energies

MDPI

Article

Dynamic Modelling of Causal Relationship between Energy Consumption, CO_2 Emission, and Economic Growth in SE Asian Countries †

Jaruwan Chontanawat

Department of Social Sciences and Humanities, School of Liberal Arts, King Mongkut's University of Technology Thonburi, 126 Prachu-Uthit Rd., Thungkru, Bangkok 10140, Thailand; j.chontanawat@gmail.com or jaruwan.cho@mail.kmutt.ac.th; Tel.: +66-89-944-5949

† This paper is an extended version of my paper published in 6th International Conference on Energy and Environment Research, ICEER 22–25 July 2019, Aveiro, Portugal.

Received: 4 July 2020; Accepted: 2 December 2020; Published: 17 December 2020

Abstract: Southeast Asian region is fast growing in terms of economy with rapid population growth, high energy consumption, and pollution. Understanding these linkages are crucial to guidance of appropriate policy. This study aims to examine the causal relationship between energy consumption with economic growth and CO_2 emissions of the four selected Asian countries, namely Indonesia, Malaysia, Philippines, and Thailand between the years 1971–2017 using Johansen cointegration method combined with Granger causality model. The results found the evidence of cointegration in all countries implying a long-run relationship among energy consumption, economy and pollution exists. The causality main results show the evidence of unidirectional causality running from economic growth to energy consumption in Indonesia, Malaysia, and Thailand, while the opposite direction was found in Philippines. The results of Indonesia, Malaysia, and Thailand support "conservative hypothesis" suggesting that energy conservation policies could be adopted in these countries as it would not constrain growth of the economies. Whereas the results of Philippines appear to support "growth hypothesis" implying that energy is a key driver to stimulate economy. Limiting the use of energy could affect the economy. Instead, the policies, therefore, should focus on promoting other alternative energy source such as renewable energy in order to maintain sustainable growth.

Keywords: energy consumption; economic growth; CO_2 emission; causality; SE Asian countries

1. Introduction

Energy-economic-environment interactions can be expected to be a crucial role in the development process. Energy is a critical resource underpinning economic growth. In the same way, economic development can be helpful to the environment and the two parts reinforce each other. Energy arguably plays an essential role in an economy on both the demand side and supply side. On the demand side, energy is a derived demand, through energy appliances; energy produces various types of services which a consumer decides to buy in order to maximize their lifestyle. Economic growth is likely to be a main driver of energy consumption. As stated by IEA [1], "economic growth almost always leads to increased energy use, at least in the early stages of economic development" (p. 331). On the supply side, energy is likely to be a key factor of production in addition to capital, labor, and materials. Energy services provide an essential input to economic growth. Therefore, energy is usually seen to play a vital role in the economic and social development of countries and to be a key factor in increasing economic growth and living standards. This suggests that there should be a causal relationship between energy consumption and national income or GDP, Chontanawat et al. [2,3].

However, there are numerous different theoretical ideas and views about the potential linkages between energy consumption and economic growth. Both mainstream/neoclassical and resource/ecological economists have addressed this issue and often come to different conclusions. Stern [4] summarizes these differences, stating that mainstream/neoclassical economists argue that energy or other natural resources play a minor or minimum role in economic growth, whereas resource/ecological economists argue that energy plays an important role in economic growth. He also states that, "Mainstream economists usually think of capital, labor and land as the primary factors of production and goods such as fuel and material as the intermediate inputs. The prices paid for all the different inputs are seen as eventually being payments to the owners of the primary inputs for the services provided directly or embodied in the produced intermediate inputs. In the theory of growth, this approach has led to a focus on the primary inputs, in particular on capital and land, and to a much lesser extent a somewhat indirect treatment of the role of energy in the growth process." (p. 37). The "resource or ecological" economists, on the other hand, have placed a very heavy emphasis on the role of energy and its availability in economic production and growth theories. They point out that the primary energy inputs such as oil deposits are stock resource and energy are important because energy is a non-reproducible factor of production while capital and labor are reproducible factors of production (see Jones [5], ch.9, Sørensen and Whitta-Jacobsen [6], ch.7). Ayres and Warr [7] and Ayres [8] also agree with the above idea about the important role of energy in an economy. They refer to the concept of "exergy" which means "available energy", or "useful energy", or energy capable of performing mechanical, chemical or thermal work. Hence, "exergy" is effectively equivalent to "potential work". They argue that consumption of natural resources especially energy (exergy) has been, and still is, an important factor of production and driver of economic growth. They conclude that it is not raw energy as an input, but exergy converted to useful (physical work) that, along with capital and labor, really explains output and drives long-term economic growth.

Another interesting issue is the degree of the causal link. It is questionable if the link is different among regions. According to IEA [1], the link is strongly influenced by the stage of economic development and the standard of living in a given region. Toman and Jemelkova [9] state that "the linkages among energy, other input, and economic activity clearly change significantly as an economy moves through different stages of development" (p. 95). Stern [4] also points out that the structure of each economy and its stage of development could be crucial factors for determining the energy-economy interaction. This implies that the causal link could well appear to be different between the developed countries and developing countries where their stages of development are different. In the developed world, the countries generally have "low energy dependency", usually characterized by large economies, good infrastructure, abundant energy supply, low population growth, high energy use per capita and per unit of GDP, efficient technology, and lower energy intensity. Whereas, in the developing world, their economies appear to be in the opposite ways in terms of energy dependency, infrastructure, population and economic growth, with high use of primitive fuel (such as biomass). Their lifestyle also changes rapidly to achieve higher living standards. Thus, the evidence of causal relationships could be different between both groups.

Southeast Asia is a region that has fast growth in terms of the economy and population. Annual economic growth has averaged around 5–6% over the past two decades. Rising incomes have spurred dramatic increases in consumer spending. Southeast Asian countries are also experiencing rapidly increasing urbanization levels. In 2018, almost 50% of Southeast Asia's population lived in urban areas, compared with below 40% in 2000. These factors have pushed up demand for conveniences and technologies that are increasingly part of the fabric of modern society. In recent years they experienced a high increase in energy use and pollution emissions. Since 2000, overall energy demand has grown by more than 80% and the major share of this growth has been met by a doubling in fossil fuel use. Oil is the largest element in the regional energy mix and coal, largely for power generation, has been the fastest growing. This has underpinned the region's development and industrial growth but has also made air pollution a major risk to public health and driven up energy-related carbon dioxide

(CO_2) emissions. Primary energy demand in Southeast Asia has increased by more than 80% since 2000, an average of 3.4% per year, far outpacing the global annual average of 2.0% over the period. This reflects Southeast Asia's rapid economic expansion as well as the insufficiency of measures to encourage more efficient patterns of energy consumption. Since 2000, the use of relatively cheap and abundant fossil fuels doubled to meet nearly 85% of the incremental demand growth. Fossil fuels now account for three-quarters of primary energy demand in the region. Overall, these trends point to Southeast Asia becoming a net-importer of fossil fuels in the next few years. IEA [10,11].

In short, based on the theoretical concept described above, there are two issues to address. First, energy is likely to play a vital role on both the demand and supply sides which undoubtedly implies that there should be a causal link between energy and economic growth. However, there are different schools of economic thought about the potential linkages between energy consumption and economic growth especially on the role of energy in economic activities. Second, the strength of the link appears to be different between regions, depending on their stage of development. The policy implication regarding these issues is that if the results are in line with the neoclassical school of thought, that economic growth of a country can be neutral to energy consumption. In this case, economic growth and energy policies are deemed independent of each other. Neither conservation nor expansive policies related to energy consumption have any effect on economic growth. On the other hand, if the results support the ecological school of thought, growth can be closely associated with the energy consumption. In this case, like any other factor of production, the energy consumption can be a limiting factor to the economic growth. Therefore, any policy relating to energy consumption would have an impact on the economy. Southeast Asia is an extremely diverse set of countries with vast differences in the scale and patterns of energy use (which affect CO_2 emissions) and energy resource endowments, together with fast growing economy and high population growth. Undoubtedly a causal linkage between energy, economic growth, and CO_2 emissions in these countries should exist. However, in which ways or which directions of the relationships are still questionable. The rest of the paper is organized as follows: Section 2 provides literature review. Section 3 introduces model and variables used. Section 4 provides results and discussion. Finally, Section 5 gives conclusions and policy implications.

2. Literature Review

Given the importance of this issue there have been a number of attempts to quantify the relationship among energy consumption, carbon emissions, and economic growth for a number of different countries.

The first group of studies aims to investigate the causal relationship between energy consumption and economic growth. The pioneer work is conducted by Kraft and Kraft [12]. Later a number of studies examine the long-run and causal relationship between energy consumption and economic output. A comprehensive list of studies are summarized in Chontanawat et al. [2,3], Payne [13], and Ozturk [14]. It is found that the empirical evidence is mixed and gives evidence of unidirectional or bidirectional causality to no causality. Results vary across different countries depending on its sources of energy uses, energy policies, level of energy consumption, institutional arrangements, etc. Regarding the direction of causality, there are four assumptions in the literature: "Neutrality Hypothesis", "Conservation Hypothesis", "Growth Hypothesis", and "Feedback Hypothesis".

The "Neutrality Hypothesis" implies that energy consumption is not correlated with economic growth. It represents the absence of causal relationship between energy consumption and economic growth. This hypothesis is based on the theorical neo-classical view which states that economic growth of a country can be neutral to energy consumption. Therefore, any policy relating to energy consumption would have little or no effect on economic growth, in the meantime, the change of economy would not affect to the consumption of energy resources. A number of studies found the evidence supporting this hypothesis. These works are such as Yu and Choi [15] for USA, UK and Poland, Masih and Masih [16] for Malaysia, Philippines, and Singapore, Asafu-Adjaye [17] for India and Indonesia (in the short run), Soytas and Sari [18] for Brazil, India, Indonesia, Mexico, Poland, South Africa, USA, UK, and Canada, Altinay and Karagol [19] for Turkey, Wolde-Rufael [20] for Africa (Benin, Congo RP, Kenya, Senegal, South Africa, Sudan, Togo, Tunisia and Zimbabwe), Huang et al. [21] for panel low income countries, Chang et al. [22] for Asian regions (China, Indonesia, Japan, Malaysia, Pakistan, Singapore, South Korea, and Taiwan), Yildirim et al. [23] for Singapore, Azam et al. [24] for (Indonesia, Philippines, Singapore and Thailand), Destek and Aslan [25] for 9 emerging countries, and Tuna and Tuna [26] for Indonesia and Thailand.

According to "Conservative Hypothesis", it indicates one way or unidirectional causality from economic growth to energy consumption. An increase in economic growth causes an increase in energy consumption, while the reduction in the use of energy may not affect economic growth. Based on this hypothesis, energy conservation policy has no adverse effect on economic growth. Therefore, the country can set energy conservation policy to reduce CO_2 emissions for preventing environmental degradation without compromising the pace of the economic growth. The studies that support this hypothesis are for example, Kraft and Kraft [12] for USA, Yu and Choi [15] for Korea, Masih and Masih [16] for Indonesia, Soytas and Sari [18] for Italy and Korea, Jumbe [27] for Malawi (electricity), Wolde-Rufael [20] for Algeria, Congo DR, Egypt, Ghana and Ivory Coast, Yoo [28] for Indonesia and Thailand (electricity), Lee and Chang [29] for panel LDCs, Huang et al. [21] for panel middle income counties, Chang et al. [22] for India, Yildirim et al. [23] for Indonesia, Malaysia and Philippines, Azam et al. [24] for Malaysia, and Destek and Aslan [25] for Egypt, Peru and Portugal.

Regarding "Growth hypothesis", it refers to one way or unidirectional causality running from energy consumption to economic growth. An increase in energy consumption would accelerate economic growth, whereas the restrictions on the use of energy may adversely affect economic growth. Base on this hypothesis, energy consumption plays a significant role in economic growth both directly and indirectly in the production process. Energy, therefore, is a limiting factor to economic growth, which is in line with the resource or ecological school of thought indicating that growth can be closely associated with energy consumption. Thus, energy conservation-oriented policies may have a detrimental impact of economic growth. There are a number of works in the literature supporting this hypothesis. Stern [30,31] found that energy is a driving factor to the economic growth in the USA. Similar results are found by Yu and Choi [15] for Philippines, Masih and Masih [16] for India, Asafu-Adjaye [17] for India and Indonesia (long run), Soytas and Sari [18] for Turkey, France, Germany, and Japan, Wolde-Rufael [32] for Shanghai, Wolde-Rufael [20] for Cameroon, Morocco, and Nigeria, Chontanawat, et al. [2] for Kenya, Nepal, and Philippines, and Huang et al. [21] for panel high income countries. The recent studies which provide the same results are conducted by Chandran et al. [33] for Malaysia (electricity), Wang et al. [34] for China, Borozan [35] for Croatia, Chang et al. [22] for Philippines, Destek and Aslan [25] for China, Colombia, Mexico, and Philippines, and Tuna and Tuna [26] for Malaysia, Philippines, and Singapore.

For the "Feedback Hypothesis", it refers to two ways or bi-directional causality between economic growth and energy consumption. Both energy and economic growth are dependent upon each other at the same time in the economy. For instance, reducing energy consumption could have an impact on economic growth, and the slow economic growth would affect to energy consumption. Therefore, any conservation or expansive policies related to energy consumption would have effect on economic growth. There are a number of studies investigating these relationships and found the evidence support the "Feedback Hypothesis". These studies are such as Masih and Masih [16] for Pakistan, Masih and Masih [36] for South Korea and Taiwan, Yang [37] for Taiwan, Asafu-Adjaye [17] for Philippines and Thailand, Hondroyianis et al. [38] for Greece, Soytas and Sari [18] for Argentina, Paul and Bhattacharya [39] for India, Jumbe [27] for Malawi (electricity), Wolde-Rufael [20] for Gabon and Zambia, Yoo [28] for Malaysia and Singapore (electricity), Lee and Chang [29] for panel DCs, Chang et al. [22] for Thailand and Vietnam, Yildirim et al. [23] for Thailand, and Destek and Aslan [25] for Turkey. The list of the past studies based on these hypotheses are shown in Table A1 in Appendix A.

Due to the environment/global warming concern, a number of studies attempt to incorporate the environmental factor in the model. It starts with introducing the well-known environmental Kuznets Curve (EKC) which has been widely discussed in the literature as it postulates that there is an inverse U-shaped relationship between economic activity and environmental pollution (Kuznets [40] and Dinda [41]). It explains that environmental degradation initially increases with the increases of income, reaches a threshold point, and then declines with increased income (Grossman and Krueger [42], Selden and Song [43], Stern et al. [44], Galeotti et al. [45], Dinda and Coondoo [46], Coondoo and Dinda [47], Managi and Jena [48]). There are several studies that attempt to test the EKC hypothesis. However, the empirical results show mixed findings. For instance, it was found that CO_2 emissions are decreasing with the increase of income in the 35% of 43 developing countries. The same evidence are also found in the Middle Eastern and the South Asian panels (Narayan and Narayan [49]). The inverse U- shape relationship are also found in Malaysia (Saboori et al. [50]), India (Kanjilal and Ghosh [51]), Pakistan (Nasir and Rehman [52]), Tunisia (Fodha and Zaghdoud [53]) and France (Iwata et al. [54]). Whereas, some studies find the monotonic increase evidences (Holtz-Eakin and Selden [55]), some find N-shaped relationship (Shafik [56], Friedl and Getzner [57]), and inverse N-shaped relationship (Özokcu and Özdemir [58]). Due to the importance of the environment factor and the issue on the omitted variables that could yield bias estimation on the energy–growth model, the latter group attempted to incorporate the environmental factor in the energy–growth model by examining the causal relationships among economic growth, energy consumption, and pollution emissions in a multivariate framework. The rationale for the combining lies in the stylized facts that countries with higher energy consumption per capita due to industrialization and urbanization are generally associated with higher GDP per capita, and the increased energy consumption is generally linked with the increased emissions of greenhouse gases such as CO_2 and SO_2. There are a number of studies conducted in this framework for the several countries. The most recent ones belong to Ozturk and Acaravci [59] for Turkey, Alam et al. [60] for India, Alam et al. [61] for Bangladesh, Farhani and Ben [62] for panel Middle East and North Africa (MENA) region, Hamit-Haggar [63] for Canada (Industrial sector), Saboori et al. [64] for the Organisation for Economic Co-operation and Development (OECD) countries, Alshehry and Belloumi [65] for Saudi Arabia, Bastola and Sapkota [66] for Nepal, Chen et al. [67] for Global 188 countries, Ahmad et al. [68] for India, Esso and Keho [69] for 12 selected African countries, Wang et al. [70] for China, Wang et al. [71] for 35 Chinese provinces. Regarding the studies for the Southeast Asian countries, surprisingly, a small number of studies have been conducted in this multivariate framework (that combined CO_2 into energy–growth model). Some works have been conducted for the individual countries such as Ang [72] for Malaysia, Etokakpan et al. [73] for Malaysia (Natural gas), Jafari et al. [74], Hwang and Yoo [75], and Odugbesan and Rjoub [76] for Indonesia. A few works have been conducted as a group of Association of Southeast Asian Nations (ASEAN). For instance, Saboori and Sulaiman [77], Munir et al. [78], and Chontanawat [79] investigate the relationships for ASEAN at the aggregate energy level, whereas Lean and Smyth [80] studied at the disaggregate level (for electricity), and Chandran and Tang [81] (for transportation sector). The list of these studies is shown in Table A2 in Appendix A.

In general, the results from the literature on both "energy–growth" model and multivariate "energy–growth–CO_2" model in terms of direction of causality are rather mixed and varied due to the differences in selection of methods, research period, and variables used. However, it is noticed that the evidence of causal relationships seems to appear more (were found more) in the multivariate framework studies. This indicates that when the CO_2 variables were incorporated in the model, it would explain the relationships better as the models cover more related variables in the system. The evidence of the causal relationship between the variables were found in the majority of the results. This supports the ecological or resource view which indicates the importance or significance of energy and environment in the economy. Unfortunately, there are not many studies investigating the relationship in this multivariate framework for the ASEAN group (as mentioned earlier). Therefore, there is a room to investigate further on this issue for the ASEAN region. Recently, Chontanawat [79] has conducted a research based on the multivariate "energy–growth–CO_2" framework aiming to explore the relationship between energy consumption, economic growth and CO_2 emission in ASEAN (as a whole) during the period 1971–2015 using "cointegration and causality" model which is well-known and widely accepted method among the scholars to examine the causal relationships. The results found the long-run relationships among these variables implying the existence of interlinkage between energy consumption, economic growth and CO_2 emissions in ASEAN region. The results also found unidirectional causality running from energy consumption to CO_2 emission in the short run, whereas the unidirectional causality running from economic growth and CO_2 emissions to energy consumption in the long run. The results in general support the "energy conservation hypothesis" implying that energy conservation policy should be adopted for the ASEAN region as a whole. The results highlight the interest point in terms of policy implication for this region. Thus, it is interesting to further investigate for the individual ASEAN countries. To complement the literature, this research, attempts to investigate the relationships for the four selected individual countries: Indonesia, Malaysia, Philippines, and Thailand. We used the latest consistent data set for a longer period (1971–2017) from IEA database. This research would enrich and contribute to the literature on the relationship between energy consumption, CO_2 emission, and economic growth in ASEAN.

3. Material and Method

In this study, Cointegration and Causality model was used to analyze the relationship between energy consumption, CO_2 emission and economic growth as the model is worldwide and widely accepted among scholars for the last few decades. The original concept of causality was proposed by Granger in 1969 [82] hereafter known as "Granger causality". Since the late 1980s the concept of "integration and stationarity" has emerged after it was found that the use of non-stationary data in causality tests can yield spurious results. To ensure that the variables are stationary, unit root tests to examine the stationary properties of variables are generally employed. There are different types of unit root tests. The most popular ones are the Augmented Dickey Fuller test [83,84], henceforth ADF. The concept of "cointegration and error correction" was first developed by Granger [85], and Engle and Granger [86]. It is a useful statistical tool to test for the long-run equilibrium relationships between non-stationary time series. There are many possible tests for cointegration. The most common ones are based on Engle and Granger [86], Johansen [87,88] and Johansen and Juselius [89]. In this study we adopt "cointegration and causality" model based on Granger [85], Engle and Granger [86], and Johansen and Juselius [89] to analyze the relationship between energy consumption, CO_2 emission, and economic growth. The method was also recently used in Chontanawat [79]. The main variables used in the models consist of energy consumption, gross domestic product, population, and CO_2 emissions. This study uses the annual time series data (from 1971 to 2017) for the four selected Southeast Asia countries namely Indonesia, Malaysia, Philippines, and Thailand. The selection of these countries has been made based on the assumption that these countries have similar characteristics in terms of highest growth economies, sharp rise in energy consumption and similar source of environmental emissions (Lean and Smyth [80], Azam et al. [24], and Chontanawat [90]). The data is extracted from the IEA database [91] and the econometric software program, EVIEW 7 was used for modelling.

In this study, we use time series analysis to avoid some of the drawbacks in panel analysis. Due to the different nature of economic structure, income and demographic reasons, as well as the different data quality across countries, the estimation using panel data may not yield robust results (Solow [92], Athukorala and Sen [93]). When heterogenous aspects prevail in the panel model with a small cross-section (N) dimension, as the case of this study (N = 4), the estimate results tend to be biased (Pesaran and Smith [94] and Robertson and Symons [95]).

The theoretical methodology framework is illustrated in Figure 1.

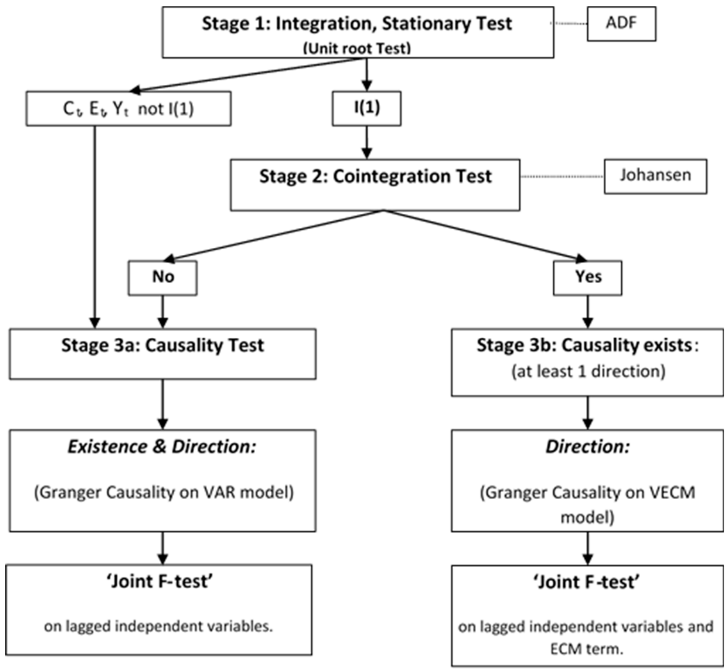

Figure 1. Cointegration and causality time series model.

where:

E_t	Energy consumption per capita (E_t = $Energy_t/Pop_t$) in Mtoe per million persons
C_t	CO_2 emission per capita (C_t = CO_t/Pop_t) in Mt of CO_2 emissions per million persons
Y_t	GDP per capita (Y_t = GDP_t/Pop_t) in billion 2010 USD per million persons
$Energy_t$	Energy consumption in Mtoe
CO_t	emission flux in Mt of CO_2 emissions
GDP_t	real GDP: defined and measured at constant price in billion 2010 USD
Pop_t	Population in million persons
t	Time
Note:	E_t, C_t, and Y_t are transformed into logarithm term.

There are three main stages regarding the cointegration and causality time-series model:

Stage 1: Testing the stationarity of each variable (C_t, E_t, Y_t) for each country using the Augmented Dickey Fuller (ADF) test. If the variables are I(1) then proceed to Stage 2. If one or all are not I(1) proceed to Stage 3a.

Stage 2: Testing for cointegration among all variables using the Johansen technique. If cointegration is not found proceed to Stage 3a. If cointegration is found proceed to Stage 3b.

Stage 3: Testing causality based on Granger causality frameworks.

Stage 3a: Testing for existence and direction of causality (in the short run) using the Vector auto-regressive model (VAR).

Stage 3b: A long run relationship exists so there must be causality for at least one direction. Therefore, testing for direction of causality using Vector error-correction model (VECM). There are two sources of causation, short-run causality, and long-run causality.

Following Chontanawat [79], the theoretical linkage of the relationship between energy consumption, economic growth, and carbon emissions can be explained as follows:

$$C_t = f(E_t, Y_t) \tag{1}$$

The purpose is to estimate the long-run relationship of the variables in the model. There are three main tests as follows.

3.1. Unit Root Test

The first stage is to examine the stationary properties of variables by performing the augmented Dickey–Fuller (ADF) test [83] to find the order of integration. Based on Engle and Granger [86], if the series are stationary and have similar order of integration such as I(1), a linear combination of these series should exist which presumes that they are cointegrated. The unit root test can be conducted via Ordinary Least Square (OLS) method as below (see also in Chontanawat [79]).

$$\Delta X_t = \alpha_1 + \alpha_2 T + \delta X_{t-1} + \sum_{i=1}^{n} \lambda_i \Delta X_{t-i} + \varepsilon_t \tag{2}$$

where X_t refers to any variables such as C_t, E_t and Y_t in the model over time. T denotes time trend. Δ represents the difference operator. δ is the coefficient of interest. The null hypothesis implies that there is a unit root or X_t is non-stationary ($\delta = 0$) against the alternative $\delta < 0$. However, if one or all variables are found not being I(1), this implies that they are not cointegrated. In other words, there are no long-run relationships among these variables. In this case, the short run causality may exist. This can proceed directly to Stage 3a to test for short run causality in VAR model.

3.2. Cointegration Test

The second stage of the testing procedure is to perform cointegration analysis. The objective is to test whether there are long run relationships among the variables in the model. The test starts with the notion that, if the variables are non-stationary but become stationary at the first difference or so called I(1), we can use the Johansen and Juselius cointegration test [89] by starting with an unrestricted vector auto-regressive (VAR) model where a vector of variables ($X \times 1$) at time t are related to the vector of past variables. Based on the Granger representation theorem, the vector X_t obtains a vector auto-regressive error correction representation shown below. (see also in Chontanawat [79]).

$$\Delta X_t = \alpha_1 + \alpha_2 T + \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \Phi D_t + \omega_t \tag{3}$$

where $\Pi = \sum_{i=1}^{P} A_i - I$ and $\Gamma_i = -\sum_{j=i+1}^{P} A_j$.

X_t refers to a ($X \times 1$) dimension vector of the variables (C_t, E_t and Y_t) in which all variables are ~I(1), the π, Γi and Φ are estimated parameter matrices, D_t refers to a vector of deterministic elements (e.g., constant and trend) and ω_t is a matrix of random error. The rank of matrix (π) which holds long-run information and the speed of adjustment is the specific of interest. If rank of matrix π is equal to one, it indicates that a linear combination is stationary or there is one single cointegrating vector. The cointegrating rank matrix π can be decomposed into $\pi = \alpha\beta'$ where α is the vector of speed of the adjustment and β is the vector of long-run equilibrium. In this respect, X_t is I(1) but the combination $\beta' X_{t-1}$ is I(0). Based on Johansen method, the π matrix is estimated from an unrestricted VAR to examine whether the restriction (implied by the reduced rank π) can be rejected. Two types of test, so called trace tests and maximum eigenvalue tests are employed for the reduced rank (π), shown below.

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} \ln\left(1 - \hat{\lambda}_i\right) \tag{4}$$

$$\lambda_{max}(r, r+1) = -T \ln\left(1 - \hat{\lambda}_{r+1}\right). \tag{5}$$

$\hat{\lambda}_i$ denotes the estimated ordered eigenvalue gained from the estimated matrix and T is the number of observations after lag adjustment. Regarding the trace tests, the null hypothesis is that the number of distinct cointegration vector is less than or equal to r against a general alternative hypothesis. For the maximum eigenvalue tests, the null hypothesis is that the number of cointegrating vector is equal to r against the alternative hypothesis of r + 1 cointegrating vector.

3.3. Causality Test

The third stage of the testing procedure is to perform causality analysis to find the direction of causal relationships. Based on the Granger causality frameworks, if the variables are not I(1) or even they are all I(1) but they are not cointegrated, implying no long-run relationship among variables. In this case, however, the short run causality relationship may exist. We can examine the existence and the direction of causality by using VAR model shown in Stage 3a. On the other hands, if they are cointegrated, this implies that a long run relationship exists so there must be causality for at least one direction. In this case, the direction of causality can be tested via Vector error correction model (VECM) shown in Stage 3b.

For Stage 3a, the VAR model can be illustrated as follows.

$$\Delta C_t = a_1 + \sum_{i=1}^{j} a_{1i}\Delta C_{t-i} + \sum_{i=1}^{j} b_{1i}\Delta E_{t-i} + \sum_{i=1}^{j} c_{1i}\Delta Y_{t-i} + \varepsilon_{1t} \tag{6}$$

$$\Delta E_t = a_2 + \sum_{i=1}^{j} a_{2i}\Delta C_{t-i} + \sum_{i=1}^{j} b_{2i}\Delta E_{t-i} + \sum_{i=1}^{j} c_{2i}\Delta Y_{t-i} + \varepsilon_{2t} \tag{7}$$

$$\Delta Y_t = a_3 + \sum_{i=1}^{j} a_{3i}\Delta C_{t-i} + \sum_{i=1}^{j} b_{3i}\Delta E_{t-i} + \sum_{i=1}^{j} c_{3i}\Delta Y_{t-i} + \varepsilon_{3t}. \tag{8}$$

Regarding the source of causation, the short-run Granger non-causality hypothesis are tested through the VAR model. The interpretation is as follows. For example, in Equation (6), E_t Granger causes C_t if the null hypothesis Ho: (all b_{1i} = 0) is statistically rejected. Similarly, Y_t Granger causes C_t if the null hypothesis Ho: (all c_{1i} =0) is statistically rejected. In Equation (7), C_t Granger cause E_t if the null hypothesis Ho: (all a_{2i} = 0) is statistically rejected. Similarly, Y_t Granger causes E_t if the null hypothesis Ho: (all c_{2i} =0) is statistically rejected. In Equation (8), C_t Granger causes Y_t if the null hypothesis Ho: (all a_{3i} = 0) is statistically rejected. Similarly, E_t Granger causes Y_t if the null hypothesis Ho: (all b_{3i} =0) is statistically rejected. This can be summarized in Table 1.

Table 1. Causality in vector auto-regressive (VAR) model.

	Causality	SR
Equation (6): $C_t = f\ (E_t, Y_t)$	C ← E	all $b_{1i} \neq 0$
	C ← Y	all $c_{1i} \neq 0$
Equation (7): $E_t = f\ (C_t, Y_t)$	E ← C	all $a_{2i} \neq 0$
	E ← Y	all $c_{2i} \neq 0$
Equation (8): $Y_t = f\ (C_t, E_t)$	Y ← C	all $a_{3i} \neq 0$
	Y ← E	all $b_{3i} \neq 0$

For Stage 3b, based on Engle and Granger [86], if the variables are cointegrated, an error correction term (ECM) must be incorporated in the model. The ECM values derive from the estimated error terms of the long run relationship equations such as from Equation (1). It represents a term for the deviation from the long-run relationship that estimates how much of the disequilibrium will dissipate in the next period. For this stage, a vector error-correction model (VECM) is created, thus allowing for long-run equilibrium and short-run dynamics. The model can be demonstrated as follows. (see also in Chontanawat [79]).

$$\Delta C_t = a_1 + \sum_{i=1}^{j} a_{1i}\Delta C_{t-i} + \sum_{i=1}^{j} b_{1i}\Delta E_{t-i} + \sum_{i=1}^{j} c_{1i}\Delta Y_{t-i} + \Phi_1 ECM_{t-1} + \varepsilon_{1t} \quad (9)$$

$$\Delta E_t = a_2 + \sum_{i=1}^{j} a_{2i}\Delta C_{t-i} + \sum_{i=1}^{j} b_{2i}\Delta E_{t-i} + \sum_{i=1}^{j} c_{2i}\Delta Y_{t-i} + \Phi_2 ECM_{t-1} + \varepsilon_{2t} \quad (10)$$

$$\Delta Y_t = a_3 + \sum_{i=1}^{j} a_{3i}\Delta C_{t-i} + \sum_{i=1}^{j} b_{3i}\Delta E_{t-i} + \sum_{i=1}^{j} c_{3i}\Delta Y_{t-i} + \Phi_3 ECM_{t-1} + \varepsilon_{3t} \quad (11)$$

ECM_{t-1} refers to the normalize cointegration equation. Causation comes from two sources, via the *ECM* term and the lagged difference terms. The *ECM* term denotes the long-run equilibrium relationship whereas the coefficients on the lagged difference terms imply the short-run dynamics. The coefficient of *ECM* term represents the speed of adjustment or an error mechanism that drives the variables back to long-run equilibrium. It indicates how quick the variables return to long-run equilibrium and it must have negative sign. Sources of causation can be interpretated per three tests: Short-run non-causality test, long-run non causality test, and joint non-causality test. For instance, in Equation (9), E_t Granger causes C_t in the short-run if the null hypothesis Ho: (all b_{1i} = 0) is statistically rejected. For the long-run causality, E_t Granger causes C_t if the null Ho: (ϕ_1 = 0) is statistically rejected. For the strong causality result, E_t Granger causes C_t if the null Ho: (all $b_{1i} = \phi_1 = 0$) is statistically rejected. Like with, Y_t Granger causes C_t in the short-run if the null hypothesis Ho: (all c_{1i} = 0) is statistically rejected. For the long-run causality, Y_t Granger causes $\mathrm{C_t}$ if the null Ho: (ϕ_1 = 0) is statistically rejected. For the strong causality result, Y_t Granger causes $\mathrm{C_t}$ if the null Ho: (all $c_{1i} = \phi_1 = 0$) is statistically rejected. The interpretation of Equations (10) and (11) can be analyzed following the same principle. This can be summarized in Table 2.

Table 2. Causality in vector error correction model (VECM) model.

	Causality	SR	LR	SR and LR
Equation (9): $C_t = f\ (E_t, Y_t)$	C ← E	$b_{1i} \neq 0$	$\phi_1 \neq 0$	all $b_{1i} \neq \phi_1 \neq 0$
	C ← Y	$c_{1i} \neq 0$	$\phi_1 \neq 0$	all $c_{1i} \neq \phi_1 \neq 0$
Equation (10): $E_t = f\ (C_t, Y_t)$	E ← C	$a_{2i} \neq 0$	$\phi_2 \neq 0$	all $a_{2i} \neq \phi_2 \neq 0$
	E ← Y	$c_{2i} \neq 0$	$\phi_2 \neq 0$	all $c_{2i} \neq \phi_2 \neq 0$
Equation (11): $Y_t = f\ (C_t, E_t)$	Y ← C	$a_{3i} \neq 0$	$\phi_3 \neq 0$	all $a_{3i} \neq \phi_3 \neq 0$
	Y ← E	$b_{3i} \neq 0$	$\phi_3 \neq 0$	all $b_{3i} \neq \phi_3 \neq 0$

4. Results

4.1. Unit Root Results

The unit root test provides good results for all counties. All variables: energy consumption, economic growth and CO_2 emission are non-stationary in their levels but become stationary after taking the first difference. Therefore, all series are integrated at order one or I(1) at 1% and 5% levels of significance. (see Table 3).

Table 3. Unit root results.

Variables	ADF							
	Indonesia		Malaysia		Philippines		Thailand	
	Level	1st Diff.	Level	1st Diff.	Level	1st Diff.	Level	1st Diff.
C_t	−1.281	−6.171 **	−0.131	−6.034 **	−1.104	−5.842 **	−0.852	−4.143 **
E_t	−0.993	−6.372 **	−1.743	−5.858 **	−2.021	−4.862 **	−1.766	−5.356 **
Y_t	−2.612	−5.019 **	−2.329	−5.867 **	−0.784	−3.409 *	−1.726	−4.066 **

*,** indicate 5% and 1% critical values.

4.2. Cointegration Results

Given all variables share common integration properties, a long run cointegrating relationship between the variables can be utilized to test for the linear deterministic trend (with no trend in the intercept). The results from the Johansen cointegration tests for all countries are presented in Table 4. Both the results of trace tests and maximum eigenvalue tests agreeingly indicate the existence of one cointegrated relationship, at the 5% level of significance.

Table 5 shows the cointegrating vector, and the loading factor (Φ) which measures the speed of adjustment back to the long-run equilibrium level, indicating how quickly the variables return to long-run equilibrium. The results show the correct sign (negative).

For Indonesia, the long-run elasticity of C_t with respect to E_t and Y_t are found to be 1.72 and 0.30 respectively. The speed of adjustment at 0.29 implies that the variables can adjust towards its long-run level with about 29 percent of the adjustment taking place within the first year. In the case of Malaysia, the long-run elasticity of C_t with respect to E_t and Y_t are found to be 0.84 and 0.39 respectively. The speed of adjustment at 0.38 implies that the variables can adjust towards its long-run level with about 38 percent of the adjustment taking place within the first year. For Philippines, the long-run elasticity of C_t with respect to E_t and Y_t are found to be 0.51 and 0.88 respectively. The speed of adjustment at only 0.07 implies that the variables can adjust towards its long-run level with about 7 percent of the adjustment taking place within the first year. In the case of Thailand, the long-run elasticity of C_t with respect to E_t and Y_t are found to be 0.24 and 1.01 respectively. The speed of adjustment at 0.15 implies that the variables can adjust towards its long-run level with about 15 percent of the adjustment taking place within the first year.

It can be seen that the speed of adjustment in the cases of Malaysia and Indonesia are slightly higher than those of Thailand and Philippines. The relative high values imply a faster adjustment process to the long-run equilibrium following the short-run shocks. The range of the number are in line with the work of Saboori and Sulaiman [77] who found high number for Malaysia and Indonesia compared with Thailand and Philippines.

Table 4. Johansen cointegration results.

	Indonesia			Malaysia			Philippines			Thailand		
Hypothesized No. of Cointegrating Vectors	Eigen Value	Trace	Max-Eigen Value	Eigen Value	Trace	Max-Eigen Value	Eigen Value	Trace	Max-Eigen Value	Eigen Value	Trace	Max-Eigen Value
None *	0.611	45.017	38.718	0.483	40.727	27.691	0.452	34.339	25.828	0.474	41.298	26.971
At most 1	0.119	6.299	5.178	0.205	13.036	9.658	0.135	8.510	6.229	0.289	14.327	14.307
At most 2	0.027	1.120	1.120	0.077	3.378	3.378	0.052	2.281	2.281	0.001	0.020	0.020

* denote rejection of null hypothesis at 5% significance.

Table 5. Cointegrating vector.

Cointegrated Equations:	Φ
Indonesia:	
$C_t = 0.97 + 1.72E_t + 0.30Y_t$	−0.29
(12.311 ***) (3.215 ***)	(−1.839 *)
$E_t = -0.71 + 0.01Y_t + 0.45C_t$	
(0.211) (12.311 ***)	
$Y_t = 0.84 + 0.09E_t + 0.64C_t$	
(0.211) (3.215 ***)	
Malaysia:	
$C_t = 0.64 + 0.84E_t + 0.39Y_t$	−0.38
(7.997 ***) (3.425 ***)	(−2.196 **)
$E_t = -1.22 + 0.16Y_t + 0.71C_t$	
(1.411) (7.997 ***)	
$Y_t = 1.05 + 0.27E_t + 0.55C_t$	
(1.411) (3.425 ***)	
Philippines:	
$C_t = -0.15 + 0.51E_t + 0.88Y_t$	−0.07
(2.867 ***) (7.967 ***)	(−1.498)
$E_t = -0.80 - 0.56Y_t + 0.31C_t$	
(−5.404 ***) (2.867 ***)	
$Y_t = -0.12 - 0.71E_t + 0.67C_t$	
(−5.404 ***) (7.967 ***)	
Thailand:	
$C_t = -0.43 + 0.24E_t + 1.01Y_t$	−0.15
(1.823 *) (7.717 ***)	(−1.914 **)
$E_t = -1.22 + 0.62Y_t + 0.30C_t$	
(3.049 ***) (1.823 *)	
$Y_t = 0.86 + 0.28E_t + 0.57C_t$	
(3.049 ***) (7.717 ***)	

Notes: The normalized variable are C_t, E_t and Y_t. Figures in parentheses denote t-statistics. *,**,*** indicate 10%, 5%, and 1% levels of significance, respectively.

4.3. Causality Results

Since our results found the evidence of cointegration for all countries, therefore, the causality models have been formulated based on error and correction model. Tables 6–9 show, the statistical results of the causal relationship among CO_2 emissions, energy consumption, and economic growth in Indonesia, Malaysia, Philippines, and Thailand, respectively. The directions of causality in the four countries are also shown in Figure 2.

Table 6. Causality results (Indonesia).

Dependent Variables	Short-Run F−Stat			Long-Run t−Stat	Short-Run and Long-Run F−Stat		
	$\sum\Delta C_{t-i}$	$\sum\Delta E_{t-i}$	$\sum\Delta Y_{t-i}$	ECM_{t-1}	$\sum\Delta C_{t-i}$ *and* ECM_{t-1}	$\sum\Delta E_{t-i}$ *and* ECM_{t-1}	$\sum\Delta Y_{t-i}$ *and* ECM_{t-1}
ΔC_t	–	−0.868 (0.390)	0.746 (0.460)	−0.854 (0.398)	–	0.718 (0.494)	0.950 (0.395)
ΔE_t	0.324 (0.748)	–	−0.309 (0.760)	−1.839 * (0.073)	1.804 (0.178)	–	1.835 (0.173)
ΔY_t	−0.414 (0.681)	0.576 (0.568)	–	−0.004 (0.997)	0.086 (0.920)	0.172 (0.842)	–

Note: * indicates 10% level of significance. *p*-values are in parentheses.

Table 7. Causality results (Malaysia).

Dependent Variables	Short-Run F−Stat			Long-Run t−Stat	Short-Run and Long-Run F−Stat		
	$\sum\Delta C_{t-i}$	$\sum\Delta E_{t-i}$	$\sum\Delta Y_{t-i}$	ECM_{t-1}	$\sum\Delta C_{t-i}$ *and* ECM_{t-1}	$\sum\Delta E_{t-i}$ *and* ECM_{t-1}	$\sum\Delta Y_{t-i}$ *and* ECM_{t-1}
ΔC_t	-	0.381 (0.705)	0.473 (0.639)	−1.082 (0.286)	-	0.955 (0.394)	0.928 (0.404)
ΔE_t	−1.267 (0.213)	-	0.952 (0.347)	−2.196 ** (0.034)	2.519 * (0.093)	-	2.771 * (0.075)
ΔY_t	−0.547 (0.587)	0.045 (0.964)	-	−0.846 (0.403)	0.404 (0.67)	0.358 (0.701)	–

Note: **,* indicate 5% and 10% levels of significance, respectively. *p*-values are in parentheses.

Table 8. Causality results (Philippines).

Dependent Variables	Short-Run F−Stat			Long-Run t−Stat	Short-Run and Long-Run F−Stat		
	$\sum\Delta C_{t-i}$	$\sum\Delta E_{t-i}$	$\sum\Delta Y_{t-i}$	ECM_{t-1}	$\sum\Delta C_{t-i}$ *and* ECM_{t-1}	$\sum\Delta E_{t-i}$ *and* ECM_{t-1}	$\sum\Delta Y_{t-i}$ *and* ECM_{t-1}
ΔC_t	-	1.102 (0.277)	1.521 * (0.136)	−0.418 (0.678)	-	0.909 (0.411)	1.165 (0.322)
ΔE_t	0.025 (0.980)	-	0.532 (0.598)	−0.586 (0.561)	0.191 (0.826)	-	0.316 (0.731)
ΔY_t	−0.578 (0.567)	0.750 (0.458)	-	−1.498 * (0.142)	1.123 (0.335)	1.127 (0.334)	-

Note: * indicates 14% level of significance. *p*-values are in parentheses.

Table 9. Causality results (Thailand).

Dependent Variables	Short-Run F−Stat			Long-Run t−Stat	Short-Run and Long-Run F−Stat		
	$\sum\Delta C_{t-i}$	$\sum\Delta E_{t-i}$	$\sum\Delta Y_{t-i}$	ECM_{t-1}	$\sum\Delta C_{t-i}$ *and* ECM_{t-1}	$\sum\Delta E_{t-i}$ *and* ECM_{t-1}	$\sum\Delta Y_{t-i}$ *and* ECM_{t-1}
ΔC_t	-	1.479 * (0.147)	0.517 (0.608)	−1.097 (0.279)	-	1.440 (0.249)	1.246 (0.298)
ΔE_t	0.305 (0.762)	-	0.571 (0.571)	−1.914 ** (0.063)	2.295 * (0.114)	-	1.949 * (0.154)
ΔY_t	−0.651 (0.519)	0.232 (0.818)	-	0.986 (0.330)	0.404 (0.67)	0.119 (0.888)	-

Note: **,* indicate 10%, 11–15% levels of significance, respectively. *p*-values are in parentheses.

Indonesia:

Table 6 presents the causality results in Indonesia. The results show to some extent evidence of some causal relationship among CO_2 emissions, energy consumption, and economic growth, particular in the long-run. There is one way or unidirectional causality running from economic growth to energy consumption. This implies that the increase of economic outputs or activities, could lead to an increase of energy consumption. However, there is no evidence of causality running from energy consumption to economic growth. Therefore, the policies aiming to reduce energy consumption could be implemented without adverse effect on economic growth. The results are consistent with the earlier works such as Masih and Masih [16], Yoo [28], and Yildirim et al. [23], who conducted causality in bivariate "energy–growth" model. They all found unidirectional causality running from economic growth to energy consumption in Indonesia. Our results are also similar to the recent work of Hwang and Yoo [75], and Odugbesan et al. [76] who examine causality in Indonesia in multivariate (energy-economic growth–CO_2 emissions) model. Furthermore, the results are also supported by the latest work of Munir et al. [78] who investigate causality in the multivariate framework but in the panel analysis for ASEAN. They found unidirectional causality running from economic growth to energy consumption in the case of Indonesia.

However, causality between CO_2 and economic growth is not found in our study, indicating that much of the country's value-added activities are not relevant to CO_2 from conventional industrial process. This is perhaps because this study only accounts for CO_2 emission from fossil fuels combustion, while disregarding net carbon release from deforestation, forest degradation and peat swamp conversion (consistent with the work of Jafari et al. [74]). In short, the results are generally in line with the "energy conservation hypothesis" which implies that the policies aiming to reduce energy consumption could be implemented in Indonesia without deteriorating the economy.

Malaysia:

Table 7 presents the causality results in Malaysia. Like the case of Indonesia, there is unidirectional causality running from economic growth to energy consumption, but the evidence is stronger (confirmed by the joint F-statistic between short-run and long-run). The results imply that the expansion of economic activities leads to the increase use of energy consumption both in the short run and long run (without feedback). Therefore, policies to reduce energy consumption and CO_2 emissions could be adopted in Malaysia as they appear not to have a negative impact on economic growth. The results are consistent with the work for ASEAN countries by Yildirim et al. [23] and Azam et al. [24] who found causality running from economic growth to energy consumption in Malaysia in their energy–growth models. The results are also in line with the results from the work on multivariate models (energy–growth–CO_2) conducted by Ang [72] who investigate the relationship and found the strong evidence of causality running from economic growth to energy consumption in Malaysia, and the later work by Munir et al. [78] who investigate causality in the panel context for ASEAN and found unidirectional causality running from economic growth to energy consumption in Malaysia. The results are also in line with the latest work by Etokakpan et al. [73] who study causality between natural gas and other variables in Malaysia in their multivariate framework and found unidirectional causality running from GDP to natural gas consumption. Causality between GDP and CO_2 is not detected in this study same as the results of our work, implying that the country could improve economic growth without tradeoff for environment quality to achieve SDGs 7 and 8 and the 11th Malaysian Plan. However, to remedy the environmental pollution problems, renewable energy is one of the important parts to be considered for improving environmental quality in Malaysia (Bekhet and Othman [96]).

It can be seen that the causality results in the case of Malaysia from our work are consistent with several previous studies, which generally support the "energy conservation" hypothesis. Hence, the policy aims to conserve energy could be adopted in Malaysia as it would not deteriorate economic growth. A significant transformation of low carbon technologies such as energy efficiency and renewable energy would contribute to reduce carbon emission to maintain long run economic growth in Malaysia (Begum et al. [97]).

Philippines

Table 8 presents the causality results in Philippines which are slightly different from the results from the cases of Indonesia, Malaysia and Thailand. The results show the evidence of unidirectional causality running from energy consumption to economic growth, this supports "Growth hypothesis" implying the high importance of energy in driving economy (energy dependency). The results are coherent with the earlier work of Yu and Choi [15], Chontanawat et al. [2], Chang et al. [22], Destek and Aslan [25], and the latest work by Tuna and Tuna [26]. They all examined causality in the "energy–growth" models and found unidirectional causality running from energy to GDP in Philippines. Unlike the results from other countries in our study, we found the relationship between economic growth and CO_2 in the case of Philippines. Causality runs from economic growth to CO_2 in the short-run, and vice versa in the long run. The results imply that an increase of economic output could lead to an increase of CO_2 emissions, and vice versa. The results are in line with the work of Munir et al. [78] who found causality running from economic growth to CO_2 in Philippines.

In short, the results indicate the unidirectional causality running from energy consumption to economy, and the interlinkage between economic growth and CO_2. Thus, any policies aiming to reduce energy consumption may have adverse effect on economic growth. Therefore, policies which focus on improving energy efficiency or use potential renewable energy sources would be more appropriate. There is a great potential for significant use particular in wind and hydro energy in Philippines. The country has set the targets for additional wind capacity of 2345 MW in 2022 and additional hydro of 5398 MW in 2023. (IRENA [98]).

Thailand

Table 9 presents the causality results of Thailand. Similar to the case of Malaysia, the results show strong evidence of unidirectional causality running from economic growth to energy consumption which supports the "conservative hypothesis". The results are consistent with the earlier work of Yoo [28] who found unidirectional causality running from GDP to energy consumption in Thailand from his "energy–growth" model. The results are also in line with the studies of Saboori and Sulaiman [77], and the latest work of Munir et al. [78] who investigate causality in the multivariate (energy–growth–CO_2) model for the ASEAN countries and found unidirectional causality running from economic growth to energy consumption for the case of Thailand. Furthermore, we found the relationship between energy and CO_2 in the study. Unidirectional causality running from energy consumption to CO_2 in the short run and vice versa in the long run are found in the study indicating that there are interlinkage between energy and CO_2 emissions. An increase in energy consumption would lead to an increase in CO_2 emissions and vice versa.

In general, the results imply that an expansion of economic activities stimulate energy consumption which also increase CO_2 emissions. The results suggest that Thailand should focus on the policy on fuel switching from fossil fuel such as from coal to natural gas and renewable energy. There are also a great potential of solar and biomass in Thailand (IRENA [98]). Since there is no evidence of causality running from energy to GDP, therefore, policies to reduce energy consumption could be implemented as it could help to reduce the level of CO_2 emissions without deteriorating the Nation's economic growth.

The summary of Granger causality relationship flows of these countries is shown in Figure 2.

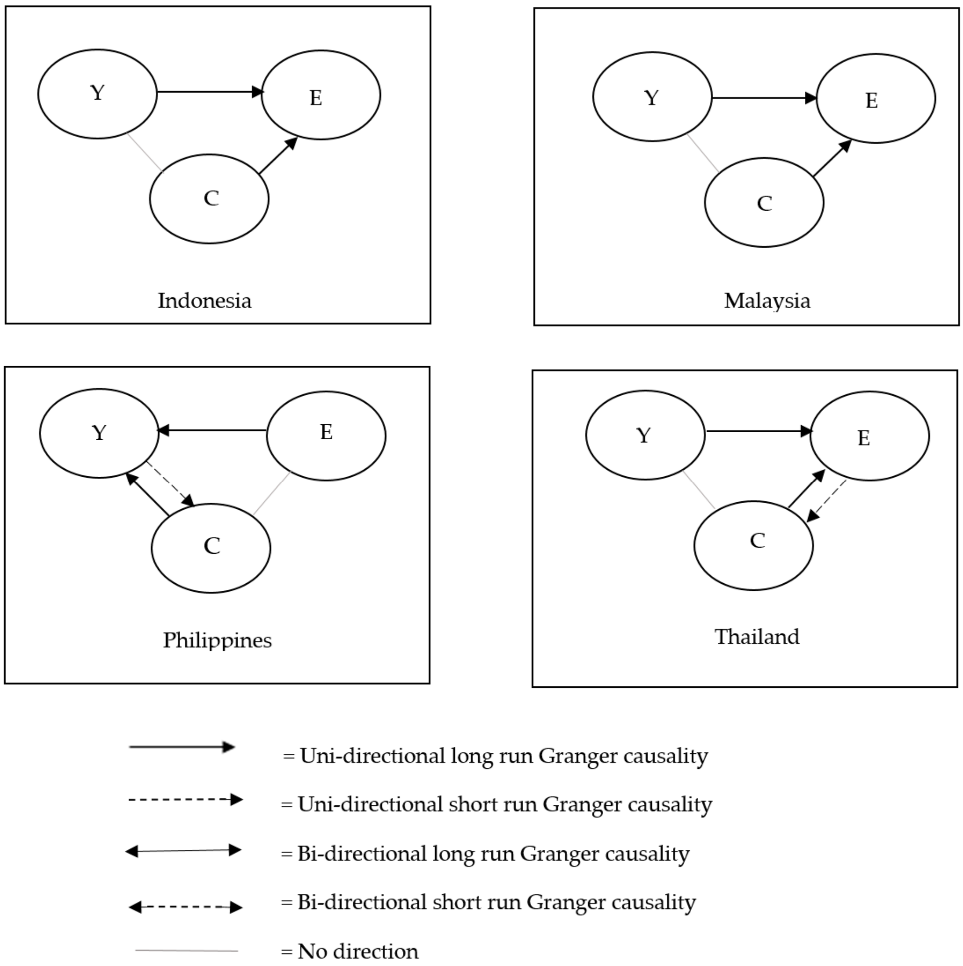

Figure 2. Granger causality relationship flows.

5. Conclusions and Policy Implications

ASEAN is one of the fastest growing economy regions in the world with rapid economic growth, high population, high energy consumption together with increasing pollution emission. Despite the importance of the region, surprisingly, there has been a small number empirical work examining the relationship between energy consumption, environmental pollution, and economic growth in the multivariate framework for ASEAN countries. Some works conducted for individual country such as Ang [72] for Malaysia, Jafari et al. [74], Hwang and Yoo [75] for Indonesia. A few work were conducted for a group of ASEAN such as Lean and Smyth [80] and Chandran and Tang [81] at disaggregate levels (electricity and transport sector), whereas a few conducted at aggregate level such as Saboori and Sulaiman [77] in the earlier period, and Munir et al. [78] and Chontanawat [79] in the latest period. Due to the special characteristic of the region and a limited number of the studies, it is important to highlight the research for the region. Our study therefore aims to enrich the literature. We investigate the relationship between energy consumption, economic growth and environmental pollution in the multivariate framework for ASEAN using consistent updated data set from IEA for a longer period (1971–2017). We adopted the concrete model so called "Cointegration and Causality" which is widely accepted among scholars (confirmed by previous studies). The four particular countries: Indonesia, Malaysia, Philippines, and Thailand have been selected for the study since they share the same characteristics suggested by the literature. Moreover, Indonesia, Thailand, Malaysia and Philippines are the top four CO_2-emitting countries during 1971–2013 (Chontanawat [90]).

The empirical results from these countries show that all variables used in the model are integrated at order one or I(1) (based on the unit root test), and there are long-run relationships among these variables (based on the cointegration test). Since the cointegration exists, the error correction model is used to examine the direction of causality. The causality results to some extent show the evidence of the relationships between these variables. In general, the results are quite close to the latest work of Munir et al. [78] and Chontanawat [79]. The causality results in the case of Indonesia, Malaysia and Thailand are rather similar showing the one way or unidirectional causality running from economic growth to energy consumption, which implies that the increase of economic outputs or activities, would lead to an increase of energy consumption. However, there is no clear evidence of causality running from energy consumption to economic growth. Therefore, the findings support the "conservation hypothesis" implying that energy conservation policy could be adopted without deteriorate economic growth of the countries. The results from these three countries are consistent with the conventional well known work by Kraft and Kraft [12], followed by a number of studies for various countries in the later periods as shown in the previous sections. The results based on "conservation hypothesis" are also supported by the country group studies of Lee and Chang [29] who investigate the causality between energy and economic growth in the panel 22 DCs and 18 LDCs and found the evidence of unidirectional causality from economic growth to energy in the LDCs (whereas bidirectional causality was found in the DCs), and Huang et al. [21] who examine the energy–growth causality for the 84 panel countries and found that economic growth leads energy consumption positively in the middle income groups (lower and upper middle income groups). Our results in the case of Philippines, however, are slightly different from the others. The results show the evidence of unidirectional causality running from energy consumption to economic growth which indicates the "growth hypothesis", implying that energy is a driving factor to economic growth. The results are consistent with the popular work by Stern [30,31] and other later studies in literature mentioned in the previous sections. Regarding the causal relationship between CO_2 emission and economic growth, surprisingly our empirical results do not find the evidence of the relationship particular in Indonesia, Malaysia, and Thailand. This is perhaps limited by the official CO_2 emission data used only account for CO_2 emission from fossil fuels combustion, while disregarding net carbon release from deforestation, forest degradation and peat swamp conservation. The results are supported by Jafari et al. [74], Alam et al. [60], and Ozturk and Acaravci [59].

In terms of policy implication and recommendations, for the three countries—Indonesia, Malaysia and Thailand—in which unidirectional causation running from GDP to energy consumption is found, (whereas, the unidirectional causality from energy consumption to GDP is not detected), this implies that economic development of these countries may not completely depend on the energy consumption. Therefore, the adoption of any policies in order to control energy demand would not adversely affect economic growth of the countries. A stronger energy conservation policy via energy efficiency policy program or fuel switching to renewable energy would be pursued in these countries. Furthermore, the governments could decrease energy-related spending, thus allowing greater expenditure in other prioritize areas that could benefit growth in the long run such as education and health. The evidence of no causal relationship between CO_2 emission and economic growth also indicates that the countries can improve economic growth without tradeoff for environment quality to achieve the national plans.

In the case of Philippines, unidirectional causality running from energy consumption to economic growth is found implying that energy is an impetus for economic growth in Philippines. Therefore, energy conservation may lead to slower pace of growth. Moreover, the causal relationships between economic growth and CO_2 are detected. Economic growth causes CO_2 implying that economic growth contributes to CO_2 and that Philippines should develop policies to reduce harmful effect of growth such as renewable energy sources. In the meantime, CO_2 causes economic growth, this implies that environmental degradation could affect economic growth such as lost productivities. Therefore, the policies to improve environmental quality are needed. One alternative to reduce the harmful effect of fossil consumption for the environment is to further explore renewable energy options. The policy in promoting potential renewable energy such as wind power would be a good strategy option to mitigate carbon emissions. This could be done via energy-efficient technologies in domestic production to reduce CO_2 emissions at the aggregate and disaggregate levels.

In fact, fossil fuel is still the dominant fuel used in the ASEAN region. Energy demand in Indonesia, Malaysia, Philippines, and Thailand are dominated by oil and gas with increasing use of coal (Chontanawat [90]). However, there is great potential for renewable energy to be developed. The region is richly endowed with diverse renewable energy sources. Solar and wind are considered to be the most promising ones for urban areas. There is a significant use of wind power in Indonesia, Thailand, Vietnam and Philippines, while solar and biomass are likely to be promising in Thailand and Malaysia (ASEAN Centre for Energy: ACE 2017) [99]. It can be seen that energy policies focusing on improving energy efficiency and promoting renewable energy are significant for the ASEAN region. The study from Chontanawat [90] indicates that energy efficiency and the fuel mix adjustment to use more renewable energy together with encouraging low carbon technology are likely to be the most effective ways to reduce emissions of the region in the future.

In fact, during the past twenty years, many countries in ASEAN have initiated and implemented energy policies and programs to improve energy efficiency of end-users, and promote renewable energy, by setting EE and RE targets. One goal is to reduce energy intensity in the region to 20% by 2020 and 30% by 2025 based on 2005 levels, through various activities. They also set the aspirational target to increase the share of renewable energy to 23% in the energy mix (ACE 2020 [100]). Each country has actually set some forms of EE and RE targets, motivated by a range of factors which are (1) "environmental protection and climate change mitigation" as part of the Paris Agreement, each country submitted nationally determined contribution (NDCs) to reducing the impacts of climate change, (2) "energy security", (3) "cost-competitiveness", and (4) "socio-economic benefits". For example, Indonesia has set the target in reduce energy consumption in 2025 by 17% in industry, 20% in transportation, 15% in household, and 15% in commercial buildings as compared to business as usual. They also set a target of 23% and 31% of renewable energy in its primary energy supply mix in 2025 and in 2050. Malaysia set the target to reduce electricity consumption by 8% in 2025 as compared with business as usual. They also set renewable energy installed capacity of 2080 MW (excluding large hydro) by 2020 contributing to 7.8% of total installed capacity in Peninsular Malaysia and Sabah. Philippines set the target to reduce TFEC by 1% per year as compared with business as usual until 2040, equivalent to the reduction of one-third of energy demand. This will reduce energy intensity (TFEC/GDP) by 40% in 2040 as compared to 2005 level. With the increasing cost-competitiveness of renewable energy technology, the country targets to install 15.3 GW of renewable energy capacity by 2030, accounting for 61% of the projected electricity demand. Thailand also set a target to reduce energy intensity (TFEC/GDP) by 30% in 2036 compared with 2010 level. They also set a target of 30% renewable energy in total energy consumption by 2036 with different breakdowns in each sector, for example, biofuels are expected to supply 25% of energy demand in transportation sector, and the share of renewables in electricity and heat is expected to reach 20% and 37% respectively. (IRENA [98]).

Even though the ambitious targets have been set in these countries, they may face or encounter with some barriers in terms of geographical, institutional and investment factors, limited renewable energy technology, lack of awareness, and limited private sector engagement, etc. Hence, to achieve the goals, a clear policy framework and robust institutions need to be developed together with the liberalization of energy markets to encourage competitiveness in the sector.

There are some recommendations for the future research. First, in terms of the data used, the official CO_2 data only accounts for CO_2 from fossil fuel, while disregarding other sources. It would be interesting to investigate more on this issue. Second, energy data could be broken down or disaggregated either by fuels or by economic sectors that could make the analysis more specific and lead to the fruitful policy implication. Third, other related factors such as institutional and investment factors could be considered to incorporate in the model of individual countries depending on the importance and the availability of the data. This could yield the concrete results. All these would create interesting works to enhance the literature.

Funding: The research was funded by King Mongkut's University of Technology Thonburi: School of Liberal Arts, grant number 2562103 and Research, Innovation and Partnerships Office (RIPO), grant number T630454.

Acknowledgments: This paper is an extension of the one presented at ICEER 2019 and published in "Energy Report". I would like to thank Department of Social Sciences and Humanities, School of Liberal Arts, and Research, Innovation and Partnerships Office (RIPO), King Mongkut's University of Technology Thonburi, for the research fund of this project. Special thanks go to the Economy and Environment program for Southeast Asia (EEPSEA) who provided the great research support and guidance for the earlier related work. I am also indebted to advice from scientific committee members and participants in the 6th International Conference on Energy and Environment Research, (ICEER 2019) on the earlier draft. Last but not least, I would like to thank the anonymous referees for their comments and suggestions. This helps very much in improving the original version of my paper. The view and opinions in the paper belong to the author and any errors or mistakes are the author's responsibility.

Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Table A1. Literature on "Energy–Growth" Causality Model.

Author(s)	Period	Country	Methodology	Main Findings
Neutral Hypothesis:				
Yu and Choi [15]	1950–1976	5 countries: (US, UK, Poland, Korea, Philippines)	Sims, Granger causality	Y–E (USA, UK, Poland)
Masih and Masih [16]	1955–1990	Asian regions: (Malaysia, India, Indonesia, Pakistan, Philippines, Singapore)	Johansen cointegration and Granger causality	Y–E (Malaysia, Philippines, Singapore)
Asafu-Adjaye [17]	1971–1995	Asian regions: (India, Indonesia, Philippines, Thailand)	Johansen cointegration and Granger causality	E–Y (SR) (India, Indonesia)
Soytas and Sari [18]	1950–1994	G7 and top emerging countries	Johansen cointegration and Granger causality	Y–E (Brazil, India, Indonesia, Mexico, Poland, S.Africa, USA, UK, Canada)
Altinay and Karagol [19]	1950–2000	Turkey	Hsiao's Granger causality	Y–E
Wolde-Rufael [20]	1971–2001	19 African countries	Toda and Yamamoto's Granger causality	Y–E (Benin, Congo RP, Kenya, Senegal, S. Africa, Sudan, Togo, Tunisia, Zimbabwe)
Huang et al. [21]	1972–2002	panel 82 countries	panel VAR and GMM-SYS model	Y–E (low income group)
Chang et al. [22]	1970–2010	Asian regions: (China, Indonesia, India, Japan, Malaysia, Pakistan, Philippines, Singapore, S. Korea, Taiwan, Thailand, Vietnam)	Bootstrap panel causality	Y–E (China, Indonesia, Japan, Malaysia, Pakistan, Singapore, S. Korea, Taiwan)
Yildirim et al. [23]	1971–2009	ASEAN-5: (Indonesia, Malaysia, Philippines, Singapore, Thailand)	Bootstrap panel and time series causality	Y–E (Singapore)
Azam et al. [24]	1980–2012	ASEAN-5: (Indonesia, Malaysia, Philippines, Singapore, Thailand)	Johansen cointegration and Granger causality	Y–E (Indonesia, Philippines, Singapore, Thailand)
Destek and Aslan [25]	1980–2012	17 emerging economies	Bootstrap panel causality	Y–E (Brazil, Chile, Greece, India, Indonesia, Malaysia, S. Africa, S. Korea, Thailand)
Tuna and Tuna [26]	1980–2015	ASEAN-5: (Indonesia, Malaysia, Philippines, Singapore, Thailand)	Hacker, Hatemi-J tests and causality	Y–E (Indonesia, Thailand)

Table A1. *Cont.*

Author(s)	Period	Country	Methodology	Main Findings
Conservative Hypothesis:				
Kraft and Kraft [12]	1947–1974	USA	Sims causality	Y→E
Yu and Choi [15]	1950–1976	5 countries: (US, UK, Poland, Korea, Philippines)	Sims, Granger causality	Y→E (Korea)
Masih and Masih [16]	1955–1990	Asian regions: (Malaysia, India, Indonesia, Pakistan, Philippines, Singapore)	Johansen cointegration and Granger causality	Y→E (Indonesia)
Soytas and Sari [18]	1950–1994	G7 and top emerging countries	Johansen cointegration and Granger causality	Y→E (Italy, Korea)
Jumbe [27]	1970–1999	Malawi (Electricity sector)	Standard Granger causality	NGDP→Elec (NGDP: Non-agriculture GDP)
Wolde-Rufael [20]	1971–2001	19 African countries	Toda and Yamamoto's Granger causality	Y→E (Algeria, Congo DR, Egypt, Ghana, Ivory Coast)
Yoo [28]	1971–2002	ASEAN-4: (Indonesia, Malaysia, Singapore, Thailand) (Electricity sector)	Hsiao's Granger causality	Y→Elec (Indonesia, Thailand)
Lee and Chang [29]	1971–2002	22 DCs and 18 LDCs	panel VARs and GMM technique	Y→E (LDCs)
Huang et al. [21]	1972–2002	panel 82 countries	panel VARs and GMM-SYS model	Y→E (middle income group)
Chang et al. [22]	1970–2010	Asian regions: (China, Indonesia, India, Japan, Malaysia, Pakistan, Philippines, Singapore, S. Korea, Taiwan, Thailand, Vietnam)	Bootstrap panel causality	Y→E (India)
Yildirim et al. [23]	1971–2009	ASEAN-5: (Indonesia, Malaysia, Philippines, Singapore, Thailand)	Bootstrap panel and time series causality	Y→E (Indonesia, Malaysia, Philippines)
Azam et al. [24]	1980–2012	ASEAN-5: (Indonesia, Malaysia, Philippines, Singapore, Thailand)	Johansen cointegration and Granger causality	Y→E (Malaysia)
Destek and Aslan [25]	1980–2012	17 emerging economies	Bootstrap panel causality	Y→E (Egypt, Peru, Portugal)
Growth Hypothesis:				
Stern [30]	1947–1990	USA	VAR Granger causality	E→Y
Stern [31]	1948–1994	USA	Johansen cointegration and Granger causality	E→Y
Yu and Choi [15]	1950–1976	5 countries: (US, UK, Poland, Korea, Philippines)	Sims, Granger causality	E→Y (Philippines)
Masih and Masih [16]	1955–1990	Asian regions: (Malaysia, India, Indonesia, Pakistan, Philippines, Singapore)	Johansen cointegration and Granger causality	E→Y (India)
Asafu-Adjaye [17]	1971–1995	Asian regions: (India, Indonesia, Philippines, Thailand)	Johansen cointegration and Granger causality	E→Y(Lr) (India, Indonesia)
Soytas and Sari [18]	1950–1994	G7 and top emerging countries	Johansen cointegration and Granger causality	E→Y (Turkey, France, Germany, Japan)
Wolde-Rufael [32]	1952–1999	Shanghai	Toda and Yamamoto's Granger causality	E→Y
Wolde-Rufael [20]	1971–2001	19 African countries	Toda and Yamamoto's Granger causality	E→Y (Cameroon, Morocco, Nigeria)
Chontanawat, et al. [2]	1971–2000	OECD and non-OECD	Hsiao's Granger causality	E→Y (Kenya, Nepal, Philippines)

Table A1. *Cont.*

Author(s)	Period	Country	Methodology	Main Findings
Huang et al. [21]	1972–2002	panel 82 countries	panel VAR and GMM-SYS model	E→Y (high income group)
Chandran et al. [33]	1971–2003	Malaysia (Electricity sector)	ARDL cointegration and Granger causality	Elec→Y
Wang et al. [34]	1972–2006	China	ARDL cointegration and Granger causality	E→Y
Borozan [35]	1992–2010	Croatia	VAR Granger causality	E→Y
Chang et al. [22]	1970–2010	Asian regions: (China, Indonesia, India, Japan, Malaysia, Pakistan, Philippines, Singapore, S. Korea, Taiwan, Thailand, Vietnam)	Bootstrap panel causality	E→Y (Philippines)
Destek and Aslan [25]	1980–2012	17 emerging economies	Bootstrap panel causality	E→Y (China, Colombia, Mexico, Philippines)
Tuna and Tuna [26]	1980–2015	ASEAN-5: (Indonesia, Malaysia, Philippines, Singapore, Thailand)	Hacker, Hatemi-J tests and causality	E→Y (Malaysia, Philippines, Singapore)
Feedback Hypothesis:				
Masih and Masih [16]	1955–1990	Asian regions: (Malaysia, India, Indonesia, Pakistan, Philippines, Singapore)	Johansen cointegration and Granger causality	E↔Y (Pakistan)
Masih and Masih [36]	1955–1991 1952–1992	East-Asian NICS: (S. Korea, Taiwan)	Cointegration and Granger causality	E↔Y
Asafu-Adjaye [17]	1971–1995	Asian regions: (India, Indonesia, Philippines, Thailand)	Cointegration and Granger causality	E↔GDP (Sr) (Philippines, Thailand)
Yang [37]	1954–1997	Taiwan	Hsiao's Granger causality	E↔Y
Hondroyiannis et al. [38]	1960–1996	Greece	Johansen cointegration and Granger causality	E↔Y
Soytas and Sari [18]	1950–1994	G7 and top emerging countries	Johansen cointegration and Granger causality	E↔Y (Argentina)
Paul and Bhattacharya [39]	1950–1996	India	Johansen cointegration and Granger causality	E↔Y
Jumbe [27]	1970–1999	Malawi (electricity sector)	Standard Granger causality	Y↔Elec
Wolde-Rufael [20]	1971–2001	19 African countries	Toda and Yamamoto's Granger causality	E↔Y (Gabon, Zambia)
Yoo [28]	1971–2002	ASEAN-4: (Indonesia, Malaysia, Singapore, Thailand) (electricity sector)	Hsiao's Granger causality	Y↔Elec (Malaysia, Singapore)
Lee and Chang [29]	1965–2002	22 DCs and 18 LDCs	panel VARs and GMM technique	Y↔E (DCs)
Chang et al. [22]	1970–2010	Asian regions: (China, Indonesia, India, Japan, Malaysia, Pakistan, Philippines, Singapore, S. Korea, Taiwan, Thailand, Vietnam)	Bootstrap panel causality	Y↔E (Thailand, Vietnam)
Yildirim et al. [23]	1971–2009	ASEAN-5: (Indonesia, Malaysia, Philippines, Singapore, Thailand)	Bootstrap panel and time series causality	Y↔E (Thailand)
Destek and Aslan [25]	1980–2012	17 emerging economies	Bootstrap panel causality	Y↔E (Turkey)

Table A2. Literature on "Energy–Growth–CO_2" causality Model.

Author(s)	Period	Country	Methodology	Main Findings
Overall Countries:				
Ozturk and Acaravci [59]	1968–2005	Turkey	ARDL cointegration and Granger causality	Y–C, E–C, E–Y.
Alam et al. [60]	1971–2006	India	Toda and Yamamoto's Granger causality	E↔C(Sr), E–Y(Lr), Y–C(Sr).
Alam et al. [61]	1972–2008	Bangladesh	Johansen cointegration and Granger causality	E→Y(Sr,Lr), Elec↔Y(Lr), E→C(Sr), C→Y(Lr), C→Y(Sr,Lr).
Farhani and Ben [62]	1973–2008	Panel MENA region	Panel cointegration and Granger causality	Y–E(Sr), E→C,Y(Sr), Y→E(Lr), C→E(Lr).
Hamit-Haggar [63]	1990–2007	Panel Canadian industrial sector	Panel FMOLS cointegration and Granger causality	E→C(Sr), Y→C(Sr), C→E(Sr), Y→E(Sr), E→C(Lr),Y→C(Lr).
Saboori et al. [64]	1960–2008	OECD (Road transport sector)	Panel FMOLS Cointegration and Granger causality	C↔Y, E↔Y, E↔C.
Alshehry and Belloumi [65]	1971–2010	Saudi Arabia	Johansen cointegration and Granger causality	E→Y(Lr), E→C(Lr), C↔Y(Lr), E→Y(Sr), C→Y(Sr).
Bastola and Sapkota [66]	1980–2011	Nepal	Johansen cointegration and Granger causality	E↔C(LR), Y→C(LR), Y→E(LR).
Chen et al. [67]	1993–2010	Global 188 countries Panel A (whole) Panel B (26 DCs) Panel C (162 LDCs)	Panel Cointegration and Granger causality	E→C (all panels) E→Y(-) (panel A,C)
Ahmad et al. [68]	1971–2014	India	ARDL cointegration and Granger causality	E↔C E↔Y C↔Y
Esso and Keho [69]	1971–2010	12 selected African countries	Cointegration and Granger causality	Mixed results
Wang et al. [70]	1990–2012	China	ARDL cointegration and Granger causality	E↔Y (Sr), E→C (Sr), Y–C (Sr).
Wang et al. [71]	1995–2012	China's provinces	Panel Cointegration and Granger causality	E↔Y (Sr,Lr), E↔C (Sr,Lr), Y→C (Sr,Lr).
ASEAN Countries				
Ang [72]	1971–1999	Malaysia	Johansen cointegration and Granger causality	Y→E (Sr, Lr).
Etokakpan et al. [73]	1980–2014	Malaysia (Natural gas sector)	ARDL cointegration and Granger causality	Y→Ng, Y–C.
Jafari et al. [74]	1971–2007	Indonesia	Toda-Yamamoto's causality	Y–E, Y–C.
Hwang and Yoo [75]	1965–2006	Indonesia	Cointegration and Granger causality	Y→E, Y→C, E↔C.
Odugbesan and Rjoub [76]	1993–2017	MINT (Mexico, Indonesia, Nigeria, and Turkey)	ARDL cointegration and Granger causality	Y→E(Lr), C→E(Lr) (Indonesia).
Saboori and Sulaiman [77]	1971–2009	ASEAN-5	ARDL cointegration and Granger causality	:E↔Y(Lr), E↔C(Lr), Y↔C(Lr), Y→C(Sr) (Indonesia). :E↔Y(Lr), E→Y(Sr), E↔C(Sr,Lr), Y↔C, (Malaysia). :E↔Y(Lr), E→Y(Sr), E↔C(Lr),Y↔C(Lr), C→Y(Sr) (Philippines). :Y→E(Lr) E→Y(Sr), E↔C (Sr,Lr), Y↔C(Sr), Y→C(Lr) (Thailand). :Y→E(Lr),E↔C(Sr,Lr), Y↔C(Sr), Y→C(Lr), (Singapore).

Table A2. *Cont.*

Author(s)	Period	Country	Methodology	Main Findings
Munir et al. [78]	1980–2016	ASEAN-5	Panel cointegration and Granger causality	:Y→E (Indonesia, Malaysia, Thailand). :Y→C (Malaysia, Philippines, Singapore, Thailand). :E↔Y (Philippines). :E→Y (Singapore).
Chontanawat [79]	1971–2015	ASEAN-8	Johansen cointegration and Granger causality	Y→E (Lr), C→E (Lr) E→C (Sr).
Lean and Smyth [80]	1980–2006	ASEAN-5 (Electricity sector)	Johansen Fisher panel cointegration and Granger causality	Elec, C→Y(Lr) C→ Elec (Sr).
Chandran and Tang [81]	1971–2008	ASEAN-5 (Transportation sector)	Johansen cointegration and Granger causality	:Y↔C(Lr), Y→C(Sr), E→Y(Sr,Lr), E→C(Lr), C→E(Sr), C→Y(Sr,Lr) (Indonesia). Y→C(Sr,Lr), :E↔Y(Sr,Lr), E↔C(Lr), C→E(Sr) (Malaysia). :E↔C(Sr), Y→E(Sr), C→Y(Sr) (Philippines). :E↔C(Sr,Lr), Y↔C(Sr,Lr), Y→C(Sr), E→Y(Lr) (Thailand). :C↔Y(Sr), E→Y(Sr) (Singapore).

References

1. International Energy Agency (IEA). *World Energy Outlook*; International Energy Agency: Paris, France, 2004.
2. Chontanawat, J.; Hunt, L.C.; Pierse, R. Does energy consumption cause economic growth?: Evidence from a systematic study of over 100 countries. *J. Policy Model.* **2008**, *30*, 209–220. [CrossRef]
3. Chontanawat, J.; Hunt, L.C.; Pierse, R. *Causality between Energy Consumption and GDP: Evidence from 30 OECD and 78 Non-OECD Countries*; Surrey Energy Economics Centre (SEEC), School of Economics, University of Surrey: Guildford, UK, 2006.
4. Stern, D.I. Economic Growth and Energy. *Encycl. Energy* **2004**, *2*, 35–51.
5. Jones, C. *Introduction to Economic Growth*, 2nd ed.; W. W. Norton & Company: New York, NY, USA, 1998.
6. Sørensen, P.B.; Whitta-Jacobsen, H.J. *Introducing Advanced Macroeconomics: Growth and Business Cycles*; McGraw-Hill Education: New York, NY, USA, 2005.
7. Ayres, R.U.; Warr, B. Accounting for growth: The role of physical work. *Struct. Chang. Econ. Dyn.* **2005**, *16*, 181–209. [CrossRef]
8. Ayres, R.U. Eco-thermodynamics: Economics and the second law. *Ecol. Econ.* **1998**, *26*, 189–209. [CrossRef]
9. Toman, M.T.; Jemelkova, B. Energy and economic development: An assessment of the state of knowledge. *Energy J.* **2003**, *24*, 93–112. [CrossRef]
10. International Energy Agency (IEA). *Southeast Asia Energy Outlook 2019*; International Energy Agency: Paris, France, 2019.
11. International Energy Agency (IEA). *Southeast Asia Energy Outlook 2017, World Energy Outlook Special Report*; 9789264285576 (PDF); International Energy Agency: Paris, France, 2017.
12. Kraft, J.; Kraft, A. Note and comments: On the relationship between energy and GNP. *J. Energy Dev.* **1978**, *3*, 401–403.
13. Payne, J.E. Survey of the international evidence on the causal relationship between energy consumption and growth. *J. Econ. Stud.* **2010**, *37*, 53–95. [CrossRef]
14. Ozturk, I. A literature survey on energy-growth nexus. *Energy Policy* **2010**, *38*, 340–349. [CrossRef]
15. Yu, E.S.; Choi, J.-Y. The causal relationship between energy and GNP: An international comparison. *J. Energy Dev.* **1985**, *10*, 249–272.
16. Masih, A.M.; Masih, R. Energy consumption, real income and temporal causality: Results from a multi-country study based on cointegration and error-correction modelling techniques. *Energy Econ.* **1996**, *18*, 165–183. [CrossRef]
17. Asafu-Adjaye, J. The relationship between energy consumption, energy prices and economic growth: Time series evidence from Asian developing countries. *Energy Econ.* **2000**, *22*, 615–625. [CrossRef]

18. Soytas, U.; Sari, R. Energy consumption and GDP: Causality relationship in G-7 countries and emerging markets. *Energy Econ.* **2003**, *25*, 33–37. [CrossRef]
19. Altinay, G.; Karagol, E. Structural break, unit root, and the causality between energy consumption and GDP in Turkey. *Energy Econ.* **2004**, *26*, 985–994. [CrossRef]
20. Wolde-Rufael, Y. Energy demand and economic growth: The African experience. *J. Policy Model.* **2005**, *27*, 891–903. [CrossRef]
21. Huang, B.-N.; Hwang, M.J.; Yang, C.W. Causal relationship between energy consumption and GDP growth revisited: A dynamic panel data approach. *Ecol. Econ.* **2008**, *67*, 41–54. [CrossRef]
22. Chang, T.; Chu, H.-P.; Chen, W.-Y. Energy consumption and economic growth in 12 Asian countries: Panel data analysis. *Appl. Econ. Lett.* **2013**, *20*, 282–287. [CrossRef]
23. Yildirim, E.; Aslan, A.; Ozturk, I. Energy consumption and GDP in ASEAN countries: Bootstrap-corrected panel and time series causality tests. *Singap. Econ. Rev.* **2014**, *59*, 1450010. [CrossRef]
24. Azam, M.; Khan, A.Q.; Bakhtyar, B.; Emirullah, C. The causal relationship between energy consumption and economic growth in the ASEAN-5 countries. *Renew. Sustain. Energy Rev.* **2015**, *47*, 732–745. [CrossRef]
25. Destek, M.A.; Aslan, A. Renewable and non-renewable energy consumption and economic growth in emerging economies: Evidence from bootstrap panel causality. *Renew. Energy* **2017**, *111*, 757–763. [CrossRef]
26. Tuna, G.; Tuna, V.E. The asymmetric causal relationship between renewable and NON-RENEWABLE energy consumption and economic growth in the ASEAN-5 countries. *Resour. Policy* **2019**, *62*, 114–124. [CrossRef]
27. Jumbe, C.B. Cointegration and causality between electricity consumption and GDP: Empirical evidence from Malawi. *Energy Econ.* **2004**, *26*, 61–68. [CrossRef]
28. Yoo, S.-H. The causal relationship between electricity consumption and economic growth in the ASEAN countries. *Energy Policy* **2006**, *34*, 3573–3582. [CrossRef]
29. Lee, C.-C.; Chang, C.-P. Energy consumption and GDP revisited: A panel analysis of developed and developing countries. *Energy Econ.* **2007**, *29*, 1206–1223. [CrossRef]
30. Stern, D.I. Energy and economic growth in the USA: A multivariate approach. *Energy Econ.* **1993**, *15*, 137–150. [CrossRef]
31. Stern, D.I. A multivariate cointegration analysis of the role of energy in the US macroeconomy. *Energy Econ.* **2000**, *22*, 267–283. [CrossRef]
32. Wolde-Rufael, Y. Disaggregated industrial energy consumption and GDP: The case of Shanghai, 1952–1999. *Energy Econ.* **2004**, *26*, 69–75. [CrossRef]
33. Chandran, V.; Sharma, S.; Madhavan, K. Electricity consumption–growth nexus: The case of Malaysia. *Energy Policy* **2010**, *38*, 606–612. [CrossRef]
34. Wang, Y.; Wang, Y.; Zhou, J.; Zhu, X.; Lu, G. Energy consumption and economic growth in China: A multivariate causality test. *Energy Policy* **2011**, *39*, 4399–4406. [CrossRef]
35. Borozan, D. Exploring the relationship between energy consumption and GDP: Evidence from Croatia. *Energy Policy* **2013**, *59*, 373–381. [CrossRef]
36. Masih, A.M.; Masih, R. On the temporal causal relationship between energy consumption, real income, and prices: Some new evidence from Asian-energy dependent NICs based on a multivariate cointegration/vector error-correction approach. *J. Policy Model.* **1997**, *19*, 417–440. [CrossRef]
37. Yang, H.-Y. A note on the causal relationship between energy and GDP in Taiwan. *Energy Econ.* **2000**, *22*, 309–317. [CrossRef]
38. Hondroyiannis, G.; Lolos, S.; Papapetrou, E. Energy consumption and economic growth: Assessing the evidence from Greece. *Energy Econ.* **2002**, *24*, 319–336. [CrossRef]
39. Paul, S.; Bhattacharya, R.N. Causality between energy consumption and economic growth in India: A note on conflicting results. *Energy Econ.* **2004**, *26*, 977–983. [CrossRef]
40. Kuznets, S. Economic growth and income inequality. *Am. Econ. Rev.* **1955**, *45*, 1–28.
41. Dinda, S. Environmental Kuznets curve hypothesis: A survey. *Ecol. Econ.* **2004**, *49*, 431–455. [CrossRef]
42. Grossman, G.; Krueger, A. Environmental impacts of a North American Free Trade Agreement, 1991. In *NBER Working Paper*; National Bureau of Economic Research: Cambridge, MA, USA, 1991.
43. Selden, T.M.; Song, D. Environmental quality and development: Is there a Kuznets curve for air pollution emissions? *J. Environ. Econ. Manag.* **1994**, *27*, 147–162. [CrossRef]
44. Stern, D.I.; Common, M.S.; Barbier, E.B. Economic growth and environmental degradation: The environmental Kuznets curve and sustainable development. *World Dev.* **1996**, *24*, 1151–1160. [CrossRef]

45. Galeotti, M.; Lanza, A.; Pauli, F. Reassessing the environmental Kuznets curve for CO_2 emissions: A robustness exercise. *Ecol. Econ.* **2006**, *57*, 152–163. [CrossRef]
46. Dinda, S.; Coondoo, D. Income and emission: A panel data-based cointegration analysis. *Ecol. Econ.* **2006**, *57*, 167–181. [CrossRef]
47. Coondoo, D.; Dinda, S. Carbon dioxide emission and income: A temporal analysis of cross-country distributional patterns. *Ecol. Econ.* **2008**, *65*, 375–385. [CrossRef]
48. Managi, S.; Jena, P.R. Environmental productivity and Kuznets curve in India. *Ecol. Econ.* **2008**, *65*, 432–440. [CrossRef]
49. Narayan, P.K.; Narayan, S. Carbon dioxide emissions and economic growth: Panel data evidence from developing countries. *Energy Policy* **2010**, *38*, 661–666. [CrossRef]
50. Saboori, B.; Sulaiman, J.; Mohd, S. Economic growth and CO_2 emissions in Malaysia: A cointegration analysis of the environmental Kuznets curve. *Energy Policy* **2012**, *51*, 184–191. [CrossRef]
51. Kanjilal, K.; Ghosh, S. Environmental Kuznet's curve for India: Evidence from tests for cointegration with unknown structuralbreaks. *Energy Policy* **2013**, *56*, 509–515. [CrossRef]
52. Nasir, M.; Rehman, F.U. Environmental Kuznets curve for carbon emissions in Pakistan: An empirical investigation. *Energy Policy* **2011**, *39*, 1857–1864. [CrossRef]
53. Fodha, M.; Zaghdoud, O. Economic growth and pollutant emissions in Tunisia: An empirical analysis of the environmental Kuznets curve. *Energy Policy* **2010**, *38*, 1150–1156. [CrossRef]
54. Iwata, H.; Okada, K.; Samreth, S. Empirical study on the environmental Kuznets curve for CO_2 in France: The role of nuclear energy. *Energy Policy* **2010**, *38*, 4057–4063. [CrossRef]
55. Holtz-Eakin, D.; Selden, T.M. Stoking the fires? CO_2 emissions and economic growth. *J. Public Econ.* **1995**, *57*, 85–101. [CrossRef]
56. Shafik, N. Economic development and environmental quality: An econometric analysis. *Oxf. Econ. Pap.* **1994**, *46*, 757–773. [CrossRef]
57. Friedl, B.; Getzner, M. Determinants of CO_2 emissions in a small open economy. *Ecol. Econ.* **2003**, *45*, 133–148. [CrossRef]
58. Özokcu, S.; Özdemir, Ö. Economic growth, energy, and environmental Kuznets curve. *Renew. Sustain. Energy Rev.* **2017**, *72*, 639–647. [CrossRef]
59. Ozturk, I.; Acaravci, A. CO_2 emissions, energy consumption and economic growth in Turkey. *Renew. Sustain. Energy Rev.* **2010**, *14*, 3220–3225. [CrossRef]
60. Alam, M.J.; Begum, I.A.; Buysse, J.; Rahman, S.; Van Huylenbroeck, G. Dynamic modeling of causal relationship between energy consumption, CO_2 emissions and economic growth in India. *Renew. Sustain. Energy Rev.* **2011**, *15*, 3243–3251. [CrossRef]
61. Alam, M.J.; Begum, I.A.; Buysse, J.; Van Huylenbroeck, G. Energy consumption, carbon emissions and economic growth nexus in Bangladesh: Cointegration and dynamic causality analysis. *Energy Policy* **2012**, *45*, 217–225. [CrossRef]
62. Farhani, S.; Ben Rejeb, J. Energy consumption, economic growth and CO_2 emissions: Evidence from panel data for MENA region. *Int. J. Energy Econ. Policy (IJEEP)* **2012**, *2*, 71–81.
63. Hamit-Haggar, M. Greenhouse gas emissions, energy consumption and economic growth: A panel cointegration analysis from Canadian industrial sector perspective. *Energy Econ.* **2012**, *34*, 358–364. [CrossRef]
64. Saboori, B.; Sapri, M.; Baba, M. Economic growth, energy consumption and CO_2 emissions in OECD (Organization for Economic Co-operation and Development)'s transport sector: A fully modified bi-directional relationship approach. *Energy* **2014**, *66*, 150–161. [CrossRef]
65. Alshehry, A.S.; Belloumi, M. Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia. *Renew. Sustain. Energy Rev.* **2015**, *41*, 237–247. [CrossRef]
66. Bastola, U.; Sapkota, P. Relationship among energy consumption, pollution emission and economic growth in Nepal. *Energy* **2015**, *80*, 254–262. [CrossRef]
67. Chen, P.Y.; Chen, S.T.; Hsu, C.S.; Chen, C.C. Modeling the global relationships among economic growth, energy consumption and CO_2 emissions. *Renew. Sustain. Energy Rev.* **2016**, *65*, 420–431. [CrossRef]
68. Ahmad, A.; Zhao, Y.; Shahbaz, M.; Bano, S.; Zhang, Z.; Wang, S.; Liu, Y. Carbon emissions, energy consumption and economic growth: An aggregate and disaggregate analysis of the Indian economy. *Energy Policy* **2016**, *96*, 131–143. [CrossRef]

69. Esso, L.J.; Keho, Y. Energy consumption, economic growth and carbon emissions: Cointegration and causality evidence from selected African countries. *Energy* **2016**, *114*, 492–497. [CrossRef]
70. Wang, S.; Li, Q.; Fang, C.; Zhou, C. The relationship between economic growth, energy consumption, and CO_2 emissions: Empirical evidence from China. *Sci. Total Environ.* **2016**, *542*, 360–371. [CrossRef]
71. Wang, S.; Zhou, C.; Li, G.; Feng, K. CO_2, economic growth, and energy consumption in China's provinces: Investigating the spatiotemporal and econometric characteristics of China's CO_2 emissions. *Ecol. Indic.* **2016**, *69*, 184–195. [CrossRef]
72. Ang, J.B. Economic development, pollutant emissions and energy consumption in Malaysia. *J. Policy Model.* **2008**, *30*, 271–278. [CrossRef]
73. Etokakpan, M.U.; Solarin, S.A.; Yorucu, V.; Bekun, F.V.; Sarkodie, S.A. Modeling natural gas consumption, capital formation, globalization, CO_2 emissions and economic growth nexus in Malaysia: Fresh evidence from combined cointegration and causality analysis. *Energy Strategy Rev.* **2020**, *31*, 100526. [CrossRef]
74. Jafari, Y.; Othman, J.; Nor, A.H.S.M. Energy consumption, economic growth and environmental pollutants in Indonesia. *J. Policy Model.* **2012**, *34*, 879–889. [CrossRef]
75. Hwang, J.-H.; Yoo, S.-H. Energy consumption, CO_2 emissions, and economic growth: Evidence from Indonesia. *Qual. Quant.* **2014**, *48*, 63–73. [CrossRef]
76. Odugbesan, J.A.; Rjoub, H. Relationship Among Economic Growth, Energy Consumption, CO_2 Emission, and Urbanization: Evidence From MINT Countries. *SAGE Open* **2020**, *10*, 2158244020914648. [CrossRef]
77. Saboori, B.; Sulaiman, J. CO_2 emissions, energy consumption and economic growth in Association of Southeast Asian Nations (ASEAN) countries: A cointegration approach. *Energy* **2013**, *55*, 813–822. [CrossRef]
78. Munir, Q.; Lean, H.H.; Smyth, R. CO_2 emissions, energy consumption and economic growth in the ASEAN-5 countries: A cross-sectional dependence approach. *Energy Econ.* **2020**, *85*, 104571. [CrossRef]
79. Chontanawat, J. Relationship between energy consumption, CO_2 emission and economic growth in ASEAN: Cointegration and causality model. *Energy Rep.* **2020**, *6*, 660–665. [CrossRef]
80. Lean, H.H.; Smyth, R. CO_2 emissions, electricity consumption and output in ASEAN. *Appl. Energy* **2010**, *87*, 1858–1864. [CrossRef]
81. Chandran, V.; Tang, C.F. The impacts of transport energy consumption, foreign direct investment and income on CO_2 emissions in ASEAN-5 economies. *Renew. Sustain. Energy Rev.* **2013**, *24*, 445–453. [CrossRef]
82. Granger, C.W. Investigating causal relations by econometric models and cross-spectral methods. *Econom. J. Econom. Soc.* **1969**, 424–438. [CrossRef]
83. Dickey, D.; Fuller, W. Distribution of the estimators for autoregressive time series with a unit root. *J. Am. Stat. Assoc.* **1979**, *74*, 427–431. [CrossRef]
84. Dickey, D.A.; Fuller, W.A. Likelihood ratio statistics for autoregressive time series with a unit root. *Econom. J. Econom. Soc.* **1981**, 1057–1072. [CrossRef]
85. Granger, C.W. Some properties of time series data and their use in econometric model specification. *J. Econom.* **1981**, *16*, 121–130. [CrossRef]
86. Engle, R.F.; Granger, C.W. Cointegration and error correction: Representation, estimation and testing. Econometrica. *Econometrica* **1987**, *55*, 251–276. [CrossRef]
87. Johansen, S. Statistical analysis of cointegration vectors. *J. Econ. Dyn. Control* **1988**, *12*, 231–254. [CrossRef]
88. Johansen, S. Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. *Econom. J. Econom. Soc.* **1991**, *59*, 1551–1580. [CrossRef]
89. Johansen, S.; Juselius, K. Maximum likelihood estimation and inference on cointegration with applications to the demand for money. *Oxf. Bull. Econ. Stat.* **1990**, *52*, 169–210. [CrossRef]
90. Chontanawat, J. Driving Forces of Energy-Related CO_2 Emissions Based on Expanded IPAT Decomposition Analysis: Evidence from ASEAN and Four Selected Countries. *Energies* **2019**, *12*, 764. [CrossRef]
91. International Energy Agency (IEA). *World Energy Statistics and Balances (Database)*; International Energy Agency: Paris, France, 2020.
92. Solow, R.M. Applying growth theory across countries. *World Bank Econ. Rev.* **2001**, *15*, 283–288. [CrossRef]
93. Athukorala, P.; Sen, K. *Saving Investment and Growth in India*; Oxford University Press: New York, NY, USA, 2002.
94. Pesaran, M.H.; Smith, R. Estimating long-run relationships from dynamic heterogeneous panels. *J. Econom.* **1995**, *68*, 79–113. [CrossRef]
95. Robertson, D.; Symons, J. Some strange properties of panel data estimators. *J. Appl. Econom.* **1992**, *7*, 175–189. [CrossRef]

96. Bekhet, H.A.; Othman, N.S. The role of renewable energy to validate dynamic interaction between CO_2 emissions and GDP toward sustainable development in Malaysia. *Energy Econ.* **2018**, *72*, 47–61. [CrossRef]
97. Begum, R.A.; Sohag, K.; Abdullah, S.M.S.; Jaafar, M. CO_2 emissions, energy consumption, economic and population growth in Malaysia. *Renew. Sustain. Energy Rev.* **2015**, *41*, 594–601. [CrossRef]
98. International Renewable Energy Agency (IRENA). *Renewable Energy Market Analysis: Southeast Asia*; IRENA: Abu Dhabi, UAE, 2018; ISBN 978-92-9260-056-3.
99. ASEAN Centre for Energy (ACE). *Asean Energy Cooperation Report*; ACE: Jakarta, Indonesia, 2017; ISBN 978-979-8978-36-4.
100. ASEAN Centre for Energy (ACE). *Policy Brief ASEAN Energy Cooperation for Shaping a Low-Carbon Energy Transition: A Baseline Assessment of the Alignment between Energy and Climate Policies*; No. 1/2020; ACE: Jakarta, Indonesia, 2020.