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-RESEARCH ARTICLE-

EXAMINING THE SUSTAINABLE ENERGY AND CARBON EMISSION ON THE ECONOMY: PANEL EVIDENCE FROM ASEAN

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─Abstract─

Currently, the role of electricity cost and associated carbon emission has become a global issue that affects financial development and economic growth. Thus, the present article analyses the role of energy cost and carbon emission on the economy of Indonesia, Malaysia, and Thailand from 2000 to 2018. For data analysis, panel models such as fixed and random effect are applied to examine the association between the constructs. The results show that there is an adverse impact of carbon emissions on GDP growth, while the share of renewable energy in total energy positively impacts the growth dynamic. Additionally, carbon emissions have a negative impact on financial development in all three ASEAN economies. Finally, electricity prices along with carbon emissions are observed as negative determinants of patent applications. Furthermore, the present study has the potential to guide upcoming researchers about the future research on this area and can also offer guidance for policymakers in developing policies related to electricity prices and carbon emission and their role in economic and financial growth.

Keywords: Energy prices, financial development, carbon emission, ASEAN, GDP growth,

JEL Classifications: Q56, F43, B26

1. INTRODUCTION AND BACKGROUND

Sustainable development is seen as one of the major concerns for various developed and developing economies. As per the research findings of the Brundtland Commission, sustainable development is defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Güney, 2019).

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Countless debates, research work, and empirical findings help provide a conceptualization of sustainable development and its usefulness. Among other sectors, the implication of the term "sustainability" has its economic, social, and financial dimensions in the context of the energy sector as well. The reason is that energy is a basic human need in the current era with a major role in the improvement of quality of life (Rauf et al., 2018). The availability of energy is to be considered as among one of the key drivers of economic growth and development in any country. At present, the energy sector is identified as the biggest contributor to greenhouse gas emissions. This is because the energy sector is significantly dependent on traditional sources like fossil fuels, coal, and gas (Østergaard et al., 2020). Over the last decade, it has been found that the electricity sector is producing almost 40 per cent of the carbon emission in 2007 which was 27 per cent during 1971. This dramatic shift in the carbon emission towards the natural climate is a major threat to sustainable development. This leads us to the dilemma that although energy is playing a key role in improving the quality of life of individuals, at the same time, its role in damaging natural resources, climate and environment is a very crucial aspect that cannot be ignored (Kılkış et al., 2018).

The ASEAN economies are projected to become the 4th largest economy in the world by the end of 2030 (Kirikkaleli et al., 2021). In addition, there is a significant increase in its population which will rise by 10%+ to 690 million by 2020. This region is significantly dependent upon traditional as well as renewable energy sources to meet the needs of its population (Crumpton et al., 2021). However, with the growing concern for environmental protection and sustainable development, ASEAN has set a target of securing a portion of 23% of its primary energy from modern, sustainable, and renewable sources, which shows a dramatic change in the contemporary trend by the end of 2025.

Figure 1 provides an overview of this target.

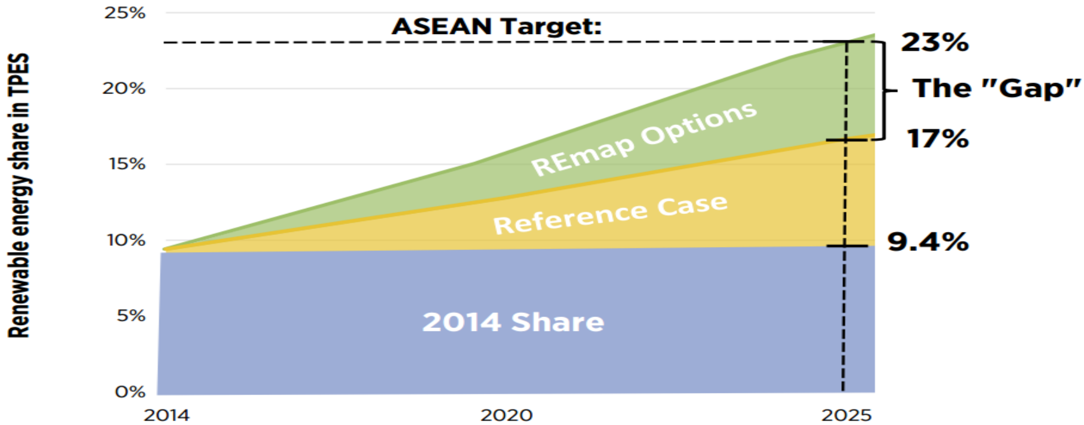

Figure 1. ASEAN target for renewable energy till 2025

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Like any other economies, ASEAN has also decided on 3A's energy objectives, that is, accessibility, availability, and acceptability. Furthermore, these objectives have further dimensions, for example, affordable prices, energy services, both short-term and long-term reliability of the supply and safety greenhouse emissions. The frameworks proposed by the 3A's is established under existing literature on sustainability (Vithayasrichareon et al., 2012). Considering these objectives as sustainable energy dimensions, this study has analyzed their relationship with economic dynamics in the context of three ASEAN (Mahajan et al., 2021).

The three ASEAN countries understudy, that is, Malaysia, Indonesia, and Thailand, are all emerging economies. An increase in economic activities enhances the consumption of energy sources and the need for the invention of new products and processes (Chang et al., 2021). The increasing use of energy has been identified as a major source of environmental pollution, and an increase in the total costs and the invention of new products and processes have certain impacts on the environment, society, and economic growth. In such a situation, achieving sustainable economic development of countries is a daunting task (Harper, 2021). Hence, there is a dire need to adopt measures to control environmental pollution, improve public well-being, improve effective patent management, enhance financial development, and steer economic growth. Through this study, the author aims to help identify what these measures should be. The aim of the study is to analyze the impacts of total energy consisting of electricity and renewable energy and carbon emission on financial development, economic growth, and patent application. The current study helps overcome existing gaps in the literature with a significant contribution to the study. First, this study establishes a criterion for improvement in three key factors like financial development, economic growth, and patent application. Second, past studies have discussed the electricity & renewable energy and carbon emission separately while analyzing a given economy, which makes this a pioneer study to study with sustainable energy, including electricity and renewable energy and carbon emission as the constructs of financial development, economic growth, and patent application within a single research framework. Thirdly, most researchers and scholars have analyzed electricity expenses and consumption but paid little attention to electricity prices. Therefore, our study, which incorporates an analysis of electricity prices along with the examination of electricity expenses and consumption, is a significant contribution to literature. Fourth, it is one of the first studies in the literature to address the impacts of sustainable energy and carbon emission on the patent application in the selected ASEAN countries.

The rest of the paper is structured as follows. Section two provides a literature review to help justify and substantiate the current study views about the relationship of total energy, including electricity prices, expenses, and consumption, as renewable energy consumption, and carbon emissions with financial development, economic growth, and patent application. Whereas the Section three deals with the description of the variables, their validity, and the analysis of the nexus among them. Following this, section four and five cover research results and discussion, whereas section six identifies study conclusions, limitations, and implications for future research on the subject.

2. LITERATURE REVIEW

For sustainable development, sustainable energy development has become a multinational policy objective. There is a growing need to develop a robust and comprehensive set of indicators that can perform a positive role in sustainable energy development. This idea is reasonably expressed by Gunnarsdottir et al. (2020), who have focused on the assessment of those factors that can reasonably contribute towards sustainable energy. A total of 57 indicators were under observation. They finally claim that energy indicators for sustainable development could be considered as an initial basket of indicators for the upcoming refinement. Hosseini (2020), has previously considered the paradigm shift of global development towards renewable and sustainable energy during the time of COVID-19. He claims that this pandemic has not only struck the renewable energy sources but has also had an impact on various manufacturing and supply chain activities as well. For this reason, a significant revision for the energy policies to restructure the entire process is needed. A study presented by Ntanos et al. (2018), focuses on sustainable and renewable energy consumption for achieving financial development and economic growth indicated by GDP per capita for 25 European countries. Authors consider datasets concerning European nations' data for the period of 2007-2016. For study analysis, descriptive statistics, cluster analysis, and autoregressive distributed lag (ARDL), are applied. The study shows that the consumption of renewable energy ensures the quality of resources in abundance, provides a clean work environment, and fosters skilled human resources. This leads the country towards effective financial management and fast economic growth.

In addition, Wang et al. (2020), analyze the trends in sustainable energy through technological adoption. They claim that an increase in sustainable energy and technology adoption is reasonably linked with changing organizational behavior. Guðlaugsson et al. (2020), have expressed their view about sustainable energy as a challenging process that involves various stakeholders who have differing opinions. They have based their study in the region of Iceland and data is collected through questionnaire. The study findings have reasonably expressed that decision makers in the region of Iceland are primarily responsible for the development of energy along with the dealing of complex challenges. Adding to the above discussion about the contemporary trend in sustainable energy, some authors have also explored its relationship with different economic dynamics. For example, Pao et al. (2013) aim to explore the role of renewable and non-renewable energy in the economic growth in Brazil during time of 1980 to 2010. More specifically, their study has considered four major types of energy consumption which are non-hydroelectric, total renewable energy consumption, renewable energy consumption and total primary energy consumption as well. Through the co-integration test, the long-run relationship between the study variables was tested and examined. Furthermore, the findings through vector correction model imply that there is a bidirectional causality between the economic growth and total renewable energy consumption, however, there is a unidirectional causality from the title of economic growth to non-renewable energy consumption. Charfeddine et al. (2019), have explored the association between sustainable energy through renewable sources, financial development, and economic growth in the MENA region through panel vector autoregressive approach. They have applied impulse response function tools to analyze the impact of renewable energy and financial development on carbon emissions and economic growth. The study findings confirm that sustainable energy sources in terms of renewable energy and financial development have good explanatory power to predict carbon emission and economic growth. Khoshnevis Yazdi et al. (2018), considers the association between financial development, economic growth, energy consumption, and trade openness and CO2 emission through pooled mean group approach. The data for the key variables is collected for 25 African economies during the time of 1985 to 2015 with yearly observations. The study findings confirm that there is a bidirectional causality among the variables like economic growth, financial development, and carbon emission as well. In-depth research by Mahlia et al. (2020), analyzes the role of sustainable and renewable energy in getting patents. For this research, 1660 patents concerned with biodiesel production were reviewed. These patents were published from January 1999 to July 2018 and were recalled from the Derwent Innovation patent database. Biodiesel is an example of renewable energy generated from animal fats and vegetable oils. As compared with non-renewable energy like fossil fuels, it has the capacity to reduce environmental pressures and help promote sustainable development. Thus, the concerned authorities feel positive about the production of biodiesel and grant patent application approval. Research by Shubbak (2019), shows that even though fossil fuel consumption and climate change have a number of adverse impacts, renewable energy like solar photovoltaics (PV) is identified as a sustainable and clean alternative. Through a huge number of scientific articles and patents, PV technologies have been invented and have progressively evolved into a significant subject of research and development. To achieve the study results, organizational, geographical, and technical trends were analyzed with the help of a review of the most effective inventions over the past six decades. The analysis reveals that 95% of the PV patent applications were sent by inventors from nations of Japan, Korea, China, the USA, Taiwan, Germany, and France. A study conducted by ---, analyzes the influences of carbon emission and energy management on a patent application. The study shows that carbon emissions which are the outcomes of consumption of energy resources, chemicals, or production of harmful wastes, which are expected to be caused by any invention or use of something new, can discourage the patent applications. In contrast, the effective management of energy sources could be a solution to carbon emission and patent application. Hence, while carbon emission has a negative, sustainable energy consumption has a positive association with the patent application.

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Moreover, there are a number of theoretical and empirical studies which explore sustainable energy through various dimensions like economic growth and financial development (Amen et al., 2021; Bekhet et al., 2018; Chien et al., 2021; Chu et al., 2017; Hussain et al., 2017; Menegaki et al., 2017; Møller et al., 2017). Although the association between sustainable energy dynamics and economic factors is widely mentioned in the literature, = various gaps are still discernible which must be addressed in the future. Specifically, for the ASEAN economies, additional research is needed to explore the dynamic relationship between sustainable energy and the economy. Therefore, the present study is conducted to fill this literature gap while using the sustainable energy dynamics as main explanatory variables, whereas the trends in economic growth, financial development, and patent applications are identified as the main dependent variables of the study. The descriptions of study variables are provided in Table 1.

3. RESEARCH METHODS

This study uses secondary data from various available resources, including World Bank Group, World Development Indicators, annual progress reports of the targeted economies, and other online available databases which contain data pertaining to the study variables. For this purpose, this study is quantitative in nature, focusing on both time series and cross-sectional units of observations. The time period of the present study considers 2000 to 2018 with yearly observations for the three cross-sectional regions named Malaysia, Indonesia, and Thailand. Due to the presence of time series and cross-sectional unit of observations, the study data is said to be a panel in nature and therefore, panel regression models are under consideration. Various panel models are prescribed in the present literature; however, two of these are among the most cited ones, which are fixed effect and random effect. To understand the relative equations of both fixed and random effect regression models, the following general regression equation is under consideration

$$Y = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \dot{\varepsilon} \quad (1)$$

In the above equation 1, various symbols are presented to define the relationship between the dependent and independent variables. Firstly, the title of y shows the main dependent variable, which is determined by the X_1, X_2 up to X_n. This means that every change in the Y is primarily directed by the set of the explanatory variables in the regression equation. In addition, the symbols like β_1, β_2 till β_n indicates the change in the value of the main dependent variable due to independent variables in each situation. Turning this general equation 1 into a more specific format can be presented with the help of Equation 2.

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Table 1. Description of the Study Variables

Name of the Variable	**Key Title**	**Definition**	**Measurement**
Gross Domestic Product, Growth Rate	Dependent Variable	The title of GDP growth rate specifies the percentage change from one year to another year in the value of total domestic production of goods and services	Measured in terms of annual change as expressed through percentage
Financial Development	Dependent Variable	Financial development specifies the generation of relevant information and possibilities through which there is more chance of capital investment, a higher governance mechanism, and finally, the development of financial markets and related institutions in any economy.	Measures in terms of the total amount of market capitalization of the listed companies in a given time.
Patent applications, residents	Dependent Variable	Patent applications are 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 being applied in a given time.
Time required to get electricity (days)	Independent Variable	This indicates the total number of days in which individuals in any local community will get access to the electricity facility.	Total number of days.
electricity prices	Independent Variable	Electricity prices specify the amount on average paid by the individuals to utilize such facility.	Measures in terms of USD
Average Expense on Electricity	Independent Variable	The value of the total amount spends on electricity during a given period of time.	Measures in terms of USD
Electricity consumption per capita	Independent variable	It indicates the consumption of electricity in any given economy in terms of per capita during a particular period.	Measures in terms of USD
Carbon Dioxide emission per capita	Independent Variable	The amount of carbon dioxide emission in the natural environment in terms of per capita during a period.	Value in terms of per capita
Share of renewable energy	Independent variable	It indicates the total value of renewable energy in the total value of energy as produced in an economy during a year.	% Of share in total energy
Carbon dioxide emission intensity		It shows the emission rate of a given pollutant relative to the intensity of a specific activity at each time.	Metric tons per capita

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$$GDPG_{it} = \alpha_0 + \beta_1 TRE_{it} + \beta_2 EP_{it} + \beta_3 AEA_{it} + \beta_4 ECPC_{it} + \beta_5 CO2PC_{it} + \beta_6 REC_{it} + \beta_7 CO2IN_{it} + e_{it} \qquad (2)$$

Where;

GDPG	=	GDP growth
i	=	Country
t	=	Time Period
TRE	=	Time required to get electricity
EP	=	Electricity price
AEA	=	Average expenses on electricity
ECPC	=	Electricity consumption per capita
CO2PC	=	Carbon emission per capita
REC	=	Renewable energy consumption
CO2IN	=	Carbon emission intensity

In the above equation 2, the main dependent variable is GDP growth which is predicted through seven explanatory variables whose effects are covered through b1 to b7, respectively. Additionally, we have two further dependent variables, which are identified as financial development and Patent applications, residents, accordingly. For this reason, Equation 3 and Equation 4 shows the relationship between these dependent variables and independent variables of the study.

$$FD_{it} = \alpha_0 + \beta_1 TRE_{it} + \beta_2 EP_{it} + \beta_3 AEA_{it} + \beta_4 ECPC_{it} + \beta_5 CO2PC_{it} + \beta_6 REC_{it} + \beta_7 CO2IN_{it} + e_{it} \qquad (3)$$

Where;

FD	=	Financial development
i	=	Country
t	=	Time Period

$$PA_{it} = \alpha_0 + \beta_1 TRE_{it} + \beta_2 EP_{it} + \beta_3 AEA_{it} + \beta_4 ECPC_{it} + \beta_5 CO2PC_{it} + \beta_6 REC_{it} + \beta_7 CO2IN_{it} + e_{it} \qquad (4)$$

Where;

PA	=	Patent application
i	=	Country
t	=	Time Period

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In addition, the researchers also examine the multicollinearity in the model using the variance inflation factor (VIF). If the values are smaller than five, then multicollinearity does not exist and vice versa. The VIF equations are as under:

$$R^2_Y \Longrightarrow Y_{it} = \alpha_0 + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + \beta_5 X_{5it} + e_{it} \quad (5)$$

$$j = R^2_Y, R^2_{X1}, R^2_{X2,} R^2_{X3,} R^2_{X4,} R^2_{X5} \quad (6)$$

$$Tolrance = 1 - R^2_j \quad VIF = \frac{1}{Tolerance} \quad (7)$$

The fixed-effect model (FEM) is used by the present study to examine the association among the constructs. It is assumed “the slope of the coefficient” to be constant across the countries. In addition, it also allowed the intercept to vary with each country. FEM equation is shown below:

$$Y_{it} = \beta_{1i} + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + \beta_5 X_{5it} + u_{it} \quad (8)$$

In addition, the random effect model (REM) is also executed by the researchers to analyze the nexus among constructs. It has preserved the “intercept inversely” and assumed that constructs are “random” and have a “mean value” of β_1 other than β_{1i} (Gujarati et al., 2003). REM equations are mentioned below:

$$Y_{it} = \beta_1 + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + \beta_5 X_{5it} + \mathcal{E}_i + u_{it} \quad (9)$$

$$Y_{it} = \beta_1 + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + \beta_5 X_{5it} + w_{it} \quad (10)$$

4. RESULTS AND DISCUSSION

Descriptive results are shown in Table 2 through mean, standard deviation, and other measures. It is observed that, on average, the level of GDP growth for all three economies during the study period was 0.547 with a deviation of 0.263, respectively. This would indicate that both growths in an economy are associated with Malaysia, Indonesia, and Thailand. The mean score for time required for electricity or TRE indicates a value of 10.52 which refers to, on an average basis, the approximate time for people to get electricity. This mean trend shows a standard deviation of 0.282. Furthermore, the mean score for the FD is 0.457 and PA average value is 0.421. In addition, the average value of AP is 0.519 while ARE mean value is 0.504. Moreover, the average value of ECPC is 0.509 while CO2PC mean value is 0.495. Finally, the mean value of REC is 0.519, while the CO2IN average value is 0.462.

Table 3 reflects the correlation matrix of the variable along with the significant level. It is observed that for GDP growth, there is no higher trend of correlation between the rest of the study variables. Similarly, financial development indicates a positive and significant correlation with TRE. However, no significant association is observed with

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the rest of the variables. Additionally, in the title of Patent applications, residents are observed to be negatively associated with the TRE and ECPC, but these correlations are also found to be insignificant. Furthermore, the level of interdependency between TRE and ECPC is 0.450, which indicates a moderate and highly significant relationship between both (i. e. p-value= 0.000). However, the association between TRE and CO2PC is -0.298, which means that both have a negative but weak association, significant at 5 per cent. Besides, there is no significant correlation between the rest of the study variables, as shown in Table 3.

Table 2. Descriptive statistics

Variables	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**	**p1**	**p99**	**Skew.**	**Kurt.**
GDPG	57	.543	.263	.034	.999	.034	.999	-.08	2.066
FD	57	.457	.288	.041	.991	.041	.991	.115	1.781
PA	57	.421	.273	.004	.99	.004	.99	.451	2.291
TRE	57	10.52	.282	8	22	.241	10.22	.051	1.913
AP	57	.519	.307	.012	.994	.012	.994	-.037	1.653
AEA	57	.504	.256	.01	.965	.01	.965	-.2	1.818
ECPC	57	.509	.303	.008	.997	.008	.997	-.052	1.658
CO2PC	57	.495	.272	.007	.975	.007	.975	.071	1.922
REC	57	.519	.303	.016	.996	.016	.996	-.185	1.755
CO2IN	57	.462	.277	.022	.995	.022	.995	.063	1.801

In addition, the researchers also examine the multicollinearity in the model using the variance inflation factor (VIF). If the values are smaller than five, then multicollinearity does not exist and vice versa. The results indicate that all the values of VIF are lower than five which means there is no multicollinearity issue. Table 4 shows these values.

For testing the impact of sustainable energy on the economy, this study utilized the panel models, namely fixed effect and random effect. Three major dependent variables were under consideration while analyzing the trends in the economy. Table 5 shows the empirical results for the first dependent variable, that is, GDP growth in the targeted economies. Comparative analysis is provided through the relative coefficient of each of the explanatory variables and their standard deviation below the coefficients. The study results predict that TRE is positively but insignificantly impacting the GDP growth in the selected economies under fixed effect. However, for the random effect, the impact of GDP growth through TRE is positively significant at 10 per cent (i. e. beta= 0.282, standard error= 0.157). This indicates that higher TRE leads towards higher economic growth in all the panel economies.

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Table 3: Pairwise correlations

Variables	**GDPG**	**FD**	**PA**	**TRE**	**EP**	**AEA**	**ECPC**	**CO2PC**	**REC**	**CO2IN**
GDPG	1.000									
FD	-0.029	1.000								
AP	-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			
CO2PC	0.078	-0.007	0.133	-0.298**	0.153	0.087	0.013	1.000		
REC	-0.066	-0.032	0.002	0.080	-0.214	0.036	0.172	-0.111	1.000	
CO2IN	-0.066	-0.068	-0.077	0.234*	-0.059	0.029	0.119	0.018	0.056	1.000
*** $p<0.01$, ** $p<0.05$, * $p<0.1$										

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Table 4: Variance Inflation Factor (VIF)

	VIEW	1/VIF
TRE	1.308	0.710
EP	1.243	0.745
AEA	1.025	0.789
ECPC	1.314	0.798
CO2PC	1.311	0.800
REC	2.412	0.802
CO2IN	3.098	0.891
Mean VIF	1.220	.

In addition, the impact of EP, AEA and ECPC on GDP growth is found to be insignificant, which means that these factors are showing no evidence for the change in the value of economic growth of all three-panel countries. However, the impact of CO2PC on GDP growth is negative and significant at 1 per cent for both the fixed effect and random effect (Model 1, beta= -0.170, standard error= 0.046, Model 2, beta= -0.370, standard error= 0.033). This means that due to higher carbon emissions in all three ASEAN regions, an adverse influence on economic growth is found. This essentially implies that for every single unit change in the value of carbon emission, lower economic growth is observed and vice versa. Furthermore, the impact of the share of renewable energy in the total energy value of all three economies is observed to be positively and significantly linked with economic growth. This means that higher economic growth is directly associated with a higher amount of renewable energy share in the total value of energy sources. More specifically, both the coefficients are significant at 1 per cent due to lower standard error, higher t score and lower p-value. Besides, the impact from the rest of the explanatory variables on GDP growth is observed to be insignificant under full sample consideration. Finally, the findings under Table 5 for both fixed and random effect models are compared through the Hausman test in Stata-13. The results are provided while testing the following null and alternative hypotheses. Based on the findings under Table 4, the value of Prob>chi2 is 0.8421, which indicates an insignificant outcome.

The second main dependent variable of the study is identified as financial development during the study period, and the findings for this are shown in Table 6. The result specifies that TRE is positively but insignificantly impacting on financial development for the three economies, while for the random effect, the impact on financial development through TRE is positively significant at 10 per cent (i. e. beta= .290, standard error, 0.171). This shows that for every single unit increase in TRE, there is an increase of 0.290 in the value of financial development for all three-panel economies. However, the impact of EP on financial development under both fixed and random effects is negative but significantly only in the case of fixed effects. This means that a

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higher EP leads towards a lower value of financial development among all three-panel countries of the study. Additionally, the impact of AEA, ECPC, is found to be positively insignificant under full sample results. This shows that there is no significant impact of either AEA or ECPC on the trends in the value of financial development during the study period.

Table 5: Impact of Sustainable Energy on The Economy: GDP Growth

	(Fixed Effect)	(Random Effect)
Variables	***Model 1: GDP Growth***	***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)
CO2PC	-0.170***	-0.370***
	(0.046)	(0.033)
REC	0.799***	0.440***
	(0.115)	(0.124)
CO2IN	-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		

Footnote: Dependent Variable: GDP growth, TRE: Time required to get electricity (days), EP; electricity prices, AEA: average expense on electricity, ECPC: Electricity Consumption per cap, CO2PC: carbon dioxide emissions per capita, REC: renewable energy consumption, CO2IN: carbon dioxide intensity, S.E in parentheses, *** indicates $p<0.01$, ** shows $p<0.05$, and * means $p<0.1$

In addition, Table 4 reveals that CO2PC is found to be negatively and significantly associated with financial development, both, in fixed effect and random effect. More specifically, the coefficient for change in financial development through fixed effect is -0.721 and 0.763 through random effect. It means that higher carbon emission in all three ASEAN economies is leading towards lower financial development and vice versa. The rest of the explanatory variables show an insignificant impact on the value of financial development for both, fixed and random effects. Moreover, the results of the Hausman test have shown that random effect coefficients are more appropriate when analyzing the trends in financial development.

Table 6. 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)
CO2PC	-0.721***	0.763***
	(0.164)	(0.156)
REC	-0.0704	-0.0661
	(0.140)	(0.134)
CO2IN	-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		

Footnote: Dependent Variable: Financial Development, TRE: Time required to get electricity (days), EP; electricity prices, AEA: average expense on electricity, ECPC: Electricity Consumption per cap, CO2PC: carbon dioxide emissions per capita, REC:

renewable energy consumption, CO2IN: carbon dioxide intensity, S.E in parentheses, *** indicates $p<0.01$, ** shows $p<0.05$, and * means $p<0.1$

Finally, the third dependent variable is a patent application, residents in all three countries for which the impact of all the explanatory variables are observed, as shown in Table 7. The results of the study show that TR has no significant impact on Patent Applications, Residents in both fixed and random effects. On the other side, EP has its negative and significant impact on the Patent Applications, Residents as observed with the coefficient of -0.660 and standard error of 0.131. This implies that higher EP means lower patent applications and vice versa. Similarly, EP is leading towards a change of -0334 in Patent Applications, Residents for the overall sample economies. However, the impact from AEA and ECPC is insignificant, which means that there is no evidence to claim their influence on the Patent Applications, Residents.

In addition, as per the research findings in several other studies, higher carbon emission is a problem for both, the economy and the natural environment in any country. This impact is significantly observed where the economy of all three sample countries in terms of Patent Applications, Residents is negatively affected by the CO2PC. This means that for every single unit increase in CO2PC, there is an impact of -0.827 in patent applications, residents under the full sample of the study. Moreover, the rest of the study variables are observed to be insignificant determinants of patent applications. The value of chi-square under Table 7 through the Hausman test is insignificant, which implies that random effect is appropriate for measuring the impact of sustainable energy dynamics on patent applications and residents.

5. DISCUSSIONS

The study findings = indicate that electricity prices or expenses have a positive impact on economic growth. These results are supported by the previous study of Costa-Campi et al. (2018), which states that the prices of electric power depend on its demand and supply balance. When there is high demand for electricity, its price goes high, indicating high consumption of electricity within the economy. All economic activities need energy sources. So, the high price of electricity means there is a high rate of economic growth. The study findings have also shown a positive relationship between renewable energy consumption and economic growth. These results are in line with the previous study of Isik et al. (2018), which states that the use of energy in sufficient amount and with the use of clean resources, the economic activities can be more conveniently undertaken, like the performance of production technologies and transport vehicles etc. This steers the country towards high economic growth. The study results have revealed that carbon emission has a negative impact on economic growth. The results agree with the study of Yao et al. (2019),which shows that carbon emission has adverse impacts on the performance of different business units by damaging the quality of natural resources, air quality, and health of living beings all of which form business factors essential to economic success.

Table 7. Impact of Sustainable Energy on the Economy: Patent Applications, Residents

	FEM	REM
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)
COE2EMPCAP	-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		

Footnote: Dependent Variable: Patent applications, residents, TRE: Time required to get electricity (days), EP; electricity prices, AEA: average expense on electricity, ECPC: Electricity Consumption per cap, CO2PC: carbon dioxide emissions per capita, REC: renewable energy consumption, CO2IN: carbon dioxide intensity, S.E in parentheses, *** indicates p<0.01, ** shows p<0.05, and * means p<0.1

It has also been indicted by the study results that electricity prices, expenses, or consumption have a positive relationship with financial development. These results are in line with the previous study of Blazsek et al. (2018), which suggests that electricity is considered a convenient source of energy with respect to usage and coverage of area through grid installation. Moreover, it provides high voltage power to run heavy electric appliances applied in financial institutions like banks, insurance companies, and enterprises dealing in loans. Therefore, high prices, expenses, and consumption improve the financial development of the country. The study results have also indicated that renewable energy consumption has a positive association with financial development. The study results match with the past study of Anton et al. (2020), which highlights that the financial development of the country is linked with economic conditions because it is the business enterprises and their functioning which requires, consumes, and ultimately results in the increase in financial resources. Renewable energy consumption brings improvement in the undertaking of economic activities and the performance of business units; thus, it accelerates the financial development of the country. The results show that carbon emission has a negative association with financial development. These results are in line with the past study Khan et al. (2020), which posits that in an economy, which has to face a large number of challenges because of increasing carbon emission into the air, the level of financial development is low or tends to go backward due to the weak performance of economic factors.

The study results indicate that electricity prices, expenses, or consumption have a negative relationship with a patent application. These results are in line with the previous study of Irandoust (2019), which states that patent application is considered and approved, and exclusive rights are granted to the new invention only when patent authorities are satisfied with the description of the invention given in the application. If the product or process to be invented requires a large amount of electricity which raises demand for electricity and poses a threat to sustainable electricity source for energy purposes, the authorities are reluctant to approve the application for a patent grant. The study findings have also shown that renewable energy consumption has a positive association with a patent application. These results are supported by the past study of Miyamoto et al. (2019),which shows that when the description of the patent application shows that the wanted invention encourages use of renewable energy resources, which is the significant source of sustainable development in economic growth, it is more likely for patent authorities to grant rights to use that product or process. The study results have also revealed that carbon emission has a negative impact on the patent application. These results are supported by the previous study of Cheng et al. (2019). This study analyzes that patent authorities grant the right to use an invention, considering its impacts on society, environment, and economic growth. If the use of the concerned product, process, or place could cause carbon emission in large amounts, the authorities may refuse to grant patent rights.

6. CONCLUSION, LIMITATIONS, AND FUTURE DIRECTIONS

In various developing economies like ASEAN, there is a growing concern for dealing with sustainable energy and its impact on the economy and various financial dynamics.

Energy sustainability objectives have various dimensions in terms of price affordability, energy services, short-term reliability of the supply, long-term continuity of the supply and finally, safety concerns vis-a-vis greenhouse emissions. Although theoretical discussion of these dimensions is reasonably addressed in existing literature, there remains a notable empirical ga analyzing the impact of sustainable energy dimensions on the economy. The key concern of this research is to focus on the relationship between sustainable energy dimensions and their impact on the economy of three ASEAN economies; Malaysia, Indonesia, and Thailand. To examine this relationship, panel data models like fixed and random effects were considered through a balanced pool of data during the study period of 2000 to 2018 with yearly observations. The study findings prove that the economy, in terms of GDP growth, is negatively influenced by carbon emission per capita, whereas the share of renewable energy in the total energy positively impacts the value of GDP growth in all three sampled economies. For the second dependent variable (financial development), the significant and negative impact of carbon emission in terms of per capita is examined. Furthermore, energy prices are also negatively and significantly linked with financial development, providing evidence that higher energy prices mean lower financial development. Lastly, the panel model findings confirm that EP and carbon emission have a negative impact on the patent application. This study finding can be of great value for industry experts, researchers, and various stakeholders who are interested in examining the relationship between sustainable energy and economic dynamics, specifically in the context of the ASEAN countries. Government officials and other environmental departments are encouraged to review and benefit from the theoretical and empirical insights provided by the present study.

It bears to note that there are several limitations linked with the present study. Firstly, the present study considers only three regional economies of ASEAN, which means that the study outcomes may only hold true or otherwise have relevant implications for only Thailand, Indonesia, and Malaysia. Secondly, this study has applied traditional panel regression approaches, which are entitled as fixed and random effects with no further consideration of advanced techniques like generalized methods of moments or GMM. Furthermore, no robust checks are applied, which also highlights the study's methodological limitations. Thirdly, this research is missing across-country comparison, which means that it has specific implications and theoretical significance. Future studies are encouraged to focus on the key gaps left unaddressed by the present study, such as, consideration of economies all the ASEAN countries, application of advanced panel models, robust checking of the empirical findings, and finally, cross-country comparisons. It is hope that consideration of all these factors or variables will be able to produce more informed and valid study implications, have greater theoretical and empirical coverage, and be of greater practical value for practitioners/managers.

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