as a country's income increases but subsequently declines after the country's income reaches a certain level (Grossman & Krueger, 1995; Dinda, 2004). The inverted U-shaped relationship between economic development and environmental quality has been extensively studied in the context of ASEAN countries (Ang, 2008; Lean & Smyth, 2010; Narayan & Narayan, 2010; Saboori et al., 2012; Chandran & Tang, 2013; Saboori & Sulaiman, 2013; Tan et al., 2014; Heidari et al., 2015; Chng, 2019; Ansari, 2022), however the findings are at best mixed, with primarily not supporting the EKC hypothesis. Furthermore, the role of tourism within the EKC framework has received less attention despite its significant environmental impact (Katircioglu, 2014; Paramati et al., 2017). To the best of our knowledge, no prior study has explored both the role of tourism development within the EKC framework and the potential N-shaped EKC hypothesis within the context of the ASEAN region.

Against this backdrop, this study aims to examine the role of tourism development in driving environmental degradation within the EKC framework for ASEAN countries from 1995 to 2019. This study makes three key contributions to the literature: firstly, given the increasing global significance of tourism and environmental quality, understanding the relationships of tourism development, economic growth, and environmental quality is critical for policymakers to design and implement sustainable tourism and development policies in ASEAN. Secondly, this study explores the role of tourism development within the EKC framework in the context of ASEAN – a regional association characterised by highly interdependent policies and integrated tourism activities – while addressing the inconclusive findings of previous research on the tourism

development-economic growth-environment nexus in the region. Lastly, this study employs Driscoll and Kraay's (1998) fixed effects (DKFE) and panel-corrected standard errors (PCSE) estimators, which are robust to cross-sectional dependence. This empirical issue may be prevalent in the analysis within the context of an official regional bloc like ASEAN.

The study reveals that tourism development in ASEAN countries significantly increases CO₂ and GHG emissions, consistent with many prior studies. While the baseline estimations and earlier robustness checks yield mixed findings on the EKC hypothesis, a more comprehensive robustness analysis reveals an inverted N-shaped EKC relationship, indicating that emissions might initially fall during early development stage of ASEAN economies, but subsequently rise with the structural shifts in the region's economic development characterized by industrialization and more energy-intensive economic activities, and fall again at higher income stages due to more environmentally friendly and sustainable economic and tourism policies. Nevertheless, the computed GDP per capita threshold values indicate that the current ASEAN economic development remains in a pollution-inducing stage. The study also shows that renewable energy has crucial mitigating effects on emissions, whereas population size is a major driver of environmental degradation. These findings underscore the significant environmental impacts of tourism and economic development in the ASEAN region, emphasising the need to adopt targeted and well-crafted policies to mitigate tourism- and growth-induced emissions.

The paper proceeds as follows: Section 2 discusses the relevant empirical literature on tourism's environmental impacts and the EKC hypothesis, particularly within the context of ASEAN countries. Section 3 discusses the materials and methods used in this study, followed by Section 4, which presents the discussion of the results from the baseline and robustness estimations. Section 5 finally concludes with several policy implications.

2. Literature review

Tourism has become a vital catalyst in both developed and developing countries, stimulating job creation, local firm expansion, economic growth, and foreign exchange inflows (Khan et al., 2020; Badulescu et al., 2021; Shimizu & Okamoto, 2021). Recognising its importance, a vast body of literature has examined the tourism-economic growth nexus, leading to numerous empirical findings in support of the tourism-led growth hypothesis, or growth-led tourism hypothesis, or bidirectional relationship between tourism development and economic growth (Aliyev & Ahmadova, 2020; Badulescu et al., 2021; Tang et al., 2025).

2.1. Tourism development-environmental degradation nexus

Recent studies have paid increasing attention to the sustainability of tourism, particularly in relation to its impact on environmental quality. Tourism development significantly boosts socio-economic growth but often results in environmental degradation (Azam et al., 2018; Raifu & Obaniyi, 2025). According to Katircioglu (2014) and Gedikli et al. (2022), the expansion of the tourism sector escalates energy consumption and subsequently deteriorates environmental quality through increased CO₂ emissions. On a similar note, Zhang and Gao (2016) identified tourism as a major contributor to GHG emissions, highlighting its substantial environmental pressure. Similarly, it has been established that tourism's reliance on energy-intensive activities, such as transportation and infrastructure development, exacerbates environmental degradation (Zhang & Gao, 2016; Ren et al., 2019; Tian et al., 2021). Additionally, Tsagarakis et al. (2011) attributed higher tourism-induced energy consumption to increased demand for accommodations.

Prior empirical studies have yielded mixed findings, highlighting the complexities of tourism's impacts on emissions and the influence of multiple factors, including region, study period, and methodological approach.

Regarding the adverse environmental effects of tourism, Katircioglu (2014) attributed the increase in energy consumption and climate change to tourism development in his study, which employed autoregressive distributed lag (ARDL) estimation to examine the relationships between tourism development, energy consumption, and environmental degradation in Turkey. Shakouri et al. (2017) similarly attributed deteriorating environmental quality to tourism development within the context of Asia-Pacific countries. In another study, Zhang and Gao (2016) used panel Granger-causality tests to find a positive influence of tourism on both economic growth and CO₂ emissions in China, with a feedback loop existing between economic growth and emissions. Gedikli et al. (2022), too, via the panel Granger-causality analysis, concluded that the negative environmental impacts of international tourism outweigh the positive economic effects within the context of OECD countries. Meanwhile, Khan et al. (2019) noted that tourism's adverse environmental effects operate primarily through the transportation sector in Asia and America, driving the promotion of eco-friendly tourism practices through sustainable transportation. Zhang & Liu (2019) found that the development of non-renewable energy and tourism harms environmental quality in Northeast and Southeast Asian countries. The study further revealed that renewable energy mitigated the negative impact. According to Zafar et al. (2023), tourism, trade, and growth factors undermine environmental sustainability, whereas ICT contributes to environmental preservation in BRICS countries.

Conversely, certain studies suggested that tourism can reduce emissions under specific conditions or within certain regions. Ghosh (2020) applied the EKC hypothesis within a tourism framework to a panel of 95 countries classified by income levels, using data from 1995 to 2014, and found evidence supporting an inverted U-shaped EKC relationship between tourism development and CO₂ emissions. In the Central and South American countries, Ben Jebli et al. (2019) found that tourist arrivals reduced CO₂ emissions in the long run. Depending on the region, Azam et al. (2018) and Ahmad et al. (2018) observed both positive and negative environmental impacts of tourism development. Azam et al. (2018) focused on Malaysia, Thailand, and Singapore, while Ahmad et al. (2018) analysed five Chinese provinces. Sghaier et al. (2019) similarly documented varying effects of tourism development on environmental quality in Morocco, Tunisia, and Egypt.

2.2. Environmental Kuznets curve (EKC) hypothesis

Notwithstanding the above studies' emphasis on the negative impacts of tourism development on environmental quality, the relationship between economic growth and environmental degradation has also been extensively explored through the EKC hypothesis. This relationship is not straightforward, as it evolves in accordance with a country's economic structure. It is often characterised by an inverted U-shaped trajectory, where environmental degradation initially increases with economic development but eventually declines after reaching a certain income level (Panayotou, 1993; Grossman & Krueger, 1995; Tian et al., 2021).

This inverted U-shaped relationship can be explained through three primary mechanisms: the scale effect, the composition effect, and the technique effect (Grossman & Krueger, 1995; Dinda, 2004; Tsurumi & Managi, 2010). In the pre-industrial stage, the development of primary and low-efficiency industries produces a scale effect, leading to increased pollution. The scale effect denotes the adverse impact of economic growth on environmental quality – economic expansion increases pollution if other conditions remain constant (Stern, 2004; Guo & Shahbaz, 2024). As the economy shifts towards light manufacturing and service-oriented industries, the composition effect emerges, whereby environmental degradation increases at a slower rate (Álvarez-Herránz et al., 2017). Pollution levels gradually decline as countries transition towards cleaner industries and activities (Dinda, 2004). Ultimately, with sustained economic growth, the technique effect emerges as technological advancements and cleaner production processes reduce pollution and enhance environmental quality (Guo & Shahbaz, 2024). This stage is characterised by the adoption of energy-efficient technologies that further reduce pollution levels.

However, the inverted U-shaped EKC may evolve into an N-shaped trajectory at higher stages of economic development, where pollution rebounds if technological progress fails to keep pace with economic growth (Lorente & Álvarez-Herránz, 2016). Álvarez-Herránz et al. (2017) described this N-shaped EKC as a three-phase relationship between income and pollution: initial economic growth and industrialisation increase pollution (scale effect), followed by a decline in pollution due to technological advancements (technique effect), and finally, an increase in pollution at higher income levels if the scale effect surpasses technological advancements due to technological obsolescence. This technological obsolescence effect reflects the resurgence of the scale effect, which overwhelms the composition and technique effects, resulting in a second turning point (Lorente & Álvarez-Herránz, 2016; Balsalobre-Lorente et al., 2018).

Recent empirical studies that supported the N-shaped EKC include Allard et al. (2018), who identified this pattern in their analysis of CO₂ emissions and GDP per capita in 74 countries. Numan et al. (2022) reached similar conclusions across country groups representing four income levels, covering 85 countries. Comparable findings were also reported for nine top nuclear-producing countries (Jahanger et al., 2023), OPEC countries (Ullah et al., 2023), OECD countries (Álvarez-Herránz et al., 2017; Ullah et al., 2024), Nigeria (Maduka et al., 2022), E-10 countries (Fakher et al., 2023), and 14 emerging economies (Rashdan et al., 2021). N-shaped relationships have also been observed in individual country studies, including Algeria (Shehzad et al., 2022), India (Hossain et al., 2023), and China (Wang et al., 2024). Given the limited exploration of the N-shaped EKC hypothesis in ASEAN countries, it is timely for the current study to reevaluate the EKC framework by incorporating the cubic GDP term (GDP³) into the model, alongside tourism development, to gain novel insights.

2.3. Environmental Kuznets curve hypothesis in ASEAN countries

Other prior studies have investigated the EKC hypothesis for ASEAN countries by analysing the relationships between CO₂ emissions, economic growth, and energy consumption, either collectively or individually. However, these studies did not yield conclusive support for a conventional EKC curve in this region.

Using the panel smooth transition regression approach and accounting for heterogeneity and time instability, Heidari et al. (2015) identified a non-linear relationship between energy consumption, CO₂ emissions, and GDP in the ASEAN-5. In line with the EKC hypothesis, the study's results revealed two threshold parameters: one indicating that environmental degradation increases with economic growth. At the same time, the other suggests that it decreases after a certain point. In another study, Chng (2019) employed time-series methods to empirically investigate the effects of economic growth, trade openness, energy consumption, and foreign direct investment on environmental degradation in six selected ASEAN countries from 1971 to 2013. The study found the presence of an EKC in Singapore, Thailand, and Vietnam, but no evidence of an EKC in Malaysia, the Philippines, and Indonesia. Saboori and Sulaiman (2013) similarly found that economic growth, CO₂ emissions, and energy consumption were cointegrated in all five countries. However, the study observed that economic growth led to lower CO₂ emissions in Singapore and Thailand, but it resulted in higher CO₂ emissions in Indonesia and the Philippines.

Meanwhile, Lean and Smyth (2010) found no evidence of the EKC hypothesis in Malaysia, Indonesia, Thailand, and Singapore. Likewise, Narayan and Narayan (2010) found no support for the EKC hypothesis in Malaysia, Indonesia, and the Philippines. Chandran and Tang (2013) also found no evidence supporting the EKC hypothesis for the ASEAN-5 collectively. The study's individual country-specific analysis also yielded similar null results. Focusing on Singapore, Tan et al. (2014) found that CO₂ emissions and GDP increased together, although the former was found to negatively affect Singapore's economic growth.

Conversely, a study focused on Malaysia by Ang (2008) identified a long-run positive relationship between increased pollutant emissions, increased energy consumption, and output growth. In a more recent study,

Ansari (2022) employed second-generation unit root and cointegration tests robust to cross-sectional dependence and demonstrated the validity of the EKC hypothesis in the ASEAN region, only when footprint-based emissions, rather than consumption-based CO₂ emissions, were used as the dependent variable.

The diverse findings of the above studies, particularly those that analysed the EKC hypothesis for ASEAN countries collectively, shared a standard limitation: the failure to account for cross-sectional dependence among the ASEAN countries, which likely contributes to the inconsistent findings. As for the mixed findings across individual country analyses, the heterogeneity in methodologies and variables, limited data availability, and variations in robustness checks may be the underlying causes. Addressing the limitations above, the current study employs estimation methods that are robust to cross-sectional dependence and conducts more comprehensive robustness checks. Furthermore, the current study's analysis is novel and timely, as no other research has examined the N-shaped EKC hypothesis in the context of the ASEAN region while accounting for the role of tourism development.

3. Materials and methods

3.1. Model and data

The following general model is proposed to examine the impact of tourism development on environmental quality within the EKC framework:

$$CO_{2it} = \beta_0 + \beta_1 TD_{it} + \beta_2 GDP_{it} + \beta_3 GDP_{it}^2 + \beta_4 GDP_{it}^3 + X\beta + \gamma_i + \varepsilon_{it} \quad (1)$$

where:

CO₂ : Total carbon dioxide emissions, for country *i* and year *t*, in kiloton (kt), capturing the level of environmental quality

TD : Total number of international tourist arrivals to ASEAN countries, for country *i* and year *t*, as a proxy for tourism development

GDP : Real GDP per capita constant at 2015 US dollars, for country *i* and year *t*

*GDP*² : Squared term of real GDP per capita

*GDP*³ : Cubic term of real GDP per capita (see discussion on robustness check below)

X : Vector of control variables (see discussion on robustness check below)

γ_i : Unobserved country-specific effects

ε_{it} : The iid error terms

The priori sign for TD is expected to be positive, based on the earlier-discussed proposition that tourism development is heavily linked with increased energy consumption, which consequently contributes to higher emissions. However, TD can also have a negative sign, as several prior studies discovered the positive impact of tourism development on environmental quality by reducing emissions, especially within the context of sustainable tourism that relies on renewable energy.

The inclusion of GDP and its squared term, GDP², in this study is intended to capture the EKC hypothesis in the model. To give support to the inverted U-shaped EKC hypothesis, GDP and GDP² are expected to have positive and negative signs, respectively. *X* meanwhile represents the vector of control variables previously shown to exert significant effects on environmental degradation, and they are included in this study's robustness checks. This study also assesses the potential N-shaped EKC hypothesis in the final and more comprehensive robustness check with the inclusion of GDP³ in the model. A more detailed explanation regarding robustness checks is provided in the subsequent section.

Table 1
Summary statistics of the variables

Variable		Mean	Standard deviations	Minimum	Maximum	Number of observations
CO ₂	Overall	106,594.80	127,709.70	674.95	605,290.60	N = 250
	Between		124,861.30	4,750.68	385,954.60	n = 10
	Within		47,139.04	-55,681.04	325,930.80	T = 25
GHG	Overall	189,011.90	225,144.60	6,207.55	1,020,914.00	N = 250
	Between		229,535.80	8,296.25	765,863.20	n = 10
	Within		55,512.64	6,790.19	444,062.30	T = 25
TD	Overall	7,142,717	7,761,535	194,000	39,900,000	N = 250
	Between		6,449,181	1,398,320	18,200,000	n = 10
	Within		4,760,079	-5,520,403	29,300,000	T = 25
GDP	Overall	9,994.27	15,175.62	210.54	61,386.23	N = 250
	Between		15,567.64	701.47	44,466.78	n = 10
	Within		3,362.64	-4,092.61	26,913.72	T = 25
REN	Overall	35.89	29.40	0.00	86.62	N = 250
	Between		29.89	0.00	78.12	n = 10
	Within		7.58	13.11	57.34	T = 25
POP _N	Overall	57,600,000	67,700,000	299,097	270,000,000	N = 250
	Between		70,700,000	375,123	235,000,000	n = 10
	Within		8,369,565	20,900,000	92,300,000	T = 25
FDI	Overall	5.47	5.68	-2.76	29.76	N = 250
	Between		4.98	1.23	18.46	n = 10
	Within		3.14	-6.34	16.77	T = 25

A balanced panel dataset consisting of observations for ten ASEAN countries over 25 years, from 1995 to 2019¹ is used in this study. All variables, obtained from The World Development Indicator (The World Bank, 2024), are converted into natural logarithmic form for analysis. Table 1 presents the summary statistics of the variables, and a closer look at the summary statistics reveals unique findings where the standard deviation is often greater between countries than it is within countries (or across time periods), despite the dataset having a greater number of years (25) compared to the number of countries (10). The pairwise correlation coefficients are included in the appendix of this study.

3.2. Pre-estimation test and estimation method

The empirical analysis begins with the cross-sectional dependence (CSD) test to determine the suitable estimation methods for the study. A certain degree of interdependence is expected among the ten ASEAN countries due to their proximity and shared characteristics, particularly since ASEAN is an official regional organisation. If this dependence is present but not accounted for by the estimation method, the classical assumption of ordinary least squares (OLS) on the independent and identically distributed error terms would be violated. Furthermore, the presence of CSD in an estimation would lead to omitted variable bias or endogeneity, resulting in inconsistent estimates (Pesaran, 2004).

With that, this study performs Pesaran's (2004) CD test for CSD, which can be applied to small and large panels, especially when $N > T$, whose null hypothesis of no CSD is expressed as follows:

$$CSD = \sqrt{2T/N(N-1)} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{i,k} \right) \quad (2)$$

Subsequently, DKFE estimation is performed as this method proposes a non-parametric covariance matrix fixed effects estimator with standard errors that are not only heteroskedasticity- and autocorrelation-consistent

¹ Although data for tourist arrivals and CO₂ and GHG emissions are available up until the year 2020, this study omits data from the year 2020 from the sample to eliminate the outlier effect due to the significant reduction in the number of tourist arrivals and CO₂ and GHG emissions because of the movement control order following the COVID-19 pandemic.

but also robust to CSD. Although the DKFE estimator may be less suitable for long panels (when $T > N$), as is the case in this study's dataset, it was selected due to the unique finding that variations between countries are greater than variations within countries, as revealed earlier in the summary statistics.

In addition, Beck and Katz's (1995) PCSE estimation method, which is capable of accounting for CSD, heteroskedasticity, and serial correlation in the residuals of panel time series models, is performed to complement the DKFE estimator. The PCSE estimator can handle datasets where the number of time periods exceeds the number of cross-sectional units (T/N)² and produces the full $N \times N$ cross-sectional covariance matrix estimates, which are precise if the ratio T/N is large.

3.3. Strategies for baseline estimation and robustness checks

For the baseline estimation, Equation (1) is estimated using the DKFE and PCSE methods, excluding GDP³ and the control variables. Meanwhile, for the robustness checks, the procedure begins by replacing CO₂ emissions with GHG emissions (measured in kt of CO₂ equivalent) and then replicating the two aforementioned estimation methods.

Secondly, three control variables — namely, the level of renewable energy in each country (REN), total population size in the country (POP_N), and net inflow of foreign direct investment to the country (FDI) — are included in the baseline estimation and re-estimated using both estimation methods. These three control variables have been widely used as independent variables in the models of CO₂ and GHG emissions. In the ASEAN context, where non-renewable energy sources continue to dominate and contribute to environmental degradation, the inclusion of REN in this study aims to capture the mitigating role of renewable energy on tourism-induced emissions. Furthermore, the inclusion of POP_N in the analysis of tourism-induced emissions is crucial for disentangling the environmental impacts of tourism development while accounting for population size. Similarly, FDI is included in this study's robustness check given its empirically proven detrimental effects on the environment despite its growth-promoting benefits. All control variables are transformed into natural logarithmic form for estimation purposes.

Notably, when estimation is made without GDP³, Equation (1) primarily tests for the inverted U-shaped EKC hypothesis. For the final robustness check, the potential presence of an N-shaped EKC hypothesis is explored for the ASEAN region by re-estimating the baseline specification and the preceding robustness checks with the inclusion of GDP³. This inclusion allows for the detection of potential turning points beyond the conventional inverted U-shaped trajectory.

4. Discussion of results

Table 2 presents the results of Pesaran's (2004) CD test for cross-sectional dependence. All variables, except for REN, are found to be cross-sectionally dependent, which justifies the selection of DKFE and PCSE estimators.

Table 2
Pesaran's (2004) CD test for cross-sectional dependence

Variables	CD statistics	p-value
CO ₂	27.967	0.000
GHG	30.095	0.000
TD	30.867	0.000
GDP	20.658	0.000
REN	1.278	0.201
POP _N	33.380	0.000
FDI	3.999	0.000

² Beck and Katz (1995) demonstrated that the PCSE estimator, which employs large-T asymptotics and adjusts standard errors for contemporaneous correlation across panels, performs well in small-panel samples.

The empirical findings of baseline estimation, robustness checks, and the final model incorporating GDP³ are presented in the subsequent subsections. These results offer critical insights into the environmental impacts of tourism development and the applicability of the EKC hypothesis in ASEAN countries.

4.1. Baseline estimation and first robustness check

Table 3 presents the results from the baseline estimation, the CO₂ model, and the first robustness check, the GHG model. Both models include only tourism development, GDP per capita, and its squared term as explanatory variables. The results demonstrate the statistically significant and positive influence of tourism development on environmental degradation. Specifically, a 1% increase in tourist arrivals is associated with a 0.3–0.4% rise in CO₂ emissions and a 0.2% increase in GHG emissions. These estimates align closely with previous empirical evidence, which highlighted the adverse environmental impacts of tourism development (Katircioglu, 2014; Zhang & Gao, 2016; Shakouri et al., 2017; Gedikli et al., 2022; Zafar et al., 2023).

Regarding the EKC hypothesis, this study obtains mixed evidence. The outcomes of the PCSE estimator support the presence of an inverted U-shaped relationship between GDP per capita and emissions, which is consistent with numerous studies on the EKC hypothesis (Grossman & Krueger, 1995; Dinda, 2004; Stern, 2004; Tsurumi & Managi, 2010; Guo & Shahbaz, 2024). The GDP per capita thresholds at which emissions begin to decline are estimated at approximately USD 6,200 for CO₂ emissions and USD 2,200 for GHG emissions. Given that the average GDP per capita across ASEAN countries is approximately USD 10,000 (as indicated in the summary statistics), this value suggests that the region's current stage of economic development may not exacerbate environmental degradation further, at least based on this estimation.

However, the DKFE estimator produces contrasting results, presenting a statistically significant U-shaped EKC pattern for the GHG model only. This divergence in the results highlights the sensitivity of the EKC relationship to the selected estimation method and the emission indicator. Thus, this study presents mixed findings on the EKC hypothesis at this stage, which should be interpreted cautiously, pending further confirmation through subsequent robustness checks.

Table 3
DKFE and PCSE estimations – baseline and robustness check 1

Dependent variable	Baseline estimation - CO ₂ emissions		Robustness check 1 - GHG emissions	
	DKFE	PCSE	DKFE	PCSE
Estimation method	(1)	(2)	(3)	(4)
TD_{it}	0.421*** (0.052)	0.281*** (0.065)	0.198*** (0.025)	0.180*** (0.042)
GDP_{it}	0.410 (0.447)	3.038*** (0.571)	-0.488*** (0.120)	1.956*** (0.337)
GDP_{it}^2	0.006 (0.023)	-0.174*** (0.033)	0.055*** (0.008)	-0.127*** (0.019)
Constant	0.314 (1.799)	-6.374*** (2.117)	8.554*** (0.535)	1.792 (1.135)
R-squared	0.738	0.975	0.772	0.993
Wald statistics	-	106.90***	-	153.75***
GDP per capita threshold of EKC	-	6,185.02 [^]	84.47	2,210.09

Note. Standard errors in parentheses. ***, **, * indicate 1%, 5% and 10% levels of significance, respectively. The number of observations is 250, and the number of countries is 10. Using the significant coefficients of GDP and GDP², the calculation of the threshold level of real GDP per capita is performed by taking the exponential of the absolute value of the ratio of the coefficient of GDP to twice the coefficient of GDP², i.e. $e^{\frac{\beta_{GDP}}{2 \times \beta_{GDP^2}}}$. [^] indicates the maximum level of real GDP per capita threshold.

4.2. Second robustness check – Estimations with control variables

Table 4 presents the results of the second robustness check, which incorporates three additional control variables, REN, POPN, and FDI, into the baseline specification. The inclusion of these control variables leads to notable changes in the estimated coefficients.

The adverse environmental impacts of tourism development remain statistically significant only through the DKFE estimator, where a 1% increase in tourist arrivals increases CO₂ emissions by approximately 3% and GHG emissions by 1%. In contrast, the PCSE estimator yields statistically insignificant coefficients for tourism development. This may be likely attributed to the inclusion of POPN as a control variable, which captures a substantial portion of the variation in emissions.

The EKC relationship continues to exhibit a model-dependent pattern. The PCSE estimator produces results that consistently support the inverted U-shaped EKC, whereas the DKFE estimator produces results that maintain the U-shaped pattern in the GHG model. However, the income thresholds substantially increase, as compared to the baseline results, reaching approximately USD 12,000 for CO₂ emissions and USD 14,000 for GHG emissions. As these thresholds exceed the average GDP per capita of ASEAN countries, the results suggest the potential environmental risks associated with the current economic development and tourism activities in the region.

Table 4
DKFE and PCSE estimations – robustness check 2

Dependent variable	CO ₂ emissions		GHG emissions	
	DKFE	PCSE	DKFE	PCSE
Estimation method	(5)	(6)	(7)	(8)
TD_{it}	0.342*** (0.074)	0.041 (0.048)	0.117*** (0.027)	-0.011 (0.024)
GDP_{it}	0.142 (0.556)	2.177*** (0.409)	-0.491** (0.210)	0.860*** (0.145)
GDP_{it}^2	0.015 (0.033)	-0.116*** (0.022)	0.052*** (0.015)	-0.045*** (0.008)
REN_{it}	-0.942*** (0.108)	-0.636*** (0.084)	-0.431*** (0.061)	-0.369*** (0.034)
$POPN_{it}$	-0.056 (0.405)	0.971*** (0.062)	0.342* (0.162)	0.926*** (0.024)
FDI_{it}	0.002 (0.007)	0.001 (0.002)	-0.010** (0.003)	-0.002 (0.001)
Constant	6.743 (8.279)	-14.555*** (1.793)	5.552 (3.330)	-6.941*** (0.589)
R-squared	0.797	0.989	0.840	0.999
Wald statistics	–	642.80***	–	3094.09***
GDP per capita threshold of EKC	–	11,892.00	112.30	14,122.94 [^]

Note. Standard errors in parentheses. ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively. More notes in Table 3.

The control variables exhibit the expected relationships. REN emerges as a robust mitigating factor; a 1% increase in REN reduces CO₂ emissions by 0.6–0.9% and GHG emissions by approximately 0.4%. These results corroborate the existing literature, highlighting the environmental benefits of renewable energy adoption (Ben Jebli et al., 2019; Zhang & Liu, 2019; Tian et al., 2021). POPN, meanwhile, is found to be a significant driver of emissions, with a 1% increase in population size leading to a 10% rise in CO₂ emissions and a 3–9% increase in GHG emissions, consistent with the results reported by Liddle (2013). However, FDI is not a significant determinant of CO₂ emissions, while its effects on GHG emissions are mixed. The study's results align with those of Kiviyiro and Arminen (2014) but

contradict the findings of Ben Jebli et al. (2019), which revealed a positive relationship between FDI and CO₂ emissions.

4.3. Third robustness check – Testing for N-shaped EKC

The final robustness check augments the model with GDP³ to test for an N-shaped EKC. This extended specification yields more consistent and robust results across both DKFE and PCSE estimation methods, as well as both emission indicators —CO₂ and GHG emissions—regardless of whether control variables are included. As shown in Table 5, this study obtains strong evidence supporting an inverted N-shaped EKC relationship. Unlike the results of previous studies on conventional N-shaped EKC, the current study's novel finding, to the best of our knowledge, represents the first empirical evidence of an inverted N-shaped EKC within the context of ASEAN countries.

The inverted N-shaped EKC suggests that environmental degradation initially declines in the early stages of economic development, increases during industrialisation, and subsequently declines again as economic growth transitions towards a sustainable trajectory. The development pathway of ASEAN economies can explain this pattern: In the early stages, economic activities in this region were primarily driven by agricultural and low-emission sectors. With the rise of industrialisation and urbanisation in the 1990s, emissions increased sharply as energy consumption intensified. More recently, ASEAN countries have begun investing heavily in green technologies, renewable energy, and environmentally sustainable policies, which has prompted a subsequent decline in emissions as their GDP reaches higher levels. However, within the inverted N-shaped EKC context of the ASEAN region, the current study finds that the second threshold value of GDP per capita³ – when economic growth corresponds to a decline in environmental degradation – is estimated to be around USD 18,000-28,000 in the CO₂ model and USD 27,000-78,000 in the GHG model. Thus, the region's average GDP per capita of approximately USD 10,000 implies that ASEAN's tourism and economic development may still be in the pollution-inducing stage.

Regarding empirical analysis of tourism development within the inverted N-shaped EKC framework, a study by Purwono et al. (2024) included tourism as one of the determinants of carbon emissions, and it noted the significant theoretical and empirical importance of the inverted N-shaped EKC. The study proposed that during the early phases of tourism development, CO₂ emissions increase with the rising demand for energy driven by the expansion of tourism activities. However, as tourism grows beyond a certain threshold, emissions begin to decline as greater financial resources are directed towards mitigating the environmental impacts of tourism, enabling the adoption of more sustainable practices. Nevertheless, beyond a further income threshold, environmental degradation may resume due to the substantial energy requirements associated with the development and enhancement of tourism destinations.

In short, while the baseline estimation and robustness checks yield mixed findings on the EKC hypothesis in this study, a more comprehensive robustness analysis reveals an interesting finding of an inverted N-shaped EKC relationship in the ASEAN region. While emissions initially declined during the early development stage of ASEAN economies, these emissions increased following the structural shifts in ASEAN economic development, characterised by industrialisation and more energy-intensive economic activities. At higher income levels, these emissions then declined due to the enforcement

³With the inclusion of GDP³ in the estimated CO₂ and GHG models for the third robustness check, the two turning points are calculated using the following steps: Firstly, the first derivative of the function with respect to GDP, i.e. $\frac{dCO_2}{dGDP} = \frac{dGHG}{dGDP} = \beta_2 + 2 * \beta_3 GDP + 3 * \beta_4 GDP^2$ is determined. Next, the derivative is set to equal to zero and solved using the formula $GDP = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ where $a=3 * \beta_4$, $b=2 * \beta_3$, and $c=\beta_2$. Lastly, since Equation (1) of the model is expressed in the natural logarithmic form, the exponential values for GDP are computed to capture the GDP per capita threshold values in USD.

of more environmentally friendly and sustainable economic and tourism policies. Nevertheless, the computed GDP per capita threshold values indicate the current ASEAN economic development's pollution-inducing stage.

Table 5
DKFE and PCSE estimations – robustness check 3

Dependent variable	CO ₂ emissions				GHG emissions			
	Without control variables		With control variables		Without control variables		With control variables	
	DKFE	PCSE	DKFE	PCSE	DKFE	PCSE	DKFE	PCSE
Estimation method	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
TD_{it}	0.273*** (0.051)	0.136** (0.056)	0.223** (0.087)	0.021 (0.045)	0.119*** (0.022)	0.027 (0.027)	0.052* (0.029)	-0.004 (0.022)
GDP_{it}	-14.899*** (1.011)	-12.076*** (3.138)	-11.401*** (1.938)	-9.732*** (2.893)	-8.694*** (0.549)	-3.311*** (1.229)	-6.808*** (0.901)	-6.396*** (0.966)
GDP_{it}^2	2.003*** (0.134)	1.720*** (0.392)	1.551*** (0.279)	1.387*** (0.358)	1.125*** (0.069)	0.468*** (0.159)	0.892*** (0.122)	0.880*** (0.120)
GDP_{it}^3	-0.083*** (0.005)	-0.075*** (0.016)	-0.065*** (0.012)	-0.060*** (0.014)	-0.044*** (0.003)	-0.019*** (0.007)	-0.035*** (0.005)	-0.037*** (0.005)
REN_{it}	-	-	-0.542*** (0.120)	-0.496*** (0.082)	-	-	-0.212*** (0.059)	-0.163*** (0.039)
POP_{it}	-	-	0.314 (0.386)	1.091*** (0.080)	-	-	0.545*** (0.153)	0.896*** (0.030)
FDI_{it}	-	-	0.010 (0.009)	0.002 (0.002)	-	-	-0.006 (0.004)	-0.000 (0.001)
Constant	39.566*** (2.669)	33.914*** (8.104)	28.461*** (5.277)	13.124* (7.406)	29.595*** (1.438)	17.899*** (3.075)	17.438*** (1.973)	10.749*** (2.491)
R-squared	0.808	0.971	0.826	0.976	0.848	0.992	0.873	0.999
Wald statistics	-	183.56***	-	513.09***	-	214.36***	-	3532.40***
GDP per capita first threshold of EKC	342.61	235.39	318.51	221.73	372.48	173.61	326.25	281.72
GDP per capita second threshold of EKC	28,332.45	18,539.48	25,439.34	22,240.38	67,864.81	77,980.68^	73,336.63	27,308.11

Note. Standard errors in parentheses. ***, **, * indicate 1%, 5%, and 10% level of significance, respectively. More notes in Table 3. Refer to footnote 3 for the computation of the first and second threshold values of GDP per capita.

5. Concluding remarks

This study examines the intricate relationships of tourism development, economic growth, and environmental quality, proxied by total CO₂ and GHG emissions, across ten ASEAN countries from 1995 to 2019. The obtained results underscore the complex interplays between tourism development, economic growth, and environmental quality within the ASEAN context.

Consistent with many prior studies, this study reveals that tourism development in ASEAN countries significantly increases CO₂ and GHG emissions, indicating the contribution of increased tourist arrivals to environmental degradation. This adverse effect is particularly evident in the results of baseline estimation and the robustness check when population size is not controlled for, particularly in the DKFE estimation. However, the significance of tourism's environmental impacts appears to be less robust when population size is incorporated as a control variable, suggesting that part of the emissions attributed to tourism may also reflect broader demographic pressures.

The analysis of the EKC hypothesis in this study yields mixed evidence. The results of PCSE estimation consistently support an inverted U-shaped relationship between economic growth and emissions. In contrast, the results of DKFE estimation suggest a U-shaped pattern in some instances, particularly for GHG emissions. A novel contribution of this study emerges from the final robustness check, which incorporates the GDP³ to test for an N-shaped EKC hypothesis. The results of both DKFE and PCSE estimations of CO₂

and GHG models (with and without control variables) consistently present evidence of an inverted N-shaped relationship between economic growth and emissions. These results challenge the conventional U-shaped EKC theory, suggesting the following situations: the environmental quality in ASEAN region might initially improve during the initial stages of economic development, given the region's dependence on agricultural and low-emissions sectors, but deteriorated during subsequent industrialization and urbanization stages that were prevalent in the 1990s onwards, and improved again with the region's transition towards more sustainable growth patterns in the 2000s. Nevertheless, the study's results suggest an association between tourism development and economic growth in ASEAN countries, as well as environmental degradation, indicating that the countries may not have yet reached the turning point at which emissions decline.

The study also highlights the importance of renewable energy and population size as key factors influencing environmental quality. Renewable energy is shown to exert a significant mitigating effect on emissions, reinforcing the importance of transitioning towards cleaner energy sources. Conversely, population growth is identified as a major driver of emissions, highlighting the pressures that demographic expansion imposes on environmental resources. However, the impacts of foreign direct investment appear to be less conclusive, with no consistent evidence of its significant influence on either CO₂ or GHG emissions.

These findings have significant implications for policymakers in ASEAN countries, suggesting that more emphasis should be placed on developing sustainable tourism practices, integrating environmental considerations into broader economic planning, and enhancing renewable energy infrastructure. The demonstrated inverted N-shaped EKC in the region suggests that unchecked economic growth alone is unlikely to yield guaranteed improvements in environmental quality. Instead, the results underscore the need for well-coordinated and proactive environmental strategies to accompany economic development policies, particularly during the region's phases of rapid industrialisation and urbanisation. Considering the transboundary nature of environmental issues, such as air pollution and climate change, regional cooperation among ASEAN member states is highly imperative. Coordinated policy responses, information sharing, and joint investments in green technologies can enhance the effectiveness of national environmental strategies.

In conclusion, this study contributes to the growing body of literature on the environmental impacts of tourism development and economic growth in ASEAN countries. The findings reveal that, while tourism development has adverse effects on environmental quality, the relationship between economic growth and emissions is more complex than the conventional EKC framework suggests. The presence of an inverted N-shaped EKC in this study underscores the need for policies that promote green growth trajectories while accommodating the unique development stages of ASEAN countries. The study provides valuable insights for policymakers and researchers seeking to strike a balance between economic progress and environmental sustainability in the region.

Nevertheless, further research is warranted to refine the estimated income-emission dynamics and to explore the nuanced interactions between tourism development, energy consumption, and environmental policies within the diverse socio-economic contexts in ASEAN. Additionally, given that transportation is a key enabler of tourism and a major contributor to carbon emissions, future research should specifically investigate the environmental impacts of tourism-induced transportation. Such an approach would offer clearer insights into the extent to which tourism-related transportation contributes to the overall emissions of the transportation sector, thereby enhancing the understanding of tourism's environmental footprint.

Abbreviations:

ASEAN: Association of Southeast Asian Nations; CO₂: Carbon dioxide; CSD: Cross-sectional Dependence; DKFE: Driscoll and Kraay's (1998) fixed effects within estimator; EKC: environmental Kuznets curve; GHG: Greenhouse gas; PCSE: Panel-corrected standard errors estimator.

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Appendix

Table A1
Pairwise correlation coefficients of variables

Variable name	CO ₂	GHG	TD	GDP	REN	POP	FDI
CO ₂	1.000						
GHG	0.968	1.000					
TD	0.543	0.380	1.000				
GDP	-0.232	-0.284	0.155	1.000			
REN	-0.274	-0.134	-0.511	-0.673	1.000		
POP	0.830	0.929	0.083	-0.385	0.058	1.000	
FDI	-0.325	-0.355	0.072	0.650	-0.236	-0.403	1.000