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DOES ENERGY PRODUCTIVITY LEAD TO ECONOMIC EFFICIENCY AND LOWER CO_2 EMISSION IN MALAYSIA? EVIDENCE FROM BOOTSTRAPPED ARDL APPROACH

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Abstract: The global demand for energy has been increasing tremendously because energy is critical for economic growth. Malaysia has a huge dependance on traditional energy sources, which are finite and emit the bulk of greenhouse gasses. It is crucial to produce energy efficiently without compromising economic growth or the ecosystem. This study employed the bootstrap autoregressive distributed lag model (BARDL) to examine the cointegration of economic efficiency, energy productivity and carbon emissions in Malaysia. It is found that energy productivity intensifies economic efficiency but degrades the environment by emitting CO_2 in the short and long run. Even though energy productivity enhances economic efficiency, it does not play any role in mitigating CO_2 emissions. Therefore, Malaysia needs to shift to energy-efficient resources to combat emissions. Consequently, renewable energy should be considered for sustainable economic growth and to resolve environmental problems.

Keywords: Energy productivity, economic efficiency, CO_2 emission, Malaysia, bootstrap ARDL.

Introduction

Energy is one of the most vital factors in sustainable economic growth and development. It greases the engine of every economy (Fotourehchi, 2017). Energy is a critical component in a country's economic growth as it is driving the day-to-day household and industrial activities that is the foundation of the whole economy. The productivity of energy is the ratio of economic output per unit of energy used. This measure informs nations on their relative performance in economic, energy and environmental issues. The global demand for energy has been increasing tremendously. It is assessed that the worldwide energy demand will rise by 30% between 2017 and 2040 (International Energy Agency, 2017). Hence, the increased demand for energy due to increased population and economic growth has become a concern for policymakers.

Some scholars consider energy to be as vital as capital and labor for economic development and believe that the reduction in energy consumption may result in the reduction of economic growth, which may restrain sustainable development (Alam *et al.*, 2012; Pao & Tsai, 2010). In contrast, neoclassical economists believe that energy is not a vital factor in production compared to capital and labor. Therefore, energy-saving policies that minimize CO_2 emissions without affecting economic growth is crucial in the economy's current state. Although the energy and economic growth nexus complements sustainable development, excessive energy use also causes environmental deterioration by emitting pollutants, especially CO_2, mostly discharged from fossil fuel combustion. Pollution that prevails in environment is highly associated with energy consumption (Soytas & Sari, 2009). Other environmental issues like particulate emissions, water contamination and greenhouse gasses, are also linked with energy production and consumption (Tang & Tan, 2015). Such emissions not only increase global warming but also threaten energy security (IEA, 2018). According to the Intergovernmental Panel report on Climate Change, the most critical problem in the last 50 years is climate change due to emissions of greenhouse gasses by anthropogenic activities (IPCC, 2007).

Among the emerging economies in South Asia, Malaysia is one of the fastest growing, with heavy reliance on energy to keep up the pace of growth but at the cost of a degraded ecosystem (World Bank, 2008). Because Malaysia heavily relies on energy to sustain economic growth, Malaysians have switched their dependence from agriculture to manufacturing. Consequently, energy demand has been growing by more than 7.0% over the years (Ong *et al.*, 2011). The National Energy Balance (NEB, 2012) estimated that if Malaysia's demand and supply of energy continues to grow at the current rate, it will become a large importer of energy by 2020. Moreover, the literature states that the economy of Malaysia hugely depends on traditional sources of energy, which are finite and emit the bulk of greenhouse gasses. The heavy reliance on conventional energy sources, such as fossil fuels, to generate electricity and carry out economic activities disrupt the environment and, in turn, lead to CO_2 emissions (Ong *et al.*, 2011).

Considering the above discussion on energy security and environmental preservation and balancing the economy and environment, it is crucial to curtail energy production without compromising economic growth or the ecosystem. Bataille and Melton (2017) stated that the efficiency with which energy is consumed by individuals (accounting for about 35% of energy consumption), corporations, and other entities directly affects the environmental quality and energy security (Bundesministerium für Wirtschaft & Energie, 2019). So, any country must change its dependence on traditional energy sources to renewables to improve the environment (Kuriqi *et al.*, 2019). The upshot from the pressure of energy demand on the environment have led to energy and environment specialists and policymakers to design and implement environmentally friendly and energy-efficient technologies.

Moreover, the dependence on energy can be balanced by improving its productivity. It should be noted that productivity is the efficiency in resource utilization which derives the maximum production through minimum consumption (Ding *et al.*, 2021). Similarly, energy productivity is the ratio of output produced by the consumption of energy resources; therefore, whenever there is improvement in the numerator and decrease in the denominator, there will be an overall improvement in the energy productivity which can lead to positive outcomes in terms of output and GDP, and also will have the least adverse effects to the ecology and environment (Ding *et al.*, 2021; Li *et al.*, 2020). In Malaysia, the trend of energy productivity and economic efficiency appears to be decreasing, as shown in Figure 1.

Given that Malaysia is highly dependent on energy for economic growth and development, the current study examines the effects of energy productivity on economic efficiency and environmental quality on the Malaysian economy. Through the present study's findings, forecasts can be made on potential investments in cleaner and more efficient technologies if a relationship has been found among the studied phenomena. This study will help Malaysia improve its accessibility to clean and efficient energy sources while supporting sustainable economic growth and the ecosystem (Langlois & Yank, 2017). Moreover, the novelty of this study also lies in the selection of advanced methods. This study uses the bootstrap ARDL bound method to test the long-term cointegration relationships, contrary to the studies available in the literature. The advantage of this approach is that it does not distinguish between independent variables and dependent ones, and it even can be used as a two-way method for verification, such as $x \rightarrow y$ or $y \rightarrow x$. Moreover, the critical values generated through the bound test of bootstrap ARDL are employed to test the ARDL model's degradation. McNown *et al.* (2018) suggested two cases of degradation without the association

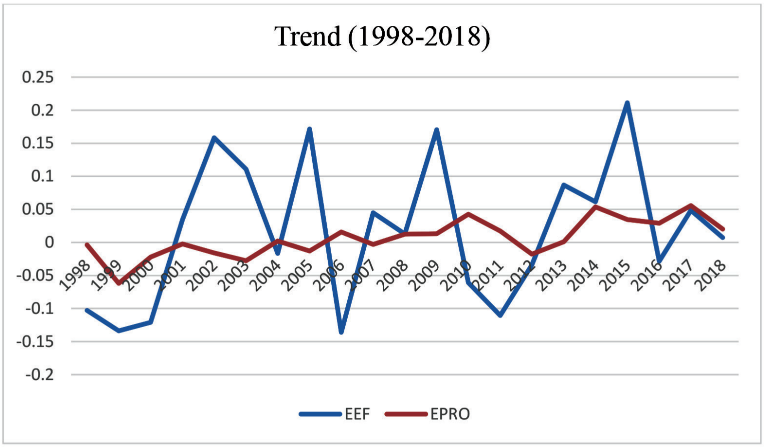

Figure 1: Trend analysis of energy productivity and economic efficiency

of cointegration, in which only one case uses the critical value to test degradation. The primary purpose of this approach is not only to solve the problem of endogeneity but also to catch cases of degradation to eliminate the likelihood of uncertain inference.

The rest of the paper is organized as follows. Section 2 reviews the literature on energy and economic growth. The methodology, including data sources and variables, is described in section 3. Section 4 discusses the results of empirical analysis. The conclusions and policy recommendations are presented in section 5.

Reviews of Literature

Energy is a significant player in sustaining economic growth and development in developed or developing countries. Nevertheless, it happens at the cost of environmental degradation. In order to understand viable economic growth, the association between energy, growth of the economy and environment has attracted much study in recent years (Antonakakis *et al.*, 2017; Saidi & Hammami, 2015). Over the past few years, numerous studies have explored the energy-economic growth nexus (Benkraiem *et al.*, 2019; Sarwar *et al.*, 2017; Shahbaz *et al.*, 2017). The first empirical study on energy and economic growth was by Kraft and Kraft (1978), who confirm a causal relationship between minimizing energy consumption and adverse effects on economic growth. On the other hand, Masih and Masih (1996) found that real income is not a Granger-caused by energy consumption. In Greece, Tsani (2010) explored the causal association between energy consumption and economic growth by using the approach of Toda and Yamamoto (1995). He found that unidirectional causality exists from energy consumption to economic growth. Similarly, Shaari *et al.* (2012) scrutinized the energy-growth nexus but failed to find the Granger causality from coal and oil consumption to economic growth, but a unidirectional causality was found to economic growth from gas consumption.

Yoo (2006) and Tang (2009) found a bi-directional causality between economic growth and electricity consumption. This is consistent with the study by Odhiambo (2009) in Tanzania that found a steady association between energy and economic growth in the long run. Tang and Shahbaz (2013) also found the same results between economic output and energy consumption in their study. Based on panel ARDL and panel quantile regression (PQR) estimations, few studies, such as Gozgor *et al.* (2018), proved that energy usage mirrored the economic development in 29 OECD countries from 1990 to 2013. In their study, Shahbaz *et al.* (2018b) found the same results among the top ten countries consuming energy heavily, and similarly by Tang *et al.* (2016) in Vietnam.

In another study, Chandran *et al.* (2010) examined the association between electricity consumption and economic growth and found Malaysia to be an energy-reliant nation. nation. This is supported by the study by Bhattacharya *et al.* (2016) on the top 38 energy-using countries. They found that renewable energy positively influences economic output between 1991 and 2012. However, Ocal and Aslan (2013) found that renewable energy negatively influences economic output in the case of Turkey.

Moving to the literature exploring the effect of energy productivity on the environment, Menyah and Wolde-Rufael (2010) examined the causal relationship in the long run between desired variables in South Africa between 1965 to 2006 by following the study of Stern (1984) and formed a framework by adding multi-variables, such as labor and capital and energy economic growth. The results favored association among the variables in the short and long run, and more explicitly, the outcome found a significant association between economic growth and pollutants. One-way causality was observed from energy consumption to economic growth and from pollutants to economic growth, and energy consumption to CO_2 emissions.

On the other hand, Saboori *et al.* (2012) found a two-way connection between economic growth and CO_2 emissions in the short-run, and unidirectional in the long run in Malaysia. Nonetheless, one-way directional causality from CO_2 to economic growth was shown by Ozturk and Al-Mulali (2015). However, Kasman and Duman (2015) and Wang *et al.* (2016) evidenced a neutral effect between CO_2 and economic growth.

In India, Galli *et al.* (2012) found that the quality of the environment is badly affected by economic activities. The causal association between environment and economic growth, in 59 Belt and Road countries was also elaborated by Baloch *et al.* (2019). Though the bulk of studies have employed CO_2 as a proxy to measure environmental deterioration, in recent years, several studies opted for the ecological footprint (EF) to measure the quality of the environment (Aziz *et al.,* 2020; Bello *et al.,* 2018; Charfeddine, 2017). It has been revealed by Imamoglu (2018) that energy and GDP elevates the EF in Turkey. Destek and Sarkodie (2019) also employed EF to measure their relationship with renewable and non-renewable energy, trade and economic growth. The outcome proved that the link between energy and economic growth is the pathway influencing environmental quality.

The link between energy, economic output and the environment has attracted much study in the last few years (Antonakakis *et al.*, 2017; Saidi & Hammami, 2015). Many studies reported the relationship between innovation and energy productivity in determining renewable energy (Li *et al.*, 2020) and determining carbon emissions (Ding *et al.*, 2021). But to the authors' knowledge the are no studies elaborating the effect energy productivity has on economic efficiency and CO_2, especially in the case of Malaysia, which the present study intends to address.

Materials and Methods

Data and Variables

We employ time series data to analyze the effects of energy productivity on Malaysia's economic efficiency and CO_2 emission from 1980 to 2017. Economic efficiency is a relatively new phenomenon that discusses the relativity of outputs and inputs. It is different from conventional measures like economic growth, which only focuses on inputs or outputs (for further discussion, see Halkos & Tzeremes, 2009a, 2009b). We estimate economic efficiency using Data Envelopment Analysis (DEA): A non-parametric approach based on linear programming techniques to estimate the relative efficiency of the production function for a particular country (Casu & Molyneux, 2003). Following Halkos and Tzeremes (2009a, 2009b), the inputs and outputs for economic efficiency are based on production functions.

The most efficient year of operation will be operating on the frontier, while those below the frontier are inefficient. The output-oriented variable return to scale (VRS) model assumes that the government maximizes output for a given input utilized in this study. Equation (1) presents the model for economic efficiency as Bankers *et al.* (1984) suggested.

$$\theta \text{ subject to} \sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{io} \quad i = 1,2,\ldots,m \sum_{j=1}^{n} \lambda_j y_{rj} \geq \theta y_{ro} \quad r = 1,2,\ldots,s \quad \sum_{j=1}^{n} \lambda_j = 1 \lambda_j \geq 0 \qquad j = 1,2,\ldots,n \tag{1}$$

Where DMU_0 (Decision Making Unit) represents one of the *n* DMUs under evaluation, and x_{io} and y_{ro} are the i^{th} input and r^{th} output for DMU_0, respectively. λ_j are unknown weights, where j = 1, 2, …*n* which represents the number of DMUs for each time period. The optimal value of θ^* represents the distance of each sector from the efficient frontier. Hence, the most technically efficient year has $\theta^* = 1$ and the inefficient years have $\theta^* < 1$. VRS is employed because it provides a better representation of efficiency analysis. After all, output levels are not proportionately increased with input levels.

Following Halkos and Tzeremes (2009a, 2009b), we measure economic efficiency based on a production function with two inputs and one output. The vector inputs in this study are capital, measured by gross fixed capital formation in constant LCU, and labor force, which is measured by the number of workers willing to work. GDP per capita was calculated using the GDP's ratio to the mid-year population as a proxy output in the economic efficiency estimation.

The study includes trade openness, measured by the adding (the number of exports and imports) ratio to GDP; inflation measured by consumer price index; the population estimated by a number of residents in a country; CO_2 emission measured in metric tons and finally, energy productivity calculated by energy consumption ratio to the gross domestic product as the main variables of interest in the analysis. The data of all variables is obtained from World Development Indicators managed by the World Bank, except for CO_2 emissions, which is gathered from the website of British Petroleum. The details of the variables are summarized in Table 1.

Table 1: Description of variables

Variables	Description	Source
EEF	It is computed using Data Envelopment Analysis (DEA) approach. For details refer Halkos and Tzeremes (2009a, 2009b)	World Bank
CO_2	Carbon emission measured in metric tons	British Petroleum
CAP	Gross fixed capital formation in constant LCU	World Bank
LAB	Total number of the working force who are willing to work	World Bank
EPRO	It is measured by energy consumption ratio to gross domestic product	World Bank
TOP	It is measured by the adding (the number of exports and imports) ratio to GDP	World Bank
INF	It is measured by consumer price index	World Bank
POP	It is measured by a number of residents in a country	World Bank
PI	Per capita income	World Bank

Model Specification

This study aims to investigate the causal relationship between the effect of energy productivity on economic efficiency and CO_2 emission in Malaysia. The neo-classical growth and IPAT environmental model are used based on Ehrlich and Holdren (1971). The following model empirically analyzes the effect of energy productivity on economic efficiency:

$$EEF_t = f(CAP_t, LAB_t, EPRO_t, TOP_t, INF_t, v_t) \quad (2)$$

where EEF, CAP, LBR, EPRO, TOP, and INF signify economic efficiency, capital, labor, energy productivity, trade openness, and inflation, respectively, and v denotes individually fixed effect over time period t. Like in previous studies, the CO_2 determinants were analyzed through empirical analyses based on the model of IPAT (Raskin, 1995; York *et al.*, 2002). We include the association of population, income, energy productivity, trade openness, and inflation, and environmental impact as mentioned in the following Equation in this study:

$$I = P * A * T \quad (3)$$

where CO_2 is denoted by I, which is sourced from the population, income, energy productivity, trade openness and inflation, the primary model is extended to a different version known as the stochastic model (STIRPAT), which is the Stochastic Impacts by Regression on Population, Affluence and Technology by Dietz and Rosa (1997). By using the STIRPAT model, we frame the below-mentioned Equation for the analysis of our data set empirically:

$$CO_{2t} = f(POP_t, PI_t, EPRO_t, TOP_t, INF_t, v_t) \quad (4)$$

where CO_2 is a function of population, per capita income, energy productivity, trade openness, and inflation respectively, in Equation (4), the model goal is to address the energy productivity impact on CO_2 emission by taking into consideration all other factors (population, income, trade, inflation) in the model.

Bootstrap ARDL Procedure

The strength of the customary ARDL model was established by the recently developed bootstrap Autoregressive Distributed Lag (ARDL) method based on the bounds test by McNown *et al.* (2018). As per the study of Pesaran *et al.* (2001), two conditions are proposed for the association of cointegration: (i) In the ARDL approach, the error correction term coefficients and the lagged independent variables should be statistically significant (ii) the lower and upper values of the critical bound test should be used.

On the other hand, there are no critical values for upper and lower bounds for the first conditions that can be employed. The rationality of the first case relies on the variables' order of integration. If the variables are stationary at first order, such as I (1), the first condition is certified, but at this point, the characteristics of low power traditional unit root tests' should be thought out (Goh *et al.*, 2020). This problem is fixed by McNown *et al.* (2018), known as the bootstrap ARDL approach, which does not make an assumption about variables' order of integration.

In the case of more independent variables, the bootstrap ARDL offers better powerful features than traditional ARDL (McNown *et al.*, 2018). The statistics of F and t dependent are used in the traditional ARDL approach. Accordingly, the cointegration association's presence is analyzed by comparing the test statistics of the lower and upper limits. The hypothesis of no cointegration is not accepted if the test statistic is greater than the critical value of upper bounds. If test statistics are between the upper and lower bounds, a determination on the presence or non-presence of cointegration cannot be made (Pesaran *et al.*, 2001). The critical values of bootstrap can fix this issue (McNown *et al.*, 2018). The models of ARDL for economic efficiency and carbon dioxide emission are employed in the current research are specified as:

$$\Delta lnEEF = \vartheta_0 + \sum_{i=1}^{p-1} \vartheta_1 \Delta lnEEF_{t-i} + \sum_{i=1}^{q-1} \vartheta_2 \Delta lnCAP_{t-i} + \sum_{i=1}^{u-1} \vartheta_3 \Delta lnLAB_{t-i} + \sum_{i=1}^{k-1} \vartheta_4 \Delta lnEPRO_{t-i} + \sum_{i=1}^{s-1} \vartheta_5 \Delta lnTOP_{t-i} + \sum_{i=1}^{t-1} \vartheta_6 \Delta lnINF_{t-i} + \sum_{i=1}^{w-1} \vartheta_7 D_{t,i} + \delta_1 lnEEF_{t-1} + \delta_2 \Delta lnCAP_{t-1} + \delta_3 \Delta lnLAB_{t-1} + \delta_4 \Delta lnEPRO_{t-1} + \delta_5 \Delta lnTOP_{t-1} + \delta_6 \Delta lnINF_{t-1} + \nu_t \quad (5)$$

$$\Delta lnCO2 = \vartheta_0 + \sum_{i=1}^{p-1} \vartheta_1 \Delta lnCO2_{t-i} + \sum_{i=1}^{q-1} \vartheta_2 \Delta lnPOP_{t-i} + \sum_{i=1}^{u-1} \vartheta_3 \Delta lnPI_{t-i} + \sum_{i=1}^{k-1} \vartheta_4 \Delta lnEPRO_{t-i} + \sum_{i=1}^{s-1} \vartheta_5 \Delta lnTOP_{t-i} + \sum_{i=1}^{t-1} \vartheta_6 \Delta lnINF_{t-i} + \sum_{i=1}^{w-1} \vartheta_7 D_{t,i} + \delta_1 lnCO2_{t-1} + \delta_2 \Delta lnPOP_{t-1} + \delta_3 \Delta lnPI_{t-1} + \delta_4 \Delta lnEPRO_{t-1} + \delta_5 \Delta lnTOP_{t-1} + \delta_6 \Delta lnINF_{t-1} + \nu_t \quad (6)$$

In Equations 5 and 6, ϑ_0 shows short-term coefficients ϑ_1, ϑ_2, ϑ_3, ϑ_4, ϑ_5 and ϑ_6 long-term coefficients ϑ_1, ϑ_2, ϑ_3, ϑ_4, ϑ_5 and ϑ_6 and dummy variable D_t that signifies the sharp structural breaks.

Besides F and t statistics, a new statistic for explanatory variables' lagged values is recommended (McNown *et al.,* 2018) and consequently, the test statistics used in this model are as follows; i) The F statistic, ii) t statistic for the dependent variable's lagged values iii) the proposed F independent statistic for independent variables' lagged values. The three test statistics with their null hypotheses are mentioned below.

i) $F_{statistics} \rightarrow H_0: \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = \vartheta_5 = \vartheta_6 = 0$,
ii) $F_{dependent} \rightarrow H_0: \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = \vartheta_5 = \vartheta_6 = 0$,
iii) $F_{independent} \rightarrow H_0: \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = \vartheta_5 = \vartheta_6 = 0$,

If statistics of F-overall, t-dependent, and F-independent at the same time are larger than the critical values of calculated bootstrap, then the association of cointegration exists between EEF, CAP, LAB, EPRO, TOP, and INF in Equation 4 and CO_2, POP, PI, EPRO, TOP and INF in Equation 5.

Results and Discussion

Descriptive Statistics

The summary of descriptive statistics is presented in Table 2. The mean economic efficiency scores for Malaysia estimated using the DEA approach for 1980-2017 is 0.033. The statistics show that trade openness and inflation have higher volatility than other factors used in the model. In contrast, the variation is small in economic efficiency, capital and labor. The results in CO_2, population and per capita income are not showing much deviation. Consistently, the results of Jarque-Bera test show that all variables in the sample data are distributed normally.

Unit Root Analysis

The stationarity of the variables is necessary for time series analysis. The conventional method, such ADF test of unit root proposed by Dickey and Fuller (1981), is applied. In Table 3, the result show that variables are stationary at first difference. Moreover, structural breaks may likely exist in series, which may give ambiguous results for the ADF test of the unit root (Shahbaz *et al.*, 2018a). So, this problem is rectified by

Table 2: Results of descriptive statistics

Variables	Mean	Minimum	Maximum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Probability
EEF	0.033	-0.146	0.353	0.121	0.613	2.830	2.492	0.288
CAP	-0.002	-0.474	0.167	0.118	-1.614	7.893	0.194	0.694
LAB	0.206	0.006	6.897	1.100	6.000	37.008	0.271	0.901
EPRO	-0.002	-0.102	0.054	0.040	-0.926	3.592	1.218	0.225
TOP	0.059	-2.086	2.329	0.816	0.499	4.477	1.578	0.191
INF	-0.036	-2.420	2.176	0.839	-0.599	4.863	0.147	0.924
CO_2	0.056	-0.085	0.181	0.056	-0.003	2.925	0.009	0.995
POP	0.022	0.013	0.030	0.005	-0.352	1.936	2.647	0.266
PI	0.029	-0.109	0.065	0.034	-2.197	8.648	1.189	0.211

Table 3: Results of analysis of unit root

Variables	Traditional ADF Test		Structural Break ADF Test		
	T-Statistics	P. Value	T-Statistics	P. Value	Break Year
EEF_t	-0.737	0.825	-4.296	0.404	1998 Q2
CAP_t	-2.274	0.185	-4.015	0.451	1997 Q1
LAB_t	0.870	0.994	-3.256	0.908	2007 Q1
$EPRO_t$	-1.702	0.422	-3.177	0.931	2006 Q4
TOP_t	-1.226	0.198	-3.018	0.939	1987 Q2
INF_t	-1.587	0.123	-2.048	0.999	1997 Q1
CO_{2t}	0.582	0.987	-3.167	0.934	1984 Q1
POP_t	-1.673	0.351	-4.536	0.389	2005 Q3
PI_t	1.093	0.997	-2.731	0.987	2008 Q4
ΔEEF_t	-5.308***	0.000	-5.701***	0.000	1996 Q1
ΔCAP_t	-4.686***	0.001	-6.506***	0.000	1998 Q1
ΔLAB_t	-4.961***	0.000	-7.441***	0.000	2007 Q1
$\Delta EPRO_t$	-5.543***	0.000	-7.891***	0.000	1996 Q2
ΔTOP_t	-10.838***	0.000	-11.731***	0.000	2009 Q4
ΔINF_t	-9.105***	0.000	-7.007***	0.000	2010 Q1
ΔCO_{2t}	-7.436***	0.000	-8.769***	0.000	2005 Q2
ΔPOP_t	-4.941***	0.000	-12.137***	0.000	1997 Q2
ΔPI_t	-5.313***	0.000	-7.785***	0.000	1999 Q1

Note: *** represents the significance level at 1%

employing the ADF test of a unit root in the advanced form (Kim & Perron, 2009), which adjusts the series' structural breaks. The unit root test results of ADF based on structural break sanctions again integrate all variables at the first difference. The results confirm the unit root robustness and depict that all variables are stationary at *I*(1).

Bootstrapped ARDL Cointegration Analysis

The cointegration association between economic efficiency and its determinants in Model 1 and CO_2 and its determinants in Model 2 are examined after confirming all the variables are integrated as *I*(1). The bootstrapped auto-regressive distributive lagged (BARDL) approach is used to confirm the long-run cointegration among variables. This approach is better than conventional ARDL (Shahbaz *et al.*, 2018) because it takes into account the joint F-test on all variables with their lagged values, t-test on a dependent variable with lagged values, and t-test (new) of the regressors with lagged values, which supports the cointegration equilibrium among the variables. While employing BARDL bounds testing, the appropriateness criteria of lag length are mandatory; otherwise, it leads to biased results. In doing so, Akaike Information Criteria (AIC) is more appropriate as it has superior features (Luetkepohl, 2006). Table 4, column 2 shows the lag lengths of the variables.

In BARDL, the value of t and F statistics are bootstrapped to explore the cointegration association in the long run among the variables, as shown in Table 4. These t and F statistics of bootstrapping, both the dependent variable and their lagged values, i.e., economic efficiency, reject the null hypothesis where the capital, labor, energy productivity, trade openness and inflation are added as explanatory variables. Likewise, a t-test on the independent variables with lagged values also rejects the null hypothesis. It proposes that the joint F and t-test on the lagged dependent while t-test on the lagged explanatory variables approves the existence of cointegration among variables in the long run at significance level 1% and 5%, respectively. The current study also assessed another model where CO_2 is taken as a dependent variable and energy productivity was taken as an explanatory variable along with population, per capita income, trade openness, and inflation. The study fails to accept the null hypothesis for the joint F and t-test on the lagged explained and t-test on the lagged explanatory variables and accepts the null hypothesis and approves the cointegration relationship in the long run. Overall, the existence of cointegration is confirmed for both models, such as economic efficiency and CO_2 and their contributing factors.

The diagnostic scrutiny is also explained by Q-stat, which accepts the null hypothesis and proposes that all variables have a parallel populace specified by the standard variance analysis and confirms that the data is normally distributed. This result is parallel to the results of Jarque-Bera (as reported in Table 2). Likewise, the outcomes showed the nonexistence of serial correlation in the models, which additionally specifies that each variable has an independent observation (Pesaran *et al.*, 2001).

Table 4: Results of analysis of bootstrapped ARDL cointegration

Bootstrapped ARDL Cointegration Analysis						Diagnostic Results			
Estimated Models	**Lag Length**	**Break Year**	F_{PSS}	T_{DV}	T_{IV}	^{2}	**Q-stat**	**LM(2)**	**JB**
Model-1	1, 1, 2, 2, 1	2005 Q1	8.154***	-8.025***	-5.087***	0.914	5.085	1.015	0.674
Model-2	1, 2, 2, 1, 1	2009 Q2	11.463***	-9.005***	-3.054**	0.953	6.115	2.115	0.551

Model-1: $EEF_t = f(CAP_t, LAB_t, EPRO_t, TOP_t, INF_t)$
Model-2: $CO_{2t} = f(POP_t, PI_t, EPRO_t, TOP_t, INF_t)$

Note: At 1% and 5% levels, the signs are shown by asterisks *** and ** respectively. The Akaike Information Criterion (AIC) decides the optimal lag length. By using the bootstrap method, F-statistic (FPSS) is generated on the basis of asymptotic critical bounds. The dependent variable t statistics are denoted by TDV while independent t statistics are denoted by TIV, LM is the Langrage Multiplier test, followed by JB for the JB test of Jarque-Bera

Bootstrapped ARDL Cointegration (Long Run)

After confirming the cointegration, the long-run effect of all variables on economic efficiency and CO_2 emission can be observed. Table 5 shows the long-run results and illustrates that energy productivity positively influences economic efficiency at a 1% significance level. An increase in 1% energy productivity increases the economic efficiency by 0.297%, holding other things constant, which corresponds well with the previous studies which reported that the upsurge in energy consumption at the industrial level pushes the output of industry up which boosts economic growth (Liu *et al.*, 2017). Keeping all the same variables, the relationship of capital, labor, and trade positively influences economic efficiency, which infers that an increase of 1% in capital and labor and trade increases economic efficiency by 0.305%, 0.198% and 0.174%, respectively. In the case of inflation, by keeping all other variables constant, the negative coefficient shows that an increase of 1% in inflation reduces economic efficiency by 0.299%.

Table 5: Results bootstrapped ARDL cointegration analysis (long run)

	Dependent Variable = EEF_t			Dependent Variable = CO_{2t}		
Variable	**Coefficient**	**T-Statistics**	**P. Value**	**Coefficient**	**T-Statistics**	**P. Value**
Constant	1.025***	3.028	0.000	-2.189***	-5.489	0.000
CAP_t	0.305***	4.115	0.000	-	-	-
LAB_t	0.198***	2.941	0.000	-	-	-
$EPRO_t$	0.297***	5.259	0.000	0.481***	2.748	0.006
TOP_t	0.174***	8.469	0.000	0.257*	1.681	0.093
INF_t	-0.299***	-4.358	0.000	0.079***	7.269	0.000
POP_t	-	-	-	0.225**	4.792	0.000
PI_t	-	-	-	0.198**	3.789	0.000
D_{2008}	-0.205***	-5.189	0.000	0.117**	2.579	0.019
R^2		0.931			0.904	
$Adj - R^2$		0.924			0.897	
Durbin Watson		2.018			2.153	
Analysis of Stability						
Test		**F-Statistics**	**P. Value**		**F-Statistics**	**P. Value**
χ^2_{NORMAL}		0.294	0.210		0.308	0.161
χ^2_{SERIAL}		0.556	0.294		0.437	0.150
χ^2_{ARCH}		0.326	0.215		0.379	0.230
χ^2_{HETERO}		0.302	0.651		0.244	0.611
χ^2_{RESET}		0.708	0.167		0.679	0.191
CUSUM		Stable			Stable	
CUSUMsq		Stable			Stable	

Note: The significance level is represented by ***, ** and * at 1%, 5% and 10% respectively

In other models having CO_2 as a dependent variable, the higher coefficient of energy productivity shows that a 1% increase in energy productivity led to a 0.48% increase of CO_2 emission by keeping all other things constant, which infers that energy productivity impedes the environment quality by emitting CO_2. The same outcome was also found by some other studies in other studies such as Soytas and Sari (2003) in G-7 countries; Arouri *et al.* (2014) in 12 countries of the Middle East and North Africa where the rise of energy consumption worsens the quality of the environment.

Holding other things constant, the effect of trade and inflation is positive on CO_2 emissions. A 1% increase in trade openness and inflation leads to 0.257% and 0.079% emissions, respectively. The results are consistent with previous studies that found that expansion in economic output is stimulated by international trade, which enhances economic growth (Zahonogo & Pam, 2017), particularly in developing economies (Malefane & Odhiambo, 2018). Moreover, when there is additional inflation, firms will move towards cheap sources of energy that are not necessarily environmentally friendly, thus further escalating carbon emissions. Moreover, it is expected that the population positively and significantly influences carbon emissions. This implies that an increase in population exerts pressure on the environment and degenerates the quality of the ecosystem. An increase of 1% in population raises CO_2 by 0.225% by keeping all variables the same. The results are aligned with previous studies by Zhang and Lin (2012) and Farhani and Ozturk (2015) who argued that increased population led to an escalation in urbanization, thus stimulating CO_2 release in China and Tunisia. By keeping all the variables same, a rise of 0.198% in CO_2 is driven by intensification per capita of 1%. Halicioglu (2009) examined the dynamic causal relations between CO_2 emissions, energy, income, and foreign trade between the years 1960 and 2005 in Turkey. The findings showed that pollutants a monotonically increase with rising income levels. Besides, Akbostanci *et al.* (2009), Halicioglu (2009) and Ozturk and Acaravci (2013) also found the same results for Turkey, where increase of per capita GDP resulted in the increase of CO_2 emission.

It is shown that the dummy variable negatively and significantly influences economic efficiency, while for CO_2, the dummy variable is positive and significant at 5% significance level. The error term's normal distribution is confirmed by stability analysis in both models. Moreover, the model also demonstrated the absence of autoregressive conditional heteroscedasticity and serial correlation. The test statistics of Ramsey reset confirmed the absence of white heteroscedasticity and proved the model as ingenious. In the long-run model, 93% of economic efficiency is explained by capital, labor, energy productivity, trade openness, and inflation, and the rest are by error terms. In other models, about 90% of CO_2 emissions are explained by energy productivity, trade openness, inflation, population, and per-capita income. The autocorrelation absence is also confirmed in the model by the test statistic of Durbin-Watson. The estimates are stable in the long run and are endorsed by CUSUM and CUSUMSQ tests.

Bootstrapped ARDL Cointegration (Short Run)

Table 6 reports the findings for the short-run relationship between energy productivity effects on economic efficiency and CO_2 emission in Malaysia. Energy productivity, capital and labor positively influence economic efficiency at a 1% level of significance. Trade openness also positively and significantly influences economic efficiency but at 5%. Alike, long-run relationship, the significant negative influence is shown by inflation on CO_2. The dummy variable has a positive but insignificant influence on economic efficiency, unlike the long-run model. The adjustment speed is shown by the lagged error term (ECMt−1) coefficient, which showed high significance at the level of 1%. The speed of adjustment from the short-run to long-run result indicates that any deviance from the long-run in the short-run is amended by 26% each quarter. Moreover, the long-run relation is also confirmed by a negative sign (Dolado *et al.,* 1998). The absence of autoregressive conditional heteroscedasticity and serial correlation is also reported in the same table.

Moving towards the results of CO_2 (refer to Table 6), we found that energy productivity, trade openness, inflation, and population are positively and significantly affecting CO2 at a 1% significance level. The significant results could be caused by Malaysia's high dependence on fossil fuels, which led to pollution (Malaysia Energy Statistics, 2019). Furthermore, it is reported that the emerging economies' share of global CO_2 emissions rose from from 34.50 to 49.71% from 1990 to 2012 (IEA, 2015). Saidi and Mbarek's (2017) found similar results, in that the increase in demand for energy spurs economic productivity but at the cost of environmental quality. The positive effect of trade openness implies that trade forces economies to minimize the cost of production to remain competitive. Hence, in such situations, interventions by the governments to encourage trade by levering existing taxes and duties can guard the ecosystem. The results are aligned with previous studies that showed that an increase in trade openness is detrimental to environmental quality (Raza & Shah, 2018; Solarin *et al.*, 2017). Overpopulation and urbanization make

Table 6: Results bootstrapped ARDL cointegration analysis (short run)

	Dependent Variable = EEF_t			Dependent Variable = CO_{2t}		
Variable	**Coefficient**	**T-Statistics**	**P. Value**	**Coefficient**	**T-Statistics**	**P. Value**
Constant	0.015***	3.105	0.001	0.079	0.685	0.875
CAP_t	0.024***	2.719	0.007	-	-	-
LAB_t	0.138***	5.579	0.000	-	-	-
$EPRO_t$	0.098***	3.629	0.000	0.357***	5.789	0.000
TOP_t	0.056**	2.189	0.030	0.118***	3.115	0.000
INF_t	-0.178**	-2.018	0.048	0.097***	2.951	0.001
POP_t	-	-	-	0.297***	5.003	0.000
PI_t	-	-	-	0.018*	1.972	0.049
D_{2008}	0.008	0.041	0.969	0.019	0.031	0.999
ECM_{t-1}	-0.267***	-6.058	0.000	-0.318***	-4.119	0.000
R^2		0.881			0.904	
$Adj - R^2$		0.804			0.897	
Durbin Watson		1.973			2.153	
Stability Analysis						
Test		**F-Statistics**	**P. Value**		**F-Statistics**	**P. Value**
		0.367	0.262		0.384	0.201
		0.694	0.367		0.546	0.187
		0.407	0.268		0.473	0.287
		0.377	0.812		0.304	0.762
		0.883	0.209		0.847	0.239
CUSUM		Stable			Stable	
CUSUMsq		Stable			Stable	

Note: ***, ** and * represent level of significance at 1%, 5% and 10% respectively great demands on water supply, pollute the air, strain sanitation facilities and increase the energy demand, which deteriorates the environmental quality (Jago-on *et al.*, 2009). Per capita income also has a significant positive effect on CO_2 emissions but at a 5% significance level.

Unlike the long-run model, the dummy variable shows positive but insignificant influences on CO_2 emission. The ECMt−1 is also highly significant at a level of 1%, which specifies that the deviation in the short-run is corrected by about 31% from the long-run path. In addition, the absence of autoregressive conditional heteroscedasticity, white heteroscedasticity is also confirmed. The cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ) reported in Figures 2 and 3 statistically show that the model is stable and empirical analysis is reliable; the lines for both cases fall between the critical bounds. It is concluded that structural instability is not present in the model.

Conclusively, our results show that energy productivity in Malaysia increases economic efficiency but adversely effects the environment. Energy productivity has increased economic efficiency and affects the environment because to generate higher economic growth requires higher energy production, and to meet the energy requirement, countries in developing economies rely on non -renewable energy sources, which significantly increases CO_2 emissions. Thus, the government should pivot towards clean energy sources to mitigate the adverse effects of economic growth on the environment in the long run. Energy from renewable sources has arisen as a substitute for non-renewable sources (Apergis & Payne, 2012). Renewable energy is the best choice to improve not only economic efficiency but also environmental quality. Ong *et al.* (2011) highlighted that the economy of Malaysia is heavily dependent on non-renewable sources of energy, which are finite and emit enormous amounts of greenhouse

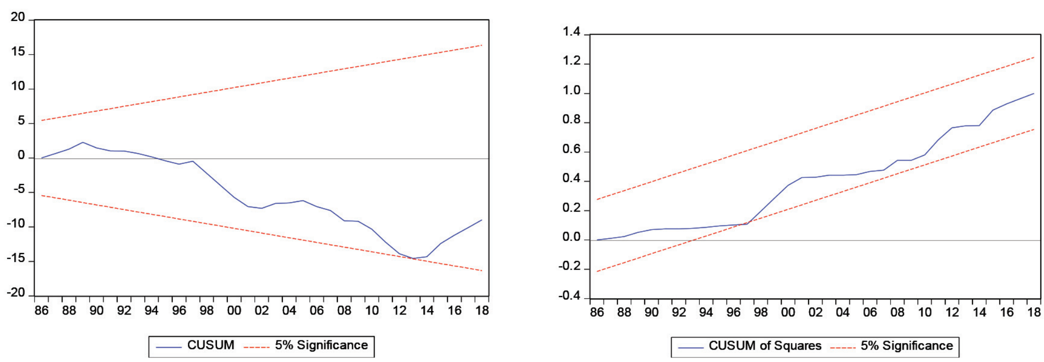

Figure 2: CUSUM and CUSM of square for economic efficiency model

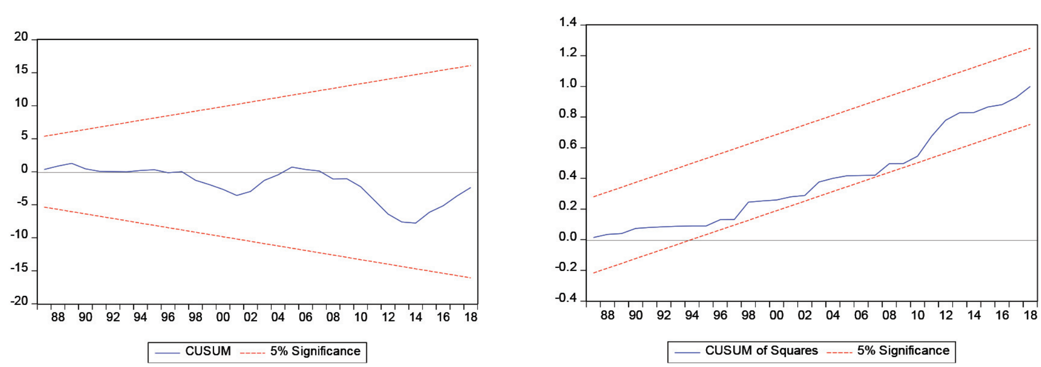

Figure 3: CUSUM and CUSM of square for CO_2 emission model

gasses and does not have the potential to rely on renewable sources of energy. Consequently, it is compulsory to curtail energy consumption at a level that efficiently boosts economic growth and development in safeguarding the energy and environment.

Conclusion and Policy Implication

This paper examines the effect of energy production on Malaysian's economic efficiency and environment over the period from 1980 to 2017 by using the bootstrap ARDL technique. The finding of this study shows that capital, labor, trade openness, and most importantly, energy productivity positively affects economic efficiency in the long run and short run, while inflation negatively influences economic efficiency. Increased economic efficiency from increased energy production will benefit the economy by increasing spending of saved energy dollars in other sectors, increased employment and personal income, and increased total economic output.

CO_2 emissions, energy productivity, trade openness, population, and income have shown positive and significant effects on CO_2 emissions. These significant results imply that energy productivity, in itself, does not significantly reduce CO_2 emissions, which might be due to intensive fossil fuel consumption. Our results suggest that policymakers should emphasize energy productivity for sustainable economic growth in the long run through its effect on the country's efficiency. While countries are moving towards higher economic growth, the welfare of e society must also be taken care of because of sustainable economic growth in the long run, including economic development, social equity and environmental protection. Therefore, managing issues related to emissions of CO_2 is critical. The management could result in the emergence of sustainable energy, such as solar and wind power, to replace the harmful CO_2-emitting source while maintaining industrialization. The government should expand energy sources by discovering alternative renewable sources in nature that are environment friendly, such as hydroelectric plants, that might deliver renewable, cheap and environmentally friendly energy. These alternatives include upgrading industrial plants and renewable energy plants to increase efficiency and preserve renewable energy sources to minimize CO_2 emissions. Minimizing CO_2 emissions would contribute to a healthier environment, hence improving productivity and living standards in the long run.

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References

Akbostancı, E., Türüt-Aşık, S., & Tunç, G. İ. (2009). The relationship between income and environment in Turkey: Is there an environmental Kuznets curve? *Energy Policy, 37*, 861-867. https://doi.org/https://doi.org/10.1016/j.enpol.2008.09.088

Alam, M. J., Begum, I. A., Buysse, J., & Huylenbroeck, G. V. (2012). Energy consumption, carbon emissions, and economic growth nexus in Bangladesh: Cointegration and dynamic causality analysis. *Energy Policy*, *45*, 217-225.

Antonakakis, N., Chatziantoniou, I., & Filis, G. (2017). Energy consumption, CO_2 emissions, and economic growth: An ethical dilemma. *Renewable and Sustainable Energy Reviews*, *68*, 808-824. https://doi.org/https://doi.org/10.1016/j.rser.2016.09.105

Apergis, N., & Payne, J. E. (2012). Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model. *Energy Economics*, *34*, 733-738

Arouri, M. E. H., Youssef, A., Ben, M'Henni, H., & Rault, C. (2014). *Energy use and economic growth in Africa: A panel Granger-Causality Investigation.* Cesifo Working Paper, 34, 1247-1258

Aziz, N., Sharif, A., Raza, A., & Rong, K. (2020). Revisiting the role of forestry, agriculture, and renewable energy in testing environment Kuznets curve in Pakistan: Evidence from Quantile ARDL Approach. *Environmental Science and Pollution Research*, *27*, 10115-10128. https://doi.org/10.1007/s11356-020-07798-1

Baloch, M. A., Zhang, J., Iqbal, K., & Iqbal, Z. (2019). The effect of financial development on ecological footprint in BRI countries: evidence from panel data estimation. *Environmental Science and Pollution Research*, *26*, 6199-6208. https://doi.org/10.1007/s11356-018-3992-9

Bataille, C., & Melton, N. (2017). Energy efficiency and economic growth: A retrospective CGE analysis for Canada from 2002 to 2012. *Energy Economics*, *64*, 118-130. https://doi.org/https://doi.org/10.1016/j.eneco.2017.03.008

Bello, M. O., Solarin, S. A., & Yuen, Y. Y. (2018). The impact of electricity consumption on CO_2 emission, carbon footprint, water footprint and ecological footprint: The role of hydropower in an emerging economy. *Journal of Environmental Management*, *219*, 218-230. https://doi.org/10.1016/j.jenvman.2018.04.101

Benkraiem, R., Lahiani, A., Miloudi, A., & Shahbaz, M. (2019). The asymmetric role of shadow economy in the energy-growth nexus in Bolivia. *Energy Policy, 125*, 405-417. https://doi.org/https://doi.org/10.1016/j.enpol.2018.10.060

Bhattacharya, M., Paramati, S. R., Ozturk, I., & Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Applied Energy, 162*, 733-741. https://doi.org/https://doi.org/10.1016/j.apenergy.2015.10.104

Bundesministerium für Wirtschaft und Energie (BMWi). (2019). *Enhancing Energy Efficiency in Buildings.* The Federal Ministry for Economic Affairs and Energy, Germany. https://www.bmwi.de/Redaktion/EN/Dossier/enhancing-energy-efficiency-in-buildings.html

Casu, B., & Molyneux, P. (2003). A comparative study of efficiency in European banking. *Applied Economics*, *35*(17), 1865-1876. https://doi.org/10.1080/0003684032000158109

Chandran, V. G. R., Sharma, S., & Madhavan, K. (2010). Electricity consumption-growth nexus: The case of Malaysia. *Energy Policy, 38*, 606-612. https://doi.org/https://doi.org/10.1016/j.enpol.2009.10.013

Charfeddine, L. (2017). The impact of energy consumption and economic development on ecological footprint and CO_2 emissions: Evidence from a Markov Switching Equilibrium Correction Model. *Energy Economics*, *65*, 355-374. https://doi.org/10.1016/j.eneco.2017.05.009

Destek, M. A., & Sarkodie, S. A. (2019). Investigation of environmental Kuznets curve for ecological footprint: The role of energy and financial development. *Science of the Total Environment*, *650*, 2483-2489. https://doi.org/10.1016/j.scitotenv.2018.10.017

Dietz, T., & Rosa, E. A. (1997). Effects of population and affluence on CO_2 emissions. *Proceedings of the National Academy of Sciences of the United States of America*, *94*, 175-179.

Ding, Q., Khattak, S. I., & Ahmad, M. (2021). Towards sustainable production and consumption: Assessing the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions (CCO2) in G-7 nations. *Sustainable Production and Consumption*, *27*, 254-268.

Dolado, J. J., Banerjee, A., & Mestre, R. (1998). Error-Correction mechanism tests for cointegration in single equation framework. *Journal of Time Series Analysis, 19*, 267-283. https://doi.org/10.1111/1467-9892.00091

Ehrlich, P. R., & Holdren, J. P. (1971). Impact of population growth. *Science*, *171*(3977), 1212-1217. https://doi.org/10.1126/science.171.3977.1212

Farhani, S., & Ozturk, I. (2015). Causal relationship between CO_2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. *Environmental Science and Pollution Research*, *22*, 15663-15676. https://doi.org/10.1007/s11356-015-4767-1

Fotourehchi, Z. (2017). Renewable energy consumption and economic growth: A case study for developing countries. *International Journal of Energy Economics and Policy*, *24*(33), 26006-26015, https://doi.org/10.1007/s11356-017-0259-9

Galli, A., Kitzes, J., Niccolucci, V., Wackernagel, M., Wada, Y., & Marchettini, N. (2012). Assessing the global environmental consequences of economic growth through the ecological footprint: A focus on China and India. *Ecological Indicators*, *17*, 99-107. https://doi.org/10.1016/j.ecolind.2011.04.022

Goh, S. K., Tang, T. C., & Sam, C. Y. (2020). Are major US trading partners' exports and imports cointegrated? Evidence from Bootstrap ARDL. *Margin: The Journal of Applied Economic Research*, *14*, 7-27. https://doi.org/10.1177/0973801019886481

Gozgor, G., Lau, C. K. M., & Lu, Z. (2018). Energy consumption and economic growth: New evidence from the OECD countries. *Energy*, *153*, 27-34. https://doi.org/https://doi.org/10.1016/j.energy.2018.03.158

Halicioglu, F. (2009). An econometric study of CO_2 emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy*, *37*, 1156-1164. https://doi.org/10.1016/j.enpol.2008.11.012

Halkos, G. M., & Tzeremes, N. G. (2009a). Exploring the existence of Kuznets Curve in countries' environmental efficiency using DEA Window Analysis. *Ecological Economics, 68*(7), 2168-2176. https://doi.org/10.1016/j.ecolecon.2009.02.018

Halkos, G. M., & Tzeremes, N. G. (2009b). Electricity generation and economic efficiency: Panel data evidence from world and East Asian countries. *Global Economic Review, 38*(3), 251-263. https://doi.org/10.1080/12265080903157300

Imamoglu, H. (2018). Is the informal economic activity a determinant of environmental quality? *Environmental Science and Pollution Research, 25*, 29078-29088. https://doi.org/10.1007/s11356-018-2925-y

International Energy Agency (IEA). (2015). *World energy outlook 2015*. https://www.iea.org/reports/world-energy-outlook-2015

International Energy Agency (IEA). (2017). *Energy Access Outlook: From Poverty to Prosperity*. https://www.oecd.org/publications/energy-access-outlook-2017-9789264285569-en.htm

International Energy Agency (IEA). (2018). *Energy Efficiency is the Cornerstone for Building a Secure and Sustainable Energy System.* https://www.iea.org/news/energy-efficiency-is-the-cornerstone-for-building-a-secure-and-sustainable-energy-system

Jago-on, K. A. B., Kaneko, S., Fujikura, R., Fujiwara, A., Imai, T., Matsumoto, T., Zhang, J., Tanikawa, H., Tanaka, K., Lee, B., & Taniguchia, M. (2009). Urbanization and subsurface environmental issues: An attempt at DPSIR Model application in Asian cities. *Science of the Total Environment*, *407*, 3089-3104. https://doi.org/https://doi.org/10.1016/j.scitotenv.2008.08.004

Kasman, A., & Duman, Y. S. (2015). CO_2 emissions, economic growth, energy consumption, trade and urbanization in new

EU member and candidate countries: A panel data analysis. *Economic Modelling, 44*, 97-103. https://doi.org/https://doi.org/10.1016/j.econmod.2014.10.022

Kim, D., & Perron, P. (2009). Unit root tests allowing for a break in the trend function at an unknown time under both the null and alternative hypotheses. *Journal of Econometrics*, *148*, 1-13. https://doi.org/https://doi.org/10.1016/j.jeconom.2008.08.019

Kraft, J., & Kraft, A. (1978). Relationship between energy and GNP. *The Journal of Energy and Development, 3*(2), 401-403.

Kuriqi, A., Pinheiro, A.N., Sordo-Ward, A., & Garrote, L. (2019). Flow regime aspects in determining environmental flows and maximising energy production at run-of-river hydropower plants. *Applied Energy*, *256*, 113980. https://doi.org/https://doi.org/10.1016/j.apenergy.2019.113980

Langlois, P., & Yank, A. (2017). Developing countries and energy efficiency potential: Strategies for low-carbon development after the Paris Agreement.

Li, J., Zhang, X., Ali, S., & Khan, Z. (2020). Eco-innovation and energy productivity: New determinants of renewable energy consumption. *Journal of Environmental Management*, *271*, 111028.

Liu, X., Zhang, S., & Bae, J. (2017). The impact of renewable energy and agriculture on carbon dioxide emissions: Investigating the environmental Kuznets curve in four selected ASEAN countries. *Journal of Cleaner Production, 164*, 1239-1247. https://doi.org/https://doi.org/10.1016/j.jclepro.2017.07.086

Luetkepohl, H. (2006). Structural vector autoregressive analysis for cointegrated variables. *Allgemeines Statistisches Arch*, *90*, 75-88. https://doi.org/10.1007/s10182-006-0222-4

Malaysia Energy Statistics. (2019). *Handbook of Energy Statistics*. https://meih.st.gov.my/documents/10620/bcce78a2-5d54-49ae-b0dc-549dcacf93ae

Malefane, M. R., & Odhiambo, N. M. (2018). *Impact of Trade Openness on Economic Growth: Empirical Evidence from South Africa.* Unisa Economic Research Working Paper Series. http://uir.unisa.ac.za/handle/10500/23654

Masih, A. M. M., & Masih, R. (1996). Energy consumption, real income and temporal causality: results from a multi-country study based on cointegration and error-correction modelling techniques. *Energy Economics*, *18*, 165-183. https://doi.org/https://doi.org/10.1016/0140-9883(96)00009-6

McNown, R., Sam, C. Y., & Goh, S. K. (2018). Bootstrapping the autoregressive distributed lag test for cointegration. *Applied Economics*, *50*, 1509-1521. https://doi.org/10.1080/00036846.2017.1366643

Menyah, K., & Wolde-Rufael, Y. (2010). CO_2 emissions, nuclear energy, renewable energy and economic growth in the US. *Energy Policy, 38*, 2911-2915. https://doi.org/https://doi.org/10.1016/j.enpol.2010.01.024

National Energy Balance (NEB). (2012). *Malaysian Projected Energy Demand Supply Balance.* https://meih.st.gov.my/documents/10620/717f207d-1308-4d2c-b5e1-9f84b24d2e0b

Ocal, O., & Aslan, A. (2013). Renewable energy consumption-economic growth nexus in Turkey. *Renewable and Sustainable Energy Reviews*, *28*, 494-499. https://doi.org/10.1016/j.rser.2013.08.036

Odhiambo, N. M. (2009). Energy consumption and economic growth nexus in Tanzania: An ARDL Bounds Testing Approach. *Energy Policy, 37*, 617-622. https://doi.org/10.1016/j.enpol.2008.09.077

Ong, H. C., Mahlia, T. M. I., & Masjuki, H. H. (2011). A review on energy scenario and sustainable energy in Malaysia. *Renewable and Sustainable Energy Reviews*, *15*, 639-

647. https://doi.org/https://doi.org/10.1016/j.rser.2010.09.043

Ozturk, I., & Acaravci, A. (2013). The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. *Energy Economics, 36*, 262-267. https://doi.org/https://doi.org/10.1016/j.eneco.2012.08.025

Ozturk, I., & Al-Mulali, U. (2015). Investigating the validity of the environmental Kuznets Curve Hypothesis in Cambodia. *Ecological Indicators*, *57*, 324-330. https://doi.org/10.1016/j.ecolind.2015.05.018

Pao, H. T., & Tsai, C. M. (2010). CO_2 emissions, energy consumption and economic growth in BRIC countries. *Energy Policy*, *38*, 7850-7860. https://doi.org/10.1016/j.enpol.2010.08.045

Pesaran, H., Smith, R., & Shin, Y. (2001). Bound testing approaches to the analysis of level relationship. *Journal of Applied Econometrics, 16*(3), 289-326. https://doi.org/10.1002/jae.616

Raskin, P. D. (1995). Methods for estimating the population contribution to environmental change. *Ecological Economics, 15*(3), 225-233. https://doi.org/10.1016/0921-8009(95)00047-X

Raza, S. A., & Shah, N. (2018). Testing environmental Kuznets curve hypothesis in G7 countries: The role of renewable energy consumption and trade. *Environmental Science and Pollution Research*, *25*, 26965-26977. https://doi.org/10.1007/s11356-018-2673-z

Saboori, B., Sulaiman, J., & Mohd, S. (2012). Economic growth and CO_2 emissions in Malaysia: A cointegration analysis of the Environmental Kuznets Curve. *Energy Policy*, *51*, 184-191. https://doi.org/https://doi.org/10.1016/j.enpol.2012.08.065

Saidi, K., & Hammami, S. (2015). The impact of CO_2 emissions and economic growth on energy consumption in 58 countries. *Energy Reports, 1*, 62-70. https://doi.org/https://doi.org/10.1016/j.egyr.2015.01.003

Saidi, K., & Mbarek, M. B. (2017). The impact of income, trade, urbanization, and financial development on CO_2 emissions in 19 emerging economies. *Environmental Science and Pollution Research*, *24*, 12748-12757. https://doi.org/10.1007/s11356-016-6303-3

Sarwar, S., Chen, W., & Waheed, R. (2017). Electricity consumption, oil price and economic growth: Global perspective. *Renewable and Sustainable Energy Reviews, 76*, 9-18. https://doi.org/https://doi.org/10.1016/j.rser.2017.03.063

Shaari, M., Hussain, N., & Ismail, M. (2012). Relationship between energy consumption and economic growth: Empirical evidence for Malaysia. *Business Systems Review, 2*(1), 17-28.

Shahbaz, M., Nasir, M. A., & Roubaud, D. (2018a). Environmental degradation in France: The effects of FDI, financial development, and energy innovations. *Energy Economics, 74*, 843-857. https://doi.org/https://doi.org/10.1016/j.eneco.2018.07.020

Shahbaz, M., Van Hoang, T. H., Mahalik, M. K., & Roubaud, D. (2017). Energy consumption, financial development and economic growth in India: New evidence from a nonlinear and asymmetric analysis. *Energy Economics, 63*, 199-212. https://doi.org/10.1016/j.eneco.2017.01.023

Shahbaz, M., Zakaria, M., Shahzad, S. J. H., & Mahalik, M. K. (2018b). The energy consumption and economic growth nexus in top ten energy-consuming countries: Fresh evidence from using the quantile-on-quantile approach. *Energy Economics, 71*, 282-301. https://doi.org/https://doi.org/10.1016/j.eneco.2018.02.023

Solarin, S. A., Al-Mulali, U., Musah, I., & Ozturk, I. (2017). Investigating the pollution haven hypothesis in Ghana: An empirical investigation. *Energy*, *124*, 706-719. https://doi.org/10.1016/j.energy.2017.02.089

Soytas, U., & Sari, R. (2003). Energy consumption and GDP: Causality relationship in G-7 countries and emerging markets. *Energy Economics, 25*(1), 33-37. https://doi.org/10.1016/S0140-9883(02)00009-9

Soytas, U., & Sari, R. (2009). Energy consumption, economic growth, and carbon emissions: Challenges faced by an EU candidate member. *Ecological Economics, 68*(6), 1667-1675. https://doi.org/https://doi.org/10.1016/j.ecolecon.2007.06.014

Stern, P. C. (1984) *Improving Energy Demand Analysis.* https://www.nap.edu/read/10457/chapter/1#ii

Tang, C. F., & Shahbaz, M. (2013). Sectoral analysis of the causal relationship between electricity consumption and real output in Pakistan. *Energy Policy, 60*, 885-891. https://doi.org/https://doi.org/10.1016/j.enpol.2013.05.077

Tang, C. F. (2009). Electricity consumption, income, foreign direct investment, and population in Malaysia: New evidence from multivariate framework analysis. *Journal of Economic Studies, 36*(4), 371-382. https://doi.org/10.1108/01443580910973583

Tang, C. F., & Tan, B. W. (2015). The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. *Energy, 79*, 447-454. https://doi.org/https://doi.org/10.1016/j.energy.2014.11.033

Tang, C. F., Tan, B. W., & Ozturk, I. (2016). Energy consumption and economic growth in Vietnam. *Renewable and Sustainable Energy Reviews*, *54*, 1506-1514. https://doi.org/https://doi.org/10.1016/j.rser.2015.10.083

The Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate Change 2007: Synthesis Report*. https://www.ipcc.ch/report/ar4/syr/

Toda, H. Y., & Yamamoto, T. (1995). Statistical inference in vector autoregressions with possibly integrated processes. *Journal of Econometrics, 66*, 225-250. https://doi.org/https://doi.org/10.1016/0304-4076(94)01616-8

Tsani, S. Z. (2010). Energy consumption and economic growth: A causality analysis for Greece. *Energy Economics, 32*(3), 582-590. https://doi.org/10.1016/j.eneco.2009.09.007

Wang, S., Li, Q., Fang, C., & Zhou, C. (2016). The relationship between economic growth, energy consumption, and CO_2 emissions: Empirical evidence from China. *Science of the Total Environment, 542*(Part A), 360-371. https://doi.org/10.1016/j.scitotenv.2015.10.027

World Bank (2008). *The Growth Report: Strategies for Sustained Growth and Inclusive Development*. https://openknowledge.worldbank.org/bitstream/handle/10986/6507/449860PUB0Box3101OFFICIAL0USE0ONLY1.pdf?sequence=1&isAllowed=y

Yoo, S-H. (2006). The causal relationship between electricity consumption and economic growth in the ASEAN countries. *Energy Policy, 34*(18), 3573-3582. https://doi.org/https://doi.org/10.1016/j.enpol.2005.07.011

York, R., Rosa, E. A., & Dietz, T. (2002). Bridging environmental science with environmental policy: Plasticity of population, affluence, and technology. *Social Science Quarterly, 83*(1), 18-34. https://doi.org/10.1111/1540-6237.00068

Zahonogo, P. (2017). Globalization and economic growth in developing countries: Evidence from Sub-Saharan Africa. *The International Trade Journal, 32*(2), 189-208. https://doi.org/10.1080/08853908.2017.1333933

Zhang, C., & Lin, Y. (2012). Panel estimation for urbanization, energy consumption and CO_2 emissions: A regional analysis in China. *Energy Policy, 49*, 488-498. https://doi.org/10.1016/j.enpol.2012.06.048