

Empowering ASEAN's Economic Growth through Renewable Energy Consumption

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Abstract: *The depletion of non-renewable energy sources and their environmental impact highlight the urgent need for a transition towards sustainable alternatives. Renewable energy emerges as a promising solution, particularly for regions like the Association of Southeast Asian Nations (ASEAN), comprising 10 countries that are vital to both the Asian and global economies. This study explores whether renewable energy consumption significantly contributes to ASEAN's economic growth by employing a comprehensive methodological approach, including classical panel models, spatial panel models, and the panel Autoregressive Distributed Lag (ARDL) model. The combined use of these models allows for a comprehensive analysis by capturing internal country dynamics, cross-border spillover effects, and both short- and long-run relationships. The empirical findings reveal that renewable energy consumption has a significant positive impact on economic growth in ASEAN, with short-run effects requiring at least three years to manifest. By integrating diverse models, this study provides a more robust and nuanced understanding of renewable energy's role in driving growth. Based on these results, ASEAN policymakers are encouraged to promote renewable energy consumption through targeted investments, incentives, and infrastructure development, aligning sustainability with pro-growth strategies like trade openness and technological innovation.*

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Keywords: Green investment policies; Energy transition; Sustainable development; Panel estimation; Environmental sustainability

JEL Classification: C33, D24, F43, Q21, Q42, Q43

1. Introduction

In the present era, energy consumption has been rising steadily due to global population growth, technological advancements, and rapid industrialisation (Naimoğlu and Özbek, 2022). Energy plays a critical role in economic growth as it underpins all production and consumption activities (Ramzan, Safdar, and Liaquat, 2022). Apergis and Danuletin (2014) found evidence of an interdependent relationship between economic growth and energy use. Energy is divided into two primary categories: renewable energy and non-renewable energy. Non-renewable energy refers to sources that are not naturally replenished within a short time frame (Jebli et al., 2016). Petroleum and coal are examples of fossil fuels, which are the primary non-renewable energy sources. These fossil fuels take millions of years to form, making them inherently unsustainable. Abidin et al. (2015) highlighted that renewable energy is derived from resources like sunlight and rainfall, which are naturally replenished on a human time scale.

Due to its relatively lower cost and widespread availability, non-renewable energy remains the predominant energy source globally. However, the overconsumption of non-renewable energy has led to numerous negative consequences globally. The increase in carbon dioxide (CO₂) emissions, primarily from fossil fuels, has significantly contributed to global warming (Ramzan, Safdar and Liaquat, 2022). UN News (2023) predicts that global temperatures will reach a record high within the next five years, largely due to the accumulation of greenhouse gases. Between 2023 and 2027, there is a 66% chance that the average global near-surface temperature will increase by 1.5°C over pre-industrial levels for at least one year, and that year would most likely be the warmest on record. Fossil fuels account for approximately 75% of global greenhouse gas emissions and 90% of CO₂ emissions (United Nations, 2023).

The depletion of non-renewable energy reserves further underscores their long-term unsustainability. According to Fadilah et al. (2020), the United Nations declared 2014–2024 to be the worldwide decade of sustainable energy. According to the UN (2023), many countries are finding it challenging to achieve sustainable development as a result of

worsening environmental degradation and natural resource depletion. To pursue a resilient and sustainable path, development efforts must integrate economic, social, and environmental dimensions (United Nations, 2023). In order to accomplish this objective, natural resources must be handled responsibly, and the use of renewable energy should dominate both the production and consumption processes, in addition to SDG objective 7—ensuring that everyone has access to affordable, dependable, sustainable, and contemporary energy.

Recognising the role of renewable energy in sustainable development, many countries are actively transitioning toward greener energy alternatives. According to the IEA (2022), in response to the sharp increase in fossil fuel prices following geopolitical tensions such as the Russia–Ukraine conflict, many countries are adopting renewable sources like solar power. Consequently, it is anticipated that between 2022 and 2027, the capacity of renewable energy worldwide will rise by 2,400 gigawatts (GW). Despite growing awareness of climate change and environmental degradation, renewable energy adoption remains relatively low in many developing economies. IEA (2021) pointed out that emissions are continuously increasing while clean energy investments remain low in many developing or emerging economies. This situation will hinder the global efforts to reach the sustainable energy goals. IEA (2021) also highlighted that the limited adoption of clean and renewable energy in these countries is attributed to various challenges, including insufficient government support and financial system constraints.

ASEAN consists of 10 members, namely, Singapore, Malaysia, Thailand, Indonesia, the Philippines, Cambodia, Myanmar, Laos and Vietnam. Since ASEAN was established in 1967, ASEAN has experienced consistent economic growth. According to the IMF, the ASEAN economy is expected to increase by 6.0% in 2023, surpassing the growth rate of the global GDP (The ASEAN Secretariat, 2023). According to the ASEAN Secretariat (2023), ASEAN's economy ranked third in the Asia-Pacific region and fifth internationally in 2019. Although all countries of ASEAN, except Singapore, are developing countries, ASEAN aims to ensure sustainable growth and prevent environmental degradation. The ASEAN Secretariat (2023) noted that ASEAN pledged to increase the consumption of renewable energy and established the ASEAN Power Grid (APG) to construct an integrated Southeast Asia power grid system. The ASEAN Secretariat (2023) showed that Vietnam is the lead country among the

ASEAN members to enhance the production and consumption of renewable energy. Currently, Vietnam is ranked the 10th largest solar power producer in the world. Meanwhile, Singapore pledged to import a maximum of 100MW low carbon and clean electricity from the neighbouring ASEAN countries, i.e., Malaysia, Indonesia, and Laos. Besides, Laos has exported more than 6GW electricity to other ASEAN countries, namely Cambodia, Myanmar, Vietnam and Thailand. Nevertheless, Thailand's Government pledged to increase the clean and renewable energy by 50% via their new power plants, while Malaysia is expected to increase the renewable capacity from 6GW to 14GW. Also, the Indonesian Government is committed to move their capital from Jakarta to a green city called Nusantara in East Kalimantan. ASEAN will surpass the renewable energy share objective by 2.9% installed capacity in 2025, according to the ASEAN Centre for Energy (2022), based on the aforementioned efforts.

ASEAN plays a pivotal role in both the Asian and global economies. Despite being developing nations, the majority of ASEAN members have made great efforts to boost their use of renewable energy. Assessing whether renewable energy consumption contributes to economic growth is crucial to achieving ASEAN's sustainable development goals. This study aims to evaluate the economic impacts of renewable energy in ASEAN, providing evidence-based insights for policymakers to advance SDG 7 and foster long-term sustainable growth.

The paper is organised as follows: The literature on the use of renewable energy is reviewed in Section 2. The study's theoretical underpinnings and methodology are described in Section 3. While Section 5 ends with policy recommendations, Section 4 gives the outcomes and discusses the findings.

2. Literature Review

The environment is greatly impacted by economic activity, particularly when it comes to carbon dioxide emissions (Nordhaus, 1977). An economic sector with a significant contribution to carbon dioxide emissions and climate change is energy production, especially through fossil fuels (Nordhaus, 1993). Therefore, switching to renewable, non-fossil fuel energy sources may be a way to mitigate the effect of economic activity on the environment. However, non-fossil fuel sources are notably lower in terms of their thermal efficiency (Nordhaus, 1977), which may affect productivity and economic

growth. Simultaneously, through climate change and catastrophic natural disasters, the environmental effects of fossil fuels can significantly impede economic growth (Chang et al., 2015). The empirical topic of how renewable energy impacts economic growth must thus be given careful consideration.

Apergis and Payne (2010) examine the relationship between economic growth and the adoption of renewable energy using a 20-year panel data set (1985–2005) for 20 OECD countries. With renewable energy consumption (measured in millions of kilowatt hours) as the primary independent variable, they concentrate on real GDP as the dependent variable. The report breaks down the use of renewable energy into five categories: waste electric power, wood, wind, solar, and geothermal. Additionally, labour and capital are accounted for using the labour force and real gross fixed capital formation, respectively. Employing the fully-modified OLS (FMOLS) technique, the authors find significant short- and long-term benefits of employing renewable energy sources for economic growth. Specifically, for every 1% increase in the utilisation of renewable energy, real GDP rises by 0.76% over time. Additionally, they discover that while labour does not directly affect economic growth, capital does. The utilization of renewable energy and economic growth have a two-way causal link, according to the authors, and estimating methods must account for this reverse causation.

A comparable study by Inglesi-Lotz (2016) uses the same sample of countries and estimates renewable energy by the percentage of renewable energy in total energy consumption. In line with the findings of Apergis and Payne (2010), she comes to the conclusion that this share considerably increases economic growth. As this illustrates, the share of renewable energy in the overall energy mix is equally as significant as the quantity of renewable energy used.

Apergis and Danuletiu (2014) extend the results of Apergis and Payne (2010) by using a larger panel that covers 22 years and 80 countries. Using the same set of factors, they focus on how renewable energy affects economic growth over the long run. Using a panel dynamic error correction model, they find a significant positive impact of renewable energy on economic growth, which is consistent with the findings of Apergis and Payne (2010). They also discover a two-way causal relationship between the use of renewable energy and economic growth, showing that the latter drives the former. The authors do point out, nevertheless, that their analysis omitted certain crucial factors that influence economic growth.

Chang et al. (2015) analyse the G7 countries from 1990 to 2013 to examine the causal relationship between economic growth and the utilisation of renewable energy. They selected the G7 because their power systems have enough renewable energy contributions, in contrast to poorer nations that do not have the resources or finance to fully utilise renewable energy. Using a panel Granger causality technique, they find that using renewable energy significantly increases economic growth for a subgroup of G7 countries. This implies that the degree to which renewable energy contributes to economic growth may depend on factors specific to each country.

Ntanos et al. (2018) examine the relationship between economic growth and the use of renewable energy in a study conducted across 25 European countries between 2007 and 2016. They apply hierarchical cluster analysis and the ARDL technique after grouping countries based on their GDP and renewable energy usage. According to their findings, employing renewable energy significantly boosts economic growth, with the advantages being more pronounced in high-income countries. They attribute this disparity to the absence of finance that prevents lower-income countries from integrating renewable energy into their energy mix.

With an emphasis on emerging nations, Bayar and Gavriletea (2019) investigate how renewable energy affects economic growth while also taking energy efficiency into account. Energy efficiency is determined by the growth rate of real GDP per unit of energy use, whereas renewable energy is evaluated based on its consumption. They draw the conclusion that, whereas renewable energy has no appreciable effect on economic growth, energy efficiency has a long-term positive benefit, based on data from 22 countries between 1992 and 2014. In line with the findings of Ntanos et al. (2018), they argue that the influence of renewable energy varies according to a country's level of development and that this result may be explained by the fact that most of the countries in their sample did not promote renewable energy. On the other hand, Sebri and Ben-Salha (2014) show a bidirectional causal relationship between the two variables and find a strong positive correlation between the BRICS countries' economic growth and their use of renewable energy.

Li, Wang, and Wang (2022) investigate whether renewable energy mitigates the trade-off between economic growth and ecological footprint. They use a threshold panel model using a panel of 120 nations from 1995 to 2014. According to their findings, economic growth is positively impacted

by renewable energy, and the impact grows in size as urbanisation rates rise. However, they also find that the influence of non-renewable energy on economic growth is greater than that of renewable energy. When the sample is broken down by income level, the authors discover that renewable energy boosts economic growth in both higher middle-income and lower middle-income nations, with the effect being larger in the latter. However, at certain levels of urbanisation, the high costs of renewable energy and the barriers to its broad use might negatively impact economic growth in high-income nations.

Shahbaz et al. (2020) examine countries that employ renewable energy using an unbalanced panel of 38 countries from 1990 to 2018. They employ dynamic ordinary least squares (DOLS) and completely modified ordinary least squares (FMOLS) methods. According to their research, a 1% increase in renewable energy leads to both short-term and long-term output increases, even though the effect is less pronounced than that of non-renewable energy. However, the problem of self-selection emerges when they restrict their sample to nations that currently use renewable energy, since these nations may already have a higher likelihood of seeing faster economic growth.

Leitao (2014) examines the connection between Portugal's economic expansion, carbon dioxide emissions, renewable energy, and globalisation between 1970 and 2010. Combustible, renewable and waste energy sources are used to quantify renewable energy, and Dreher's (2006) Globalization Index is used to measure globalisation. The study comes to the conclusion that renewable energy greatly accelerates economic growth using OLS and GMM methodologies. Additionally, the vector error-correction model reveals a unidirectional causal relationship between economic growth and renewable energy.

Between 1980 and 2010, Pao and Fu (2013) investigated the relationship between Brazil's real GDP and four categories of energy consumption: total primary energy, non-renewable energy, non-hydroelectric renewable energy, and total renewable energy. Using the error correction model and cointegration tests, they come to the conclusion that non-hydroelectric renewable energy and total renewable energy have a significant positive influence on real GDP. Additionally, there is a short-term bidirectional causal relationship between economic growth and non-hydroelectric renewable energy, suggesting that economic progress enables the use of renewable energy for sustainable development. Like Pao and Fu (2013), Yildirim,

Sarac, and Aslan (2012) examine several categories of renewable energy consumption and come to the conclusion that the only energy consumption that is causally related to real GDP is that which comes from biomass waste.

Though opinions vary on whether the effect is short- or long-term, most research concludes that renewable energy has a beneficial impact on economic growth overall. For studies that include control variables, most control for capital and labour using the Cobb-Douglas production function (Apergis and Payne, 2010; Inglesi-Lotz, 2016; Apergis and Danuletiu, 2014; Bayar and Gavriletea, 2019; Shahbaz et al., 2020; Pao and Fu, 2013; Yildirim, Sarac and Aslan, 2012). Other control variables include trade openness (Sebri and Ben-Salha, 2014; Leitao, 2014). In terms of how renewable energy is measured, studies have generally gone by kilogram/ton of oil equivalent per capita (Bayar and Gavriletea, 2019; Sebri and Ben-Salha, 2014; Shahbaz et al., 2020; Leitao, 2014), millions of kilowatts per hour/terawatts per hour (Apergis and Payne, 2010; Apergis and Danuletiu, 2014; Chang et al., 2015) and proportion of total energy consumption (Inglesi-Lotz, 2016; Ntanos et al., 2018), although it is noted that these different measurements do not seem to noticeably affect results.

While many studies on renewable energy and economic growth provide valuable insights, they often overlook the specific dynamics at play in ASEAN countries, given their unique economic structures, policy frameworks, and regional interdependencies. This study addresses these gaps by applying a comprehensive and multi-method approach, focusing specifically on ASEAN nations. Unlike previous research, such as Fadilah et al. (2020), which used the Generalised Method of Moments (GMM), this study combines classical panel models, spatial panel models, and the panel Autoregressive Distributed Lag (ARDL) model to offer a more thorough understanding. The classical models establish fundamental relationships, while the spatial models capture the inter-country spillover effects of renewable energy consumption—a critical factor in a highly interconnected region like ASEAN. Finally, the ARDL model allows for the examination of both long-term and short-term dynamics. This multifaceted approach enhances the robustness of our findings, revealing not only how renewable energy consumption drives economic growth in ASEAN but also how these effects manifest differently across countries and time horizons. By integrating spatial and dynamic analyses, this study contributes a more nuanced and comprehensive view of the renewable energy-growth nexus

in ASEAN, offering region-specific insights that can guide more effective policy interventions.

3. Methods

3.1 Theoretical framework

In order to improve energy security and lower greenhouse gas emissions, developed economies encourage the use of renewable energy sources. On the other hand, developing economies often perceive renewable energy as a solution to issues like rural electrification and limited electricity access (Munasinghe, 1990; Pereira et al., 2010). Previous studies have shown that promoting renewable energy not only benefits the energy industry but also advances sustainability and economic growth objectives (Kaygusuz et al., 2007; Kaygusuz, 2007). Global policies aiming at promoting sustainability place a strong emphasis on renewable energy because of its tight ties to various aspects of sustainable development (Stiglitz, 2002).

Given these factors, the aim of this study is to examine the relationship between economic growth and the use of renewable energy. It is believed that using renewable energy will boost economic productivity and positively affect economic growth trends. To investigate this connection, the study will apply a Cobb-Douglas production function framework as follows:

$$Y_t = AL^\alpha K^\beta \quad (1)$$

In this equation, Y denotes the output of a country, A is the total factor productivity, L is the labour input, K is the capital input, and α and β are the elasticities of labour and capital, respectively. This study adds to the findings of Inglesi-Lotz (2016) by arguing that the use of renewable energy can promote economic expansion. Furthermore, the importance of international trade as a contributing factor is highlighted in the research on economic growth (Grossman and Helpman, 1990; Barro and Sala-I-Martin, 1995; Sebri and Ben-Salha, 2014; Leitao, 2014). All pertinent elements are seen in this study, with the exception of variable A , which cannot be observed.

The augmented production function is the outcome of the study's incorporation of international trade and renewable energy usage (R) into the production function framework to account for these elements:

$$Y_t = f(L_t, K_t, R_t, T_t) \quad (2)$$

where Y represents the Gross Domestic Product (GDP) or the GDP per capita. Both GDP and GDP per capita denote the economic growth of a country. The variable L denotes the employment to population ratio, K represents the gross capital formation, and T signifies the trade openness.

3.2 Empirical estimation

The analysis in this study begins with classical panel models to establish foundational relationships, followed by spatial models to explore inter-country dependencies, and concludes with the Autoregressive Distributed Lag (ARDL) model to examine temporal dynamics. A strong, multifaceted understanding of the connections between the use of renewable energy and economic growth is made possible by this all-encompassing approach.

The best model specification for the static models—whether it be fixed effects, random effects, or pooled ordinary least squares (Pooled OLS)—is found using the Hausman Test and the Breusch-Pagan Lagrange Multiplier Test. The empirical model for country i over period t is structured as follows:

$$\ln Y_{i,t} = \beta_0 + \beta_1 \ln L_{i,t} + \beta_2 \ln K_{i,t} + \beta_3 \ln R_{i,t} + \beta_4 \ln T_{i,t} + \epsilon_{i,t} \quad (3)$$

To account for spatial dependence and capture the effects of adjacent nations' economies, the study uses the Spatial Error Model (SEM), Spatial Lag Model (SLM), and Spatial Durbin Model (SDM) in its spatial models. The SEM, recognising that errors across countries may correlate spatially, is specified as:

$$v_{it} = \zeta \sum_{j=1}^N W_{ij} \epsilon_{jt} + u_{it} \quad (4)$$

where ζ is the spatial error coefficient, N represents the sample size, and $u_{it} \sim N(0, \sigma^2 I)$. In this case, equation (4) becomes:

$$\ln Y_{i,t} = \beta_0 + \beta_1 \ln L_{i,t} + \beta_2 \ln K_{i,t} + \beta_3 \ln R_{i,t} + \beta_4 \ln T_{i,t} + v_{i,t} \quad (5)$$

Consequently, a shock in one country impacts not only its own economic growth but also the growth rates of others through spatial transformation, represented by $(1 - \zeta \sum_{j=1}^N W_{ij})^{-1}$. Here, W denotes the weight matrix measuring spatial interactions among countries.

The Spatial Lag Model (SLM) addresses spatial dependence by relating a country's economic growth rate to both its own growth and that of other countries:

$$\ln Y_{i,t} = \beta_0 + \gamma \sum_{j=1}^N W_{ij} Y_{i,t} + \beta_1 \ln L_{i,t} + \beta_2 \ln K_{i,t} + \beta_3 \ln R_{i,t} + \beta_4 \ln T_{i,t} + v_{i,t} \quad (6)$$

This specification implies that each country's economic growth is influenced by its initial growth level and the growth levels of other countries.

To further capture spatial dependence, the Spatial Durbin Model (SDM) is formulated as:

$$Y_{it} = \beta_0 + \beta_1 \ln L_{it} + \beta_2 \ln K_{it} + \beta_3 R_{it} + \beta_4 \ln T_{it} + \beta_5 \sum_{j=1}^N W_{ij} Y_{it} + \beta_6 \sum_{j=1}^N W_{ij} \ln L_{it} + \beta_7 \sum_{j=1}^N W_{ij} \ln K_{it} + \beta_8 \sum_{j=1}^N W_{ij} R_{it} + \beta_9 \sum_{j=1}^N W_{ij} \ln T_{it} + \epsilon_{it} \quad (7)$$

In this model, spatial dependencies for economic growth, labour, capital, renewable energy, and trade openness are captured by the respective terms, $\sum_{j=1}^N W_{ij} Y_{it}$ offering insights into how neighbouring countries' factors influence domestic growth.

Finally, in the dynamic model, multicollinearity among variables is checked, and homogeneity is tested using Pesaran and Yamagata's (2008) adjusted delta tilde test. The Im, Pesaran, and Shin W-stat unit root tests, as well as the ADF Fisher Chi-square, are used to examine the integration levels of the variables. The details of the generalised ARDL(p, q) model are as follows:

$$\ln Y_{i,t} = \beta_0 + \sum_{j=1}^p \beta_{1,j} \ln L_{i,t-j} + \sum_{j=1}^p \beta_{2,j} \ln K_{i,t} + \sum_{j=1}^p \beta_{3,j} \ln R_{i,t} + \sum_{j=1}^p \beta_{4,j} \ln T_{i,t} + \epsilon_{i,t} \quad (8)$$

The study employs the Pooled Mean Group (PMG) estimator, which estimates both long-term and short-term coefficients across countries, accommodating varying short-term dynamics while assuming common long-term effects. The ARDL model's versatility in handling both I(1) and I(0) series supports the simultaneous estimation of long- and short-term impacts,

contributing a nuanced view of renewable energy’s role in ASEAN’s economic growth.

3.3 Data

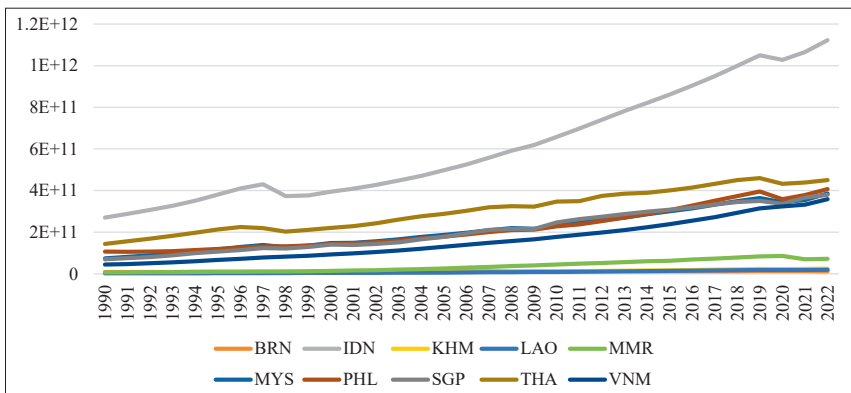
Ten ASEAN nations, Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam, are included in this study’s yearly panel time series data, which spans the years 1990–2022. The data, sourced from the World Bank’s World Development Indicators (WDI), have been transformed into natural logarithms for analytical consistency (see Table 1). To enhance reader comprehension and provide an overview of the data trends, Figures 1, 2, and 3 illustrate the trajectories of GDP, GDP per capita, and renewable energy usage, respectively, across the ten countries.

Table 1: Summary of the data set

Variable	Description
GDP	GDP (constant 2015 US\$)
GDPC	GDP per capita (constant 2015 US\$)
Renewable	Renewable energy consumption (% of total final energy consumption)
Capital	Gross capital formation (% of GDP)
Labor	Employment to population ratio, 15+, total (%) (modelled ILO estimate)
TO	Trade (% of GDP)

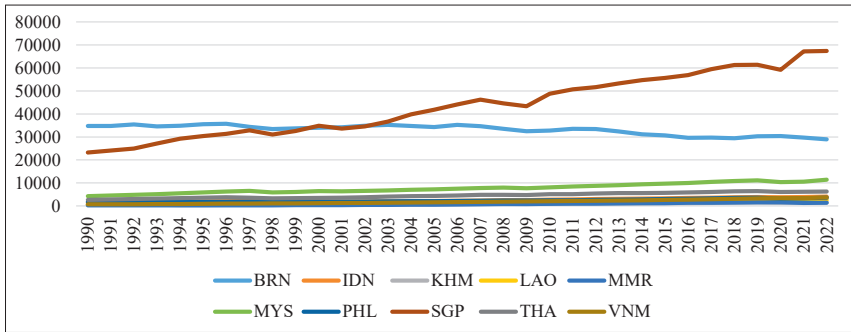
Source: World Bank’s World Development Indicators

Figure 1: GDP (constant 2015 US\$)



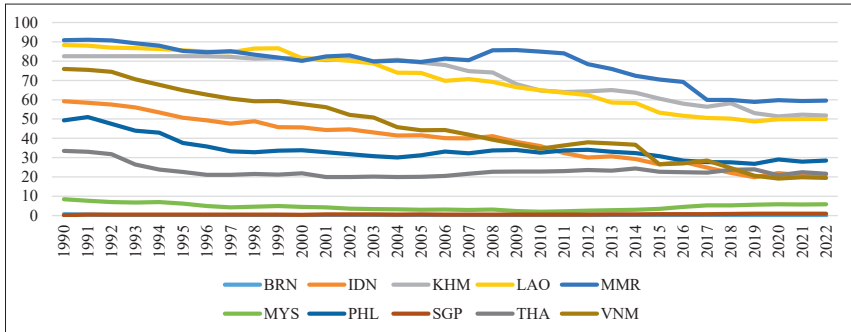
Source: Authors’ plots based on data extracted from the World Bank’s World Development Indicators

Figure 2: GDP per capita (constant 2015 US\$)



Source: Authors' plots based on data extracted from the World Bank's World Development Indicators

Figure 3: Renewable energy consumption (% of total final energy consumption)



Source: Authors' plots based on data extracted from the World Bank's World Development Indicators

4. Results and Discussions

The summary statistics of various variables, all in natural logarithm, based on data collected from 10 ASEAN countries with a total of 330 observations was first presented in Table 2. The mean GDP across these countries is approximately 24,996, with a standard deviation of 1.596, indicating some variability around the mean GDP values. The lowest recorded GDP in the sample is approximately 21,730, while the highest is around 27,746. The mean GDP per capita (GDPC) is approximately 8.136, with a standard deviation of 1.452, reflecting variations in GDPC values. The minimum GDPC in the sample is approximately 5.243, and the maximum is around 11.118. Additionally, the study examines renewable energy consumption, which has an average value of approximately 2.090, but with a higher

standard deviation of 3.433, suggesting a wider dispersion of renewable energy consumption values.

Table 2: Variables' summary statistics (in natural logarithm)

Variable	Mean	Standard deviation	Min	Max	Number of countries	Observation
GDP	24.996	1.596	21.730	27.746	10	330
GDPC	8.136	1.452	5.243	11.118	10	330
Renewable	2.090	3.433	-9.210	4.512	10	330
Capital	3.211	0.304	2.345	3.776	10	330
Labor	4.180	0.091	3.977	4.381	10	330
TO	4.535	0.723	2.473	6.081	10	330

In the classical panel models (pooled OLS, fixed effects, and random effects), each country is treated as largely independent of the others. These models focus solely on the relationships between variables within individual countries, without accounting for how neighbouring countries might influence each other. As shown in Table 3, renewable energy appears insignificant for both GDP and GDP per capita because these models overlook the spillover effects of renewable energy between countries. These spillover effects can be particularly strong in regions like ASEAN, where countries are economically and geographically interconnected.

Table 3: Estimation results of classical panel models

	(1) Pooled OLS	(2) Fixed OLS	(3) Random OLS
Dependent variable: ln(GDP)			
Intercept	1.046 (1.14)	-4.950 (3.23)	1.046 (1.14)
ln(Renewable)	0.002 (0.01)	0.005 (0.02)	0.002 (0.01)
ln(Capital)	0.172 (00.8)**	0.103 (0.10)	0.172 (0.08)**
ln(Labor)	-0.381 (0.26)	0.746 (0.69)	-0.381 (0.26)
ln(TO)	0.0003 (0.04)	0.331 (0.10)***	0.0003 (0.04)
R ²	0.025	0.00005	0.025
Adjusted R ²	0.013		
BP LP			0
Hausman		12.32**	

	(1) Pooled OLS	(2) Fixed OLS	(3) Random OLS
Dependent variable: ln(GDPC)			
Intercept	1.538 (1.03)	3.919 (2.92)	1.538 (1.03)
ln(Renewable)	0.002 (0.01)	-0.020 (0.02)	0.002 (0.01)
ln(Capital)	-0.001 (0.07)	-0.035 (0.09)	-0.001 (0.07)
ln(Labor)	-0.446 (0.24)*	-1.054 (0.63)*	-0.446 (0.24)*
ln(TO)	0.070 (0.03)**	0.140 (0.09)	0.070 (0.03)**
R ²	0.029	0.023	0.029
Adjusted R ²	0.017		
BP LP			0
Hausman		5.37	

Table 4 presents the results of the spatial panel models, which show that renewable energy is significant for GDP but insignificant for GDP per capita. This finding is consistent across the error, lag, and Durbin models. GDP captures the total economic output of a country and may respond more quickly to large-scale investments in renewable energy infrastructure, particularly in capital-intensive sectors such as solar or hydroelectric power. These investments can drive aggregate output without immediately improving individual income levels.

In contrast, GDP per capita reflects the average income per person. In several ASEAN countries, rapid population growth or persistent income inequality may dilute the per capita gains from renewable energy development. For example, while countries like Indonesia and Vietnam may experience substantial increases in total GDP from infrastructure expansion, these gains may not be evenly distributed across regions or social groups. This suggests important distributional implications: the benefits of renewable energy investments may disproportionately accrue to specific industries or urban areas, leaving rural communities or low-income households with limited direct gains. Therefore, complementary policies, such as inclusive energy access, skills training, and equitable infrastructure development—are essential to ensure that renewable energy contributes not only to economic growth but also to broad-based improvements in living standards.

Table 4: Estimation results of Spatial Panel Models

Determinants	(2) Spatial Error Model	(3) Spatial Lag Model	(4) Spatial Durbin Model
Dependent variable: ln(GDP)			
Intercept	-3.176 (2.23)	-3.423 (2.23)	-0.427 (0.51)
ln(Renewable)	0.057 (0.02)***	0.054 (0.02)***	0.049 (0.02)***
ln(Capital)	0.075 (0.07)	0.040 (0.07)	0.046 (0.08)
ln(Labor)	0.539 (0.48)	0.606 (0.48)	0.485 (0.51)
ln(TO)	0.128 (0.07)*	0.143 (0.07)**	0.219 (0.09)**
W*ε	2.206 (0.12)***		
W*ln(GDP)		2.217 (0.12)***	2.292 (0.13)***
W*ln(Renewable)			0.036 (0.33)
W*ln(Capital)			-0.243 (0.39)
W*ln(Labor)			-0.537 (2.75)
W*ln(TO)			-0.581 (0.43)
R ²	0.368	0.38	0.026
Dependent variable: ln(GDPC)			
Intercept	1.730 (0.90)*	1.394 (0.90)	1.053 (1.05)
ln(Renewable)	0.006 (0.01)	0.004 (0.01)	0.009 (0.01)
ln(Capital)	-0.014 (0.06)	-0.001 (0.06)	-0.003 (0.08)
ln(Labor)	-0.487 (0.21)**	-0.410 (0.21)**	-0.371 (0.24)
ln(TO)	0.074 (0.03)***	0.068 (0.03)**	0.102 (0.04)**
W*ε	1.454 (0.15)***		
W*ln(GDPC)		1.421 (0.15)***	1.484 (0.16)***
W*ln(Renewable)			-0.155 (0.16)
W*ln(Capital)			-0.153 (0.44)
W*ln(Labor)			0.655 (0.69)
W*ln(TO)			-0.380 (0.34)
R ²	0.250	0.250	0.254

Table 5 presents the multicollinearity test results for the two dependent variables, GDP and GDPC. The variance inflation factor (VIF) values are low, around 1.27 for Renewable energy and approximately 1.26 for Trade Openness (TO), with even lower values for Labour (1.10) and Capital (1.09). The credibility of the estimates for the GDP and GDPC models is ensured by these results, which imply that there is no significant multicollinearity between the independent variables.

Table 5: Test of multicollinearity

Dependent variable	VIF	
	GDP	GDPC
Renewable	1.27	1.27
TO	1.26	1.26
Labor	1.10	1.10
Capital	1.09	1.09

Table 6 shows the correlation analysis among key variables. Weak negative correlations are observed between GDP and both Labour and Renewable energy, while a linear correlation exists between GDP and Capital, and a weak positive correlation with Trade Openness. Similar patterns are seen for GDPC, with weak negative correlations with Labour and Renewable energy, but minimal positive correlations with Capital and Trade Openness.

Table 6: Correlation analysis

	GDP	GDPC	Labor	Capital	Renewable	TO
GDP	1					
Labor	-0.092		1			
Capital	0.135		-0.110	1		
Renewable	-0.008		0.273	-0.038	1	
TO	0.032		-0.076	0.261	-0.381	1
GDPC		1				
Labor		-0.113	1			
Capital		0.046	-0.110	1		
Renewable		-0.059	0.273	-0.038	1	
TO		0.136	-0.076	0.261	-0.381	1

The homogeneity test results in Table 7 reveal significant heterogeneity across country groups, with the delta tilde ($\tilde{\Delta}$) and adjusted delta tilde (adj $\tilde{\Delta}$) statistics rejecting the null hypothesis of homogeneous slope coefficients at the 1% level. This confirms the need for heterogeneous panel methods to account for differences in parameters across countries.

Table 7: Pesaran-Yamagata’s homogeneity test

Groups	Test	Statistic	P-value
GDP	$\tilde{\Delta}$	2.378	0.017
	adj $\tilde{\Delta}$	2.629	0.009
GDPC	$\tilde{\Delta}$	2.613	0.009
	adj $\tilde{\Delta}$	2.888	0.004

Notes: H_0 : slope coefficients are homogenous; *** indicates statistical significance at 1% level.

Panel unit root tests performed before variable estimation reveal that the variables are non-stationary at the level but become stationary after first differencing, indicating the presence of unit roots at the level and stationarity upon differencing (Table 8).

Table 8: Panel unit root test

	ADF - Fisher Chi-square		Im, Pesaran and Shin W-stat	
	Level	Δ	Level	Δ
GDP	19.050	118.838***	0.456	-8.558***
GDPC	28.066	133.593***	-1.129	-9.602***
Renewable	27.842	183.731***	-0.622	-14.136***
Capital	25.076	191.283***	-0.959	-14.373***
Labor	22.518	105.003***	-0.822	-7.786***
TO	11.325	179.536***	0.978	-13.569***

Notes: H_0 : The time series contains a unit root; Δ denotes the first differences; ***, ** and * indicate statistical significance at 1%, 5% and 10% level respectively.

The study used an ARDL model with the Pooled Mean Group (PMG) estimator to look into the long-term associations between the variables. Each variable in the selected ARDL (4,4,4,4) model has four lags. Both GDP and GDPC have negative error correction terms (ECTs) that are statistically significant at the 1% level. This implies that deviations from the long-term equilibrium are corrected by 0.57% for GDP and 0.60% for GDPC in each period, indicating strong cointegration among the variables.

Table 9 presents the results of the PMG estimation, which reveal that all variables, except capital, have a substantial effect on economic growth. Consistent with previous research, a 1% increase in renewable energy use

results in a 0.003% increase in GDP or GDPC, highlighting the long-term benefits of renewable energy in ASEAN countries. Although this coefficient may appear small in magnitude, it reflects a positive and statistically significant contribution of renewable energy to long-term economic growth. Given the scale of national GDPs, even a 0.003% increase can translate into millions of dollars in additional economic output over time. This underscores the strategic importance of expanding renewable energy use, especially as ASEAN countries pursue their target of a 23% renewable energy share by 2025 (ASEAN Centre for Energy, 2016). The result suggests that renewable energy not only contributes to environmental goals but also supports sustainable economic development.

ASEAN's dependence on trade is evident from the strong positive impact of trade that a 1% increase in trade openness leads to a 0.024% increase in GDP and a 0.016% increase in GDPC. This aligns with the region's export-oriented growth model. Meanwhile, the negative coefficient on labour (-0.02% for GDP and -0.028% for GDPC) could reflect structural shifts such as the automation of labour-intensive industries, as highlighted by Ikeshita et al. (2023). Although capital has a negligible effect on aggregate GDP, its positive association with GDPC indicates that capital investment may improve individual income levels without necessarily driving total output growth.

Finally, the short-term PMG results show a delayed but significant effect of renewable energy on economic growth, with impacts materialising from the third lag onward. This suggests that consistent and forward-looking investment in renewable energy infrastructure is crucial to realising its long-term growth benefits.

Table 9: PMG estimation results

Dependent variable	GDP	GDPC
Long-run coeff.		
Renewable	0.003***	0.003***
Capital	0.004	0.019***
Labor	-0.020***	-0.028***
TO	0.024***	0.016***
Short-run coeff.		
$\hat{\varphi}$	-0.566***	-0.602***
D(GDP(-1))	-0.131	-0.147
D(GDP(-2))	-0.139	-0.172

Dependent variable	GDP	GDPC
D(GDP(-3))	-0.030	-0.064
D(Capital)	0.012	-0.010
D(Capital(-1))	-0.132**	-0.121*
D(Capital(-2))	0.038	0.036
D(Capital(-3))	0.087	0.090
D(Labor)	-0.328	-0.295
D(Labor(-1))	0.179	0.036
D(Labor(-2))	0.053	-0.006
D(Labor(-3))	1.188**	1.089*
D(Renewable)	-0.019	-0.015
D(Renewable(-1))	-0.121	-0.105
D(Renewable(-2))	-0.122	-0.097
D(Renewable(-3))	0.129*	0.130**
D(TO)	-0.105	-0.087
D(TO(-1))	0.027	0.040
D(TO(-2))	0.017	0.021
D(TO(-3))	-0.013	-0.015

Notes: ***, ** and * indicate statistical significance at 1%, 5% and 10% level respectively.

5. Conclusions And Policy Implications

This study investigates whether renewable energy use positively influences economic growth in ASEAN countries. The study uses panel data from 10 ASEAN member countries between 1990 and 2022 and a modified Cobb-Douglas production function. It uses both classical and spatial panel models, as well as dynamic autoregressive distributed lag (ARDL) models, to evaluate both short- and long-term effects.

The main findings indicate that the usage of renewable energy significantly boosts economic growth in ASEAN countries, proving that renewable energy promotes both environmental sustainability and economic advancement. While both short- and long-term effects are evident, the short-term benefits tend to materialise more gradually, becoming significant after approximately three years.

While the analysis acknowledges the existence of potential negative externalities and transition costs associated with the shift toward renewable energy, these issues are not examined in depth. A just energy transition necessitates careful attention to distributional consequences, including

possible employment displacement in fossil fuel-dependent industries, energy affordability concerns for low-income populations, and unequal access to renewable technologies across ASEAN member states. If left unaddressed, these challenges may exacerbate existing socio-economic inequalities and hinder public acceptance of renewable energy policies. Therefore, a comprehensive and inclusive transition strategy is imperative to ensure that the economic benefits of renewable energy adoption are equitably distributed and that vulnerable groups are not disproportionately affected.

The study concludes that increasing the share of renewable energy in the energy mix can foster sustainable regional economic growth. Therefore, by implementing effective green investment legislation, ASEAN officials should encourage the use of renewable energy. Policymakers could use measures like feed-in tariffs, tax credits, and subsidies to promote the usage of renewable energy sources. Investments in renewable energy infrastructure, such as wind and solar power plants, should also be prioritised. When combined with pro-growth policies like open trade and technology-driven industrialisation, these green investment efforts can help the region's economy grow more quickly.

Finally, this study makes a number of recommendations for further research, especially in examining how coordinated ASEAN policies and regulations might support the use of renewable energy sources and economic expansion. This includes considering ASEAN as an integrated green trade and investment region, aimed at fostering shared economic growth. Such efforts are critical, as disparities remain among ASEAN members in their green investment commitments despite rising demand for renewable energy (The ASEAN Secretariat, 2023).

CRedit Author Statement

Mui-Yin Chin contributed to the conceptualization of the study. **Sheue-Li Ong** was responsible for the design of the methodology, data collection and curation, as well as formal analysis. The original draft was prepared collaboratively, with all authors involved in writing and reviewing the manuscript.

Declarations

- I. **Ethical Statement:** All authors have endorsed the content and have provided explicit consent for submission.
- II. **Funding:** This publication is partially funded by the Faculty of Business and Economics, Universiti Malaya Special Publication Fund.
- III. **Conflict of Interest:** No competing interests to declare.
- IV. **Availability of Data and Materials:** All data originate from reputable open-access sources, specifically the World Bank World Development Indicators database.
- V. **Ethics Approval:** Not applicable, as all data used are secondary and do not require ethics approval.

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