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Article

Renewable energy generation in ASEAN: The influence of economic factors, infrastructure, and governance quality

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Abstract: This paper examines the relationship between renewable energy (RE) generation, economic factors, infrastructure, and governance quality in ASEAN countries. Based on the Fixed Effects regression model on panel data spanning the years 2002–2021, results demonstrate that domestic capital investment, foreign direct investment, governance effectiveness, and crude oil price exhibit an inverse yet significant relationship with RE generation. An increase in those factors will lead to a decline in RE generation. Meanwhile, economic growth and infrastructure have a positive relationship, which implies that these factors act as stimulants for RE generation in the region. Hence, it is advisable to prioritise policies that foster economic growth, including offering tax breaks specifically for RE projects. Additionally, it's crucial to streamline governance processes to facilitate infrastructure conducive to RE generation, along with investing in RE infrastructure. This could be achieved by establishing one-stop centres for consolidating permitting processes, which would streamline the often-bureaucratic process. However, given the extensive time period covered, future research should examine the short-term relationship between the variables to address any potential temporal trends between the factors and RE generation.

Keywords: renewable energy; developing countries; energy policy; energy development; ASEAN countries; economic factors; infrastructure; governance quality

1. Introduction

Without energy, there is no route to economic development. According to the International Renewable Energy Agency (2016), energy fuels global economic activity, generates new sources of growth, boosts income, creates employment opportunities, and enhances human welfare.

Owing to rapid growth, ASEAN countries have witnessed a notable increase in energy consumption. According to the International Energy Agency's Southeast Asia Energy Outlook 2019 report, energy demand in ASEAN rose by more than 80% from 2000 to 2019. Additionally, projections indicate a subsequent 60% increase in energy demand by 2040, constituting 12% of the global rise in energy consumption. ASEAN countries heavily rely on fossil fuels (oil, coal, and gas) to drive economic and industrial growth (Shah et al., 2023), with fossil fuels making up about 80% of the region's energy mix in 2019. However, continuous reliance on these energy sources can present several challenges, including sustainability issues, supply insecurity, and increased carbon emissions (Ndlovu and Inglesi-Lotz, 2020). As the impacts of

climate change become more pronounced, there has been a shift in the global energy consumption landscape, highlighting the pressing demand for clean and sustainable energy sources.

Renewable energy (RE) is regarded as the more environmentally friendly, resilient, and cost-effective source of energy (Ghosh et al., 2023; Jaiswal et al., 2022; Osman et al., 2023; Yang et al., 2024). To accommodate the ever-growing population and rapid economic development, there is a call to explore RE options for those whose sources are already available in abundance. This concurs with Bonsu and Wang's (2022) conclusion that countries should prioritise the diversification of their existing energy production paths, with a primary focus on RE sectors. They further added that such an initiative will contribute to the maintenance of a green economy while mitigating concerns related to global price fluctuations in oil and natural gas. When investigating the degree of influence that energy has on economic growth, Rahman and Velayutham (2020) found that RE has a much stronger influence compared to non-RE. Considering this finding, they advocate the substitution of non-RE with RE sources, together with designing relevant incentives by the governments.

The geographical advantages of ASEAN enable the region to utilise vast amounts of natural resources to promote RE consumption (Shah et al., 2021). At present, the potential options for RE encompass a range of sources, including geothermal, hydropower, biomass, solar, and wind energy. A significant portion of the RE in the region is attributable to hydropower, which contributes to approximately half of the installed renewable capacity and over two-thirds of the renewable electricity output. At the country level, the International Energy Agency (2023) reported that Vietnam saw the largest renewable power deployment, with solar photovoltaic and wind energy escalating from near zero in 2017 to over 22 GW by 2021. Meanwhile, the renewables capacity in Thailand has grown by more than 3 GW since 2017, followed by Indonesia (2.2 GW), the Philippines (1.3 GW), and Malaysia (0.9 GW). Nevertheless, there remains largely untapped potential for RE in ASEAN in terms of its capacity and generation.

To meet the goal of 23% RE in its total primary energy supply by 2025[1], securing access to a significant amount of capital is of utmost importance in ensuring successful implementation of RE projects. According to Vakulchuk et al. (2023), the ASEAN region would require an annual investment totalling USD 27 billion in RE development. However, the region only attracted up to USD 8 billion annually from 2016 to 2021, just nearly 30% of the amount required. To facilitate investment in RE initiatives, Qamruzzaman and Karim (2023) emphasised the importance of promoting public-private partnerships, in addition to introducing a favourable investment climate, financial incentives, green bonds, and venture capital funding. Moreover, Ölz and Beerepoot (2010) asserted that other crucial factors propelling the deployment of RE include promoting the liberalisation of energy markets in the majority of ASEAN countries and the development of favourable policy frameworks.

Although past studies have extensively explored the relationship between energy and growth, the results remain mixed. These studies provided evidence either in favour of the (i) growth hypothesis—increase in energy use leads to higher growth (Rahman and Velayutham, 2020); (ii) conservation hypothesis—higher growth leads to increased energy use (Furuoka, 2017); (iii) feedback hypothesis—bidirectional

causality between energy and growth (Okumus et al., 2021; Salari et al., 2021); or (iv) neutrality hypothesis—no causality between energy and growth (Jalil and Feridun, 2014). These four hypotheses have important implications for energy policies. If the growth (one-way causality from energy to growth) and feedback (two-way causality between energy and growth) hypotheses are not rejected, this advocates for policies focusing on energy-efficient measures while discouraging stringent energy policies. Meanwhile, failure to reject the conservation (one-way causality from growth to energy) and neutrality hypothesis (no causality between energy and growth) call for policies on energy conservation (Narayan, 2016). Within the ASEAN setting, rapid economic development is often accompanied by growing demand for energy. Giving priority to energy conservation may result in more efficient distribution of resources, reduced environmental impact, and greater energy security. This study, therefore, aims to test the conservation hypothesis by examining the effect of economic growth on RE in ASEAN countries. Additionally, investments in RE tend to follow economic progress stimulated by development in digital infrastructure (Lee et al., 2023; Salahudin and Alam, 2016). The consequent rise in energy-intensive digital services has led to an increase in the number of applications and devices in use, thus necessitating the development of sustainable and RE. Moreover, good governance must be in place for formulating environmental regulations and policies that facilitate the development of RE (Mahmood et al., 2021). Based on the aforementioned past literature, the economic, infrastructure and governance factors selected for testing in this study are hypothesised to have a positive relationship with RE.

While RE consumption is important, assessment of issues related to RE generation is equally crucial, as it directly addresses the increasing global energy demand and changing climate conditions, helps in meeting RE goals, and brings about various socio-economic benefits (International RE Agency, 2016). Numerous past studies have explored the drivers of RE consumption (Kumaran et al., 2020; Omri and Nguyen, 2014; Sharif et al., 2019; Salim and Rafiq, 2012); however, only a small number of studies have empirically investigated the factors influencing RE generation (Marques et al., 2019; Lin and Omoju, 2017; Przychodzen and Przychodzen, 2020). Hence, this study aims to address the lack of empirical evidence by examining the effect of various economic, infrastructure, and governance factors on the region's RE generation. The testing of infrastructure and governance factors is scant in the literature on RE generation, especially within the context of ASEAN.

For ASEAN to accelerate its RE transition and ultimately achieve sustainable growth, understanding the factors driving RE development is important. Findings of this study can contribute to an increased understanding of how the factors drive RE generation and facilitate informed decision-making among policymakers on the implementation of RE policies in ASEAN. It also enables stakeholders to identify potential opportunities for investment and collaboration and navigate challenges in the RE sector.

The remainder of this paper is structured as follows: Section 2 reviews the existing literature on RE. Section 3 describes the data and methodology employed in the study. Section 4 reports on and discusses the empirical results. Lastly, Section 5 presents the conclusion and policy implications.

2. Literature review

2.1. Theoretical foundation and regeneration

Previous scholars have expressed that economic theory can support internalising externalities in the study of RE, and they have stated that the shift to RE would have advanced significantly if the externality costs were factored into the cost of all energy sources (Timmons et al., 2014). The economic theory offers a context for recognising the relationship of energy with productivity growth and technological advancement (Wen et al., 2022). Moreover, AlDarraji and Bakir (2020) have found a positive relationship between investment in RE and economic growth based on economic theory.

RE plays a pivotal role in addressing global challenges such as climate change implications and is imperative for the commitment to attain Sustainable Development Goal 7 of affordable, clean energy access for all. The necessity for RE is further highlighted by the anthropogenic consequences of conventional energy sources, or non-renewables. Concerns about sustainable development have grown over the past two decades with ASEAN's expanding economy, declining energy security, environmental pollution, and the high costs associated with energy investment. As such, studies such as Abdullah (2005), Lidula et al. (2006), Veng et al. (2020), and Vidinopoulos et al. (2020) have assessed the potential and challenges of ASEAN's energy transition as it progresses slowly towards RE generation. Additionally, some studies, such as Bamati and Raoofi (2020), Przychodzen and Przychodzen (2020), Vakulchuk et al. (2023), and Zhao et al. (2019) have explored the drivers that promote RE generation.

Lidula et al. (2006) draw a conclusion from their finding that ASEAN has yet to utilise its RE resources anywhere near their potential. In one such example, a considerable gap has been found between the technical potential and hydropower utilisation in ASEAN countries. Some of the most common barriers highlighted included a lack of funding, a lack of experience and knowledge, and limited policy frameworks. The solution to these obstacles would lie in the amendment of policies and regulations that promote RE generation.

Karki et al. (2005) highlighted that the ASEAN region continues to face difficulties such as institutional infrastructure and technological limitations in its efforts to undertake measures of environmental protection. The environmental degradation in the ASEAN region has been attributed to the emissions from fossil fuel combustion (coal, oil, and gas). The contribution of RE remains relatively low, with high emissions of carbon dioxide in the region. This called upon both the government and non-government organisations to increase their research and development efforts devoted to the development of sustainable energy. Meanwhile, although Abdullah (2005), Shi (2016) and Veng et al. (2020) have revealed how policies and government actions are imperative in RE development, the current studies have failed to incorporate the determinants that play critical roles in ensuring the success of such policies. Hence, the implications from these past studies may fail to shed light on how future policies or strategies with better future prospects can be developed.

2.2. Determinants of re generation

2.2.1. Domestic capital investment

There are few studies that have proven the importance of domestic capital in supporting domestic energy transitions to RE. For instance, Best (2017) found that domestic private debt securities are positively related to RE involvement. Domestic investors are more likely to support RE development when there is transparency in the development project and financial return certainty (Riansyah and Chalid, 2020). Furthermore, Paramati et al. (2017) have stated that domestic capital investment supports RE generation, provided the government provides incentives for shifting conventional energy to clean energy projects. Thus, this study develops the first hypothesis:

H1: Domestic capital investment significantly influences RE generation in ASEAN countries.

2.2.2. Foreign Direct Investment (FDI)

Weak environmental restrictions attract FDI to many developing countries (Awan et al., 2022). However, it has been discovered recently that FDI positively associates with RE due to awareness of environmental issues among the population and environmental policies enforced by the government (Islam et al., 2022; Shahbaz et al., 2022). Moreover, Djellouli et al. (2022) and Wei et al. (2022) have proved that FDI is beneficial and crucial for RE development in the long run. Hence, the following hypothesis is proposed:

H2: FDI significantly influences RE generation in ASEAN countries.

2.2.3. Economic growth

Przychodzen and Przychodzen (2020), Song et al. (2023), and Zeraibi et al. (2021) have advocated that economic development can promote RE generation, and their major findings further highlighted that higher renewable electricity capacity and technological innovation were factors that could improve the quality of the environment; however, higher economic growth may increase ecological footprints. Meanwhile, Lin and Omoju (2017) employed panel cointegration estimation techniques for a panel of 46 countries. Their results also reported the significance of economic factors for RE generation. The past findings clearly provide robust evidence in support of the significance of economic factors in driving RE generation. Furthermore, Bamati and Raoofi (2019) have provided a comprehensive analysis of the drivers of RE production by employing variables of economic factors, technological factors, and environmental factors. Their findings proved that the economic factor of Gross Domestic Product per capita (GDP) yields a positive impact on RE production per capita in developing countries too. Therefore, this research proposes the hypothesis below:

H3: Economic growth (i.e., GDP) significantly influences RE generation in ASEAN countries.

2.2.4. Governance effectiveness

Yu (2003) pointed out the weakness of legislation and policies for energy sector reform as the major obstacle to RE transition initiatives in ASEAN. Besides, Veng et al. (2020) reviewed RE development and its policies in ASEAN countries. By

employing an integrated RE policy and long-term planning based on systematic learning, the benefits of RE development were captured. Their finding advocated the revision of the fossil fuel subsidy policy, reduction of energy poverty through RE efficiency, leveraging market integration through regional connectivity and globalisation, and emphasising national energy plans as parts of the ASEAN roadmap. Furthermore, development standards should be strictly followed to ensure long-term benefits. According to Shi (2016), the national government should prioritise implementing action-based initiatives that necessitate competent management, astute leadership, political will, well-defined policies, and practical measures for pertinent stakeholders. Furthermore, Islam et al. (2022) have posited the importance of institutional quality to meet the goal of sustainable development, and their results indicated that the greater promotion of renewables can be made possible by strengthening institutional quality in ASEAN countries. Fatima et al. (2021) have also identified crucial factors for RE generation, such as good governance, RE adaptation, and government energy policies. Among these factors, the lack of good governance has been indicated as the largest obstacle to RE generation. Moreover, Dossou et al. (2023) and Saba and Biyase (2022) have also indicated a significant impact of governance indicators and institutional quality on RE development. Hence, the following hypothesis is proposed:

H4: Governance effectiveness significantly influences RE generation in ASEAN countries.

2.2.5. Urban population

In growing economies, the pattern of energy demand is influenced by urbanisation, such as the shift from conventional sources to RE sources (Fang et al., 2022). However, Koengkan et al. (2020) found that although urbanisation increases fossil fuel consumption, fossil fuel consumption increases RE consumption. The result is similar to the study conducted by Islam et al. (2022), which stated that urbanisation negatively influences RE consumption. Meanwhile, Khuong et al. (2019) have argued that the gap between national policies and local governance, especially in urban areas, requires specific attention. The insufficient regulatory framework with clear, specific targets lacking at the national level and missing targets at the local level were reported as the main challenges in the RE policy in the region. Therefore, this research proposes the hypothesis below:

H5: Urban population (i.e., urbanisation) significantly influences RE generation in ASEAN countries.

2.2.6. Crude oil price

Jin and Kim (2023), Mejdoub and Ghorbel (2018), Sahu et al. (2022), and Zhao et al. (2021) have found that the rising global oil price directly increases investment in RE development. Furthermore, Zhao et al. (2021) have also emphasised that if the oil price decreases, support policies from the government can reduce the negative effect of the decreased oil price, potentially encouraging more investment from industries in RE development. Jin and Kim (2023) have also indicated that oil price have a negative effect on economic growth; however, the negative impact can be mitigated by increasing the use and development of RE. Thus, the hypothesis below is proposed:

H6: Crude oil price significantly influences RE generation in ASEAN countries.

2.2.7. Infrastructure

Xu et al. (2018) have studied the influencing factors of RE generation production efficiency. Their empirical evidence pointed out that the construction of infrastructure for large-scale RE power generation is needed as part of the effort to promote carbon emission reduction. Moreover, Song et al. (2023) employed numerous panel econometric approaches to investigate the impact of energy infrastructure investments (public-private partnerships) on RE generation in major Asian developing economies. Their findings also concluded that investments in energy infrastructure play a significant role in promoting RE generation. Particularly, Zheng and Wang (2021) have argued that infrastructure such as cellular networks can be beneficial to electrical power generation, as rising trends in mobile-cellular subscriptions indicate the fast development of ICTs and result in increasing trends in RE generation. Thus, the following hypothesis is presented:

H7: Infrastructure (i.e., cellular subscriptions) significantly influences RE generation in ASEAN countries.

2.3. Gaps in the literature

The literature has clearly signified the importance of RE generation in the ASEAN region, with empirical research conducted to explore the driving factors of RE development. The robust findings have pointed out the critical factors of infrastructure and governance in determining RE generation. Meanwhile, some other studies shed light on the role of economic factors in promoting RE development as well. However, the major limitation of past studies is that the focus on the factors has been explored separately. In other words, the combined effect or interaction among these different factors in promoting RE generation has been scarcely empirically examined in ASEAN. The interaction mechanisms formed by the factors identified for RE production development are important. The factors affecting the development of RE generation are interrelated with each other. Vakulchuk et al. (2023) have highlighted three key factors—RE legislation, energy governance, and general conditions—for investors to invest in ASEAN's RE generation. The findings from these studies implied the significance of governance and regulation for RE generation development in any country. However, the scope of these studies has been confined to examining the governance impacts, and the impacts of other equally important factors (such as economic factors and infrastructure) have been largely neglected. In other words, past studies were not able to shed light on the interactions between these multi-factor impacts on RE generation in the ASEAN region. Moreover, while the study by Dossou et al. (2023) was focused on examining the moderation of governance quality in RE in 37 sub-Saharan African economies, Saba and Biyase (2022) were contributing to filling the literature gap for a panel of 35 countries in Europe to understand the factors that influence RE generation in Europe. However, their findings were limited to European economies.

Hence, this current study attempts to fill the current gaps by pursuing the driving factors in a multi-aspect manner, incorporating not just the economic factors but also the governance and infrastructure aspects as well. Realising how significant the issue has grown in the ASEAN region, it seems pertinent to investigate the impact of these

factors on RE generation, with a specific focus on the ASEAN countries. The contribution of this study will be threefold. Firstly, this study contributes theoretically by formulating a framework for explaining the identified factors that influence RE development in ASEAN. Secondly, this research addresses the existing literature gap by adding governance quality and infrastructure as part of the identified drivers of RE generation. Thirdly, this study contributes methodologically by employing a Fixed Effects model to explore the drivers' joint effect empirically.

3. Data and methodology

3.1. Data

This study uses panel data from 2002 to 2021 for six ASEAN countries, taking into account the availability of data for the entire period in those nations: Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam. The six independent variables utilised and selected in accordance with prior research are as described in **Table 1** below, and all associations that were hypothesised are presented in **Figure 1**. The variables are selected by referring to their significance as indicated by previous research. These variables represent a diverse range of economic, social, and political dimensions, providing a comprehensive framework for evaluating important factors of RE generation in the region.

Table 1. Measurement for variables.

Acronym	Variable	Measurement	Source[2,3]	Prior research
RE	Renewable Energy Generation	Cumulative RE produced (GWh) by electricity plants, combined heat and power plants (CHP) and distributed generators.	International RE Agency (IRENA)	(Malik et al., 2014; Shah et al., 2018)
DCT	Domestic Capital Investment	Gross capital formation (% of GDP)	World Bank Databank	(Khan et al., 2021; Song et al., 2023)
FDI	Foreign Direct Investment	Net inflows of investment in an economy	International Monetary Fund	
GDP	Economic Growth (i.e., GDP)	Gross domestic product converted to international dollars using purchasing power parity rates	World Bank Databank	(Przychodzen and Przychodzen, 2020; Zeraibi et al., 2021)
GE	Governance Effectiveness	Perceptions of the quality of public services, civil service, policy formulation and implementation.	World Governance Indicator	(Yu, 2003; Veng et al., 2020)
UP	Urban Population (i.e., Urbanisation)	Urban population growth as defined by national statistical offices.	World Bank Databank	(Mrabet et al., 2019)
COP	Crude Oil Price	Crude Oil Price in USD	World Bank Databank	(Muktarov et al., 2020)
CS	Infrastructure (i.e., Cellular Subscriptions)	Mobile cellular subscriptions (per 100 people)	World Bank Databank	(Karki et al., 2005; Xu et al., 2018)

By referring to the objective, the empirical form of the panel data model is developed as:

$$\mathrm{RE}_{it} = \alpha_i + \beta_1 \mathrm{DCT}_{it} + \beta_2 \mathrm{FDI}_{it} + \beta_3 \mathrm{GDP}_{it} + \beta_4 \mathrm{GE}_{it} + \beta_5 \mathrm{UP}_{it} + \beta_6 \mathrm{COP}_{it} + \beta_7 \mathrm{CS}_{it} + u_{it} \quad (1)$$

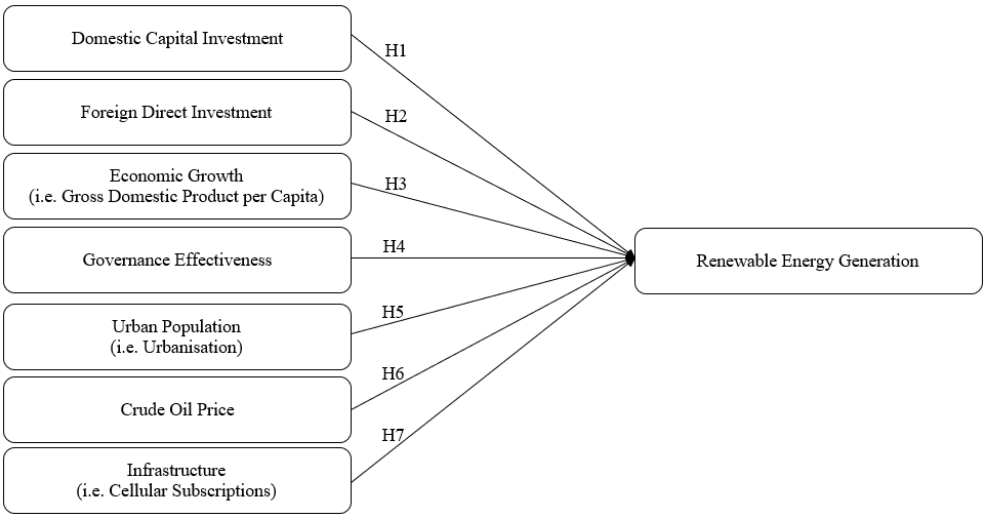

Figure 1. Research framework.

3.2. Fixed effects model

The panel data analysis in this study is conducted using the Fixed Effects model, following confirmation through the Hausman (1978) test that it is more favourable than the Random Effects model. Allison (2006) argues that the Fixed Effects model is advantageous due to its ability to account for all stable individual characteristics, regardless of whether they are measured or not. Moreover, according to Hsiao (2007), the Fixed Effect model permits the correlation of time-specific and/or individual effects with the independent variables.

Fixed Effects model is a linear regression model with the intercept term (α) vary over the individual units (i):

$$y_{it} = \alpha_i + x'_{it}\beta + u_{it}, \qquad i = 1, \ldots$$
$$N(\text{individual countries}),\ t = 1, \ldots, T\ (\text{Time})\ u_{it} \sim \text{IID}(0, \sigma_u^2) \tag{2}$$

In this context, the dependent variable (y_{it}) is calculated using a set of independent variables (x'_{it}), an individual specific intercept (α_i), and an error term (u_{it})[4].

To estimate the parameters in Equation (2), a transformation or within-group estimator may be utilised; Parameter β is estimated using deviations from the means of the individual variables ($\bar{y}_i$, $\bar{x}_i$ and $\bar{u}_i$). The intercept (α_i) will then be removed from this regression by converting the model into:

$$y_{it} - \bar{y}_i = (x_{it} - \bar{x}_i)'\beta + (u_{it} - \bar{u}_i) \tag{3}$$

When OLS estimation is employed to derive β from the within transformation, the resulting estimator is referred to as the Fixed Effects estimator.

$$\hat{\beta}_{FE} = \left(\sum_{i=1}^{N} \sum_{t=1}^{T} (x_{it} - \bar{x}_i) - (x_{it} - \bar{x}_i)' \right)^{-1} \sum_{i=1}^{N} \sum_{t=1}^{T} (x_{it} - \bar{x}_i) - (y_{it} - \bar{y}_i) \tag{4}$$

In order for Fixed Effects model to consistently estimate parameter β, it is necessary that all x_{it} variables are strictly exogenous, denoted as $E\{x_{it}u_{is}\} = 0$ for all s, t, and x_{it} should be independent of any present, past, or future values of the error term (u_{it}) (Wooldridge, 2010). Furthermore, Verbeek (2017) said that the consistency of the Fixed Effects estimator can be compromised even when $E\{x_{it}u_{is}\} = 0$,

provided that x_{it} is correlated with the lag value of y_{it}. In contrast, the intercepts (α_i) are estimated in an unbiased manner when all error terms are independent of the independent variables and $T \to \infty$.

$$\hat{\alpha}_i = \bar{y}_i - \bar{x'}_i \hat{\beta}_{FE}, \qquad i = 1, \ldots, N \tag{5}$$

Thus, the covariance matrix for the fixed effects estimators $\hat{\beta}_{FE}$ will be:

$$V\{\hat{\beta}_{FE}\} = \sigma_u^2 \left(\sum_{i=1}^{N} \sum_{t-1}^{T} (x_{it} - \bar{x}_i)\,(x_{it} - \bar{x}_i)' \right)^{-1} \tag{6}$$

In equation (6), the error term (u) is Independent and Identically Distributed or IID across all individuals and time points. Meanwhile, the variance (σ_u^2) is systematically calculated by dividing the sum of squared residuals of the within estimation by $N(T-1)$ (Baltagi, 2008).

$$\hat{\sigma}_u^2 = \frac{1}{N(T-1)} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{u}_{it}^2 \tag{7}$$

In Equation (7), $\hat{u}_{it}^2$ is equal to $y_{it} - \hat{\alpha}_i - x'_{it}\hat{\beta}_{FE} = y_{it} - \bar{y}_{it} - (x_{it} - \bar{x}_{it})'\hat{\beta}_{FE}$.

The Fixed Effects model, as described by Verbeek (2017), focuses on variations 'within' specific cross-sections, which in this instance are the distinct ASEAN countries. The extent to which y_{it} differs from $\bar{y}_i$ is elucidated. In contrast, the parametric assumption regarding β stipulates that any modification in x yields an equivalent consequence, irrespective of whether the modification occurs across periods or between individuals.

3.3. Diagnostic tests

The study employed the Breusch Pagan (1980) LM and the Pesaran (2004) tests to assess the cross-sectional dependence in order to ascertain the reliability of the model[5,6]. In addition, the Jochmans (2019) portmanteau and Greene (2004) groupwise heteroskedasticity tests are performed to determine the presence of serial correlation and heteroskedasticity, respectively[7,8].

4. Results and discussion

Table 2 shows the summary statistics of the data in their natural logarithm form, and it is shown that the standard deviations of the variables are small. Furthermore, the medians of all variables are close to their respective arithmetic means and noticeably fall in between the minimum and maximum values. This indicates minimal variability in the data with a low likelihood of outliers and conforms to a normal distribution, facilitating the use of inferential statistics.

The study then uses static panel data estimation to investigate the effects of infrastructure, governance, and economic factors on the generation of RE in ASEAN countries. It was determined by the Hausman (1978) test that the residuals have a correlation with the regressors, which indicates that it is appropriate to use a Fixed Effects regression model for the analysis[9]. Subsequently, the Breusch-Pagan (1980) and Pesaran (2004) tests for cross-sectional dependence were conducted to identify contemporaneous correlation within the model. Both cross-sectional dependence tests revealed significant correlations among the residuals across countries, potentially

resulting in biassed estimation. Furthermore, the Greene (2000) test for groupwise heteroskedasticity and the Jochmans (2019) portmanteau test of correlation indicate homoscedasticity with serially correlated residuals within each country.

Table 2. Summary statistics.

Descriptive Statistics	RE	Domestic Capital Formation	FDI	GDP	Governance Effectiveness	Urban Population (Urbanisation)	Crude Oil Price	Infrastructure (Cellular Subscriptions)
Mean	9.5779	3.2537	1.9448	27.3591	0.3887	0.9145	5.9700	4.4447
Median	9.8918	3.2371	1.8593	27.3031	0.2025	0.9351	6.0083	4.7979
Maximum	11.5553	3.6780	4.1805	28.8086	1.6359	1.6718	6.5545	5.2027
Minimum	7.0557	2.7735	−0.8733	26.1688	−0.5658	−2.4237	5.0587	0.8583
Standard Deviation	1.1438	0.2028	0.9844	0.6061	0.6414	0.4364	0.4221	0.8392

To address the issues, the current research chooses to retain the Fixed Effects model and correct the standard errors by following the approach proposed by Driscoll and Kraay (1998). As exhibited in **Table 3**, domestic capital formation is shown to be significant in influencing RE generation for ASEAN countries, and the negative coefficient sign indicates the adverse impact of the regressor. An increase of 10 percent in domestic capital formation will result in a decrease of 7 percent in RE generation. In line with Khan et al. (2021), there is a notable inverse relationship between FDI and RE generation. Specifically, a 10 percent increase in FDI in the region will result in a 1.5 percent decrease in RE generation.

Table 3. Fixed-effects estimations.

Variable	Coefficient
Domestic Capital Investment	−0.6996** (0.2785)
FDI	−0.1568*** (0.0331)
Economic Growth (GDP)	1.2471*** (0.1403)
Governance Effectiveness	−0.4092* (0.2146)
Urban Population (Urbanisation)	−0.1885 (0.1191)
Crude Oil Price	−0.0963* (0.0554)
Infrastructure (Cellular Subscriptions)	0.1507*** (0.0471)
Constant	−21.7101*** (3.6667)

Note: Dependent variable is the RE generation. All variables are expressed in natural logarithm and the Driscoll-Kraay (1998) standard errors are shown in parentheses. *, **, *** indicate statistical significance at 10%, 5% and 1% level, respectively.

Giroud (2023) provided further clarification regarding the inverse relationships by asserting that investor preferences regarding fossil fuels and renewable sources are notably influenced by capital expenditures. However, due to the intermittent nature of

RE sources in developing countries, which raises concerns about their dependability, financial capital primarily facilitates the shift from sustainable to fossil fuel energy sources (Best, 2017). Domestic capital formation is also demonstrated to have a greater impact on RE generation in ASEAN compared to FDI. This is evident from the higher coefficient values, which show the relative significance of domestic investment.

As expected, there is a positive relationship between economic growth and RE production, with a high coefficient suggesting the elastic nature of RE. Moreover, it is postulated that economic expansion is the main factor influencing RE generation. The region is expected to experience a 12 percent increase in RE generation as a result of a 10 percent improvement in economic growth. According to Przychodzen and Przychodzen (2020), substantial economic growth acts as a stimulant for the production of RE, enabling it to lead the shift towards renewable sources by generating sufficient economic resources for the required investments. Furthermore, economic growth is linked to higher RE production due to the increasing demand for sustainable energy, as demonstrated by Chen et al. (2021).

Government effectiveness presents a counterintuitive relationship with RE, such that a 10 percent improvement in government effectiveness results in a significant 4 percent decline in RE generation. This study argues that despite the increase in government effectiveness, efforts made by the governments in the region to stimulate RE generation are rather insufficient, which has translated into the fall of RE generation. The International Energy Agency (2023) has recognised the insufficient regulatory and investment frameworks in the region as the cause of the slow progress in renewable power production. It is crucial for the government to effectively remove legal barriers and implement steps through various organisations to validate RE technologies and ensure the availability of resources for RE generation. In addition, market failures resulting from government monopolies in the energy industry and restrictions on private sector participation are major obstacles to the development of RE.

Meanwhile, the growth in urban population is demonstrated to be insignificant in explaining RE generation. Compared to RE, Mrabet et al. (2019) said that urbanisation is more closely contributing to non-renewables in both developed and developing markets. Conversely, there is an inverse correlation between the price of crude oil and the generation of RE. Specifically, a 10 percent increase in the price of crude oil will result in a 9 percent decrease in RE generation. Muktarov et al. (2020) stated that in the presence of high oil prices, oil-exporting nations have access to ample resources and provide subsidies to domestic users. Consequently, this leads to a rise in the consumption of conventional energy and does not incentivize producers to explore alternative energy sources. However, despite its significance, the crude oil price presents a relatively smaller influence, as indicated by its smaller coefficient. This is probably caused by the limited demand for RE in emerging nations (Salim and Rafiq, 2011).

Lastly, the viability of infrastructure, as represented by cellular subscriptions, posits a positive relationship with RE generation. Specifically, a 10 percent rise in cellular subscriptions is projected to result in a 1.5 percent increase in RE output. This indicates the positive impact of infrastructure on stimulating further RE generation. It

aligns with Song et al. (2023), who argue that investments in energy infrastructure have a substantial impact on fostering the development of renewable electricity generation in developing nations in Asia. Moreover, Ghorashi and Maranlou (2021) asserted that the advancement of crucial infrastructure, encompassing both physical and intangible components, is indispensable for the advancement of sustainable RE.

5. Conclusion

This research explores the impact of key factors on RE generation, with a specific focus on ASEAN countries. The findings have shown that two factors—economic growth (represented by GDP) and infrastructure (represented by cellular subscription)—posit a positive and significant relationship with RE generation. However, domestic capital investment, FDI, governance effectiveness, and crude oil prices have inverse relationships towards RE generation in the context of the ASEAN region. This research contributes to the existing field of study by filling that gap by pursuing the driving factors in a multi-aspect manner, considering not just the economic factors but also the governance and infrastructure aspects as well. Moreover, empirical research was conducted to explore factors that drive RE generation, specifically in the ASEAN region. In terms of practical implications, the findings of this study urge policymakers to streamline governance processes by facilitating an economic environment conducive to RE generation, along with investing in RE infrastructure. There is a need for policy amendments and creative strategies to guarantee the ASEAN countries a sustainable and resilient energy future. One of the main limitations of this research is that secondary data was employed for the empirical study. The data utilised in this research was obtained from the World Bank Databank. The second limitation is that only six ASEAN nations—Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam—were involved in this study. In the future, primary data can be collected to better understand the factors that drive policymakers, industries, and institutions to be involved in RE development. Besides the six ASEAN nations that have been included in this study, the remaining ASEAN nations—Brunei, Cambodia, Laos, and Myanmar—can be included in the future study too. Moreover, a multi-group analysis is suggested to be conducted to examine how the driving factors differ across different ASEAN countries. Finally, an increasing number of sub-categories within RE generation, such as wind, hydropower, solar, and bioenergy, are being documented. This presents a significant opportunity for future research endeavours within ASEAN. By conducting in-depth analyses of these sub-categories, researchers can significantly enhance our understanding of the dynamics of RE generation and its optimal implementation within the region.

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Notes

1 Phase II of the 2021–2025 ASEAN Plan of Action for Energy Cooperation (APAEC).

2 In ensuring the validity, the current research collected the data from relevant publicly accessible official data sources.

3 Alternative data could be sourced from the statistical departments of relevant ASEAN countries. However, acquisition may be time-consuming or incur additional charges.

4 The parameters in Equation (1) can be estimated based on least square dummy variable (LSDV) estimator and Within Group estimator where a dummy variable for each country is included in the model (Baltagi, 2008). Nevertheless, one of the disadvantages of LSDV model is that it requires large number of regressors to represent equal number of countries Verbeek (2017) and too many dummy variables will increase the issue of multicollinearity (Baltagi, 2008).

5 The cross-sectional dependence test is carried out to ascertain the contemporaneous correlation of the residuals, given the extensive time series of the data spanning over 20 years. This correlation can lead to inflated standard errors and, consequently, biased estimation (De Hoyos and Sarafidis, 2006).

6 De Hoyos and Sarafidis (2006) said that while Breusch Pagan (1980) LM test is valid for fixed N as $T \to \infty$, the Pesaran (2004) is designed for panel data models with sufficiently large T as $N \to \infty$. Even though the dataset in the current paper displays $T > N$ and would ideally employ the Breusch Pagan (1980) LM test, the test statistics may distort for finite T, a concern addressed in Pesaran (2004). Therefore, the current study utilizes both tests, taking into account their respective strengths and weaknesses.

7 Greene (2000) groupwise heteroskedasticity is preferred over the Lagrange multiplier, likelihood ratio and standard Wald test statistics due to their sensitivity to the assumption of error normality.

8 Jochmans (2019) said that the portmanteau test can be conducted in the presence of heteroskedasticity and missing data, and powerful over the conventional Lagrange Multiplier or Drukker (2003) and Wursten (2018) serial correlation tests, which may fail even under relatively mild forms of heteroskedasticity.

9 Fixed Effects or Within model explores the relationship of the variables within each ASEAN country and is preferred over Random Effects under the Generalized Least Square model in the presence of correlated residuals.

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