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DOES ENERGY PRODUCTIVITY AFFECT A COUNTRY'S ECONOMIC EFFICIENCY? EVIDENCE FROM SELECTED ASEAN COUNTRIES

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ABSTRACT

With the continuous increase in the demand for energy, rapid and sustained growth in energy consumption and low growth in energy production, one of the top priorities for sustainable development and environmental protection is to reduce energy usage and improve economic efficiency. Although it is clear that energy productivity has a positive impact on a country's economic efficiency, how sensitive is the response of economic efficiency is to the increase in energy productivity needs to be analyzed. Hence, our study intends to analyze the effect of energy productivity on economic efficiency in the ASEAN countries. The present study utilizes the advanced methodology of CS-ARDL, which is known for producing robust and reliable results, on the ASEAN region which comprises countries that are still dependent on non-renewable energy, thereby drastically polluting the environment. The findings from the CS-ARDL method revealed that energy productivity has a positive and significant relationship with economic efficiency. Based on the findings, several recommendations are proposed, such as adopting renewable energy resources that support environmentally friendly energy production to ensure sustainable energy and encouraging smart energy systems to be installed at government buildings or manufacturing buildings which deploy new technologies that increase energy efficiency.

Keywords: Energy consumption, energy productivity, economic efficiency, CS-ARDL, ASEAN.

INTRODUCTION

Energy is a key source of economic growth because many production and consumption activities use energy as a basic input. Consequently, the energy sector plays an important role in a country's development and people's well-being. The world has witnessed a remarkable global economic growth since the Industrial Revolution, when the global GDP per capita multiplied 10-fold during a period of approximately 200 years, i.e., from less than USD1000 in 1820 to over USD10,000 in 2017 (de Oliveira, 2018). Likewise, this income growth leads to the rapid rise in the demand for energy worldwide. The International Energy Agency's World Energy Outlook 2018 estimated that the energy demand is expected to grow by more than 25 percent by 2040, requiring more than USD 2 trillion a year of investment in a new energy supply. The global energy demand rose by nearly 2 percent in 2018 alone, with over 70 percent of the global energy demand growth to be met by the supply of oil, natural gas and coal.

With the continuous increase in the demand for energy, rapid and sustained growth in energy consumption and low growth in energy production, one of the top priorities for sustainable development and environmental protection is to reduce energy usage and improve economic efficiency. For over a decade, a wide range of robust evidence has shown that energy conservation is not at levels it could be expected to be in a world concerned with climate change (the World Bank, 2009). To put it another way, this means that the amount of energy inputs utilized to run the processes needed to produce a given output, such as heating and cooling, lighting, or transportation, could be a lot lower than what it is today.

The inefficient use of energy could be detrimental not only to climate change but, arguably, also to a country's economy through its effect on economic efficiency. Efficiency is the foundation for economic prosperity. Countries seek economic growth as their primary purpose to increase their society's living standard. To increase and sustain economic growth, a country needs to be efficient and produce goods at lower costs in order to remain globally competitive. Achieving economic efficiency is essential for all ASEAN countries, given the region's ambition to attain high-income status.

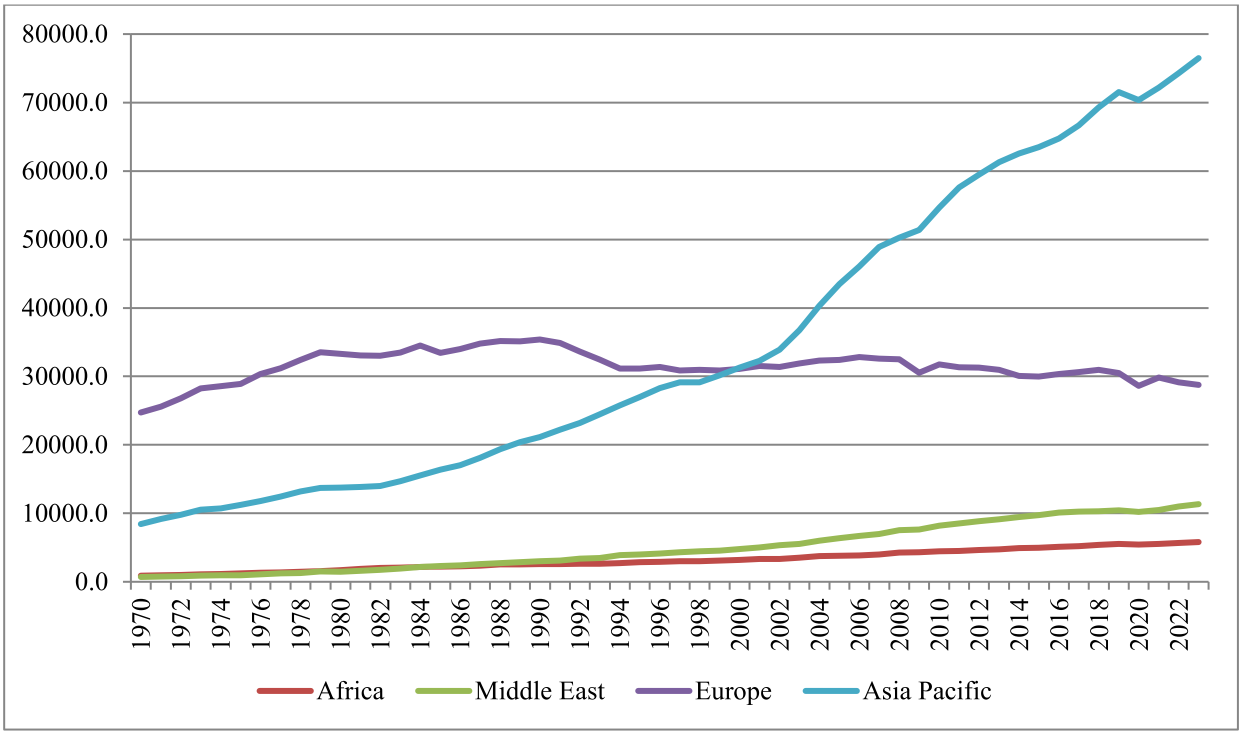
Lowering energy consumption per unit of output (energy intensity), or equivalently, increasing output per unit of energy (energy productivity), is widely regarded as a critical measure to enhance economic efficiency while mitigating greenhouse gas emissions. With rising energy costs and increasing taxation on emissions, including those from energy generation, improving energy efficiency can provide industries and countries with a competitive advantage. As energy is a major factor in production, more energy-efficient industries and countries enjoy a cost advantage (McKinsey, 2011).

Energy consumption in the Asia Pacific region has been steadily increasing over the years. Figure 1 illustrates energy consumption in the Asia Pacific, the Middle East, Europe, and Africa from 1970 to 2023. While energy consumption in Europe has remained largely stagnant—or even declined at times—since 1990, it has shown moderate increases in the Middle East and Africa throughout the period, and a remarkable rise in the Asia Pacific region, particularly since 2000.

Next, if we look at the statistics for selected ASEAN countries (namely, Indonesia, Malaysia, Singapore and Thailand), the trend is even more impressive: all four selected ASEAN countries recorded a significant increase in energy consumption during the same period (see Figure 2).

Figure 1

World Energy Consumption by Region 1970-2023 (in Terawatt-hours, TWh)



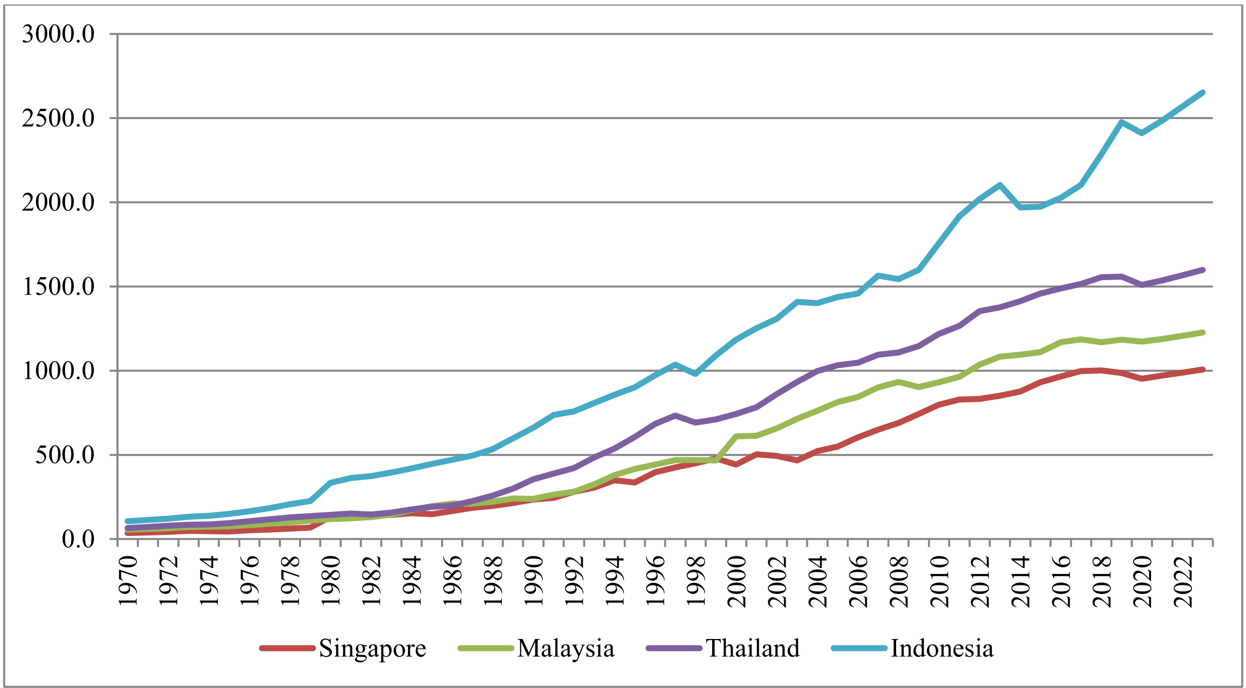
Source: International Energy Agency (2020, 2021, 2022, 2024), YCharts (n.d.), Eurostat (n.d.), Statista (n.d.), and Energy Institute (n.d.).

Despite this impressive trend of energy consumption in these ASEAN countries, it should be noted that they are still mainly dependent on non-renewable energy, which drastically pollutes the environment. According to the International Energy Agency's Southeast Asia Energy Outlook 2020, the share of renewable energy in the regional primary energy supply in 2019 was only around 15 per cent. The population of this region has exceeded 654 million and has a potential economy of USD 3.1 trillion because of the presence of countries that are financially stable and sound, such as Vietnam, Singapore, and Malaysia (Anwar et al., 2021). Being a holder of a significant portion of the total global population and the respective market potential, countries in this region are using mainly non-renewable energy which makes this region the third biggest greenhouse gas emitter (Ahmed et al., 2017). In addition to this, it is also anticipated that by the year 2035, the total energy demand in this region would have increased by 80 percent (Nathaniel & Khan, 2020).

The use of energy per person is relatively high in many ASEAN countries compared to that in other Asian countries (The World Bank, 2015). Being far more energy efficient could not only save plenty of money but it could also reduce the impact of energy generation on the environment. Most cross-country studies on energy productivity focus on high-income countries at the expense of developing countries (Mulder and de Groot, 2011). There are many empirical studies on the effect of energy consumption on economic growth (among others, Ockwell, 2008; Gales et al., 2007; Ozturk, 2010; and Payne, 2010) and only a handful of studies looking at the effect of energy efficiency on GDP (Hu & Wang, 2006; Madlener & Alcott, 2009). In fact, studies on the effect of energy productivity on economic efficiency, to our knowledge, are lacking. It is clear that energy productivity should have a positive impact on a country's economic efficiency but how sensitive economic efficiency is to the increase in energy productivity needs to be analysed. Hence, our study intends to analyse the effect of energy productivity on economic efficiency in the ASEAN countries.

Figure 2

Energy Consumption in Selected ASEAN Countries 1970-2023 (in Terawatt-hours, TWh)



Source: ASEAN Center for Energy (2023, 2025), Our World in Data (n.d.), and Energy Market Authority of Singapore (2025)

In addition to the geographical contribution based on the region of the ASEAN countries, the present study intends to contribute to existing literature in a few other ways as well. Precisely, this study attempts to expand the literature of energy productivity and economic efficiency and evaluate its findings in accordance with the existing literature. Moreover, the present study uses the advanced methodology of CS-ARDL which has been known to produce robust and reliable results in the panel data analysis (Choi and Yu, 2017).

This paper is organized as follows. The next section reviews the relevant literature, followed by a description on the methodology and a discussion of the empirical results, and concluded by a summary of the study and recommendations.

LITERATURE REVIEW

It is almost impossible to attain economic growth without consuming any source of energy. The overall process of transforming raw materials into finished goods is highly dependent on energy consumption. However, the consumption of energy inadvertently damages the ecological health of society which constitutes an interesting and crucial area of research across the globe (Antonakakis et al., 2017; Saidi & Hammami, 2015). Because of the inevitability of the nexus between economic growth, energy consumption and environment, various researchers have contributed to the literature by exploring the aforementioned relationship (Benkraiem et al., 2019; Ismail et al., 2020; Shahbaz et al., 2017; Sarwar et al., 2017). Historically, the exploration of this relationship has been documented by Kraft and Kraft (1978) who initially identified that environmental degradation was brought about by the consumption of energy in the context of the United States. Later on, different researchers have used different types of energy for the purpose of validating the relationship between energy consumption and economic growth and reported different findings. For instance, the study of Shaari et al. (2012) reported the relationship between energy consumption and economic growth in the case of gases. However, the same study did not confirm the role of oil and coal by Granger causality on economic growth. In addition to this, the relationship between energy consumption and economic growth was also confirmed by the findings of Tsani (2010) in the context of Greece whereas the findings of Odhiambo (2009) showed a stable relationship in the longer period of time in the case of Tanzania.

In the context of ASEAN region, the existing literature is filled with different findings contributed by different researchers. For instance, the nexus between the consumption of electricity, economic growth and the level of carbon dioxide emissions was studied by Lean and Smyth (2010) who reported a direct relationship between the consumption of electricity and the level of carbon dioxide emissions in the longer period of time but validated the premise that an increase in the level of electricity consumption significantly contributes to the economic growth of the country. In addition to this, there is a co-integration relationship for these variables in each of the five countries in the ASEAN region (namely, Indonesia, Malaysia, the Philippines, Singapore and Thailand) as documented by Saboori and Sulaiman (2013). They reported the presence of co-integration between the consumption of energy, economic growth and the level of carbon dioxide emissions in all of the five countries studied. Similarly, Heidari et al. (2015) studied the same variables by employing the methodology of Panel Smooth Transition Regression whereas the individual case of Malaysia was explored by Husaini and Lean (2015) and Ang (2008) while Singapore by Tan et al. (2014). All of these studies report similar findings of cointegration and mutual causal links although their scopes might differ from each other.

More recently, the relationship between the aforementioned variables in the framework of Environment Kuznet Curve was explored by Munir, Lean and Smyth (2020) in the ASEAN region where the findings have reported evidence of the presence of Environment Kuznet Curve for all the countries in the ASEAN region. A review of the relevant literature suggests that, to the best of our knowledge, Karim et al. (2022) is the only study that examined the relationship between energy productivity and economic efficiency. Nonetheless, their study was confined to a single country, Malaysia.

METHODOLOGY

Economic Efficiency

Economic efficiency is estimated using the Data Envelopment Analysis (DEA) approach, which is a non-parametric approach based on the linear programming technique to estimate the relative efficiency of the production function for a particular country (Casu & Molyneux, 2003). The efficiency level of the decision-making units (DMUs) is calculated by comparing a given producer’s efficiency with the best producer’s efficiency in the sample.

The most efficient year of operation will be operating on the frontier while those below the frontier are inefficient. The output-oriented variable return to scale (VRS) model with the assumption that the government maximizes output for a given input amount is utilized in this study. Following Banker et al. (1984), the model for economic efficiency is described as follows:

$$Max.\theta \; s.t.\sum_{j=1}^{n}\lambda_j x_{ij} \leq x_{i0}, \sum_{j=1}^{n}\lambda_j y_{rj} \geq \theta y_{r0}, \sum_{j=1}^{n}\lambda_j = 1, \text{and } \lambda_j \geq 0 \quad (1)$$

where θ is a scalar (whose value ranges from 0 to 1) which indicates the level of technical efficiency, x_{ij} is input i (i = 1, 2, …, m) which is employed in country j (j = 1, 2, …, n), y_{rj} is output r (r = 1, 2, …, s) which is produced by country j, and λ_j is the weight for country j.

In this study, DMUs are the countries (which are indexed by j = 1, 2, …, n). Hence, DMU_0 is one of the n DMUs under evaluation, and x_{i0} and y_{r0} are the i^{th} input and r^{th} output, respectively, for o^{th} DMU or, DMU_0. Of the n countries (j = 1, 2, …, n), the most technically efficient one operates on the efficient frontier. Then, θ^* represents the distance of country 0 from the efficient frontier, the most technically efficient country exhibits $\theta^* = 1$ whereas any other country (which is inefficient) exhibits $\theta^* < 1$.

Following Halkos and Tzeremes (2009a, 2009b), economic efficiency is measured based on a production function which has two inputs and one output. The two inputs are capital (which is measured by the gross fixed capital formation of a given country in constant dollars) and labor (which is measured by the total number of the workforce of a given country) whereas the (single) output is proxied by the GDP per capita (which is measured by the ratio of real GDP of a country to mid-year population of the country).

Model

The empirical model showing the role of energy productivity in affecting economic efficiency is presented as follows:

$$EEF_t = f(CAP_t, LAB_t, EPRO_t, TOP_t, INF_t, v_t) \tag{2}$$

where EEF is economic efficiency, CAP is capital, LAB is labor, EPRO is energy productivity, TOP is trade openness, INF is inflation, and v is the fixed effect by individuals which varies over time represented by t.

For measuring trade openness (TOP), the ratio of imports and exports to GDP is used; and the measurement of inflation (INF) is done by the consumer price index. The data for all of the variables are extracted from the World Bank database. Moreover, to achieve homogeneity in terms of the units and measures of the studied variables, natural log is taken.

This study is conducted based on the panel data set of four countries from the ASEAN-4 region (i.e. Indonesia, Malaysia, Singapore, and Thailand) during the period 1971-2017.

ESTIMATION STRATEGY

Unit Root Testing

Prior to performing any statistical analysis in the data set comprised of cross sections, it is crucial to assess the existence of cross-sectional dependence (CD) within the data set. By the help of prior assessment of CD, the researcher can easily shortlist the unit root and the subsequent tests from the available alternatives which are capable enough to address CD during data analysis. There is a high probability of the presence of CD when the data set is based on the panel data of countries that are either from the same region or share similar economic, financial, political, and social issues which eventually result in the presence of common variance in the data set that needs to be addressed by a technique which has the capability to generate robust results while addressing such issue. Therefore, that technique should be applied to handle the issue of CD and generate more reliable, sound and robust results (Westerlund, 2007; Salim et al., 2017). In this regard, Pesaran (2015) has proposed a test to address CD which was applied in the present study after the evaluation of unit root within the data set. There are a variety of alternatives available in evaluating unit root (see Breitung & Pesaran, 2008; Moon & Perron, 2012, and Phillips & Moon 1999). However, each of them has its own strengths and weaknesses. Accordingly, the available tests can be divided into three categories. For instance, in a panel data set having homogenous attributes, the assessment of unit root can be easily done by the method of Maddala and Wu (1999), Choi (2001), and Levin et al. (2002). However, when the panel data set has heterogeneous attributes, Im et al. (2003) method is preferred. In the same way, Lluís Carrion-i-Silvestre et al. (2005) method is recommended in the situation where multiple structural breaks are present in the data set, but this test has the limitation of not addressing CD.

On the other hand, the tests which have the capability of addressing CD when the data set is heterogeneous, have been categorized as the second-generation tests, which include a variety of tests such as Moon and Perron (2012), Choi (2006), and Pesaran (2007). However, this category fails to assess the presence of multiple structural breaks which deteriorates the strength of the predictions. Hence, the third category belongs to the tests which can assess the presence of multiple structural breaks in the data set which are heterogeneous, while at the same time, are capable of addressing CD. Therefore, based on the nature of the panel data set used in the present study, the test proposed by Pesaran (2007) and Bai and Carrion-i-Silvestre (2009) is employed for the assessment of CD and stationarity.

Co-integration Testing

After assessing stationarity, the advanced version of Swamy's test (1970), which is presented by Pesaran and Yamagata (2008), is applied to order to evaluate the homogenous slope. This test has the null hypothesis of the presence of homogenous slope versus the alternative hypothesis of the presence of heterogeneous slope. Since the conventional tests fail to generate robust outcomes while addressing CD, the tests developed by Banerjee and Carrion-i-Silvestre (2017) and Westerlund and Edgerton (2008) are applied. Specifically, the test by Banerjee and Carrion-i-Silvestre (2017) has the capability to deal with CD regardless of its power as it is established on Common Correlated Effects Mean Group (CCEMG) which mimics the regression methods that address the stationarity and homogenous slope concerns. Moreover, the test by Westerlund and Edgerton (2008) is capable of addressing stationarity and homogenous slope issues while also incorporating the structural breaks without disturbing the homogenous slope and rejection of the null hypothesis.

Cross-sectionally Augmented Autoregressive Distributed Lags (CS-ARDL)

Whenever there is a panel data set which comprises multiple cross sections and/or countries that share similar geographic locations and other political, economic and financial pressures and circumstances, there is a high probability of having CD. Therefore, there is also a high probability of severe multi-collinearity in the studied variables. In this case, the CS-ARDL model is preferred since it is capable of addressing the issue of CD and homogenous slope. Being founded on the dynamic common correlated effects, the estimation of this method starts from the model shown in Equation 3.

$$W_{i,t} = \sum_{I=0}^{p_w} \gamma_{I,i} W_{i,t-1} + \sum_{I=0}^{p_z} \beta_{I,i} Z_{i,t-1} + \varepsilon_{i,t} \tag{3}$$

where all of the studied independent variables are represented by $Z_{i,t}$ while the dependent variables are represented by W_{it}. The model shown in Equation 3 is based on the Autoregressive Distributed Lags (ARDL) model. However, if Equation 3 is followed, then there is a probability of the generation of distorted findings in the case where CD is present. Therefore, when the average cross sections of all the independent variables are substituted into Equation 3, the presence of CD is addressed which could result in distorted inference and effects (Chudik & Pesaran, 2015). The revised form of Equation 3 is stated in Equation 4.

$$W_{i,t} = \sum_{I=0}^{p_w} \gamma_{I,i} W_{i,t-1} + \sum_{I=0}^{p_z} \beta_{I,i} Z_{i,t-1} + \sum_{I=0}^{p_x} \alpha'_{i,} I\bar{X}_{t-1} + \varepsilon_{i,t} \tag{4}$$

Referring to Equation 4, the average of all of the studied constructs is represented by $\bar{X}_{t-1} = (\bar{W}_{l,t-1}, \bar{Z}_{l,t-1})$, and the total number of lags of the variables are represented by p_w, p_z, and p_x. In addition to this, the averages of the cross section are represented by $\bar{X}$ which is possibly due to spill-over effects (Liddle, 2018). It is important to note that, in the CS-ARDL model, the coefficients for the long run are calculated on the basis of the short-run coefficients. The long-run coefficients and the mean group are represented by Equations 5 and 6, respectively.

$$\bar{\pi}_{CS-ARDL,i} = \frac{\sum_{I=0}^{pz} \hat{\beta}_{I,i}{}^{pw}}{1-\Sigma_{I=0}} \hat{\gamma}_{l,t} \tag{5}$$

$$\hat{\bar{\pi}}_{M,G} = \frac{1}{N} \sum_{i=1}^{N} \hat{\pi}_i \tag{6}$$

The short-run coefficients are computed based on the model shown in Equation 7.

$$\Delta W_{i,t} = \vartheta_i \left[W_{i,t-1} - \pi_i Z_{i,t} \right] - \sum_{I=1}^{p_{w-1}} \gamma_{I,i}, \Delta_I W_{i,t-1} + \sum_{I=0}^{p_z} \beta_{I,i}, \Delta_I Z_{i,t} + \sum_{I=0}^{p_x} \alpha'_i, I\bar{X}_t + \varepsilon_{i,t} \tag{7}$$

where $\Delta_I = t - (t-1)$, and

$$\hat{T}_i = -\left(1 - \sum_{I=1}^{pw} \widehat{\gamma_{I,\iota}}\right) \tag{8}$$

$$\hat{\pi}_i = \frac{\sum_{I=0}^{pz} \hat{\beta}_{I,i}}{\hat{T}_i} \tag{9}$$

$$\hat{\bar{\pi}}_{M,G} = \frac{1}{N} \sum_{i=1}^{N} \hat{\pi}_i \tag{10}$$

In the methodology of the CS-ARDL model, the speed of adjustment to equilibrium from the normal equilibrium is represented by the Error Correction Mechanism, ECM (−1), which has the similarity with the pooled mean group (PMG).

Robustness Tests

As discussed earlier, in the situations where the homogenous slope and CD are present and the conventional approaches are applied, the outcome is distorted and inferior (Çoban & Topcu, 2013; Yao et al., 2019). Moreover, in the case where structural breaks are also present, the Augmented Mean Group (AMG) (Eberhardt & Teal, 2010) or the Common Correlated Effect Mean Group (CCEMG) (Pesaran, 2006) is preferred. These two methods help in generating more reliable and robust results even in the presence of non-stationarity and unobserved common factors. Moreover, the time-based variance (which is unobserved) and the homogenous slope are determined without identifying CCEMG. Moreover, this test also helps in eliminating the spill-over effects that emerge because of the existence of CD by taking the average of all of the variables studied. On the other hand, robustness can also be assessed with the help of AMG, which is a substitute for CCEMG and includes dummies in the data year-wise, which further enables the generation of more vigorous outcomes (Eberhardt & Teal, 2010). Lastly, the application of all the aforementioned statistical techniques is in accordance with the methodology followed and discussed in the existing literature (see Khan et al., 2020 and Chudik & Pesaran, 2015).

ESTIMATION RESULTS

In view of the significance of addressing CD and its repercussions if ignored, the presence of CD is assessed. The null hypothesis of this test assumes the absence of CD. The alternative hypothesis of the presence of CD is supported when the significance values are below the threshold level of 0.05 (Pesaran, 2015). The findings of the CD test are reported in Table 1 where all of the studied variables are found to be individually significant.

Table 1

Results of Cross-sectional Dependence Analysis

Variable	Test Statistics (p-values)
EEF	16.621*** (0.000)
CAP	31.380*** (0.000)
LAB	18.524*** (0.000)
EPRO	27.079*** (0.000)
TOP	20.437*** (0.000)
INF	29.329*** (0.000)

Note: ***, ** & * denote the level of significance at 1 percent, 5 percent and 10 percent, respectively, whereas the values in parentheses are p-values

After assessing the existence of CD, the stationarity of the data set is ensured. For the said purpose, two tests which can ascertain the heterogeneity of the slope, CD and multiple structural breaks were employed. These tests include Pesaran (2007) and Bai and Carrion-i-Silvestre (2009). The results of both tests indicate that the null hypothesis of the absence of CD can be rejected and all variables are stationary at the level. However, after ascertaining the presence of structural breaks, the data series was found to be stationary as per the test of Pesaran (2007), whereas the findings of Bai and Carrion-I-Silvestre (2009) test negate the presence of stationarity. Therefore, after computing the first difference of the data, the findings of Bai and Carrion-i-Silvestre (2009) test confirm the presence of stationarity. The results of these two tests confirming the presence of stationarity are reported in Table 2.

In the following step, the homogeneity of the slope is assessed by the test of Pesaran and Yamagata (2008) which is a modified version of Swamy's (1970) test. The assessment of homogeneity of the slope is of crucial importance as failure to ascertain it resulted in inferior and distorted findings (Alam et al., 2018). As per this test, the null hypothesis assumes homogeneity of the slope, whereas the alternative hypothesis assumes heterogeneity of the slope. This test indicates the presence of heterogeneity of the slope as all of the statistics are found to be significant at the 1 percent level of significance (see Table 3).

Table 2

Results of Unit Root Test with & without Structural Break

a) Pesaran (2007)				
	Level I(0)		First Difference I(1)	
Variables	CIPS	M-CIPS	CIPS	M-CIPS
EEF	-2.958***	-7.648**	-	-
CAP	-3.059***	-8.048**	-	-
LAB	-3.285***	-7.448**	-	-
EPRO	-2.194**	-4.996*	-	-
TOP	-3.184***	-9.694**	-	-

b) Bai and Carrion-i-Silvestre (2009)						
	Z	P_m	*P*	*Z*	P_m	*P*
EEF	0.268	0.853	21.550	-3.448***	7.593***	49.257**
CAP	0.376	0.948	20.841	-5.581***	9.428***	65.218***
LAB	0.221	0.725	28.097	-4.593***	11.436***	53.600**
EPRO	0.362	1.482	25.594	-2.185**	8.694***	70.456***
TOP	0.195	0.586	17.328	-3.539***	6.792***	67.260***
INF	0.392	1.005	26.427	-4.582***	10.530***	82.485***

Note: The level of significance is denoted by 1, 5, and 10 percent, indicated through ***, ** and * respectively. For Bai & Carrion-i-Silvestre (2009) test, 1, 5 and 10 percent critical values (CV) for *Z* and *Pm* statistics are 2.326, 1.645 and 1.282, while the critical values (CV) for *P* are 56.06, 48.60 and 44.90, respectively.

Table 3

Results of Slope Heterogeneity Analysis

Dependent Variable: EEF	
Statistics	Test value (P-value)
Delta tilde	18.912*** (0.000)
Delta tilde Adjusted	19.711*** (0.000)

Note: ***, ** & * denote the level of significance at 1percent, 5 percent and 10 percent, respectively, whereas the values in parentheses are p-values.

After assessing the slope, the evaluation of co-integration is done by employing the test proposed by Westerlund and Edgerton (2008) in which the null hypothesis assumes the absence of co-integration, whereas the alternative hypothesis assumes the existence of co-integration. The results reported in Table 4 indicate the existence of co-integration as all of the statistics for both the dependent variables are found to be statistically significant at the 1percent level of significance.

As a robustness check, the assessment of co-integration is also done by the test proposed by Banerjee and Carrion-i-Silvestre (2017), which shares similar assumptions in stating the null and alternative hypotheses as the previously applied test proposed by Westerlund and Edgerton (2008). The results reported in Table 5 indicate the existence of co-integration, as all of the statistics for both the dependent variables are found to be statistically significant at the 1 percent level of significance. The only difference between the two tests is that the Westerlund and Edgerton (2008) test reports the results variable-wise, whereas the test proposed by Banerjee and Carrion-i-Silvestre (2017) reports the results country-wise. Nevertheless, all the studied countries' series are found to be co-integrated, as shown in Table 5.

Table 4

Results of Westerlund and Edgerton (2008) Panel Cointegration Analysis

Test	No break	Mean shift	Regime shift
Dependent Variable: EEF			
$Z_{\varphi}(N)$	-3.284***	-3.009***	-2.847***
P_{value}	(0.000)	(0.000)	(0.000)
$Z_{\tau}(N)$	-3.847***	-3.375***	-3.093***
P_{value}	(0.000)	(0.000)	(0.000)

Note: ***, ** & * denote the level of significance at 1 percent, 5 percent and 10 percent, respectively, whereas the values in parentheses are p-values. The structural break test for mean and regime shift for both models will be made available upon request.

Table 5

Results of Banerjee and Carrion-i-Silvestre (2017) Cointegration Analysis

Countries	No deterministic specification	With constant	With trend
	Dependent Variable: EEF		
Full Sample	-5.646***	-6.451***	-6.399***
Indonesia	-4.281***	-4.378***	4.223***
Malaysia	-9.020***	-9.129***	-8.848***
Singapore	-5.507***	-5.702***	-6.280***
Thailand	-4.595***	-4.986***	-4.692***

Note: Critical Value (CV) at 5 percent** and 10 percent*with constant is −2.32, −2.18 and with trend is −2.92 and − 2.82.

Once the presence of co-integration is confirmed, the relationships between independent and dependent variables are assessed with the help of CS-ARDL in both the long run and short run. As shown in Table 6, the coefficient of energy productivity was found to be positive and statistically significant at the 1 percent level of significance. This means that an increase in energy productivity will increase economic efficiency. This relationship enables the economies to channel additional resources towards improving the productivity of energy consumption, which eventually leads to an improvement in the overall efficiency of the economy.

The coefficient of capital was found to be positive and statistically significant at the 1 percent level of significance. This means that adding more capital will contribute to economic efficiency. This relationship enables the economies to invest additional capital in the processes and operations so that the overall efficiency of the economy can be improved. Similarly, the coefficient of labor was also found to be positive and statistically significant at the 5 percent level of significance, indicating that an increase in the labor force availability will increase a country's economic efficiency. This relationship suggests that the utilisation of the available labor force more optimally would increase the overall efficiency of the economy. The coefficient of trade openness was also found to be positive and statistically significant at the 1 percent level of significance, indicating that an increase in trade openness will increase economic efficiency. This result suggests that countries should devise strategies and policies that encourage trade openness which eventually leads to improvement in the overall economic efficiency. On the other hand, the coefficient of inflation was found to be negative and statistically significant at the 1 percent level of significance, indicating that inflation deteriorates economic efficiency. This result is hardly surprising because when there is high inflation, the cost of production will increase and as a result, the profit margin decreases which negatively affects the level of economic efficiency.

Table 6

Results of CS-ARDL Analysis (Long run CS-ARDL Results)

Variables	Coefficients	t-statistics	p-values
Dependent Variable: EEF			
CAP	0.301***	4.583	0.000
LAB	0.248**	2.018	0.045
EPRO	0.327***	3.385	0.000
TOP	0.295***	3.186	0.000
INF	-0.186***	11.402	0.000
CSD-Statistics	-	0.019	0.938

Note: ***, ** & * denote the level of significance at 1 percent, 5 percent and 10 percent, respectively.

The results of the short-run regression are very similar to the results of the long-run regression, except for two cases: trade openness and inflation. The coefficient of energy productivity is positive and statistically significant at the 5 percent level, indicating that energy productivity has a positive effect on economic efficiency in both the long run and short run. This suggests that to make a country more economically efficient, energy should be used efficiently. For trade openness and inflation with economic efficiency, the coefficients of both trade openness and inflation were found to be statistically insignificant. However, the nature of the relationship is the same for all of the relationships. Similarly, for income and inflation with carbon dioxide emissions, both coefficient results were found to be statistically insignificant. However, the nature of the relationship is the same for all of the relationships. This is understandable as these phenomena have their impact over a longer period of time; therefore, it is difficult to study the relationship of these phenomena in a short period of time. All of these results, along with the path coefficients and significance of the short run, are summarized in Table 7.

Table 7

Results of CS-ARDL Analysis (Short Run CS-ARDL Results)

Variables	Coefficients	t-statistics	p-values
Dependent Variable: EEF			
CAP	0.185***	3.686	0.000
LAB	0.137*	1.938	0.060
EPRO	0.143**	2.042	0.048
TOP	0.057	0.314	0.755
INF	0.093	1.512	0.139
ECT(-1)	-0.196	-3.586	0.000

Note: ***, ** & * denote the level of significance at 1 percent, 5 percent and 10 percent, respectively.

Lastly, the robustness of the findings is evaluated by employing the augmented mean group (AMG) and the common correlated effect mean group (CCEMG). The results of these two tests are found to be similar to the findings of CS-ARDL. The coefficients of the independent variables are all found to be statistically significant except for the coefficient of inflation, which is found to be positive and significant in these two tests (it was statistically insignificant in the previous estimation). As before, the coefficient of energy productivity is statistically significant in both equations. Hence, the findings that energy productivity has a positive effect on economic efficiency are robust to various estimation methods, suggesting its importance in enhancing economic efficiency. The results, along with the path coefficients and significance, are summarized in Table 8.

Table 8

Results of AMG & CCEMG for Robustness Check

Variables	Augmented Mean Group (AMG)					
	Coefficients	t-statistics	p-values	Coefficients	t-statistics	p-values
			Dependent Variable: EEF			
CAP	0.228***	3.598	0.000	0.175***	2.953	0.003
LAB	0.186***	4.242	0.000	0.224***	3.330	0.000
EPRO	0.332***	5.661	0.000	0.296***	4.976	0.000
TOP	0.486***	3.096	0.000	0.513***	2.586	0.038
INF	0.226***	8.342	0.000	0.167***	11.330	0.000
Wald test	-	32.583	0.000	-	29.440	0.000

Note: ***, ** & * denote the level of significance at 1 percent, 5 percent and 10 percent, respectively.

CONCLUSION AND RECOMMENDATIONS

The present study used the advanced methodology of CS-ARDL, which is known for producing robust and reliable results. The present study focuses on the ASEAN region, which consists of countries that remain heavily dependent on non-renewable energy, resulting in significant environmental pollution. After addressing the concerns of stationarity, cross-sectional dependence and assessing slope homogeneity, the findings from CS-ARDL reveal that energy productivity is found to have a positive and significant relationship with economic efficiency. The results show that an increase in energy productivity will increase economic efficiency. The results suggest that ASEAN countries can increase their economic efficiency, producing goods at a lower cost, hence becoming globally competitive by increasing energy productivity. The positive effect on economic efficiency suggests the need for more aggressive energy efficiency.

A few suggestions to improve energy productivity can be proposed to the policymaker. First, ASEAN countries should adopt alternative or renewable energy resources that support environmentally friendly energy production to ensure sustainable energy. Second, ASEAN countries should encourage smart energy systems to be installed at government buildings or manufacturing buildings that deploy new technologies that increase energy efficiency.

Based on the findings, it is recommended that the countries belonging to this region take certain initiatives collectively. These include establishing laws and regulations and policies that safeguard the environment.

Although these countries possess significant natural resources, particularly forests, they need to introduce or strengthen rules and regulations for the preservation and conservation of natural resources, especially forests and wildlife. Therefore, Southeast Asian countries should invest in the development of green technologies in the short term and long term to reduce the release of pollutants and hazardous waste into the environment. By proposing this strategy, they can eliminate the waste materials as well as promote recycling waste to improve energy efficiency and to reduce dependence on imported energy.

In addition, countries need to invest in technology to increase energy productivity so that maximum output can be achieved with the least energy consumption. Moreover, the government needs to invest more in renewable energy so that the balance between economic prosperity and environmental deterioration is maintained. Nevertheless, the role of energy productivity in environmental efficiency cannot be ignored and hence careful considerations by the government bodies of all the countries of the ASEAN region need to be taken, as discussed.

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