# Tourism development, renewable energy, and environmental quality in Asean: New evidence from panel estimators robust to cross-sectional dependence and heterogeneity

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**Tourism development, renewable energy, and environmental quality in ASEAN: New evidence from panel estimators robust to cross-sectional dependence and heterogeneity.**

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## Abstract

Tourism is widely recognized as a key driver of economic growth and development, yet its dependence on the energy sector has raised concerns regarding its environmental impact. Aiming to elucidate the roles of tourism and renewable energy in shaping the environmental outcomes, this study investigates the nexus between tourism development, renewable energy utilization, and environmental quality across 10 ASEAN countries over a 25-year period from 1995 to 2019 by employing panel estimators robust to heterogeneity and cross-sectional dependence such as Panel Corrected Standard Errors (PCSE), Feasible Generalized Least Squares (FGLS), and Augmented Mean Group (AMG) that are rarely utilized in the ASEAN context. Our findings reveal that tourism activity contributes to CO2 and greenhouse gas emissions, with a 1% increase in tourist arrivals associated with a 0.1 to 0.3% rise in emissions. Moreover, we observe a significant mitigating effect of renewable energy on tourism-induced emissions. Our analysis also lends strong support to the Environmental Kuznets Curve (EKC) hypothesis, indicating a threshold level of GDP per capita of USD 13,000, beyond which the adverse environmental impact of GDP turns positive. The common dynamic process in AMG estimator is found to raise emissions, implying the ASEAN strategic policies on sustainable tourism and energy cooperation may not yet come to fruition given the region's heavy reliance on non-renewable energy sources to sustain tourism and meet population demands. We conclude with policy implications aimed at fostering sustainable tourism and development in the region.

Keywords: CO2 emissions, Environmental Kuznets Curve, Environmental quality, Renewable energy, Tourism development.

**JEL code: O13, Q56, Z32**

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## 1. Introduction

The escalating levels of greenhouse gas (GHG) emissions, predominantly driven by carbon dioxide ($CO_2$), methane, and nitrous oxide, have been identified as the primary catalysts for climate change (Shivanna, 2022). Notably, $CO_2$ alone accounts for over three-quarters of all GHG emissions globally (Hammoudeh et al., 2014), with a staggering increase of over 50% since 1990, particularly accelerating between 2000 and 2010 (UNEP, 2024). Addressing this trajectory is imperative for achieving long-term sustainable development, as outlined by Sustainable Development Goal (SDG) 13, which underscores the urgency of combating climate change. Compliance with the Paris Agreement mandates a 45% reduction in emissions by 2030 and achieving net zero emissions by 2050 to limit global warming to 1.5°C (United Nations, 2024).

The Association of Southeast Asian Nations (ASEAN) is a 10-country regional organization consisting of Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. Within the ASEAN, nine countries have pledged to attain net-zero emissions by 2050, apart from the Philippines (Lin, 2022). Despite its dynamism and diversity, ASEAN countries remains highly vulnerable to climate change (Lau, 2022). Figure 1 illustrates the annual growth rates of $CO_2$ and GHG emissions in ASEAN and globally from 1995 to 2020. Over the past 26 years, ASEAN has witnessed a more rapid increase in $CO_2$ emissions growth (4.2%) and GHG emissions growth (3.0%) compared to the global averages of 1.7% and 1.5%, respectively. In 2020, ASEAN's $CO_2$ emissions totalled 1.7 billion metric tons, with Indonesia, Malaysia, the Philippines, Thailand, and Vietnam contributing approximately 93% of this total.

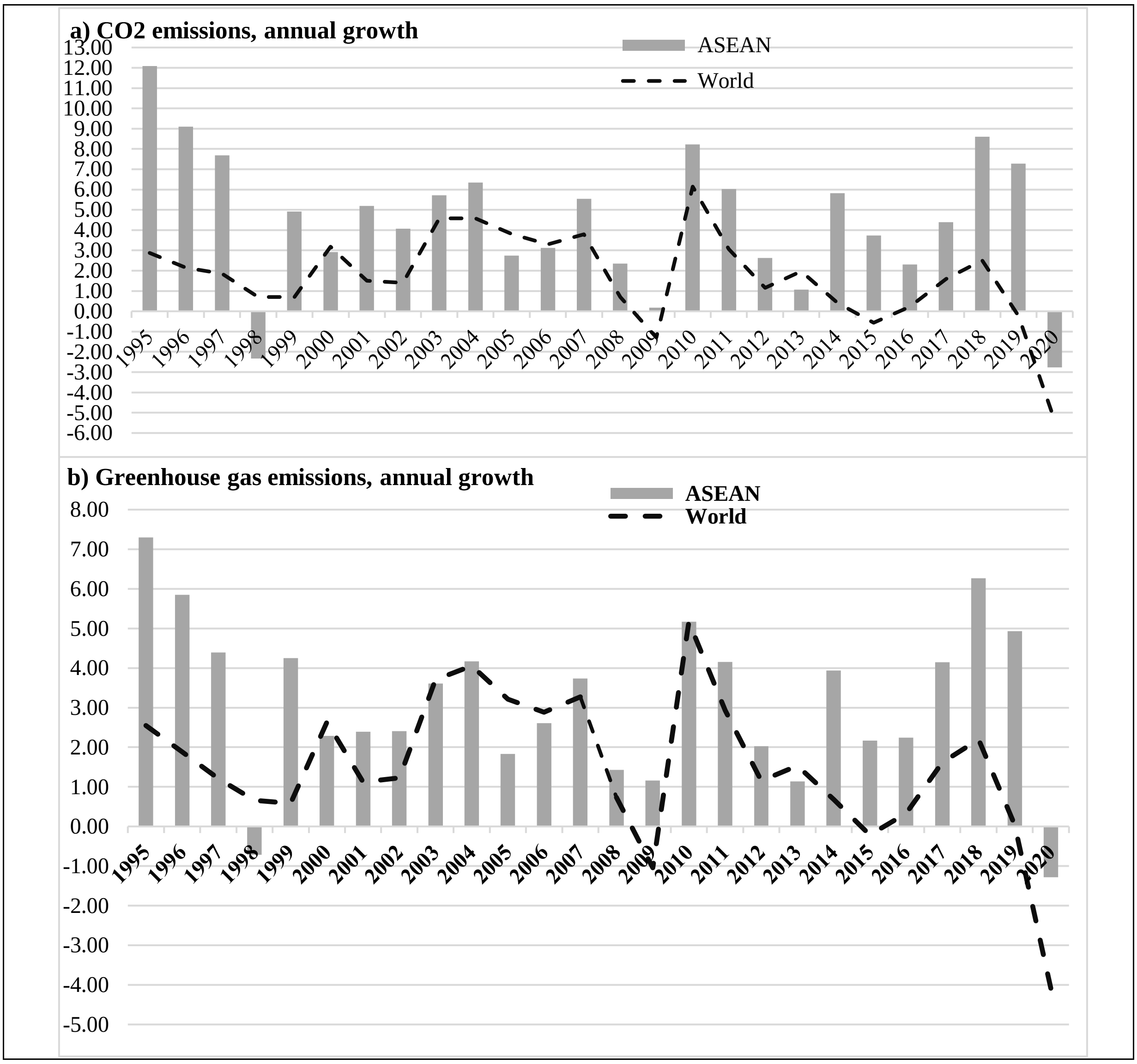
The surge in carbon emissions can be largely attributed to various factors, including tourism development, economic growth, and the (lack of) utilization of renewable energy sources. Tourism, a significant economic sector globally, has been a major contributor to GDP growth and job creation (UNWTO, 2020). Tourism is found to promote economic growth in Malaysia (Tang & Tan, 2015), BRICS economies (Rasool et al., 2021), China and Turkey (Isik et al., 2017), MENA countries (Tang & Abosedra, 2014), Chinese ethnic autonomous counties (Tu & Zhang, 2020), and North European countries (Pérez-Rodríguez et al., 2021). Meanwhile, the World Travel and Tourism Council reported that travel and tourism contributed to 10.4% of the world's GDP (USD 9.2 trillion) in 2019, created 10.3% of all jobs (334 million), and resulted in one in five new jobs globally between 2014 and 2019. After fuels and chemicals, tourism is the world's third-largest export sector (Rasool et al., 2021). However, the symbiotic relationship between tourism and the environment is undeniable (Robaina-Alves et al., 2016).

While tourism promotes economic advancement, it can also lead to environmental degradation and the erosion of traditional civilizations (Malaysia Biodiversity Information System (MyBIS), 2015). A rise in tourism activities brings a corresponding increase in energy demand such as accommodation, transportation, and catering services, and lead to major burning fossil fuels, like coal, oil, and gas, and resulting in $CO_2$ emissions. According to Liu et al. (2023) tourism is responsible for about 8% of all GHG emissions. World Tourism Organization and International Transport Forum (2019) meanwhile forecast a 45% increase in transport-related emissions from international tourism between 2016 and 2030.

According to the UNWTO (2020), international tourist arrivals reached approximately 1,460 million in 2019, generating USD 1,481 billion in international tourism receipts. Over the same period, Southeast Asian countries has outperformed other subregions of the world at a growth rate of 7.8% in arrivals and closely followed by South Asia (7.5%) (UNWTO, 2021). Figure 2 provides a breakdown of international tourist arrivals in ASEAN, indicating a consistent upward trend from 1995 to 2019. Thailand emerged as the most popular destination within ASEAN, recording nearly 40 million international tourist arrivals in 2019, followed by Malaysia, Singapore, and Vietnam. Malaysia came in second, with approximately 26 million arrivals over the same period, followed by Singapore and Vietnam with 19 million and 18 million arrivals, respectively.

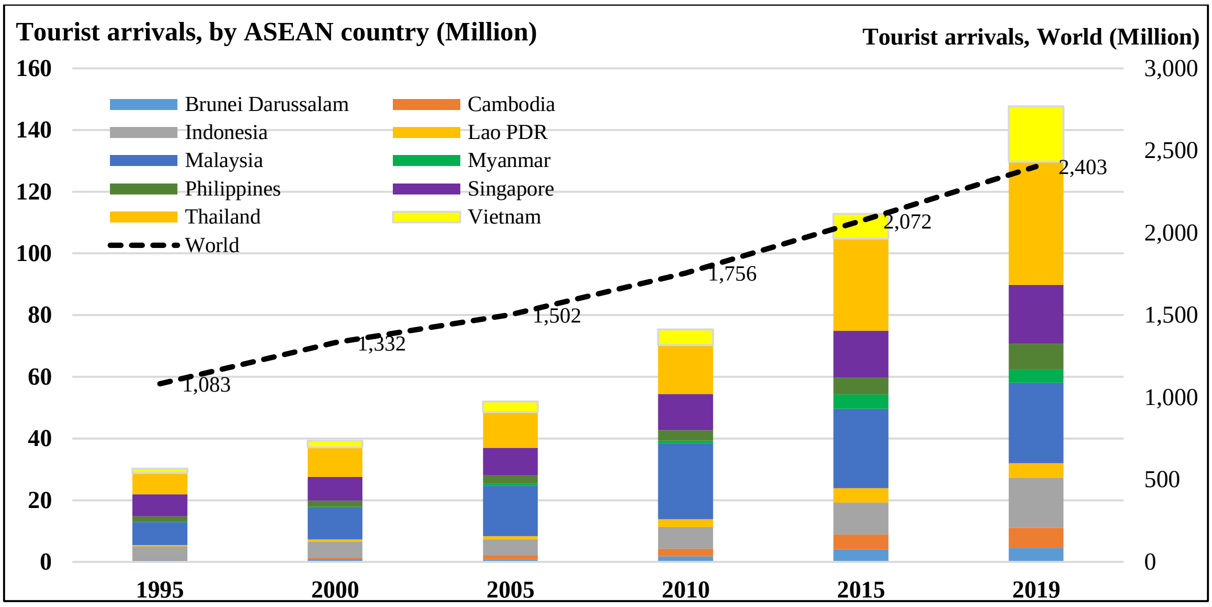
Moreover, ASEAN remains among the world's fastest-growing regions, with its economy projected to rank fourth globally by 2030, trailing only China, India, and the United States (AEIB, 2023). Table 1 presents the real GDP per capita growth and renewable energy consumption trends in ASEAN and globally from 1995 to 2022. Notably, between 1995 and 2019, ASEAN's real GDP per capita grew at an average annual rate of 3.9% during this period, outpacing the global average of 1.8%. Conversely, renewable energy consumption, despite its potential to mitigate $CO_2$ emissions, witnessed a downward trend in ASEAN, accounting for 29.8% of total final energy consumption in 2020. Renewable energy sources are the most affordable ways to boost electricity access, lessen air pollution and a key strategy for reducing $CO_2$ emissions globally (UN Press, 2018). As noted by Szetela et al. (2022), an increase in renewable energy consumption by one percentage point is associated with a 1.25% decrease in $CO_2$ emissions per capita in 43 most resource dependent countries between 2000 and 2015.

**Figure 1. Annual growth rate of CO2 and GHG emissions of ASEAN and World**




Source: Authors' own computation based on data collected from (The World Bank, 2024)

**Figure 2. International tourist arrivals in ASEAN and World**




Source: Based on data collected from World Development Indicators from The World Bank (2024) and authors own interpolation using cubic spline method for missing observations.

**Table 1: Real GDP per capita growth and renewable energy consumption of ASEAN and World**

| Year | Real GDP per capita growth (annual change in %) | | Renewable energy consumption (% of total final energy consumption) | |
|---|---|---|---|---|
| | ASEAN | World | ASEAN | World |
| 1995 | 5.3 | 1.6 | 49.4 | 17.4 |
| 2000 | 5.3 | 3.1 | 46.2 | 17.6 |
| 2005 | 5.3 | 2.7 | 42.5 | 16.7 |
| 2010 | 6.2 | 3.3 | 39.1 | 16.7 |
| 2015 | 3.8 | 1.9 | 33.8 | 17.4 |
| 2019 | 3.9 | 1.5 | 29.7 | 18.6 |
| 2020 | -4.3 | -4.0 | 29.8 | 19.8 |
| 1995-2019 | 3.9 | 1.8 | 40.9 | 17.3 |

Source: Authors' own computation based on data collected from World Development Indicators (The World Bank, 2024)

The purpose of this study is to contribute to the empirical debate on the nexus between tourism development, renewable energy and environmental degradation in ASEAN countries for a period of 25 years between 1995 and 2019. Specifically, the study **aims** at exploring the dynamics nexus between tourism development and renewable energy that influence environmental quality. In addition, the study seeks to find evidence of the mitigating effects of renewable energy on the tourism-induced CO2 and GHG emissions. The study also seeks to find evidence on the Environmental Kuznets Curve (EKC) framework in the ASEAN countries. Finally, the study seeks to examine the environmental impact of ASEAN common policies, since ASEAN as a group has worked extensively to promote sustainable and competitive tourism industry and energy cooperation among its member states through advanced strategic plans namely The ASEAN Tourism Strategic Plan: 2016-2025, and The ASEAN Plan of Action for Energy Cooperation Phase I (2016-2020) and Phase II (2021-2025).

The contribution of this study is threefold. Firstly, this study explicitly focuses on the ASEAN region. This is because, ASEAN, despite the above strategic plans on its tourism and energy cooperation, currently has two major obstacles to achieve the plan; one where ASEAN is seeing the greatest rise in GHC and CO2 emissions globally, and another where ASEAN's economic growth and tourist arrivals growth are expected to continue to surpass that of the rest of the world. Therefore, this study seeks to examine the apparent dynamics between the ASEAN's common economic policies and the level of environmental degradation in the region. Secondly, this study aims to examine the joint effects of tourism development and renewable energy consumption on environmental degradation, hitherto has been rarely explored in the ASEAN tourism literature. Lastly, this study employs a battery of testing and various panel estimators that are robust to cross-sectional dependence, heterogeneity, and autocorrelation such as panel corrected standard error (PCSE), feasible generalized least squares (FGLS), and augmented mean group (AMG) estimators. AMG specifically allows the impact of cross-sectional dependence to be explicitly estimated, which can be used to identify the impact of ASEAN strategic policies on the region's level of CO2 and GHG emissions.

Overall, the analysis confirms the significant adverse impact of tourism development on environmental quality. Regardless of estimation methods, tourist arrivals are shown to raise CO2 and GHG emissions in the region, and the estimated coefficients imply that a 1% increase in tourist arrivals raises around 0.1 to 0.3% emissions. Apparently, this finding points to the fact that ASEAN countries' tourism industry may still be heavily reliant on non-renewable energy sources leading to higher emissions. The findings also show that renewable energy reduces CO2 emissions, albeit its inconsistent role in GHG emissions due to empirical issue with FGLS estimator. Subsequently, we show the presence of mitigating impact of renewable energy on the tourism-induced emissions in the region, specifically, renewable energy moderates the tourism-induced CO2 emissions, but completely diminishes the tourism-induced GHG emissions. Meanwhile, Environmental Kuznets Curve (EKC) hypothesis is strongly supported in ASEAN countries, and the maximum threshold level of GDP per capita is computed to be slightly below USD13,000 (2015 constant) when the adverse impact of GDP on environment becomes positive. Finally, ASEAN common policies are found to raise emissions, which can be interpreted that the ASEAN strategic plans like The ASEAN Tourism Strategic Plan (2016-2025) to raise its tourism competitiveness may be successful, but it comes at the expense of environmental degradation, implying a trade-off against its energy cooperation plan i.e. The ASEAN Plan of Action for Energy Cooperation Phase I (2016-2020) and Phase II (2021-2025). In other words, the ASEAN's objective of attaining sustainable tourism practices and environmentally friendly and sustainable energy cooperation may not yet come to full fruition.

The study's findings have important policy implications for policymakers in ASEAN countries specifically and emerging countries on overall. Several policy recommendations to address the detrimental effects of tourism on the environment and promote sustainable tourism and climate action in ASEAN countries are made in the conclusion section of this study.

The paper proceeds as follows, Section 2 discusses the relevant literature on the empirical studies of tourism-renewable energy-environmental quality nexus. Section 3 follows with the discussion of materials and methods including model and data sources, pre-estimation tests, and estimation methodologies. In Section 4, the results of pre-estimation tests, baseline and robustness estimations are discussed and interpreted, and Section 5 finally concludes with several policy implications.

## 2. Literature review

Tourism sector has become one of the vital catalysts in developed and developing countries as it stimulates job creations, local firm expansion, economic growth, and foreign exchange inflows (Khan et al., 2020; Badulescu et al., 2021; Shimizu and Okamoto., 2021). It was estimated that tourism industry contributed approximately 12% of the world GNP (OECD, 2021; Gedikli et al., 2022).

Given the importance of tourism sector to the nation, extensive literatures have been conducted to study the tourism-economic growth nexus which includes the tourism-led growth hypothesis, the growth-led tourism hypothesis, and the bidirectional relationship between tourism and growth (Badulescu et al., 2021). Recently, the sustainability of tourism has become the central of discussion that examining the relationship between tourism and environment quality. Though tourism development contributes substantially towards socioeconomic growth, the development is achieved at the cost of environmental pollution and deterioration (Azam et al., 2018). It is claimed that as the tourism sector develops, it also increases the energy consumption that degrade the environmental quality through carbon dioxide ($CO_2$) and greenhouse gas (GHG) emissions (Katircioglu, 2014; Gedikli et al., 2022). As pointed out by Zhang and Gao (2016), one of the major sources of greenhouse gas emissions was originated from tourism sector. Hence, tourism sector puts considerable pressure on the environment. Tourism sector intensively relies on energy sector, for instance, transportation and infrastructure, construction of hotel and restaurants that consume heavy energy and overwhelm the environmental degradation (Ren et al., 2019; Zhang and Gao, 2016, Tian et al., 2021).

Furthermore, United Nations World Tourism Organization (UNWTO) asserted that tourism accounted for 5% of global $CO_2$ emissions where air transport contributed around 40% of the total emissions (Dubois and Ceron, 2006). To avoid $CO_2$ emissions from plane, it was suggested to take slow travel like by buses and trains that consume less energy and less $CO_2$ emissions (Dickinson et al., 2001). Besides, Tsagarakis et al. (2011) also confirmed the relation between energy consumption and accommodation. In view that $CO_2$ and GHG discharges are likely to bring about the global warming and climate change, enormous studies have been performed to analyse the linkages among tourism, economic development, energy use, and environment, either through causality analysis or through the estimation of macroeconomic framework. Empirical results revealed that tourism induces economic growth, however, the association between tourism and environmental quality is mixed as presented in Table 2.

Among the earlier studies, Katircioglu (2014) used autoregressive distributed lag (ARDL) estimate to investigate the relationship between tourism, energy consumption, and environmental degradation in Turkey. The findings indicated that tourism development not only contributed to energy use but also climate change. Tourism development in Asia-Pacific countries also deteriorates the environmental quality as revealed by Shakouri et al. (2017). Zhang and Gao (2016) demonstrated the panel Granger-causality test on China. The study found that tourism causally affected economic growth and $CO_2$ emissions and the feedback effect exist between economic growth and $CO_2$ emission. In the meantime, Gedikli et al. (2022) also applied panel Granger-causality in selected OECD countries within 1995-2020. It was concluded that the adverse impact of international tourism on environmental quality is greater than its positive impact on economic growth. Hence, it was suggested that policymakers should take actions and measures to mitigate the impact of international tourism on environmental deterioration, for instance, improvements and dissemination of eco-friendly technologies in all tourism.

Zhang and Liu (2019) examined the association between international tourism, CO2 emissions, real GDP, non-renewable energy and renewable energy consumption in a panel of ten Northeast and Southeast Asian countries. The results verified that EKC was empirically not found in the whole sample. However, non-renewable energy and tourism development caused environmental degradation while renewable energy saved the environment. On the other hand, a study that covered Asia, Europe and America continents was attempted by Khan et al. (2019). The study recommended an environment-friendly tourism by introducing eco-friendly transportation in Asia and America. The educational syllabus should also highlight the importance of clean environment. Furthermore, the efficient use of energy resources should be adopted, and financial aid should be allocated to the eco-friendly programs at low interest rates.

In the most recent study, Badulescu et al. (2021) asserted that in the long run, CO2 emissions and GDP per capital have a negative impact on the tourism development in European Union. In contrast, energy consumption and the squared GDP per capita have a positive impact on tourism sector. This also captured that the tourism sector was initially decrease and then increase over time with the influence of GDP. The study of Zafar et al. (2023) indicated the adverse effect of tourism, trade, and growth factors on environmental sustainability while ICT helped to promote a sustainable environment in BRICS countries. The results suggested the integration of ICT in trade and tourism industries to reduce the negative ecological impacts. Besides, Pablo-Romero et al. (2023) revealed that energy consumption and tourist arrivals were positively related in the 15 most visited countries in the world. Hence, it was highly advisable to increase the economies of scale, coupled with a greater awareness on the use of renewable energy.

In contrast to the above literatures claiming that tourism degrades the environmental quality, some studies discovered that tourism development has the ability to mitigate the pollution, and these opposite results may be caused by the different sample sizes, time frames of the study, estimation methods and sample group of countries. For example, Tian et al. (2021) examined the impact of tourism development, renewable energy consumption and GDP on environmental quality for G20 economies during the period of 1995-2015 and found that tourism development and renewable energy consumption promotes environmental quality in the long-run. The study also confirmed the validity of EKC where there was an inverted U-shape relation between pollution and GDP in the long-run. Meanwhile, Ben Jebli et al. (2019) investigated the panel of 22 Central and South American countries and found that that tourism arrival decreased the CO2 emissions in the long-run. There are also some of the previous works, for instance, Azam et al. (2018), Ahmad et. al (2018) and Sghaier et al. (2019), that have presented mixed findings in their studies. Azam et al. (2018) assessed the dynamic impact of tourism on environmental pollution in Malaysia, Singapore and Thailand and the results showed that tourism increases the environmental pollution in Malaysia but improves the environmental quality in Thailand and Singapore through CO2 reduction. The findings also indicated that EKC hypothesis was valid in Malaysia and Thailand. Moreover, Ahmad et al. (2018) also revealed mixed findings in their study using data of five provinces in China. Although they found negative environmental impact of tourism in Ningxia, Qinghai, Gansu, and Shanxi provinces, in Xinjian province they found tourism development improved the environment quality. Thus, the mixed relationship between tourism and environment could be depending upon the specific provincial features and government policies in the province. Finally, the study by Sghaier et al. (2019) that examined the association between tourism and environmental quality in Morocco, Tunisia, and Egypt has shown a negative impact in Morocco and Egypt, but a positive impact in Tunisia.

**Table 2: Summary of some selected literatures on tourism development and environmental quality**

| Author (s) | Country (ies) | Duration | Variables | Method | Results |
|---|---|---|---|---|---|
| Katircioglu (2014) | Turkey | 1960-2010 | Tourism, GDP, energy consumption, $CO_2$ | ARDL | 1) TR → $CO_2$ (+), EU (+) |
| Zhang and Gao (2016) | China (regional) | 1995-2011 | Tourism, energy use, economic growth, environmental pollution | Panel Granger-Causality | 1) TR → GROWTH, $CO_2$ |
| Shakouri et al. (2017) | 12 Asia-Pasific countries | 1995-2013 | Tourism, GDP, energy consumption, $CO_2$ emissions | GMM, Granger-Causality | 1) TR → $CO_2$ (+) |
| Azam et al. (2018) | Malaysia, Singapore, Thailand | 1990-2014 | Tourism, environmental pollution, GDP per capita, energy use | FMOLS | 1) TR → $CO_2$ (-) in Thailand & Singapore.<br>2) TR → $CO_2$ (+) in Malaysia.<br>3) EKC hypothesis was valid in Malaysia and Thailand. |
| Zhang and Liu (2019) | 10 Asian countries | 1995-2014 | Tourism, $CO_2$ emissions, real GDP, non-renewable energy, renewable energy consumption | Panel FMOLS, AMG | 1) TR & NRE → $CO_2$ (+)<br>2) RE → $CO_2$ (-)<br>3) EKC was invalid. |
| Tian et al. (2021) | G20 economies | 1995-2015 | Tourism, renewable energy consumption, GDP, environmental quality | Panel FMOLS | 1) EKC was valid.<br>2) TR & RE→ $CO_2$ (-) |
| Badulescu et al. (2021) | European Union (27 countries) | 1995- 2016 | Tourism development, economic growth, $CO_2$ emissions, energy consumption | Panel ARDL | 1) $CO_2$ & GDPPC→TR (-)<br>2) EC & GDPPC SQ→ TR (+) |
| Zafar et al. (2023) | BRICS economies | 1990- 2019 | Tourism, ICT, trade, economic growth, $CO_2$ | CSARDL | 1) TR, TRA, GROWTH → $CO_2$ (+)<br>2) ICT→ $CO_2$ (-) |
| Gedikli et al. (2022) | OECD countries | 1995-2020 | Tourism, economic growth, carbon emissions | Panel Granger-Causality | 1) TR → $CO_2$ (+) |
| Pablo-Romero et al. (2023) | 15 most visited countries. | 2000-2019 | Tourism development, GDP, urban population, energy consumption | Panel FGLS, OLS-DK, DOLS | 1) EC → $CO_2$ (+) |

Notes: TR (Tourism), $CO_2$ (Carbon dioxide) , NRE (Non-renewable energy), RE (renewable energy), GDPPC (GDP per capita), GDPPC SQ (squared GDP per capita), EC (Energy consumption), TRA (Trade), ICT (information communication technology).

## 3. Materials and methods

### *3.1. Empirical model and data sources*

The following linear models are proposed to investigate of the impact of tourism development on environmental quality:

$$CO2_{it} = \beta_0 + \beta_1 TA_{it} + \beta_2 RE_{it} + \beta_3 GDP_{it} + \beta_4 GDPSQ_{it} + \gamma_i + \varepsilon_{it} \quad (1)$$

$$GHG_{it} = \beta_0 + \beta_1 TA_{it} + \beta_2 RE_{it} + \beta_3 GDP_{it} + \beta_4 GDPSQ_{it} + \gamma_i + \varepsilon_{it} \quad (2)$$

Where CO2 and GHG are total carbon dioxide and greenhouse gas emissions, respectively, for country $i$ and time $t$, and they are used to capture the level of environmental quality. TA meanwhile is number of tourist arrivals as a proxy for tourism development, and RE is renewable energy consumption to examine their roles on the environmental quality. To examine the EKC hypothesis, GDP and GDPSQ are included in the model, and they are real GDP per capita and its square term, respectively. $\gamma_i$ denotes unobserved country-specific effect, and $\varepsilon_{it}$ is the iid error term. All variables are converted into natural logarithm in the analysis.

The expected priori sign for TA is positive due to the earlier discussed proposition that tourism development is heavily linked with the higher demand for energy use and eventually leading to higher emissions. However, TA also can have negative sign as there were studies indicating tourism's positive impact on environmental quality by reducing emissions, especially in the context of renewable energy-supported tourism. Thus, a negative priori sign is expected for RE since the use of environmental-friendly energy is expected to improve environmental quality by lowering total CO2 and GHG emissions. Finally, to support EKC hypothesis, GDP and GDPSQ are expected to have positive and negative signs, respectively, i.e. economic development is expected to raise environmental degradation during its initial stage, but after a specific development threshold, the degradation will fall.

To explore a more nuanced understanding on the interplay between tourism development and renewable energy, so that an informed energy-efficient tourism policies can be proposed, additional estimations are done with the inclusion of an interaction term between TA and RE, (TA*RE), in the models as follows:

$$CO2_{it} = \beta_0 + \beta_1 TA_{it} + \beta_2 RE_{it} + \beta_3 (TA * RE)_{it} + \beta_4 GDP_{it} + \beta_5 GDPSQ_{it} + \gamma_i + \varepsilon_{it} \quad (3)$$

$$GHG_{it} = \beta_0 + \beta_1 TA_{it} + \beta_2 RE_{it} + \beta_3 (TA * RE)_{it} + \beta_4 GDP_{it} + \beta_5 GDPSQ_{it} + \gamma_i + \varepsilon_{it} \quad (4)$$

The inclusion of the interaction term $\beta_3(TA * RE)_{it}$ means the total effect of tourism development on CO2 and GHG emissions therefore can be gauged by taking partial derivative of CO2 and GHG with respect to TA as the following:

$$\frac{\partial CO2}{\partial TA} = \beta_1 + \beta_3 RE_{it} \quad \text{and} \quad \frac{\partial GHG}{\partial TA} = \beta_1 + \beta_3 RE_{it} \tag{5}$$

The total impact of TA on CO2 and GHG is therefore dependent on RE, and due to the expected priori sign of negative for TA and positive for RE, it is expected that RE is going to attenuate the adverse impact of TA on the environmental quality. It therefore implies that a country's tourism development must be supported by environmentally friendly energy use to mitigate the adverse impact of tourism on environment.

A panel dataset is used in this study consisting of observations for a period of 25 years beginning from 1995 to 2019[1] for 10 ASEAN countries, namely Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. Table 3 below outlines the variables measurement, data sources, descriptive statistics, and pairwise correlation coefficients of the variables.

### *3.2. Pre-estimation tests*

The empirical analysis starts with the application of the cross-sectional dependence (CSD) test among the ten ASEAN countries to determine the suitable estimation methods for the study. We expect a certain degree of dependence between the ten countries to exist due to the close proximities of the countries and given the possibility of these countries sharing common features, especially since ASEAN is an official regional association comprising of the ten countries. If this dependence is not accounted for by the estimation method, it is expected to violate the basic ordinary least square (OLS) assumption of an independent and identically distributed error term. Furthermore, CSD can lead to omitted variable bias or endogeneity leading to inconsistent estimates (Pesaran, 2004). Therefore, we utilize Pesaran (2004) test for CSD which can be applied to small and large panels, especially when $N>T$. The CSD test by Pesaran (2004) whose null hypothesis of no CSD is expressed as:

$$CSD = \sqrt{2T/N(N-1)} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{i,k}\right) \tag{5}$$

[1] Although data for tourist arrivals, CO2 emissions, and GHG emissions are available up until year 2020, we omit year 2020 data from the sample to eliminate the outlier effect due to the significant reduction in number of tourist arrivals and emission size as a result of movement control order following Covid-19 pandemic.

**Table 3: Variable measurements, sources, descriptive statistics, and pairwise correlations**

| Variable name | CO2 | GHG | TA | GDP | RE | POP | FDI |
|---|---|---|---|---|---|---|---|
| Variable measurement | Total carbon dioxide emissions in kiloton. | Total greenhouse gas emissions in kiloton of CO2 equivalent. | Total number of international tourist arrivals to ASEAN countries. | Real GDP per capita constant at 2015 US dollars. | Renewable energy consumption as percentage of total final energy consumption. | Total population of the country – number of all residents regardless of legal status or citizenship. | Net inflow of foreign direct investment as percentage of GDP. |
| Sources | World Development Indicators (WDI) by the World Bank (2024) | | | | | | |
| No. of observations | 250 | 250 | 250 | 250 | 250 | 250 | 250 |
| Mean | 106,594.76 | 189,011.87 | 7,142,717.40 | 9,994.27 | 35.89 | 57,569,853 | 5.47 |
| Std. Deviation | 127,709.65 | 225,144.61 | 7,761,535.20 | 15,175.62 | 29.40 | 67,705,280 | 5.68 |
| Minimum | 674.95 | 6,207.55 | 194,000 | 210.54 | 0 | 299,097 | -2.76 |
| Maximum | 605,290.63 | 1,020,913.70 | 39,916,000 | 61,386.23 | 86.62 | 269,600,000 | 29.76 |
| **Pairwise correlation coefficients** | | | | | | | |
| CO2 | 1.000 | | | | | | |
| GHG | 0.968 | 1.000 | | | | | |
| TA | 0.543 | 0.380 | 1.000 | | | | |
| GDP | -0.232 | -0.284 | 0.155 | 1.000 | | | |
| RE | -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 |

In the presence of CSD, second-generation panel unit root and cointegration tests that are capable to account for the CSD in the data must be used. For panel unit root test, Pesaran (2007) cross-sectional Im, Pesaran, and Shin (CIPS) test is used. The test is obtained from the averaging of the cross-sectional augmented Dicky-Fuller statistics ($CADF_i$), calculated from the OLS regression performed on individual panels augmented with the cross-sectional averages of lagged levels and first differences of the variables, thereby capturing the unobserved common factor. Pesaran (2007) CIPS test statistic is a modified version of the Im et al. (2003) t-bar test statistics and $CADF_i$ is the t-ratio statistics calculated using the OLS estimates obtained from the cross-section regressions. The CIPS statistics test for the null hypothesis of the presence of the unit root for all panels vs. the alternative of some panels being stationary. Hence, rejecting the null would indicate that at least one panel in the data is stationary. CIPS test statistics can be written as:

$$CIPS = N^{-1}(\sum_{i=1}^{N1} CADF_i) \quad (6)$$

In addition to Pesaran (2007) CIPS test, Fisher-type ADF panel unit root test based on Maddala and Wu (1999) is also used to test for panel unit root. According to Maddala and Wu (1999), the Fisher-type tests dominate the Levin et al. (2002) or the Im et al. (2003) tests in terms of size and power in the presence of the cross-correlation of errors. Like Pesaran (2007), Fisher-type ADF test statistic evaluates the null of unit root in all panels vs. an alternative where at least one panel is stationary. Although Fisher-type ADF test assumes cross-section independence of error, it allows time demean application on the variables to mitigate the effects of CSD.

For panel cointegration test, Pedroni (1999, 2004) and Westerlund (2005)[2] are used. Via three t-statistics, namely Modified Phillips-Perron t, Phillips-Perron t, and Augmented Dickey-Fuller t, Pedroni (1999, 2004) tests for the null hypothesis of no cointegration against the alternative hypothesis of all panels are cointegrated. Westerlund (2005) produces variance ratio statistics to test for the null hypothesis of no cointegration against the alternative of some panels are cointegrated. Although both tests are first generation cointegration test, they too allow time demean application on the variables to deal with CSD.

[2] The only second-generation panel cointegration test available is Westerlund (2007), developed based on error-correction model to control for CSD via the bootstrapping technique of the test statistics so that a robust p-value can be generated. However, Westerlund (2007) test requires $T$ to be substantially larger than $N$ otherwise the p-value is sensitive to selection of lags and kernel width. We have implemented Westerlund (2007) cointegration test and, unlike Westerlund (2005) result, the p-values are consistently insignificance regardless of different lags, kernel width, and bootstrapping values, most likely due to shorter time periods of our sample (25 years) which is not substantially larger than the ten ASEAN countries.

### *3.3. Estimation methods*

The empirical strategy begins with the baseline estimation of Equations (1) and (2) and subsequently Equations (3) and (4) using various estimation methods discussed below. For robustness check, Equations (3) and (4) above is augmented with two additional control variables to become a general model and re-estimated using the same estimation methods. The followings are explanation of the estimation methods:

*3.3.1. Baseline estimations*

*i. Panel corrected standard error (PCSE) and feasible generalised least square (FGLS) estimations:*

Given the presence of cross-sectional dependence in the data and cointegration among the variables, we use panel-corrected standard errors (PCSE) estimation proposed by Beck and Katz (1995) and feasible generalised least square (FGLS) estimation by Parks (1967) and Kmenta (1986). Hoechle (2007) highlights that both estimators are capable to account for CSD, heteroscedasticity, and serial correlation in residuals of the panel time series models, especially suitable when the cross-sectional units $N$ is less than the time periods $T$. From the econometrics point of view, Beck and Katz (1995) convincingly demonstrate that PCSE estimator, with its large-$T$ asymptotics–based standard errors that correct for contemporaneous correlation between the subjects, performs well in small panels. PCSE method estimates the full $N \times N$ cross-sectional covariance matrix, and this estimate will be precise if the ratio $T/N$ is big. PCSE method also improves the FGLS method that usually produces small standard errors.

*ii. Augmented Mean Group (AMG) estimation capturing ASEAN common policies on tourism and energy:*

As stated earlier, PCSE and FGLS produce estimators with residuals that are robust in the presence of CSD, heteroscedasticity, and serial correlation, but a meaningful interpretation of the CSD is ignored. On the other hand, Augmented Mean Group (AMG) estimation produces a specific coefficient that captures the impact of CSD in the model. This is particularly crucial especially in the context of an official association of countries like ASEAN that arguably have common policies and strategies on their tourism, environment, and energy sectors. Originally proposed by Eberhardt (2012) and argued by Xia et al. (2022) as relatively ignored in the tourism-economics literature, we also employ AMG estimation with the sole purpose of examining the common processes between the ASEAN countries under study.

AMG is estimated via the following steps: 1) The overall model, with year dummies included, is firstly estimated via first-differenced Pooled OLS, and the coefficients for the differenced year dummies are collected as they represent the "common dynamic process," often denoted c_d_p, that indicates the common factor across panels. 2) The common dynamic process is then included in the panel-specific regression model, either as an explicit variable or imposed as a unit coefficient by subtracting the estimated process from the dependent variable. In our AMG estimation we choose to include the c_d_p variable explicitly in the model, and a positive (negative) sign of the variable's coefficient can imply the current ASEAN policies and strategies that causing higher (lower) emissions in the region. 3) Apart from the common dynamic process, each panel-specific regression must also include an intercept to capture time-invariant fixed effects, and finally 4) The panel-specific model parameters are then averaged across panels.

*3.3.2. Robustness estimation - PCSE, FGLS, and AMG with additional control variables*

For robustness check, the estimation of Equations (3) and (4) are done with two additional control variables: namely POP, representing the total population size in the country, and FDI, the net inflow of foreign direct investment. These variables are frequently used as control variables in CO2 and GHG emissions models. In regions like ASEAN, where the use of non-renewable energy is prevalent and contributes to higher emissions, the inclusion of population size as a control variable in the tourism-emission model helps isolate the environmental impact of tourism while accounting for population size. Similarly, since FDI have been shown to have detrimental effects on the environment, despite its growth-promoting benefits, its inclusion helps differentiate the environmental impact of tourism from that of FDI. Both variables are transformed into natural logarithms for estimation purposes

## 4. Discussion of results

### *4.1. Pre-estimation tests results:*

In Table 4, the results of Pesaran (2004) CD test for CSD, and Pesaran (2007) CIPS and Maddala and Wu (1999) ADF tests for panel unit root are produced. Table 5 presents the results of panel cointegration tests by Pedroni (1999, 2004) and Westerlund (2005). As is seen in Table 4, all variables in the model are found to have cross-sectional dependence apart from renewable energy consumption, RE. Subsequently, both panel unit root tests indicate that all variables have unit root in level but stationary at first difference, except net inflow of foreign direct investment FDI in both tests and GDP in Maddala and Wu (1999) ADF test, as both variables are stationary at level. Finally, panel cointegration tests results in Table 5 shows that the long-term cointegrating relationship between the variables are present, especially based on the Modified Phillips-Perron t-statistics by Pedroni (1999, 2004).

**Table 4: Cross-sectional dependence and panel unit root tests**

| Variables | Pesaran (2004) CD statistics | Pesaran (2007) CIPS statistics | | Maddala & Wu (1999) ADF statistics | |
|---|---|---|---|---|---|
| | | Level | First difference | Level | First difference |
| CO2 | 27.967*** | -2.389 | -3.456*** | 4.509 | 58.745*** |
| GHG | 30.095*** | -1.706 | -3.434*** | 15.549 | 84.159*** |
| TA | 30.867*** | -2.163 | -3.525*** | 9.373 | 85.856*** |
| GDP | 20.658*** | -1.751 | -2.925** | 44.846*** | - |
| RE | 1.278 | -1.145 | -3.196*** | 17.192 | 68.813*** |
| POP | 33.380*** | -1.891 | -2.844** | 13.344 | 29.635* |
| FDI | 3.999*** | -3.360*** | - | 50.035*** | - |

Note: Pesaran (2007) CIPS and Maddala and Wu (1999) Fisher-type ADF tests above include constant and trend as the deterministic terms. Similar results are obtained when only constant included, hence not shown here for brevity.

**Table 5: Panel cointegration tests**

| Model | CO2 model | | GHG model | |
|---|---|---|---|---|
| Deterministic term | constant | constant & trend | constant | constant & trend |
| Test name: | Pedroni (1999, 2004) test: | | | |
| Modified Phillips-Perron t | 3.259*** | 4.150*** | 3.181*** | 3.372*** |
| Phillips-Perron t | 1.424* | 2.036** | 0.886 | 0.146 |
| Augmented Dickey Fuller t | 1.008 | 1.330* | 0.757 | -0.065 |
| Test name: | Westerlund (2005) test: | | | |
| Variance ratio statistics | -0.702 | 1.617* | -0.843 | 0.132 |

Note: Although both are first-generation cointegration tests, cross-sectional averages are removed from the procedure of both tests (ie. the variables are time-demeaned) to mitigate the CSD effect.

### *4.2. Baseline estimation – PCSE, FGLS and AMG estimations:*

Table 6 presents the results of PCSE, FGLS, and AMG estimations for the CO2 and GHG emissions models. For both models, the results from all estimation methods support our earlier proposition and are consistent with previous findings in the literature, indicating that tourism development has adverse impacts on environmental quality. In the majority of estimations, tourism is found to increase CO2 and GHG emissions, with the coefficient of TA consistently positive and significant at the 1% level. The estimated coefficient size suggests that a one percent increase in the number of tourist arrivals corresponds to a 0.1 to 0.3% rise in $CO_2$ and GHG emissions. However, the significance of TA diminishes in estimations that include an interaction term between tourism and renewable energy (TA*RE), particularly in PCSE and AMG estimations. In FGLS estimations (8 and 11), TA remains positive and significant.

Independently, RE consistently exhibits a negative effect on $CO_2$ emissions, and its coefficients are significant in PCSE and AMG estimations (1 and 3), thereby affirming its role in reducing $CO_2$ emissions and environmental degradation. Specifically, a one percent increase in the use of renewable energy corresponds to a reduction in $CO_2$ emissions of up to 1.2%. Conversely, results are mixed in the GHG model, where negative significant coefficients are only found in AMG estimations, but positive in PCSE and FGLS. The presence of positive significant coefficients of RE in the FGLS estimation of the GHG model (estimation 5 and 11) is not surprising given the previously discussed weakness of the FGLS method, which tends to produce small standard errors, thus inflating the significance of coefficients.

Moving to the interaction term of tourism and renewable energy (TA*RE), it is consistently positive for $CO_2$ emissions but negative for GHG emissions. However, the coefficient is only significant in the PCSE estimation of the $CO_2$ model and the FGLS estimation of the GHG model. For $CO_2$ model, the positive significant coefficient of the interaction term (TA*RE) may suggest that while tourism initially contributes to environmental degradation by raising $CO_2$ emissions, the presence of renewable energy moderates this impact, albeit to a lesser degree. Conversely, the negative significant coefficient of (TA*RE) in GHG model can be interpreted as the presence of renewable energy eliminating the adverse effects of tourist arrivals on the environment by reducing tourism-induced GHG emissions. Interpreting the mitigating effect of renewable energy on tourism-induced emissions, the coefficient size of (TA*RE) suggests that a one percent increase in tourist arrivals is moderated by RE leading to less than 0.1% increase in $CO_2$ emissions, or reduction of about the same size in GHG emissions.

However, the mixed findings regarding the moderating effect of renewable energy on tourism-induced $CO_2$ and GHG emissions may suggest that in the context of ASEAN countries, the prevalent use of non-renewable energy sources by the tourism sector outweighs the positive influence of renewable energy. We believe this is the reason behind the smaller degree of moderation of tourism-induced $CO_2$ emissions or reduction of tourism-induced GHG emissions, which underscores the potential limitations in the development and utilization of renewable energy sources within these nations.

In all estimations, the support for EKC hypothesis in ASEAN countries is robust. The estimated coefficients for GDP and GDPSQ demonstrate an inverted U-shaped relationship with CO2 and GHG emissions, where GDP has a positive coefficient and GDPSQ has a negative coefficient. However, both GDP and GDPSQ terms are significant only in PCSE and FGLS estimations, not in AMG estimations. Based on the significant coefficients of GDP and GDPSQ and taking exponential of the calculated threshold values, the maximum level of real GDP per capita before its positive coefficient becomes negative is computed to be slightly below USD13,000 (estimation 8). Comparing this range to the mean value of GDP per capita at about USD10,000, this implies that on average the ASEAN countries are still in the early stage of economic development leading its prevalence adverse impact on the environment. Once the real GDP per capita exceeds USD13,000, it is expected that the economic development's negative environmental impact will become positive due to the increasing number of energy-efficient drivers of development including tourism sector.

As stated earlier, the AMG estimation offers a meaningful interpretation of cross-sectional dependence by producing the common dynamic process, c_d_p, coefficient, which captures the impact of cross-sectional dependence in the CO2 and GHG models, otherwise only controlled and eliminated in the PCSE and FGLS estimations. This is an important aspect, particularly in the context of an official association of countries like ASEAN, which arguably shares common policies and strategies on tourism, environment, and energy sectors. As is shown in Table 6, the common dynamic process c_d_p coefficients are consistently positive and significant in all AMG estimations, indicating that the ASEAN countries common policies causing higher CO2 and GHG emissions. This finding has one notable implication which can be linked to the implementation of ASEAN Tourism Strategic Plan 2016-2025 which may be successful in driving greater inter-regional tourism activities and enhancing ASEAN competitiveness to become a single tourism destination, but perhaps the manner this strategic plan is implemented is not environmentally sustainable due to ASEAN's heavy reliant on non-renewable energy leading to higher emissions. Similarly, this finding may also indicate a trade-off between the success of ASEAN Tourism Strategic Plan against its Plan of Action for Energy Cooperation hence leading to higher emissions amidst these strategic plans. In other words, the ASEAN's objective of attaining sustainable tourism practices and environmentally friendly and sustainable energy cooperation may not yet come to full fruition.

**Table 6: Panel Corrected Standard Error (PCSE), Feasible Generalised Least Square (FGLS), and Augmented Mean Group (AMG) estimations**

| Dependent variable | CO2 | | | GHG | | | CO2 | | | GHG | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Estimation | PCSE | FGLS | AMG | PCSE | FGLS | AMG | PCSE | FGLS | AMG | PCSE | FGLS | AMG |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| $TA_{it}$ | 0.265*** (0.063) | 0.222*** (0.030) | 0.118*** (0.042) | 0.147*** (0.039) | 0.149*** (0.019) | 0.003 (0.049) | -0.073 (0.086) | 0.217*** (0.054) | -0.623 (0.855) | 0.101 (0.073) | 0.276*** (0.039) | -0.084 (0.499) |
| $RE_{it}$ | -0.228** (0.098) | -0.052 (0.052) | -1.213*** (0.462) | 0.052 (0.072) | 0.123*** (0.035) | -0.336** (0.156) | -1.569*** (0.456) | -0.053 (0.283) | -3.400 (4.503) | 0.012 (0.303) | 0.722*** (0.167) | -0.444 (2.746) |
| $(TA*RE)_{it}$ | | | | | | | 0.070** (0.028) | 0.013 (0.017) | 0.135 (0.306) | -0.002 (0.018) | -0.043*** (0.010) | -0.011 (0.184) |
| $GDP_{it}$ | 2.970*** (0.515) | 3.045*** (0.264) | 5.953 (5.695) | 2.041*** (0.356) | 1.586*** (0.169) | 3.472 (3.514) | 0.564 (0.573) | 2.766*** (0.288) | 7.724 (4.843) | 1.191*** (0.324) | 1.720*** (0.152) | 1.952 (4.065) |
| $GDPSQ_{it}$ | -0.181*** (0.029) | -0.178*** (0.015) | -0.255 (0.299) | -0.128*** (0.021) | -0.100*** (0.010) | -0.189 (0.210) | -0.009 (0.037) | -0.146*** (0.018) | -0.491 (0.301) | -0.065*** (0.022) | -0.102*** (0.009) | -0.197 (0.278) |
| c_d_p | | | 0.683** (0.331) | | | 0.659** (0.326) | | | 0.551* (0.311) | | | 0.423*** (0.162) |
| Constant | -4.546** (2.019) | -5.161*** (1.094) | -21.393 (25.214) | 1.503 (1.188) | 2.993*** (0.607) | -1.123 (15.547) | 9.934*** (3.041) | -3.998** (1.781) | -8.337 (28.553) | 5.201*** (1.779) | 0.327 (0.969) | 1.528 (21.586) |
| R-squared | 0.978 | - | - | 0.992 | - | - | 0.985 | - | - | 0.995 | - | - |
| RMSE | - | - | 0.00356 | - | - | 0.00124 | - | - | 0.00265 | - | - | 0.00104 |
| Wald statistics | 124.65 *** | 293.32 *** | 16.78 *** | 114.14 *** | 380.91 *** | 6.428 | 422.45 *** | 984.37 *** | 6.501 | 126.43 *** | 382.30 *** | 0.789 |
| No. of countries | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| No. of obs. | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 |
| GDP per capita threshold of EKC | 3,657.08 | 5,184.20 | - | 2,900.55 | 2,779.43 | - | - | 12,998.68^ | - | 9,523.70 | 4,588.79 | - |

Note: Standard errors in parentheses; ***, **, * indicate significance level at 1%, 5%, and 10% respectively; c_d_p is common dynamic process produced by AMG estimator – see Section III(c) for explanation. Using the significant coefficients of GDP and GDPSQ, the calculation of the threshold level of real GDP per capita is done by taking exponential of the absolute value of the ratio of coefficient of GDP to twice coefficient of GDPSQ, i.e. $e^{\left|\frac{GDP}{2*GDPSQ}\right|}$. ^ indicates the maximum level of real GDP per capita threshold.

### *4.3. Robustness estimation – PCSE, FGLS and AMG estimation with control variables*

Table 7 presents the results of the robustness check estimations comprising of PCSE, FGLS, and AMG estimations for CO2 and GHG emissions models augmented with two additional control variables: population size (POP) and net inflow of foreign direct investment (FDI), both of which are frequently recognized determinants of environmental degradation. In contrast to the findings in the baseline estimations, the robustness estimation results in Table 7 suggest that tourism development contributes to environmental quality; the TA variable consistently shows negative coefficients, indicating a tourism-induced reduction in CO2 and GHG emissions. However, the variable's significance is only achieved in FGLS estimations, not in PCSE and AMG.

Nevertheless, we believe that the finding of tourism development promoting environmental quality in a general model containing POP and FDI variables must be cautiously interpreted. The inclusion of POP in the general model has undoubtedly obscured the true effect of TA on emissions, rendering TA insignificant in PCSE estimations (13 and 16) and producing contradicting negative sign in FGLS estimations (14 and 17). Without the POP variable, as observed in the baseline results, TA remains consistently positive and significant.

There are two possible reasons for this finding. Firstly, the negative TA coefficient is only significant in FGLS estimations, whose small standard errors often cause its coefficients to become significant easily, even when they contradict the baseline estimation. Recall that PCSE improves upon these FGLS weaknesses, leading to an insignificant TA coefficient in PCSE estimations (13 and 16). Secondly, in both PCSE and FGLS estimations, population size (POP) consistently shows a significant positive association with CO2 and GHG emissions, indicating that population size significantly contributes to emissions growth in ASEAN countries, with a seemingly greater effect than tourism development. Generally, a one percent increase in population size is associated with an equivalent one percent rise in CO2 and GHG emissions. The sizable impact of POP on CO2 and GHG emissions suggests that ASEAN countries, on the whole, are still heavily reliant on non-renewable energy sources to meet the needs of their population and indirectly implies that the adoption of renewable energy by these countries is still limited.

The other control variable, net inflow of FDI, does not exhibit significant effects on CO2 emissions across all estimations and only displays weak significance in GHG estimation (16) via the PCSE method at the 10% level and in estimation (17) via the FGLS method at the

1% level. The latter should be interpreted cautiously due to the previously mentioned FGLS weaknesses.

The estimated effects of renewable RE on CO2 and GHG emissions in the general model continues to be negative mirroring the baseline results, hence underscoring its support to the environmental quality by reducing CO2 and GHG emissions. Similarly, the interaction term of tourism and renewable energy (TA*RE) is also consistently positive for CO2 and GHG emissions, again implying the renewable energy's mitigating impacts on tourism-induced CO2 and GHG emissions. The EKC hypothesis too continues to be fully supported in the general model, with the threshold level of GDP per capita computed to be around USD17,500. Finally, AMG estimations in contrast do not produce any significant coefficients for all variables.

**Table 7: PCSE, FGLS, and AMG estimations with control variables**

| Dependent variable | CO2 | | | GHG | | |
|---|---|---|---|---|---|---|
| Estimation | PCSE | FGLS | AMG | PCSE | FGLS | AMG |
| | (13) | (14) | (15) | (16) | (17) | (18) |
| $TA_{it}$ | -0.095<br>(0.061) | -0.158***<br>(0.048) | -0.621<br>(1.091) | -0.048<br>(0.034) | -0.075***<br>(0.024) | -0.094<br>(0.425) |
| $RE_{it}$ | -1.862***<br>(0.353) | -1.930***<br>(0.232) | -3.489<br>(4.461) | -0.863***<br>(0.163) | -0.790***<br>(0.101) | -0.343<br>(2.284) |
| $(TA*RE)_{it}$ | 0.072***<br>(0.021) | 0.081***<br>(0.014) | 0.157<br>(0.291) | 0.030***<br>(0.010) | 0.025***<br>(0.006) | -0.003<br>(0.156) |
| $GDP_{it}$ | 1.389***<br>(0.395) | 1.518***<br>(0.228) | 5.700<br>(6.046) | 0.476**<br>(0.193) | 0.508***<br>(0.103) | 2.271<br>(3.567) |
| $GDPSQ_{it}$ | -0.077***<br>(0.021) | -0.079***<br>(0.013) | -0.294<br>(0.378) | -0.026**<br>(0.011) | -0.026***<br>(0.006) | -0.134<br>(0.210) |
| $POP_{it}$ | 1.036***<br>(0.051) | 1.117***<br>(0.038) | 0.234<br>(0.798) | 0.914***<br>(0.024) | 0.958***<br>(0.016) | 0.276<br>(0.513) |
| $FDI_{it}$ | -0.001<br>(0.002) | -0.001<br>(0.001) | -0.001<br>(0.002) | -0.003*<br>(0.002) | -0.003***<br>(0.001) | 0.000<br>(0.002) |
| c_d_p | | | 0.030<br>(0.265) | | | 0.260<br>(0.240) |
| Constant | -9.389***<br>(1.989) | -10.845***<br>(1.217) | 4.106<br>(37.829) | -4.237***<br>(0.952) | -4.776***<br>(0.536) | 4.308<br>(23.239) |
| R-squared | 0.998 | - | - | 0.999 | - | - |
| RMSE | - | - | 0.00189 | - | - | 0.000892 |
| Wald statistics | 2028.90<br>*** | 3914.71<br>*** | 2.931 | 8285.82<br>*** | 14021.6<br>*** | 1.182 |
| No. of countries | 10 | 10 | 10 | 10 | 10 | 10 |
| No. of obs. | 250 | 250 | 250 | 250 | 250 | 250 |
| GDP per capita threshold of EKC | 8,258.51 | 14,883.37 | - | 9,452.17 | 17,483.28 | - |

Note: Standard errors in parentheses; ***, **, * indicate significance level at 1%, 5%, and 10% respectively. See notes of Table 6 too.

## 5. Concluding Remarks

This research delves into the intricate relationship between tourism development, renewable energy utilization, and environmental quality, proxied by total carbon dioxide (CO2) and greenhouse gas (GHG) emissions, across 10 ASEAN countries from 1995 to 2019. The key findings from our analysis are summarized as follows:

1. Regardless of estimation methods, tourist arrivals exhibit an adverse impact on environmental quality by increasing CO2 and GHG emissions. A 1% rise in tourist arrivals correlates with a 0.1 to 0.3% increase in emissions, underscoring the heavy reliance of ASEAN countries' tourism industries on non-renewable energy sources.

2. Meanwhile, renewable energy demonstrates a capacity to reduce CO2 emissions, although its effectiveness in curbing GHG emissions is inconsistent due to empirical issues with the FGLS estimator.

3. Renewable energy is shown to moderate CO2 emissions induced by tourism (with a positive small TA*RE coefficient) and completely diminishes GHG emissions caused by tourism (with a negative TA*RE coefficient). This implies that while RE mitigates CO2 emissions partially, it effectively eliminates other types of GHG emissions attributed to tourism development.

4. The Environmental Kuznets Curve (EKC) hypothesis is strongly supported in ASEAN countries, with the threshold level of GDP per capita is estimated at slightly below USD 13,000 (2015 constant), beyond which the adverse impact of GDP on the environment becomes positive.

5. Common policies adopted by ASEAN countries appear to elevate emissions, suggesting a trade-off between the ASEAN Tourism Strategic Plan with the aim at enhancing tourism competitiveness and its Action Plan of Energy Cooperation to ensure environmental sustainability. This underscores the need for concerted efforts to achieve sustainable tourism practices and energy cooperation within the region.

6. The inclusion of population size as a control variable in the general model obscures the true effect of TA on emissions, highlighting the ongoing reliance of ASEAN countries on non-renewable energy sources to meet its population demands.

*Policy recommendations:*

The study underscores the importance of increasing awareness and engagement among all stakeholders to address the environmental impact of tourism. Policymakers should initiate comprehensive campaigns to educate governments, businesses, local communities, and tourists about the CO2 and GHG emissions associated with tourism, promoting sustainable practices. Collaborative efforts among tourism boards, environmental organizations, and local governments can enhance message dissemination and foster collective environmental stewardship. Furthermore, a robust policy framework is needed to promote sustainable tourism, focusing on reducing the carbon footprint through renewable energy, eco-friendly regulations, green infrastructure development, and responsible tourism certifications, tailored to the unique environmental challenges of each ASEAN country.

Investment in renewable energy infrastructure is crucial for mitigating tourism-induced emissions, as renewable sources like solar, wind, and hydroelectric power significantly reduce the carbon footprint. Policymakers should support these projects with financial aid, tax incentives, and conducive regulations, while also promoting electric vehicles for tourism-related transportation. Additionally, economic development strategies should align with environmental sustainability by investing in green growth sectors such as renewable energy, eco-tourism, and sustainable agriculture. Governments should implement robust environmental regulations and incentivize clean technologies through financial incentives and research grants. Promoting a circular economy focused on recycling, reuse, and resource recovery, along with fostering innovation in sustainable product design and manufacturing, is essential for long-term sustainability.

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