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EXAMINING THE IMPACT OF SUSTAINABLE ENERGY ON THE ECONOMY: PANEL EVIDENCE FROM ASEAN

Vu Minh Hieu[1+]
Tran Duc Tai[2]
Doan Dang Phi Hung[3]

[1,2,3]*Faculty of Business Administration, Van Lang University, Viet Nam.*
[1]*Email: hieu.vm@vlu.edu.vn*

(+ Corresponding author)

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ABSTRACT

Among the fast-developing economies in the Association of Southeast Asian Nations (ASEAN), a significant trend can be observed towards sustainable energy objectives. Although there is a strong trend of social and economic growth in the ASEAN region, the theoretical and empirical significance of sustainable energy is yet to be explored. This study aims to analyse the impact of sustainable energy on the economies of three countries – Indonesia, Malaysia, and Thailand – using yearly observations from the years 2000 to 2019. Several dynamics of sustainable energy are investigated as explanatory variables, while economic trends are explored through GDP growth, financial development, and patent applications. For the purposes of data analysis, descriptive statistics, correlation matrices and fixed and random effect panel models are applied. The study findings of the correlational matrix indicate that there is no higher correlation among the study variables. The results of the panel models provide evidence that carbon emissions have an adverse impact on GDP growth, while the proportion of renewable energy out of total energy positively impacts the growth dynamic. Additionally, carbon emissions adversely impact financial development in all three ASEAN economies. Lastly, electricity prices and carbon emissions are observed to have an adverse effect on patent applications. However, this study has three major limitations, as it fails to apply advanced panel regression models like GMM, only considers three economies out of the total sample of the ASEAN region, and lacks comparative analyses between countries. Future studies are highly recommended to address these limitations.

Contribution/Originality: This study contributes to the existing literature by analyzing the impact of sustainable energy on the economies of three countries – Indonesia, Malaysia, and Thailand – using yearly observations from the years 2000 to 2019.

1. INTRODUCTION AND BACKGROUND

Sustainable development is considered to be one of the major concerns of various developed and developing economies. As per the research findings of the Brundtland Commission, sustainable development is defined as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs." However, countless debates, studies, and research findings are further conceptualizing sustainable development and the usefulness thereof. The term "sustainability" has its own implications in the energy sector, when taking into account the economic, social and financial perspectives. This is because, in the current era, energy is seen as a basic human need which plays a significant role in the improvement of quality of life. The availability of energy can be considered one of the key drivers towards economic growth and economic development in any country. At present, the energy sector is the biggest contributor towards greenhouse gas emissions. This is because the energy sector depends to a significant extent on traditional energy sources, i.e., fossil fuels – coal and gas. In 2007, the electricity sector produced almost 40 percent of the carbon emission worldwide, up from 27 percent in 1971. This dramatic shift in carbon emissions is among the major threats to the natural world. It would justify the argument that, although energy plays a major role in raising the quality of life of individuals, at the same time its part in damaging natural resources, climate and the environment is crucial and cannot be ignored.

By the end of 2030, the ASEAN economies are predicted to hold the position of the 4th largest economy in the world. In addition, the population of this area is rising significantly by 10%+ to 690 million in 2020. This region is dependent on both traditional as well as renewable energy sources to meet the needs of its people. However, with the growing concerns of sustainability and the natural environment, ASEAN has set a target of ensuring that 23% of its primary energy is obtained from modern, sustainable, and renewable sources by the end of 2025, which will necessitate a dramatic change from the current trend. Figure 1 provides a breakdown of this target.

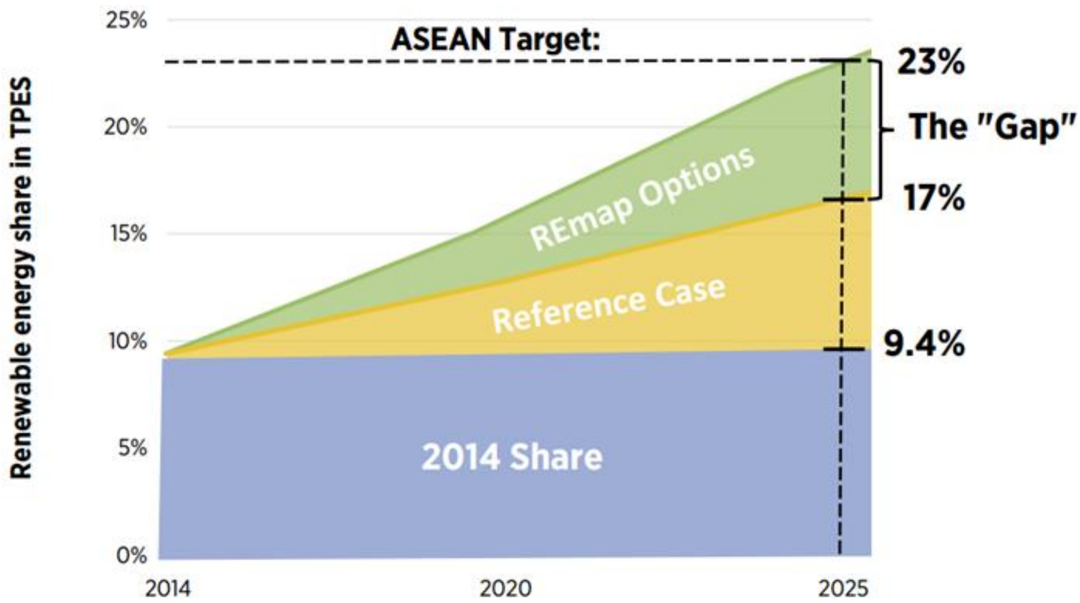

Figure-1. ASEAN target for renewable energy up to 2025.

Like other economies, ASEAN has also committed to the 3A energy objectives of accessibility, availability, and acceptability. These objectives have further dimensions, for example, affordable prices, energy services, both short-term and long-term reliability of the supply and safe levels of greenhouse emissions. Taken together, the 3A energy objectives can be defined as sustainability (Vithayasrichareon, MacGill, & Nakawiro, 2012). Regarding these objectives as dimensions of sustainable energy, this study analyzes their relationship with the economic dynamics of three ASEAN countries. The rest of the paper is structured as follows. Section two presents a review of the literature, while section three provides a description of the variables and the research methods. Section four covers the results and discussion, and section five provides theoretical considerations about the conclusions, limitations, and possible future directions.

2. LITERATURE REVIEW

To move towards sustainable development, sustainable energy development has become a policy objective in many countries. There is a growing need to develop a robust and comprehensive set of indicators which can track the progression towards sustainable energy development. This idea is expressed by Gunnarsdóttir, Davidsdottir, Worrell, and Sigurgeirsdóttir (2020) who focused on the assessment of those factors which can reasonably be supposed to contribute towards energy sustainability. A total of 57 indicator sets were studied. They concluded that the Energy Indicators for Sustainable Development could be considered a promising initial basket of indicators for further refinement. Hosseini (2020) considered the global development towards renewable and sustainable energy during the time of COVID-19. He claims that the pandemic has not only had a negative impact on renewable energy sources but also shows its impact on the various manufacturing and supply chain activities. For this reason, he argues, a significant revision of energy policies is required in order to restructure the entire process.

Wang, Morabito, Payne, and Robinson (2020) analyzed the trends in sustainable energy through the adoption of various technologies. They claim that an increase in the adoption of sustainable energy and technology is linked with changing organizational behavior. Guðlaugsson, Fazeli, Gunnarsdóttir, Davidsdottir, and Stefansson (2020) express their view that sustainable energy is a challenging process which involves various stakeholders with differing opinions. Their study was conducted in Iceland and data was collected using a questionnaire. The study findings demonstrate that, in Iceland, decision makers are primarily responsible for the development of energy, as well as dealing with complex challenges.

In addition to the above discussion of the current trends in sustainable energy, some researchers have also explored its relationship with different economic dynamics. For example, Pao and Fu (2013) investigated the contribution of renewable and non-renewable energy to economic growth in Brazil between 1980 and 2010. Specifically, their study considered four major types of energy consumption – non-hydroelectric, total renewable energy consumption, renewable energy consumption and total primary energy consumption. Using a cointegration test, the long run relationships between the study variables were tested and examined. Their findings using a vector correction model imply the existence of a bidirectional causality between economic growth and total renewable energy consumption, but only a unidirectional causality from economic growth to non-renewable energy consumption. Charfeddine and Kahia (2019) explored the association between sustainable energy from renewable sources, financial development and economic growth in the MENA region by using a panel vector autoregressive approach. They applied an impulse response function tool to analyze the impact of renewable energy and financial development on carbon emissions and economic growth. Their study findings confirm that sustainable energy from renewable sources and financial development have a good explanatory power in predicting carbon emissions and economic growth.

Khoshnevis Yazdi and Ghorchi Beygi (2018) investigated the connections between financial development, economic growth, energy consumption, trade openness and CO_2 emissions using a pooled mean group approach. The data for the key variables consisted of yearly observations of 25 African economies between the years of 1985 and 2015. The study findings confirm the existence of a bidirectional causality among the variables economic growth, financial development and carbon emissions. In addition, a number of theoretical and empirical studies have investigated various dimensions of sustainable energy, economic growth and financial development (Amen et al., 2020; Bekhet & Othman, 2018; Chien, Kamran, Albashar, & Iqbal, 2020; Chu, Cui, & Liu, 2017; Hussain, Arif, & Aslam, 2017; Kamran, Haseeb, Nguyen, & Nguyen, 2020; Menegaki & Tugcu, 2017; Møller, Jensen, Akiba, & Li, 2017). Although the association between sustainable energy dynamics and economic factors has been widely observed in the literature, there still exist various gaps which require further investigation. Specifically, with regards to the ASEAN economies, few studies have yet been conducted to explore the dynamic relationship between sustainable energy and the economy. The present study, therefore, is intended to fill this gap in the literature by using the sustainable energy dynamics as the main explanatory variables, whereas the trends in economic growth, financial development, and patent applications fill the role of the main dependent variables of the study.

Table-1. Description of the study variables.

Variable	Variable Type	Definition	Measurement
Gross Domestic Product growth rate	Dependent Variable	The GDP growth rate refers to the percentage change from one year to the next in the value of total domestic production of goods and services	Measured in terms of annual change as expressed through a percentage
Financial development	Dependent Variable	Financial development refers to the generation of relevant information and possibilities through which there is a greater chance of capital investment, higher levels of governance, and development of financial markets and related institutions in an economy.	Measured in terms of total amount of market capitalization of the listed companies in a given time period
Patent applications	Dependent Variable	Worldwide patent applications filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention – a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years	Total number of patents applied for in a given time period
Time required to get electricity (days)	Independent Variable	This indicates the total number of days required for an individual in a local community to gain access to electricity	Total number of days
Electricity prices	Independent Variable	Electricity prices refer to the amount on average paid by an individual to utilize this facility.	Measured in USD
Average electricity expenditure	Independent Variable	The total amount spent on electricity during a given time period	Measured in USD
Electricity consumption per capita	Independent variable	This indicates the per capita electricity consumption in a given economy during a given time period	Measured in USD
Carbon dioxide emissions per capita	Independent Variable	The amount of carbon dioxide emitted into the natural environment per capita during a given period	Value per capita
Share of renewable energy	Independent variable	This indicates the amount of renewable energy as a percentage of the total energy produced in an economy over the course of a year	% of total energy
Carbon dioxide emission intensity		This shows the emission rate of a given pollutant relative to the intensity of a specific activity during a given time period	Metric tons per capita

3. RESEARCH METHODS

This study makes use of secondary data from a variety of available resources including the World Bank Group, World Development Indicators, the annual progress reports of the targeted economies, and other databases available online that offer suitable data for the study variables. This study is quantitative in nature, focusing on both time series and cross-sectional units of observation. The time period explored in the present study is from 2000 to 2018, with yearly observations for the three cross sectional regions: Malaysia, Indonesia and Thailand. Due to the combination of time series and cross-sectional units of observation, the study data can be considered panel in nature, and a panel regression model might therefore be applied. Various panel models are currently prescribed in the literature, however, two of these are among the most cited: fixed effect and random effect. To understand the relative equations of both fixed and random effect regression models, the following general regression equation is considered.

$$y = bo + b_1x_1 + b_2x_2 + \ldots + b_nx_n + U \qquad (1)$$

In Equation 1 above, various symbols are used to represent the relationship between the dependent and independent variables. Firstly, y represents the main dependent variable, which is determined by x_1, x_2 through x_n. This means that every change in the dependent variable y is controlled by the set of explanatory variables in the regression equation. In addition, the symbols b_1, b_2 through b_n indicate a change in the value of the main dependent variable due to independent variables in a given situation. The transformation of this general Equation 1 into a more specific format is presented as Equation 2.

$$y(\text{GDP growth}) = b0 + b_1(TRE) + b_2(EP) + b_3(AEA) + b_4(ECPC) + b_5(CO_2EMPCAP) + b_6(SHAREOFRE) + b_7(CO_2INTENS) + U \quad (2)$$

In the above Equation 2, the main dependent variable is GDP growth, which is predicted through seven explanatory variables, the effects of which are covered by b_1 through b_7, respectively. Additionally, there are two further dependent variables: financial development and patent applications. Equation 3, and Equation 4 show the relationship between these dependent variables and the independent variables of the study.

$$y(\text{Financial Development}) = b0 + b_1(TRE) + b_2(EP) + b_3(AEA) + b_4(ECPC) + b_5(CO_2EMPCAP) + b_6(SHAREOFRE) + b_7(CO_2INTENS) + U \quad (3)$$

$$y(\text{Patent Applications}) = b0 + b_1(TRE) + b_2(EP) + b_3(AEA) + b_4(ECPC) + b_5(CO_2EMPCAP) + b_6(SHAREOFRE) + b_7(CO_2INTENS) + U \quad (4)$$

Having determined the general relationship between the variables in the study, the next step is to consider the panel regression equations through which the empirical association between these variables can be tested and subsequently presented. As mentioned previously, this study has applied both the fixed and random effect model, resulting in the following equations:

$$y_{it}(\text{GDP growth}) = b0 + b_1(TRE_{it}) + b_2(EP_{it}) + b_3(AEA_{it}) + b_4(ECPC_{it}) + b_5(CO_2EMPCAP_{it}) + b_6(SHAREOFRE_{it}) + b_7(CO_2INTENS_{it}) + \alpha i + u_{it} \quad (5)$$

Equation 5, above, shows the fixed effect model for the first dependent variable – GDP growth – as expressed by the study's set of explanatory variables. The results of Equation 5 are shown in Table 4, model 1. After examining the relationship between the study variables through the fixed effect regression equation, the random effect model was applied, using Equation 6.

$$y_{it}(\text{GDP growth}) = b0 + b_1(TRE_{it}) + b_2(EP_{it}) + b_3(AEA_{it}) + b_4(ECPC_{it}) + b_5(CO_2EMPCAP_{it}) + b_6(SHAREOFRE_{it}) + b_7(CO_2INTENS_{it}) + \alpha i + u_{it} + \varepsilon_{it} \quad (6)$$

The findings of Equation 6, above, are presented in Table 4, model 2. Additionally, for the second dependent variable of the study, financial development, the following fixed and random effect model equations were developed, the results of which are presented in Table 5.

$$y_{it}(\text{Financial Development}) = b0 + b_1(TRE_{it}) + b_2(EP_{it}) + b_3(AEA_{it}) + b_4(ECPC_{it}) + b_5(CO_2EMPCAP_{it}) + b_6(SHAREOFRE_{it}) + b_7(CO_2INTENS_{it}) + \alpha i + u_{it} \quad (7)$$

$$y_{it}(\text{Financial Development}) = b0 + b_1(TRE_{it}) + b_2(EP_{it}) + b_3(AEA_{it}) + b_4(ECPC_{it}) + b_5(CO_2EMPCAP_{it}) + b_6(SHAREOFRE_{it}) + b_7(CO_2INTENS_{it}) + \alpha i + u_{it} + \varepsilon_{it} \quad (8)$$

Lastly, the third dependent variable was patent application, for which the relationship between the variables was tested using the following fixed and random effect equations.

$$y_{it}(\text{Patent Applications}) = b0 + b_1(TRE_{it}) + b_2(EP_{it}) + b_3(AEA_{it}) + b_4(ECPC_{it}) + b_5(CO_2EMPCAP_{it}) + b_6(SHAREOFRE_{it}) + b_7(CO_2INTENS_{it}) + \alpha i + u_{it} \quad (9)$$

$$y_{it}(\text{Patent Applications}) = b0 + b_1(TRE_{it}) + b_2(EP_{it}) + b_3(AEA_{it}) + b_4(ECPC_{it}) + b_5(CO_2EMPCAP_{it}) + b_6(SHAREOFRE_{it}) + b_7(CO_2INTENS_{it}) + \alpha i + u_{it} + \varepsilon_{it} \quad (10)$$

4. RESULTS AND DISCUSSION

The descriptive results are shown in Table 2, using the calculated mean, standard deviation, and other measures. On average, the level of GDP growth during the study period for all three economies was 0.547 with a standard deviation of 0.263. This indicates that economic growth took place in Malaysia, Indonesia, and Thailand. The mean value for time required to electricity, or TRE, shows a value of 10.52, which means that on average people waited 10.52 days to get electricity. The standard deviation for this variable is 0.282.

Table-2. Descriptive statistics.

Variables	Obs	Mean	Std. Dev.	Min	Max	p1	p99	Skew.	Kurt.
gdpgrowth	57	0.543	0.263	0.034	0.999	0.034	0.999	-0.08	2.066
findevolp	57	0.457	0.288	0.041	0.991	0.041	0.991	0.115	1.781
pa	57	0.421	0.273	0.004	0.99	0.004	0.99	0.451	2.291
tre	57	10.52	0.282	8	22	0.241	10.22	0.051	1.913
ep	57	0.519	0.307	0.012	0.994	0.012	0.994	-0.037	1.653
aea	57	0.504	0.256	0.01	0.965	0.01	0.965	-0.2	1.818
ecpc	57	0.509	0.303	0.008	0.997	0.008	0.997	-0.052	1.658
co2empcap	57	0.495	0.272	0.007	0.975	0.007	0.975	0.071	1.922
shareofre	57	0.519	0.303	0.016	0.996	0.016	0.996	-0.185	1.755
co2intens	57	0.462	0.277	0.022	0.995	0.022	0.995	0.063	1.801

Table 3 reflects the correlation matrix of the variables, along with the levels of significance. It can be observed that, for the GDP growth, there is no higher trend of correlation between it and the rest of the studied variables. Similarly, although financial development demonstrates a positive and significant correlation with the TRE, no significant association can be observed with the other variables. Additionally, the number of patent applications is shown to be negatively associated with the TRE and ECPC; however, these correlations are found to be insignificant. Furthermore, the level of interdependency between TRE and ECPC is 0.450, which indicates a moderate but highly significant relationship between the two (i.e., p-value = 0.000). However, the association between TRE and CO_2EMPCAP is -0.298, which indicates the presence of a negative but weak association, significant at 0.05. Aside from these, no significant correlations have been demonstrated between the rest of the study variables, as shown in Table 3.

To test the impact of sustainable energy on the economy, this study utilized fixed effect and random effect panel models. Three major dependent variables were under consideration while analyzing the economic trends. Table 3 shows the empirical results for the first dependent variable, GDP growth, in the targeted economies. Comparative analysis is provided through the relative coefficient of each of the explanatory variables and their standard deviation from the coefficients. The study results predict that TRE positively but insignificantly impacts on GDP growth in the selected economies, using the fixed effect model. However, using the random effect model, the impact of TRE on GDP growth is positively significant at 0.1 (i.e., beta = 0.282, standard error = 0.157). This would indicate that higher TRE leads to higher economic growth in all the panel economies.

In addition, the impact on GDP growth of EP, AEA and ECPC is found to be insignificant, which means that these factors show no evidence of contributing to the change in the value of economic growth of the three panel countries. However, the impact of CO_2EMPCAP on GDP growth is negative and significant at 0.01, in both the fixed effect and random effect models (Model 1, beta = -0.170, standard error = 0.046, Model 2, beta = -0.370, standard error = 0.033). This means that higher carbon emissions are found to have an adverse influence on economic growth in all three ASEAN region countries. This would justify the argument that for every rise in the value of carbon dioxide emissions, lower economic growth is observed and vice versa. Furthermore, the proportion of renewable energy in the total energy value of all three economies is observed to be positively and significantly linked to economic growth. This means that greater economic growth is directly associated with a higher percentage of renewable energy, when compared to the total value of energy from all sources. More specifically both the coefficients are significant at 0.01 due to lower standard error, higher t score and lower p value. Aside from the variables mentioned, the impact of the rest of the explanatory variables on GDP growth is observed to be insignificant when considering the full sample.

Table-3. Pairwise correlations.

Variables	(GDPGROWTH)	(FINDEVOLP)	(PA)	(TRE)	(EP)	(AEA)	(ECPC)	(CO2EMPCAP)	(SHAREOFRE)	(CO2INTENS)
GDPGROWTH	1.000									
FINDEVOLP	-0.029	1.000								
PA	-0.045	-0.034	1.000							
TRE	0.113	0.226*	-0.176	1.000						
EP	-0.054	-0.049	-0.027	0.012	1.000					
AEA	0.050	0.123	0.052	-0.093	-0.001	1.000				
ECPC	-0.097	0.151	-0.127	0.450***	0.023	0.077	1.000			
CO2EMPCAP	0.078	-0.007	0.133	-0.298**	0.153	0.087	0.013	1.000		
SHAREOFRE	-0.066	-0.032	0.002	0.080	-0.214	0.036	0.172	-0.111	1.000	
CO2INTENS	-0.066	-0.068	-0.077	0.234*	-0.059	0.029	0.119	0.018	0.056	1.000

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Finally, the findings in Table 4 for both fixed and random effect models were compared using a Hausman test in Stata-13. The following null and alternative hypotheses were tested.

H_0: The difference in coefficients is not systematic / the random effect model is more appropriate.

H_1: The difference in coefficients is not systematic / the fixed effect model is more appropriate.

Based on the findings reported in Table 3, the value of Prob>chi2 is 0.8421, which indicates an insignificant outcome; hence H_0 is supported, favoring the random effect model.

Table-4. Impact of sustainable energy on the economy: GDP growth.

Variables	(Fixed Effect) Model 1: GDP Growth	(Random Effect) Model 2: GDP Growth
TRE	0.263	0.285*
	(0.159)	(0.157)
EP	-0.0502	-0.0840
	(0.122)	(0.121)
AEA	8.66e-05	0.0875
	(0.151)	(0.142)
ECPC	-0.162	-0.189
	(0.143)	(0.138)
CO2EMPCAP	-0.170***	-0.370***
	(0.046)	(0.033)
SHAREOFRE	0.799***	0.440***
	(0.115)	(0.124)
CO2INTENS	-0.125	-0.114
	(0.134)	(0.134)
Constant	0.532***	0.484***
	(0.166)	(0.165)
Observations	57	57
R-squared	0.284	0.214
Number of Country IDs.	3	3
Hausman's Test Results chi2 = 3.43 Prob>chi2 = 0.8421		

Note: Dependent Variable: GDP growth, TRE: Time required to get electricity (days), EP; electricity prices, AEA: average expenditure on electricity, ECPC: electricity consumption per cap, CO2EMPCAP: carbon dioxide emissions per capita, SHAREOFRE: share of renewable energy, CO2INTENS: carbon dioxide intensity, S.E in parentheses, *** indicates p<0.01, ** indicates p<0.05, and * indicates p<0.1.

The second main dependent variable of the study is the financial development during the study period, for which the findings are displayed in Table 5. The results demonstrate that TRE positively but insignificantly impacts the financial development in the three economies; while using the random effect model, the impact of TRE on financial development is positively significant at 0.1 (i.e., beta = .290, standard error, 0.171). This indicates that for every single unit increase in TRE, there is an increase of 0.290 in the value of the financial development for all three panel economies. However, the impact of EP on financial development under both the fixed and random effect models is negative, and significant only under the fixed effect model. This means that higher EP lead to decreased financial development in all three panel countries included in the study. Additionally, the impact of AEA and ECPC are found to be positive but insignificant when considering the full sample results. This indicates that neither AEA nor ECPC have a significant impact on the trends in the value of financial development over the course of the study period. Further, Table 5 reveals that CO_2EMPCAP is negatively and significantly associated with the financial development both under the fixed effect and random effect models. More specifically, the coefficient for change in financial development under the fixed effect model is -0.721 and using the random effect model -0.763. This means that in all three ASEAN economies higher carbon emissions lead to decreased financial development and vice versa. The rest of the explanatory variables display an insignificant impact on the value of financial development using both fixed and random effect models. Furthermore, the results of the Hausman test indicate that random effect coefficients are more appropriate for analyzing the trends in financial development.

Table-5. Impact of sustainable energy on the economy: financial development.

	Fixed Effect	Random Effect
Variables	**Model 1: Financial Development**	**Model 2: Financial Development**
TRE	0.284	0.290*
	(0.178)	(0.171)
EP	-0.807***	-0.720
	(0.137)	(0.132)
AEA	0.160	0.164
	(0.169)	(0.154)
ECPC	0.0469	0.0400
	(0.160)	(0.149)
CO2EMPCAP	-0.721***	-0.763***
	(0.164)	(0.156)
SHAREOFRE	-0.0704	-0.0661
	(0.140)	(0.134)
CO2INTENS	-0.151	-0.152
	(0.150)	(0.146)
Constant	0.320*	0.315*
	(0.185)	(0.179)
Observations	57	57
R-squared	0.102	0.254
Number of Country IDs.	3	3
Hausman's Test Results chi2 = 6.214 Prob>chi2 = 0.421		

Note: Dependent Variable: Financial Development, TRE: Time required to get electricity (days), EP; electricity prices, AEA: average expenditure on electricity, ECPC: electricity consumption per cap, CO2EMPCAP: carbon dioxide emissions per capita, SHAREOFRE: share of renewable energy, CO2INTENS: carbon dioxide intensity, S.E in parentheses, *** indicates $p<0.01$, ** indicates $p<0.05$, and * indicates $p<0.1$.

Table-6. Impact of sustainable energy on the economy: patent applications.

	(1)	(2)
VARIABLES	Model 1	Model 2
TRE	-0.0958	-0.0840
	(0.170)	(0.167)
EP	-0.660***	-0.334**
	(0.131)	(0.129)
AEA	0.120	0.0442
	(0.162)	(0.150)
ECPC	-0.0636	-0.0819
	(0.153)	(0.146)
CO2EMPCAP	-0.827***	0.115
	(0.157)	(0.152)
SHAREOFRE	0.0395	0.0276
	(0.134)	(0.131)
CO2INTENS	-0.0304	-0.0527
	(0.144)	(0.142)
Constant	0.429**	0.454***
	(0.177)	(0.175)
Observations	57	57
R-squared	0.154	0.127
Number of cid	3	3
Hausman's Test Results chi2 = 1.77 Prob>chi2 = 0.971		

Note: Dependent Variable: Patent applications, TRE: Time required to get electricity (days), EP; electricity prices, AEA: average expenditure on electricity, ECPC: electricity consumption per cap, CO2EMPCAP: carbon dioxide emissions per capita, SHAREOFRE: share of renewable energy, CO2INTENS: carbon dioxide intensity, S.E in parentheses, *** indicates $p<0.01$, ** indicates $p<0.05$, and * indicates $p<0.1$.

Finally, the third dependent variable is patent application, for which the impact of all the explanatory variables in the three countries is recorded in Table 6. The results of the study show that TR has no significant impact on patent applications, under either the fixed or random effect models. On the other hand, EP has a negative and significant impact on patent applications, as demonstrated by the coefficient of -0.660 and standard error of 0.131. This indicates that higher EP lead to a lower number of patent applications and vice versa. Similarly, a raise in EP causes a change of -0334 in patent applications for the studied economies overall. However, the impact of AEA and ECPC is insignificant, meaning that there is no evidence that they have an influence on the number of patent applications. In addition, in line with the research findings in various other studies, higher carbon emissions are a problem for both the economy and the natural environment of any country. This significant impact can be observed in the economies of all three studied countries in terms of the number of patent applications, which are negatively affected by the variable CO_2EMPCAP. This means that every single unit increase in CO_2EMPCAP has an impact of -0.827 on patent applications, when considering the full sample of the study. Aside from this, the rest of the study variables are insignificant in their impact on patent applications. The value of chi-square for Table 6 using the Hausman test is insignificant, which implies that the random effect model is appropriate for measuring the impact of sustainable energy dynamics on patent applications.

5. CONCLUSION, LIMITATIONS, AND FUTURE DIRECTIONS

In developing economies like ASEAN, there is a growing concern for the use of sustainable energy and its impact on the economy and various financial dynamics. Energy sustainability objectives have various dimensions in terms of affordable prices, energy services, short-term reliability of the supply, long-term continuity of the supply and finally the safe levels of greenhouse gas emissions. Although the theoretical discussion of these dimensions is addressed to a reasonable extent in the existing literature, yet a large empirical gap still remains, in the analysis of the impact of these sustainable energy dimensions on the economy. The key concern of this study is to examine the relationship between the dimensions of sustainable energy and their impact on the economy of three ASEAN countries: Malaysia, Indonesia and Thailand. To analyze this relationship, fixed effect and random effect panel data models were applied to a balanced pool of data, consisting of yearly observations covering the study period of 2000 to 2018. The study findings proved that the economy in terms of GDP growth is negatively impacted by carbon emissions per capita, whereas the share of renewable energy out of the total energy has a positive impact on GDP growth in all three sampled economies. In terms of the second dependent variable – financial development – a significant and negative impact from carbon emission per capita has been observed. Furthermore, energy prices are also negatively and significantly linked with financial development, providing evidence that higher energy prices lead to decreased financial development. Lastly, the panel model findings confirm that energy prices and carbon emissions have a negative impact on the number of patent applications. These results will be of great support to the industry experts, researchers, and various stakeholders who are interested in examining the relationship between sustainable energy and economic dynamics, specifically in ASEAN countries. Government officials and other environmental departments are highly encouraged to review the theoretical and empirical discussions as provided in the present study. Aside from the above conclusions, the present study also displays various limitations :

- First, this study only considers three regional economies of the ASEAN region, which limits its applicability to Thailand, Indonesia and Malaysia.
- Secondly, this study applied the traditional panel regression approaches of fixed and random effect models with no further consideration of advanced techniques such as generalized methods of moments (GMM). Furthermore, no robust checks were applied, which also highlights the methodological limitations.
- Thirdly, this research is lacking a comparison between countries, which means that its implications and theoretical significance are limited.

Future studies would be encouraged to focus on the key gaps, such as the inclusion of all the ASEAN countries, the application of advanced panel models, robust checking of all empirical findings, and finally the comparison between countries. Consideration of all these points will lead to broader applicability and theoretical and empirical thoroughness, along with practical policy suggestions.

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