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CO_2 Emissions, Energy Consumption, and Economic Growth: New Evidence in the ASEAN Countries

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Abstract: The members of the Association of Southeast Asian Nations (ASEAN) have made several attempts to adopt renewable energy targets given the economic, energy-related, environmental challenges faced by the governments, policy makers, and stakeholders. However, previous studies have focused limited attention on the role of renewable energy when testing the dynamic link between CO_2 emissions, energy consumption and renewable energy consumption. As such, this study is conducted to test a common hypothesis regarding a long-run environmental Kuznets curve (EKC). The paper also investigates the causal link between carbon dioxide (CO_2) emissions, energy consumption, renewable energy, population growth, and economic growth for countries in the region. Using various time-series econometrics approaches, our analysis covers five ASEAN members (including Indonesia, Myanmar, Malaysia, the Philippines, and Thailand) for the 1971–2014 period where required data are available. Our results reveal no long-run relationship among the variables of interest in the Philippines and Thailand, but a relationship does exist in Indonesia, Myanmar, and Malaysia. The EKC hypothesis is observed in Myanmar but not in Indonesia and Malaysia. Also, Granger causality among these important variables varies considerably across the selected countries. No Granger causality among carbon emissions, energy consumption, and renewable energy consumption is reported in Malaysia, the Philippines, and Thailand. Indonesia experiences a unidirectional causal effect from economic growth to renewable energy consumption in both short and long run and from economic growth to CO_2 emissions and energy consumption. Interestingly, only Myanmar has a unidirectional effect from GDP growth, energy consumption, and population to the adoption of renewable energy. Policy implications have emerged based on the findings achieved from this study for each country in the ASEAN region.

Keywords: ASEAN; CO_2 emissions; economic growth; EKC; energy consumption; Granger causality; VECM

JEL Classification: C22; C32; Q43; Q56

1. Introduction

The Association of Southeast Asian Nations (ASEAN) has experienced a profound economic transformation, attained high economic growth, and become the most dynamic economic area in the world in recent years (De Grauwe and Zhang 2016). The region, which is home to around 630 million people and has gross domestic production (GDP) of approximately US$2.4 trillion, plays a large role in boosting regional integration and cooperation in East Asia and is becoming a driving force behind global growth, according to the fifth ASEAN energy outlook, in 2017. This economic development requires an enormous supply of energy, which heavily depends on fossil fuel with the consequence of environmental degradation.

In its 2017 report on the Southeast Asia energy outlook, the International Energy Agency (IEA) highlighted that achieving stable economic growth, meeting energy demand in a secure, affordable, and sustainable manner, as well as maintaining an acceptably low level of environment degradation, are multiple challenges that the governments in the Southeast Asia nations encounter. Many ASEAN countries have made tremendous efforts to tackle those challenges. A wide range of policies aimed at the adoption and use of renewable energy have been implemented as a result of not only the influence of the Paris Agreement but also the national plans for energy consumption. The fifth ASEAN energy outlook indicated that the members of the ASEAN countries have made several attempts to adopt targets for renewable energy. For example, Indonesia has developed and implemented a plan to increase new and renewable energy as a share of total primary energy supply (TPES) to 23 percent in 2025 and approximately 30 percent in 2050, and the country expects to reduce greenhouse gas (GHG) emissions to under 30 percent by 2020 below the business-as-usual level. Malaysia has set a target for increasing the capacity of renewable electricity supply to around 8 percent of total installed capacity by 2020 and decreased the ratio of GHG emissions to GDP by 35 percent by 2030, compared to the level in 2005. In its national renewable energy program roadmap to 2030, the Philippine government set a goal for every source of renewable energy that will triple the installed capacity of renewables-based supply by 2030 compared to its 2010 level, together with controlling GHG and stabilizing it at less than 16 percent of the business-as-usual level. Thailand has the more profound objective of increasing renewable energy to 30 percent of total energy usage by 2036 in power generation, heating, and transport fuel consumption. These efforts in the expansion of renewable energy use to rebalance the energy mix could depend significantly on a country's resource availability, energy security, and environmental targets. On these grounds of these strong, committed and ambitious policies formulated and implemented by various ASEAN nations, it is the claim of this paper that it is vitally important to understand the relationship among economic growth, energy demand, renewable energy use, and environmental degradation in the context of gradual population growth. Findings from this paper will enhance greatly understanding and rationales for policies from these ASEAN nations and other emerging markets.

The context of economic growth in the region raises the question of the environment in the EKC hypothesis. This hypothesis stipulates that an increase in a country's income leads to a corresponding increase in the level of CO_2 emissions at the early stage of economic development, but in the later stage, the impact is reversed at a certain income threshold. The adoption of environmentally harmful technology in economic activities, lack of awareness of environmental problems, and the goal of higher profit in premature economic development can explain the parallel pattern in the level of per capita income and environmental degradation at this stage. However, higher per capita income, improved social indicators, and safer technology in the mature stage create a turning point in the growth-environment nexus (Zoundi 2017).

Many scholars have tested the EKC in the context of the ASEAN region focused only on economic growth, energy consumption, and CO_2 emissions. For instance, Tang and Tan (2015) confirmed the validity of the EKC hypothesis in Vietnam over the 1976–2009 period. Yet Al-Mulali et al. (2015) found no evidence to support the existence of the EKC over the 1981–2011 period, and Shahbaz et al. (2019) arrived at the same conclusion for the period 1976 to 2016. Ozturk and Al-Mulali (2015) failed to confirm the validity of the EKC but found a U-shaped relationship between economic growth and CO_2 emissions in Cambodia in 1996–2012 period. Begum et al. (2015) reached the same conclusions as those from Ozturk and Al-Mulali (2015) in a study for Malaysia over the 1980–2009 period. In contrast, Saboori et al. (2016) found the opposite result, supporting the existence of the EKC in Malaysia. Saboori and Sulaiman (2013) used a recently developed cointegration approach based on the autoregressive distributed lag (ARDL) model to examine the cointegration among economic growth, CO_2 emissions, and energy consumption in five ASEAN countries over the 1971–2008 period. They supported the EKC hypothesis in Singapore and Thailand, found a U-shaped relationship (the inverted EKC hypothesis) in Indonesia and the Philippines. The different levels of economic development may reflect their mixed results although these countries are housed in the same region.

The paper makes significant contributions to the contemporary literature on this important issue. Our attempt is to supplement empirical evidence in relation to an EKC hypothesis in the ASEAN region. Although numerous scholars have investigated the link between economic growth, energy consumption, and environmental degradation, little attention has been paid to renewable energy, which has emerged as an alternative source of fossil fuel energy. The only exception is a study from Liu et al. (2017), who analyzed Granger causality among per capita CO_2, economic growth, renewable and nonrenewable energy consumption, and agricultural value added in four ASEAN members—Indonesia, Malaysia, the Philippines, and Thailand—over the 1970–2013 period. Their findings show a long-run relationship among those variables but a turning point in the EKC hypothesis is not observed. As such, our empirical study will bridge the gap on this important link. We critically examine the relationship among economic development, energy consumption, environmental degradation, and population growth in the ASEAN region. A special focus on renewable energy usage is the most significant contribution of the paper.

Useful insights on renewable energy also benefit the governments, policy makers, and stakeholders in the ASEAN region in dealing with economic, energy-related and environmental challenges. The EKC hypothesis and the causality between economic growth, energy consumption and CO_2 emissions were tested using a panel of ASEAN countries in previous studies (e.g., Heidari et al. 2015; Le and Quah 2018; Lean and Smyth 2010; Nasreen and Anwar 2014). These studies ignored the usage of renewable energy in the context that ASEAN countries have a strong desire for such kind of energy in coming years. Also, pooling a panel of countries in a whole sample can potentially suffer a difficulty in relation to policy implementations on this important link. The ASEAN countries vary considerably in terms of economic development and size as well as their targets for renewable energy. Thus, it is essential to analyze the interrelationship among economics, energy consumption, environmental degradation, the use of renewable energy for a case-by-case country. A thorough understanding of this interrelationship at a country level enables the governments not only to design proper strategies for sustainable economic development, energy security, and environmental protection but also to achieve an optimal, effective, and efficient level of consumption and supply of renewable energy.

To achieve our objectives, a common validity of the EKC hypothesis is tested in the long run and investigate the causal link between CO_2 emissions, energy consumption, renewable energy, population growth, and economic growth for five ASEAN members, including Indonesia, Myanmar, Malaysia, the Philippines, and Thailand over the 1971–2014 period. The selection of countries is based on data availability. We use several econometrics techniques on time series, including advanced cointegration tests, two long-run estimators—the fully modified ordinary least squares (FMOLS) and the dynamic ordinary least squares (DOLS)—and a causality test based on the vector error correction model (VECM) framework. Using these techniques will strengthen the validity of our conclusions.

The paper is organized as follows. Following this Introduction, Section 2 discusses relevant theories and empirical studies related to the EKC hypothesis as well as the causal relationship among the variables of interests. The methodology is presented in Section 3, while Section 4 describes the data and empirical results. Our conclusions are discussed in Section 5.

2. Literature Review

2.1. The Environmental Kuznets Curve (EKC) Hypothesis

To date, many studies on the EKC hypothesis have failed to reach a consensus; some failed to reject the null hypothesis of the validity of the EKC while others found supporting evidence. One major factor causing such an unclear conclusion is the econometrics testing method, the countries in the sample, and the period studied in the analysis.

Several studies have reported mixed evidence on the EKC hypothesis using a country panel over a particular time period with the use of CO_2 emissions as pollutants. The EKC appears to be present in the member countries of the Organization for Economic Cooperation and Development (OECD) (Bilgili et al. 2016; Jebli et al. 2016), in G-7 countries (Raza and Shah 2018), in the European Union region (Dogan and Seker 2016), in Central America (Apergis and Payne 2014), among a wide group of developed and developing countries globally (Ibrahim and Law 2014), as well as in Asia (Heidari et al. 2015). Other scholars failed to confirm the validity of the EKC hypothesis based on empirical evidence in both developed and developing countries (Apergis et al. 2010).

The same pattern of inconclusive findings in relation to the EKC hypothesis with the use of CO_2 emissions is observed in various studies on a particular country using time-series data. Supporting evidence is observed in France (Iwata et al. 2010), Indonesia (Sugiawan and Managi 2016), China (Jalil and Mahmud 2009; Jayanthakumaran and Liu 2012), and Pakistan (Shahbaz et al. 2015; Shahzad et al. 2017). Other papers failed to confirm the validity of EKC—for instance, Soytas et al. (2007) found no presence of the EKC in the US, which is further supported by Dogan and Ozturk (2017), even when taking a structural break into consideration.

The most striking characteristic in earlier empirical studies is that they used the same sample of a country with different timespans and econometrics techniques but come to a completely different conclusion regarding the EKC hypothesis. One example is a study for Malaysia, where Saboori et al. (2016) confirmed the presence of the EKC over the 1980–2008 period, while Ali et al. (2017), Begum et al. (2015), and Gill et al. (2018) presented the opposite outcome. A contradictory finding is observed in Vietnam (Tang and Tan 2015; Al-Mulali et al. 2015) and in Turkey (Pata 2018; Soytas et al. 2007).

Another potential factor contributing to the mixed findings arising from previous empirical studies on the validity of the EKC hypothesis is the proposed model tested with diverse additionally controlled variables. Various factors have been added to a traditional EKC model. These variables include energy consumption (Le and Quah 2018; To et al. 2019), trade openness (Halicioglu 2009; Halicioglu and Ketenci 2018; Jayanthakumaran and Liu 2012; Ozturk and Acaravci 2013), financial development (Dogan and Seker 2016; Dogan and Turkekul 2016; Shahbaz et al. 2013), population (Dong et al. 2018; Zoundi 2017), and urbanization (Ozturk and Al-Mulali 2015; Dogan and Turkekul 2016; Saidi and Mbarek 2016). Other studies integrated all sorts of variables and used them to test the EKC hypothesis (Ozatac et al. 2017; Pata 2018). For example, Ozatac et al. (2017) confirmed the EKC hypothesis in Turkey over the 1971–2013 period, integrating energy consumption, trade openness, financial development, and urbanization into the proposed model. So, the role of these variables should not be ignored in testing the EKC hypothesis.

Many studies investigated the relationship between energy use and the amount of CO_2 emissions produced by economic development. Some scholars have tested the link between economic growth and carbon emissions (Nguyen and Kakinaka 2019). The role of renewable energy in the EKC hypothesis has gained attention among scholars as part of efforts to reverse the effects of environment degradation. It is well recognized renewable energy sources have many benefits in terms of increased energy security, sustainable economic growth, and pollution reduction (Şener et al. 2018).

Contemporary studies have also employed the variable of renewable energy in models testing the EKC hypothesis. Raza and Shah (2018) confirmed the EKC hypothesis in the G7 countries due to the trade openness and renewable energy consumption based on panel data over the 1991–2016 period. Pata (2018) confirmed the EKC hypothesis using a model including renewable energy, urbanization, and financial development in Turkey over the 1974–2014 period after controlling for structural breaks over the selected period.

The adoption of parametric approach in testing the EKC hypothesis may face the problem of misspecification. As such, the nonparametric strand of the EKC literature has emerged to further explain the mixed results as it does not require the specification of a functional form (Shahbaz et al. 2017). Using a novel nonparametric econometrics approach is expected to yield a more insightful understanding of the EKC literature. For example, Azomahou et al. (2006) revealed a contradict result in relation to the EKC hypothesis using both parametric and non-parametric method. While the estimation of a parametric specification supported the EKC, the non-parametric approach opposed to the parametric finding. Similarly, when employing a non-parametric approach in the MENA region, Fakih and Marrouch (2019) found the none-existence of an EKC in contrast to the findings from Arouri et al. (2012), who presented evidence of EKC relationship between CO_2 emissions and GDP. Recently, based on a nonparametric approach with the data over nearly two centuries, Shahbaz et al. (2017) argued for an existence of the EKC in six out of the G-7 countries—Canada, France, Germany, Italy, UK and the US with an exception for the case of Japan. Recently, Kalaitzidakis et al. (2018) used a semiparametric smooth coefficient model to investigate the impact of CO_2 emissions on economic growth, as measured by total factor productivity, among a set of the Organization for Economic Co-operation and Development (OECD) countries during the 1981–1998 period. Their results reported a robust non-linear relationship between these variables and showed that CO_2 emissions contributes marginally to productivity growth, approximately 0.07 percent on average. These findings highlighted the nature of nonlinearity in the relationship between income and environment degradation.

2.2. The Causal Link between Renewable Energy Use, Economic Growth, and Environmental Degradation

From a theoretical perspective, a causal link is observed between the use of renewable energy, economic growth, and environmental degradation. Higher income raises demand for energy consumption and consequently exacerbates degradation of the environment. Increasing concerns about energy security and global warming, in turn, create greater pressure for the use of renewable energy. Renewable energy is an ideal substitute for fossil fuels and results in fewer CO_2 emissions (Bilgili et al. 2016). As such, sustainable economic growth is compatible with the use of renewable energy.

On the empirical aspect, the directional effect among renewable energy consumption, economic growth, and environmental degradation varies considerably across studies. Some scholars recognized a unidirectional causal effect. The short-run unidirectional casual effect from renewable energy consumption to CO_2 emissions was found in 25 African countries by Zoundi (2017), in BRICS (Brazil, Russia, India, China, and South Africa) countries by Sebri and Ben-Salha (2014). Shafiei and Salim (2014) showed unidirectional causality from renewable energy consumption to CO_2 emissions in the long run in 29 OECD member countries between 1980 and 2011. The same pattern was observed in Bilgili et al. (2016) in a smaller sample of 17 OECD countries in the 1977–2010 period. Additionally, Sadorsky (2009) demonstrated that increases in real per capita income and per capita CO_2 emissions led to an increase in the use of renewable energy in the long run in the G7 countries. Based on a sample of nine developed countries, Saidi and Mbarek (2016) revealed a unidirectional effect from renewable energy consumption to economic growth, but in the long run, they Granger-cause each other. In contrast, Jebli et al. (2016) observed short-run Granger causality from economic growth to renewable energy.

Several studies revealed reverse causality among economic growth, renewable energy, and CO_2 emissions. Apergis et al. (2010) reported a bidirectional causal relationship between each pair of three variables of interest in seven Central American countries both in the short and long run. Raza and Shah (2018) found that economic growth is positively associated with CO_2 emissions in the long run, as well as the reverse causality from CO_2 emissions to renewable energy consumption in G7 countries. The bidirectional Granger causality between renewable energy and CO_2 emissions is observed by Dogan and Seker (2016) in 15 EU member countries in the short run and by Dong et al. (2017) in BRICS countries in the long run.

In consistency with studies that use panel data on several countries over a long period, an investigation on Granger causality in particular countries presents mixed directions, either unidirectional or bidirectional. A unidirectional effect from renewable energy to CO_2 emissions is observed in the US (Jaforullah and King 2015), Denmark and Finland (Irandoust 2016), Indonesia (Sugiawan and Managi 2016), and Algeria (Belaid and Youssef 2017). Recently, using a VECM-based

Granger-causality test, Bekhet and Othman (2018) found unidirectional causality from CO_2 emissions to renewable energy in Malaysia. Reverse causality is observed in Sweden and Norway by Irandoust (2016). The varying patterns in the directional effect among economic growth, renewable energy, and CO_2 emissions demonstrate the need for more investigation on the complicated relationship among those variables.

3. Methodology

3.1. Model Specification and Data Source

Stern (2004) proposed three causes of the EKC relationship via the scale, technique, and composition effects. The scales effect implies the expansion of production which will lead to a corresponding increase in the amount of polluted emissions. The component effect postulates the heterogeneity of pollution intensities across industries. The technique effect indicates the improvement of the state of technology which will lead to a lower pollutant generated. This can be achieved through either a higher productivity, meaning a reduction of inputs for a given output, or lowering emissions per unit of input with innovations. On the ground of those effects, in this paper, we shed a light on the importance of using renewable energy for the growth-environment nexus using the following model specification.

$$LnCO_{2t} = \alpha_0 + \alpha_1 LnY_t + \alpha_2 LnY_t^2 + \alpha_3 LnEC_t + \alpha_4 LnRE_t + \alpha_5 LnPOP_t + \varepsilon_t \tag{1}$$

in which CO_2 represents per capita CO_2 emissions at year t. EC_t is per capita energy consumption; RE_t is per capita consumption of renewable energy; Y_t and Y_t^2 denote real per capita GDP and the square of real per capita GDP at year t, respectively; and POP_t is the population of the country at year t. The residuals ε_t are assumed to be normally distributed and white noise.

We focus on long-run coefficients ($\alpha_i, i = 1, \ldots, 4$), which indicate the effect of the independent variables—economic growth, use of renewable energy, and population size—on the dependent variable, CO_2 emissions. α_1 and α_2 are expected to be positive and negative, respectively, so that the EKC hypothesis holds. An increase in the consumption of renewable energy is expected to mitigate CO_2 emissions, thus α_3 is expected to be negative while the impact of population growth on CO_2 emissions is expected to be positive, as higher population growth is more likely to raise CO_2 emissions.

All the data on the five ASEAN countries including Indonesia, Myanmar, Malaysia, the Philippines, and Thailand are collected from the World Bank's World Development Indicators, over the 1971–2014 period. Renewable energy is proxied by combustible renewables and waste. Income is measured by real per capita GDP in constant 2010 US dollars. Population is total population, and CO_2 emissions is total CO_2 emissions from energy consumption in millions of metric tons, which is converted into kilograms per capita. Table 1 describes the data, with all variables transformed into their natural logarithmic form.[1]

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[1] We have rescaled all the variables so that a number of values falls between zero and one. As such, these values are negative when taking the logarithm.

Table 1. Data description.

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
Indonesia					
$LnCO_2$	44	−0.04	0.53	−1.11	0.94
LnY	44	0.58	0.43	−0.22	1.31
LnY^2	44	0.51	0.50	0.00	1.71
$LnEC$	44	−0.61	0.37	−1.21	−0.12
$LnREC$	44	−0.02	1.78	−3.06	1.98
$LnPOP$	44	5.21	0.23	4.77	5.54
Myanmar					
$LnCO_2$	44	−1.73	0.29	−2.29	−0.88
LnY	44	−1.14	0.64	−1.79	0.24
LnY^2	44	1.70	1.11	0.00	3.21
$LnEC$	44	−1.26	0.07	−1.37	−0.99
$LnREC$	44	−1.11	0.64	−1.89	0.39
$LnPOP$	44	3.69	0.20	3.30	3.95
Malaysia					
$LnCO_2$	44	1.31	0.58	0.41	2.08
LnY	44	1.62	0.47	0.72	2.34
LnY^2	44	2.85	1.51	0.52	5.48
$LnEC$	44	0.34	0.56	−0.65	1.09
$LnREC$	44	0.49	0.54	−0.66	1.35
$LnPOP$	44	2.94	0.31	2.40	3.41
Philippines					
$LnCO_2$	44	−0.24	0.16	−0.66	0.05
LnY	44	0.50	0.16	0.25	0.92
LnY^2	44	0.27	0.19	0.06	0.84
$LnEC$	44	−0.79	0.06	−0.90	−0.67
$LnREC$	42	1.75	1.08	−0.88	2.62
$LnPOP$	44	4.16	0.30	3.61	4.61
Thailand					
$LnCO_2$	44	0.54	0.75	−0.68	1.53
LnY	44	0.92	0.57	−0.05	1.72
LnY^2	44	1.16	1.00	0.00	2.96
$LnEC$	44	−0.20	0.57	−1.02	0.69
$LnREC$	44	−0.35	0.33	−1.47	0.18
$LnPOP$	44	4.02	0.17	3.64	4.23

Notes: Std. Dev. is standard deviation. All variables are in logarithm.

3.2. Cointegration Tests

We examine the long-run relationship among the variables of interest employing the traditional Johansen cointegration approach and the bounds-testing approach to cointegration. The first test is proposed by Johansen (1988) and further developed by Johansen and Juselius (1990) while the second approach, a relatively new technique based on the ARDL model, is constructed by Pesaran et al. (2001). Using two well-known cointegration tests yields a more robust conclusion, and between the two, the ARDL bounds-testing approach has greater advantages (Sebri and Ben-Salha 2014). First, the ARDL technique works well with a small sample such as ours, and it can test a cointegrating relationship among underlying regressors and a regressand with uncertainty as to whether they are I(0) or I(1) (Narayan 2005; Pesaran et al. 2001). Second, the ARDL bounds-testing approach can address potential endogeneity problems, thus yielding an unbiased long-run estimation and interpreting the short-and long-run effects with a single regression (Sebri and Ben-Salha 2014). Based on Equation (1), the ARDL-based approach to cointegration can be represented as follows:

$$\begin{aligned}\Delta LnCO_{2t} = \gamma_0 \quad & + \sum_{i=1}^{k1} \gamma_{1i} \Delta LnCO_{2t-i} + \sum_{i=0}^{k2} \gamma_{2i} \Delta LnY_{t-i} + \sum_{i=0}^{k3} \gamma_{3i} LnY^2_{t-i} \\ & + \sum_{i=0}^{k4} \gamma_{4j} \Delta LnRE_{t-i} + \sum_{i=0}^{k5} \gamma_{5i} \Delta LnPOP_{t-i} + \varnothing_{11} LnCO_{2t-1} \\ & + \varnothing_{12} LnY_{t-1} + \varnothing_{13} LnY^2_{t-1} + \varnothing_{14} LnRE_{t-1} + \varnothing_{15} LnPOP_{t-1} + \epsilon_t\end{aligned} \tag{2}$$

where Δ denotes the first difference of the selected variables while γ_{1i} and $\varnothing_{1i}$ ($i = 1, \ldots, 4$) are the estimated parameters. ki ($i = 1, \ldots, 4$) are the optimal lag length determined by Akaike's information criterion (AIC), and ϵ_t is an error term of white noise.

Under the ARDL model as expressed in Equation (2), Pesaran et al. (2001) proposed two standard cointegrating tests, namely, the F- and t-statistics, for the purpose of testing a null hypothesis of no cointegration. These tests examine the significance of the lagged level of the regressors on the regressand using a univariate equilibrium correction mechanism. The confirmation of conintegration checks whether all the estimated coefficients of the lag level equal zero. That is, the t-statistics test the null hypothesis $\varnothing_1 = 0$ against the alternative $\varnothing_1 \neq 0$, whereas the F-statistics test the null hypothesis $\varnothing_i = 0 \left(i = \overline{1,4}\right)$ against the alternative of at least $\varnothing_i \neq 0$ $(i = 1, \ldots, 4)$. If the estimated F-statistic is smaller than the lower-bound critical value (larger than an upper one), then the null hypothesis is rejected (accepted); otherwise, there knows no conclusion.

Pesaran et al. (2001) supplemented the critical value bounds for the F- and t-test in their analysis, but Narayan (2005) used a simulation method to reproduce critical values for the ARDL bounds test with a small sample size (between 30 and 80 observations). As the time span of our study is quite short, we refer to Narayan (2005)'s critical values for confirmation of a cointegrating relationship among the variables in the proposed model. Before calculating these two statistics, we ensure that the error terms are serially uncorrelated and homoskedastic and select optimal lags using AIC.[2]

3.3. Granger-Causality Test

To test whether a cointegrating relationship exists among CO_2 emissions, energy consumption, the use of renewable energy, income, and the square of income, and population size, we perform a long-run Granger-causality test in the framework of the VECM. The VECM specification provides both short- and long-run Granger-caused relationships among all the variables. Equation (1) is revised with a VECM framework as follows:

$$\begin{aligned}\Delta LnCO_{2t} = \pi_0 \quad & + \sum_{j=1}^{n} \pi_{1j} \Delta LnCO_{2t-j} + \sum_{j=0}^{n} \pi_{2j} \Delta LnY_{t-j} + \sum_{j=0}^{n} \pi_{3j} LnY^2_{t-j} \\ & + \sum_{j=0}^{n} \pi_{4j} \Delta LnRE_{t-j} + \sum_{j=0}^{n} \pi_{5j} \Delta LnPOP_{t-j} + \varphi_1 ECT_{t-1} + \epsilon_{1t}\end{aligned} \tag{3}$$

$$\begin{aligned}\Delta LnY_t = \delta_0 + \quad & \sum_{j=0}^{n} \delta_{1j} \Delta LnCO_{2t-j} + \sum_{j=1}^{n} \delta_{2j} \Delta LnY_{t-j} + \sum_{j=0}^{n} \delta_{3j} \Delta LnY^2_{t-j} \\ & + \sum_{j=0}^{n} \delta_{4j} \Delta LnRE_{t-j} + \sum_{j=0}^{n} \delta_{5j} \Delta LnPOP_{t-j} + \varphi_2 ECT_{t-1} + \epsilon_{2t}\end{aligned} \tag{4}$$

$$\begin{aligned}\Delta LnY^2_t = \theta_0 + \quad & \sum_{j=0}^{n} \theta_{1j} \Delta LnCO_{2t-j} + \sum_{j=0}^{n} \theta_{2j} \Delta LnY_{t-j} + \sum_{j=1}^{n} \theta_{3j} \Delta LnY^2_{t-j} \\ & + \sum_{j=0}^{n} \theta_{4j} \Delta LnRE_{t-j} + \sum_{j=0}^{n} \theta_{5j} \Delta LnPOP_{t-j} + \varphi_3 ECT_{t-1} + \epsilon_{3t}\end{aligned} \tag{5}$$

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[2] For details of the procedures in the bounds test, see earlier studies, such as Pesaran et al. (2001) and Vo et al. (2019).

$$\begin{aligned}\Delta LnRE_t = \beta_0 + & \sum_{j=0}^{n} \beta_{1j}\Delta LnCO_{2t-j} + \sum_{j=0}^{n} \beta_{2j}\Delta LnY_{t-j} + \sum_{j=0}^{n} \beta_{3j}\Delta LnY^2_{t-j} \\ & + \sum_{j=1}^{n} \beta_{4j}\Delta LnRE_{t-j} + \sum_{j=0}^{n} \beta_{5j}\Delta LnPOP_{t-j} + \varphi_4 ECT_{t-1} + \epsilon_{4t}\end{aligned} \tag{6}$$

$$\begin{aligned}\Delta LnPOP_t = \rho_0 & + \sum_{j=0}^{n} \rho_{1j}\Delta LnCO_{2t-j} + \sum_{j=0}^{n} \rho_{2j}\Delta LnY_{t-j} + \sum_{j=0}^{n} \rho_{3j}\Delta LnY^2_{t-j} \\ & + \sum_{j=0}^{n} \rho_{4j}\Delta LnRE_{t-j} + \sum_{j=1}^{n} \rho_{5j}\Delta LnPOP_{t-j} + \varphi_5 ECT_{t-1} + \epsilon_{5t}\end{aligned} \tag{7}$$

where Δ denotes the first difference of the selected variables, and n is the number of optimal lags. The residuals ($\epsilon_{it}, i = 1, \ldots, 5$) are assumed to be serially independent with a zero mean and a finite covariance matrix. ECT_{t-1}, the error correction term (ECT), is its one-period lagged estimation derived from the long-run regression in Equation (1).

Within the VECM framework, short-run Granger causality from income to CO_2 emissions is tested via the null hypothesis that all the coefficients of income and the square of income in Equation (3) are zero, simultaneously. So, we test $\pi_{2j} = \pi_{3j} = 0 \; \forall n$, using the Wald test. Rejection of the null hypothesis means that a unidirectional causal effect exists from income to CO_2 emissions. To confirm whether CO_2 emissions Granger-cause income, after estimating Equations (3) and (4), we test the significance of $\delta_{1j} = \theta_{1j} = 0 \; \forall n$ using the Wald test. If we find at least $\delta_{1j} \neq \theta_{1j} \neq 0$, we can conclude that a unidirectional causal effect exists from CO_2 emissions to income. Furthermore, a rejection of both $\pi_{2j} = \pi_{3j} = 0 \; \forall n$ and $\delta_{1j} = \theta_{1j} = 0 \; \forall n$ implies a bidirectional Granger-causal relationship between income and CO_2 emissions. Meanwhile, acceptance of these conditions illustrates that the two variables of interest have no causal relationship. A similar procedure can be performed for each pair of variables in Equations (3)–(7) to examine the Granger causality.

The long-run Granger-causality test is based not only on the conditions in short-run Granger causality but also a coefficient of the ECT. Specifically, we test the significance of $\varphi_1 = \pi_{2j} = \pi_{3j} = 0$, and rejecting this test indicates that income Granger-causes CO_2 emissions in the long run. Similarly, a rejection of the test $\varphi_2 = \varphi_2 = \delta_{2j} = \theta_{3j} = 0$ means a reverse Granger-caused relationship from CO_2 emissions to income in the long run. Using the same procedure, we examine the long-run Granger-caused relationship between other pairs of variables in the equations.

If Equation (1) shows no cointegration, we do not examine long-run causality. Instead, we conduct a short-run Granger-causality test using the vector autoregression (VAR) framework, in which we take the first difference of the variables to ensure that the data are stationary for our analysis.

4. Empirical Results and Discussions

4.1. Results of Unit-Root and Cointegration Tests

We begin our analysis by checking whether the time series of the given variables is stationary because regressing non-stationary variables leads to spurious estimation. We employ the Dickey–Fuller generalized least squares (DF-GLS) unit-root test by Elliott et al. (1996). The DF-GLS test is a modified version of traditional augmented Dickey–Fuller (ADF) test (Dickey and Fuller 1979), in which the time series is transformed via a GLS regression before the test is performed. Thus, it is perceived to be more robust and significantly powerful than the ADF test.

Table 2 illustrates the DF-GLS tests for all the variables of interest, namely CO_2 emissions, energy consumption, the use of renewable energy, income and the square of income, and population size. We find that the five ASEAN countries including Indonesia, Myanmar, Malaysia, the Philippines, and Thailand reject the null hypothesis of containing a unit root in population size at level. In other words, this variable is stationary or integrated I(0) although relatively week evidence is observed in Thailand at a level of 10 percent significance. Meanwhile, the test for the remaining variables—CO_2 emissions, energy consumption, renewable energy consumption, real income, and the square of real income—rejects the null hypothesis at the first difference, meaning they are integrated at I(1).

Table 2. The results of unit-root tests.

Country	Variable	Level			1st Difference			Order of Integration
		DF-GLS	DF	PP	DF-GLS	DF	PP	
Indonesia	$LnCO_2$	−2.13	−3.08	−2.96	−3.97 ***	−6.00 ***	−6.02 ***	I(1)
	lnY	−2.03	−1.98	−2.24	−3.26 **	−4.80 ***	−4.74 ***	I(1)
	LnY^2	−0.78	−0.33	−0.60	−3.38 **	−4.83 ***	−4.77 ***	I(1)
	$LnEC$	−1.29	−1.24	−1.22	−3.81 ***	−3.63 **	−6.68 ***	I(1)
	$LnREC$	−1.18	−0.65	−0.86	−3.09 *	−5.30 ***	−5.26 ***	I(1)
	$LnPOP$	−5.81 ***	−7.57 ***	−4.16 **	−3.86 ***	0.55	−0.35	I(0)
Myanmar	$LnCO_2$	−1.01	−1.57	−1.50	−2.99 *	−5.01 ***	−4.71 ***	I(1)
	lnY	−1.50	−0.15	−0.59	−1.86	−3.06	−3.12	I(2)
	LnY^2	−2.33	−1.22	−1.71	−1.84	−3.32 *	−3.78 **	I(1)
	$LnEC$	−1.50	−0.21	−0.95	−2.36	−3.51 *	−3.53 *	I(1)
	$LnREC$	−0.93	−1.32	−1.11	−3.86 ***	−7.13 ***	−7.37 ***	I(1)
	$LnPOP$	−6.07 ***	−2.38	−1.52	−5.54 ***	0.24	−1.28	I(1)
Malaysia	$LnCO_2$	−1.91	−2.02	−2.11	−3.31 **	−7.86 ***	−7.79 ***	I(1)
	lnY	−1.68	−2.20	−2.35	−3.01 *	−5.75 ***	−5.72 ***	I(1)
	LnY^2	−2.01	−2.24	−2.38	−3.22 **	−5.98 ***	−5.96 ***	I(1)
	$LnEC$	−1.69	−1.84	−1.72	−3.89 ***	−7.03 ***	−7.39 ***	I(1)
	$LnREC$	−1.92	−1.81	−1.97	−3.96 ***	−5.17 ***	−5.08 ***	I(1)
	$LnPOP$	−3.59 **	−3.71 **	1.53	−2.96 *	−1.49	−1.78	I(0)
Philippines	$LnCO_2$	−1.89	−1.44	−1.74	−2.81	−5.70 ***	−5.79 ***	I(1)
	lnY	−1.22	0.04	−0.69	−3.07 *	−3.56 **	−3.52 *	I(1)
	LnY^2	−0.81	1.78	0.84	−2.63	−3.53 *	−3.52 *	I(1)
	$LnEC$	−2.04	−2.49	−2.53	−2.51	−8.62 ***	−8.33 ***	I(1)
	$LnREC$	−1.93	−1.57	−1.69	−2.60	−3.67 **	−3.58 **	I(1)
	$LnPOP$	−6.67 ***	6.10 ***	3.42 ***	−3.99 ***	−1.67	−1.92	I(1)
Thailand	$LnCO_2$	−1.54	−0.74	−1.17	−3.14 *	−4.48 ***	−4.44 ***	I(1)
	lnY	−1.81	−0.71	−1.29	−2.85	−4.04 **	−4.04 **	I(1)
	LnY^2	−1.81	−2.35	−2.41	−3.02 *	−4.33 ***	−4.34 ***	I(1)
	$LnEC$	−2.01	−1.60	−1.97	−2.39	−4.8 ***	−4.91 ***	I(1)
	$LnREC$	−4.79 ***	−5.36 ***	−5.27 ***	−5.17 ***	−8.97 ***	−10.1 ***	I(1)
	$LnPOP$	−2.94 *	−6.60 ***	4.04 ***	−5.05 ***	−1.36	−2.02	I(0)

Notes: For comparison purposes, we use the Dickey–Fuller Generalized Least Square (DF-GLS), augmented Dickey–Fuller (ADF) and Phillips Pearson (PP) tests with a constant and trend. The DF-GLS test is based on two lags and the remaining tests have three lags. ***, **, and * denote significance level of 1%, 5%, and 10%, respectively. In corresponding to these significant levels, the DFGLS test critical values are −3.77, −3.19, and −2.89 while the ADF and PP tests have interpolated critical values of −4.24, −3.52, and −3.20.

Our study uses two advanced cointegration tests, namely, the Johansen cointegration test developed by Johansen and Juselius (1990) and the bounded approach to cointegration by Pesaran et al. (2001). We then conduct a Granger-causality test with a multi-equation framework to examine whether a causal relationship exists among the variables of interest. In other words, when a long-run relationship exists among the selected variables, we use a VECM; otherwise, we use a vector autoregressive model (VAR).

Table 3 presents the results of the two cointegration tests, in which Panel A presents the Johansen method and Panel B depicts the bounds-testing approach. First, the Johansen test results show that both the maximum lambda and trace statistics are statistically significant at least at the 5 percent level of significance, indicating that the null hypothesis of no cointegration is rejected and that a long-run relationship among the variables exists in all of the selected countries. Interestingly, Indonesia, Myanmar, and Malaysia have as many as three conintegrating vectors in the test. Second, both the *F*- and *t*-statistics fail to confirm a cointegrating relationship among CO_2 emissions, energy consumption, renewable energy consumption, income and the square of income, and population size in the Philippines and Thailand, but not in Indonesia, Myanmar, and Malaysia. Because all the variables in the model are integrated at different levels, the bounds cointegration approach appears to be more appropriate for testing a long-run relationship and yields more consistent results. As such, we rely on the bounds approach rather than the Johansen cointegration test to reach our final conclusions about the long-run relationship.

Table 3. Results of the cointegration tests.

ASEAN Countries		Indonesia		Myanmar		Malaysia		Philippines		Thailand	
Panel A: Johansen cointegration test											
Ho	H1	λ	trace	λ	trace	λ	trace	λ	trace	λ	trace
r = 0	r ≥ 1	84.42 **	186.27 **	91.29 **	201.37 **	54.22 **	152.94 **	67.90 **	167.58 **	49.73 **	117.12 **
r ≤ 1	r ≥ 2	46.51 **	101.85 **	54.58 **	110.08 **	43.64 **	98.72 **	41.53 **	99.68 **	34.12 **	67.40
r ≤ 2	r ≥ 3	31.71 **	55.33 **	24.37	55.50 **	25.19	55.08 **	33.00 **	58.15 **	15.06	33.27
r ≤ 3	r ≥ 4	14.59	23.62	22.23 **	31.14 **	17.3	29.89 **	15.61	25.14	9.43	18.21
r ≤ 4	r ≥ 5	8.22	9.03	8.36	8.90	11.76	12.59	9.38	9.53	6.05	8.77
r ≤ 5	r ≥ 6	0.81	0.81	0.54	0.54	0.83	0.83	0.16	0.16	2.72	2.72
Panel B: Bound cointegration test											
		F-stat	*t*-stat	*F*-stat	*t*-stat	*F*-stat	*t*-stat	*F*-stat	*t*-stat	*F*-stat	*t*-stat
Ho: No cointegration		8.24 ***	−6.37 ***	8.09 ***	−3.81 *	5.04 **	−3.98 *	3.25	−3.07	3.03	−1.14
Model		ARDL (1, 1, 2, 1, 1, 1)		ARDL (1, 2, 2, 1, 1, 2)		ARDL (1, 1, 1, 1, 2, 1)		ARDL (1, 1, 2, 1, 1, 2)		ARDL (1, 1, 1, 1, 1, 1)	

Notes: λ is max lambda value. Panel A shows the Johansen cointegration test by Johansen and Juselius (1990) and Panel B indicates the Bound cointegration test by Pesaran et al. (2001). Due to the small sample size, the critical values for the bounds test in Panel B refer to Narayan (2005), rather than Pesaran et al. (2001). The values are in the third case of the bounds test, which includes unrestricted intercept and no trend. ***, **, and * denote a significance level of 1%, 5%, and 10%, respectively. ASEAN: Association of Southeast Asian Nations.

4.2. Results of Long-Run Relationship

Because of the confirmation of the cointegration test in Indonesia, Myanmar, and Malaysia, we use the FMOLS and DOLS to estimate the long-run relationship with a particular stress on testing the EKC hypothesis as well as on investigating the impact of energy consumption, renewable energy consumption, and population growth on CO_2 emissions. Table 4 shows the estimation results for the long run relationship. Our findings support the presence of an EKC only in Myanmar, as both the FMOLS and DOLS have provided consistent results in which estimated coefficients are statistically positive for income per capita and negative for its square transformation. Because of conflicting results between the FMOLS and DOLS estimators, we did not come to a conclusive result about the EKC hypothesis in Indonesia and Malaysia.[3]

Table 4. The results from long-run estimations.

Variable	Indonesia	Myanmar	Malaysia
FMOLS			
LnY	0.66 ***	−0.12	0.87 ***
LnY^2	−0.09 **	−0.35 ***	0.08
$LnEC$	0.47 ***	1.72 ***	0.43 **
$LnREC$	−0.15 ***	−0.0.003	−0.0004
$LnPOP$	1.58 ***	−0.89 ***	−0.62 *
Const	−8.32 ***	4.15 ***	1.35
DOLS			
LnY	−0.68 ***	0.43 ***	−0.78
LnY^2	0.15 ***	−0.41 ***	0.64 ***
$LnEC$	1.76 ***	2.8 ***	0.8 ***
$LnREC$	−0.27 ***	−0.49 ***	−0.14 **
$LnPOP$	3.6 ***	−1.84 ***	−0.86 **
Const	−18.19 ***	10.33 ***	1.87 *

Notes: ***, **, and * indicate significance levels of 1%, 5% and 10%, respectively.

Our mixed results on the EKC hypothesis in the selected ASEAN countries are in line with previous studies on the region. Some scholars are in favor of the EKC hypothesis. For example, Saboori and Sulaiman (2013) did confirm it in Singapore and Thailand and Saboori et al. (2016) revealed the same conclusion for the case of Malaysia. Our findings in Myanmar support this strand of an EKC literature. In contrast, Saboori and Sulaiman (2013) failed to confirm the EKC hypothesis in Indonesia, Malaysia, and the Philippines while Al-Mulali et al. (2015) reached the same outcome using the Vietnamese data over the 1981–2011 period. Our results are in line with this trend of empirical evidence as we found no conclusion of the EKC hypothesis in the long run in Indonesia, Malaysia, Thailand and the Philippines.

In the long run, the driving forces behind carbon emissions vary considerably from one surveyed country to another. In Indonesia, energy consumption is a contributing factor to CO_2 emissions, and the use of renewable energy mitigates their impact. The population growth also leads to higher carbon emissions. Similar patterns are observed in the driving determinants of CO_2 emissions in Myanmar and Malaysia, whose level of CO_2 emissions is positively associated with energy consumption and negatively related to population growth. The adoption of renewable energy in these two countries would help

[3] It should be noted that although the coefficients of the income per capita and its square form are appropriate in terms of signs and significance levels, the estimation results could be spurious if there is a failure of cointegration of the conventional EKC estimation. The spurious regression is caused not by the quadratic function form, but by the fundamental trend relationship between income per capita and pollutants (Wang 2013). Thanks to the confirmation of the two advanced cointegration tests, our regressions do not suffer spurious estimations.

mitigate the negative environmental impact by reducing the quantity of CO_2 emissions, though the findings are less supported by the FMOLS estimator because of the statistically insignificant coefficients.

4.3. Results of Granger-Causality Tests

Table 5 reveals the causality effect of the variables of interests adopted in this paper. In Indonesia, Myanmar, and Malaysia, we see both long- and short-run causality but only a short-run causal relationship in the Philippines and Thailand. In general, the five countries included in our sample have considerable differences in the causality effect, as shown in Figure 1. In Malaysia, the neutrality effect on one another is observed among energy consumption, renewable energy, and CO_2 emissions in the short and long run, and a causal effect is reported from economic growth to CO_2 emissions and energy consumption. GDP growth unidirectionally Granger causes not only energy consumption but also carbon emissions, and a feedback effect is found between GDP growth and population growth. These findings imply that GDP growth is a key determinant of the amount of energy consumption and environmental degradation. Consistent with our results, Ang (2008) posited that there was an impact of economic growth on energy consumption for Malaysia over the 1971–1999 period.

In Indonesia, GDP growth also plays a key role in causing energy consumption, carbon emissions, and renewable energy use. Economic growth and population growth cause each other. Unidirectional causality is found from energy consumption to population growth and from carbon emissions to energy consumption in both the short and long run. Our results are consistent with those of Sugiawan and Managi (2016) in supporting a unidirectional effect from GDP growth to carbon emissions in the long run in Indonesia. However, unlike Sugiawan and Managi (2016), we detect unidirectional causality from GDP growth to the use of renewable energy, which further supports the EKC hypothesis, as found in earlier studies (Bento and Moutinho 2016).

Several interesting findings are found for Myanmar. It has a complicated causality relationship among five selected variables, and renewable energy usage seems to be an issue of concern as it is significantly affected by different determinants. Specifically, a statistically strong inter-relationship is seen among carbon emissions, GDP growth, population growth, and energy consumption as a bidirectional causal relationship exists between each pair of those variables, except for unidirectional causality from energy consumption to carbon emissions. Additionally, the country has a unidirectional causal relationship from energy consumption, GDP growth, and population growth to renewable energy consumption in both the short and long run.

With respect to the short-run causal relationship among the selected variables in the Philippines and Thailand, the feedback hypothesis is confirmed between economic growth and population growth. Carbon emissions, energy consumption, and renewable energy use do not cause one another. The Philippines has a unidirectional effect from economic growth to energy consumption as well as to carbon emissions, and Thailand does not show any causal effect among these three variables. Population growth is observed to cause both energy consumption and renewable energy use in the Philippines, whereas population growth and energy consumption cause each other in Thailand.

In summary, we found a unidirectional causality running from economic growth to CO_2 emissions in Indonesia, Malaysia, and the Philippines, a bidirectional causality in Myanmar, and no causal relationship between these two variables in Thailand. Our findings are different from those from Azam et al. (2015) as they reported no causal relationship between these two variables in Indonesia, Thailand, Singapore, and the Philippines with an exception being a unidirectional causality from economic growth to CO_2 emissions in Malaysia.

Table 5. Results of Granger-causality test.

Null Hypothesis	Short-Run Granger-Causality Test					Long-Run Granger-Causality Test		
	Indonesia	**Myanmar**	**Malaysia**	**Philippines**	**Thailand**	**Indonesia**	**Myanmar**	**Malaysia**
$\Delta LnCO_2 \neq \Delta LnEC$	6.20 *	1.52	0.52	0.13	4.22	6.62 *	2.80	0.52
$\Delta LnCO_2 \neq \Delta LnREC$	0.35	3.67	1.97	1.44	4.85 *	0.42	4.48	2.02
$\Delta LnCO_2 \neq \Delta LnY, \Delta LnY^2$	1.77	12.88 **	4.26	6.23	6.95	1.78	14.08 **	4.40
$\Delta LnCO_2 \neq \Delta LnPOP$	2.1	7.39 **	5.91 *	0.17	4.44	2.1	9.15 **	6.95 *
$\Delta LnEC \neq \Delta LnCO_2$	0.34	12.24 ***	3.50	0.54	5.62 *	3.45	24.60 ***	3.91
$\Delta LnEC \neq \Delta LnREC$	2.34	5.60 *	0.35	1.00	2.86	3.86	20.99 ***	1.22
$\Delta LnEC \neq \Delta LnY, \Delta LnY^2$	1.54	25.8 ***	5.17	1.71	1.44	6.52	27.57 ***	5.27
$\Delta LnEC \neq \Delta LnPOP$	8.06 **	22.74 ***	1.91	3.87	1.29	9.00 **	25.66 ***	3.10
$\Delta LnREC \neq \Delta LnCO_2$	0.96	3.56	3.83	0.02	0.46	2.85	4.05	4.06
$\Delta LnREC \neq \Delta LnEC$	0.44	0.23	2.41	1.04	3.50	2.29	3.56	3.02
$\Delta LnREC \neq \Delta LnY, \Delta LnY^2$	4.09	3.87	0.79	5.87	18.48 ***	4.36	9.47 *	0.98
$\Delta LnREC \neq \Delta LnPOP$	2.93	2.73	1.19	1.21	9.17 **	3.84	3.38	1.33
$\Delta LnY, \Delta LnY^2 \neq \Delta LnCO_2$	4.93	14.08 ***	9.58 **	17.7 ***	6.22	37.3 ***	28.67 ***	12.00 *
$\Delta LnY, \Delta LnY^2 \neq \Delta LnEC$	6.69	13.52 ***	6.46	15.77 ***	5.01	36.65 ***	24.56 ***	12.55 *
$\Delta LnY, \Delta LnY^2 \neq \Delta LnREC$	10.77 ***	11.08 **	3.10	2.34	4.28	34.82 ***	11.61 *	9.43
$\Delta LnY, \Delta LnY^2 \neq \Delta LnPOP$	22.41 ***	3.96	11.72 **	17.35 ***	19.68 ***	52.13 ***	12.17 *	12.57 *
$\Delta LnPOP \neq \Delta LnCO_2$	0.12	13.03 ***	0.98	19.29 ***	2.70	0.93	18.93 ***	94.44 ***
$\Delta LnPOP \neq \Delta LnEC$	0.13	15.17 ***	18.04 ***	15.07 ***	9.7 ***	0.59	19.63 ***	63.13 ***
$\Delta LnPOP \neq \Delta LnREC$	2.09	19.48 ***	6.38 **	2.88	0.19	2.09	22.61 ***	69.21 ***
$\Delta LnPOP \neq \Delta LnY, \Delta LnY^2$	6.71	21.26 ***	18.13 ***	31.45 ***	9.47 **	32.22 ***	21.41 ***	87.40 ***

Notes: ***, **, and * indicate significance levels of 1%, 5% and 10%, respectively.

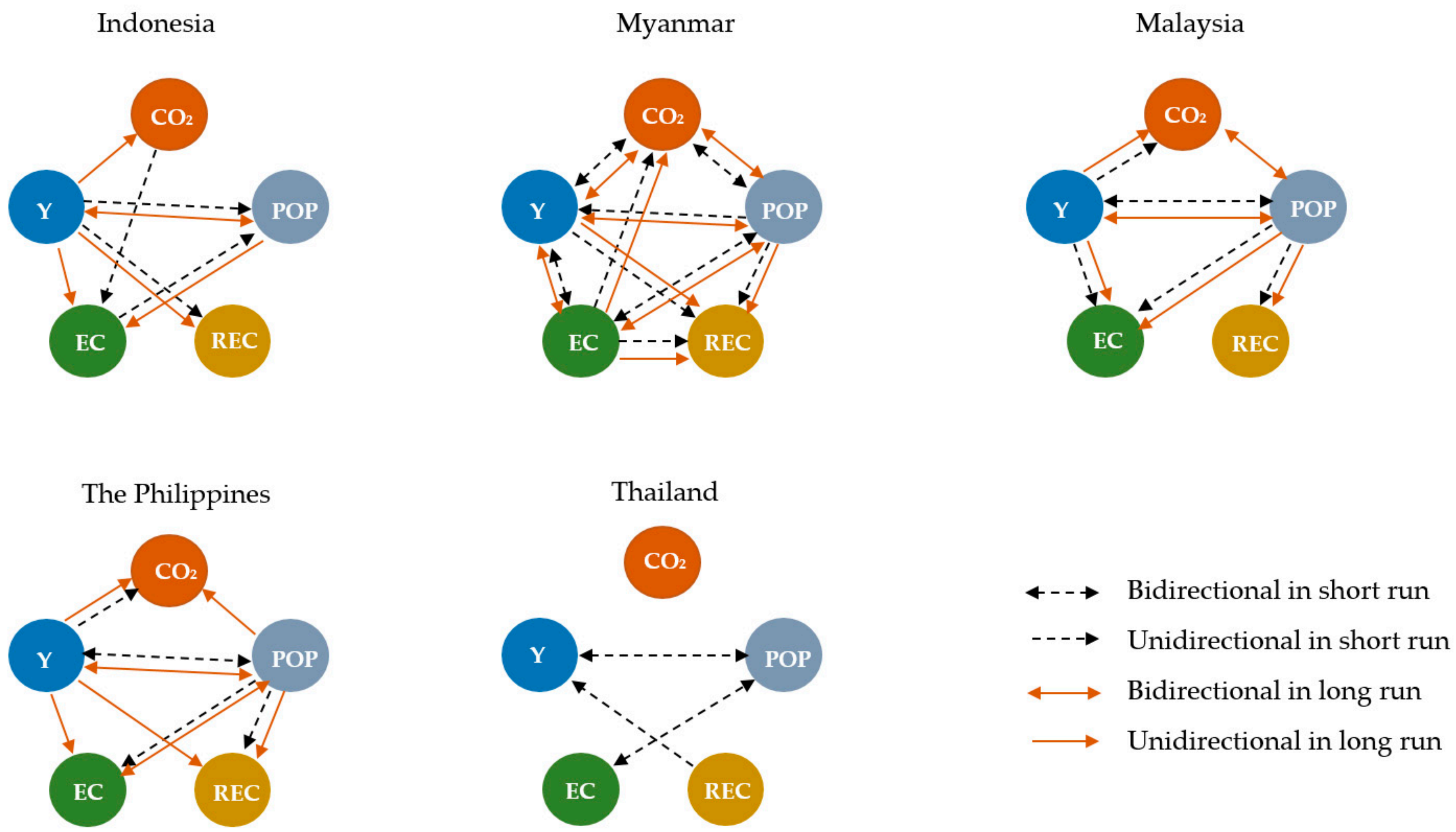

Figure 1. Summary of Granger causality tests. CO_2—per capita CO_2 emissions; EC—per capita energy consumption; Y: real per capita GDP and its square form; POP—population growth rate; REC—per capita consumption of renewable energy.

5. Concluding Remarks and Policy Implications

By using the ARDL bounds test of cointegration, the Johansen cointegration test, and the Granger-causality test based on both VECM and VAR framework, this paper examines a long-run relationship and direction of Granger causality between economic growth, energy consumption, renewable energy usage, environment degradation (i.e., carbon dioxide emissions), in a multivariate model including population growth as an additional variable. Also, we test the validity of a well-known EKC hypothesis using two long-run estimators, FMOLS and DOLS. Our sample consists of five ASEAN members: Indonesia, Myanmar, Malaysia, the Philippines, and Thailand. The primary reasons we conduct the study are the lack of empirical studies that examines the remedial role of renewable energy to address the increasing CO_2 emissions in the region. In addition, we observe and respond to the desire and efforts made by the governments in these countries to achieve their energy mix targets, with a major focus on renewable energy in recent years.

The main findings of this paper can be summarized as follows. First, a cointegrating relationship exists among economic growth, energy consumption, renewable energy usage, environment degradation in Indonesia, Myanmar, and Malaysia but not in the Philippines and Thailand. The validity of the EKC hypothesis is confirmed in Myanmar, but not in Indonesia and Malaysia because of the inconsistent results from the FMOLS and DOLS. Second, the outcomes from the Granger-causality test vary considerably across the selected countries, among variables such as economic growth, energy consumption, renewable energy use, CO_2 emissions, and population growth. The Granger-causality test was performed with the VECM framework with variables that have a long-run relationship; otherwise the VAR framework was adopted. Our findings serve as a critically empirical source of inputs for policy suggestions and implementation to balance sustainable economic growth, conserve energy, and preserve the environment.

The findings from this paper can be used in future research and for public policy purposes. The varying characteristics of different countries cause them to develop and implement different paths to achieving the proposed renewable energy targets in the short run and long run. Our findings appear to imply that academic studies in the future should examine the relationship among GDP growth, energy use, carbon emissions, renewable energy consumption, and other macroeconomics factors, including population growth for each country separately.

The varying findings across ASEAN countries can be a useful source of policy implications. No Granger causality is found among carbon emissions, energy consumption, and renewable energy consumption in Malaysia, Thailand, and the Philippines. This implies that the current level of renewable usage is not sufficient enough to mitigate the level of CO_2 emissions and to support the total of energy usage in these two countries. Malaysia experiences a unidirectional Granger caused from economic growth to energy consumption and to CO_2 emissions which indicates energy still plays a vitally important part in the country's economic development while pollution degradation creates a concern. This policy implication could be applied for the case of Indonesia in which economic growth is observed to have a unidirectional impact not only on CO_2 emissions and energy consumption but also on renewable energy in the long run. Furthermore, for the case of Thailand, no links among economic growth, CO_2 emissions, energy consumption and renewable energy usage were found in the short run. Not only does Myanmar have a unidirectional effect from GDP growth, energy consumption, and population growth to the adoption of renewable energy, but the country also has the particular causal effect among the variables, most of which bidirectionally cause one another. Our results show that there is a trade-off between higher level of economic growth and higher levels of CO_2 emissions as well as energy consumption. More importantly, the usage of renewable energy in curbing environment degradation gains little assistance. Our study reinforces a view that while the current level of renewable energy usage is an ineffective measure for environment protection, a transformation toward less polluted renewable energy would be crucial to achieve goals of sustainable development in Malaysia as mentioned by Gill et al. (2018).

The paper has a limitation that a number of observations are relatively small, making a traditional causality test less powerful. Like previous studies, the data for analyzing the relationship among energy consumption, economic growth and environment degradation rely on the World Bank indicators, starting in 1970. Using the so-called bootstrap causality test to deal with small sample size can be a proper robustness check. This opens a potential for future studies on a single country.

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