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Energy consumption and economic growth in Vietnam

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ABSTRACT

This study attempts to analyse the relationship between energy consumption and economic growth in Vietnam using the neoclassical Solow growth framework for the 1971–2011 period. The concept and methods of cointegration and Granger causality are used to establish the relationship between the variables of interest. Our results confirm the existence of cointegration among the variables. In particular, energy consumption, FDI and capital stock were found positively influence economic growth in Vietnam. The Granger causality test revealed unidirectional causality running from energy consumption to economic growth. Hence, Vietnam is an energy-dependent economy and any energy or environment policy drawn up in an attempt to conserve energy will jeopardise the process of economic development in Vietnam. For this reason, the renewable energy policy should be given attention to provide sufficient supplies of energy to speed up economic expansion. Investment in R&D may be required to incentivise private/public institutions to engage in this innovation, while the awareness for energy-saving policy among public could be integrated to meet social economic development.

Contents

1. Introduction

Despite the large literatures on the energy-growth nexus, the direction of causality between energy consumption and economic growth remains an unsettled issue. Moreover, empirical studies of low income countries like Vietnam are almost non-existent. Over the past decades, consumption of energy in Vietnam increased tremendously in accordance with the rapid development of the Vietnamese economy towards industrialisation and economic reform in catching-up with the global economy. Before the onset of global economic downturn in 2008, the economic growth rates were fluctuating along 7 percent to 8 percent from 1990 to 2007. This rapid development is mainly attributed to the liberalisation of

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economic production and exchange in 1989. Likewise, the per capita energy consumption in Vietnam also increased by 9.3 percent per annum from 1990 to 2007 [1]. Do and Sharma [2] too revealed that the total energy consumption in Vietnam is projected to increase from 55.6 Mtoe in 2007 to 146 Mtoe in 2025. This impressive performance has sparked the interest among economists and policymakers to investigate whether energy consumption is the cause or effect of economic growth in Vietnam as it had direct implications on the formulation of economic and environmental policies. If energy consumption causes economic growth, the aim of energy conservation policies to protect the environment may jeopardise the process of economic growth and development in Vietnam. Therefore, the control of energy conservations in Vietnam can give way by allowing the use of energy from renewable resources, together with energy savings policy. Cultivating these policies is very encouraging when this study intends to pursue additional usage of energy to support economic development in Vietnam. On the other hand, if the increase of energy consumption is an effect of economic growth, energy conservation policies can be used to combat global warming with less or no impact on economic growth in Vietnam. In light of this, it is of utmost importance to investigate the relationship between energy consumption and economic growth in the context of the Vietnamese economy.

To the best of our knowledge, the empirical papers by Binh [3], Canh [4], Chontanawat et al. [5] and Loi [6] appear to be the only published works that examined the energy-growth nexus in Vietnam. Based on the bivariate regression model, Canh [4] investigated the causality relationship between electricity consumption and economic growth in Vietnam during the period of 1975–2010. Loi [6], on the other hand, examined the Granger causality relationship between energy consumption, GDP and trade in Vietnam for the period 1986–2006. Canh [4] and Loi [6] pointed to the evidence that there is a cointegration relationship between GDP and electricity consumption, coupled with a long-run causality relationship that is running from GDP to electricity consumption in Vietnam. Similarly, both of these studies mean that an increase in income would expand electricity-intensive production since electricity is one of the most important and effective inputs for the industrial sectors in Vietnam. Chontanawat et al. [5] examined the relationship between energy consumption and economic growth over 100 countries using the concept and method of cointegration and Granger causality. In the case of Vietnam, they found that energy consumption and economic growth are not cointegrated, but there is evidence of Granger causality running from energy consumption to economic growth. Likewise, Binh [3] also concurred that energy consumption and economic growth are not cointegrated. However, the study found evidence of uni-directional Granger causality running from economic growth to energy consumption in Vietnam.

Testing the causal relationship between energy consumption and economic growth has important policy implications. Therefore, many empirical studies have been conducted on this issue. Ozturk [7], Payne [8] and Tang and Tan [9] provided a rigorous literature survey on energy-growth nexus. A general observation from these studies is that the Granger causality results between energy consumption and economic growth have been mixed. Some studies support the view of energy consumption Granger-cause economic growth [10–12], while other studies argue that economic growth is not the result of energy consumption [13–15]. Ozturk [7] and Payne [8] summarised that the conflicting causality results can be attributed to the omission of relevant variable bias and the differences in causality approaches as well as time periods and a country's characteristics. As Vietnam is one of the members of the Association of Southeast Asia Nations (ASEAN) and most of the energy-growth studies have been covered by Ozturk [7] and Payne [8], we deem a brief discussion of previous empirical studies for ASEAN economies would suffice for an insight. The summary of empirical studies on the relationship between energy consumption and economic growth are presented in Table 1. Previous empirical studies for ASEAN can be divided into two major groups. The first group of studies analysed the relationship between energy consumption and economic growth using a bi-variate model, while the second group of studies focused on the relationship using a multivariate model.

This paper contributes to energy economics literature and different from the papers of Binh [3], Canh [4], Chontanawat et al. [5] and Loi [6] in at least five ways. First, this study analyses the relationship between energy consumption and economic growth in Vietnam using a multivariate rather than a bi-variate setting. Theoretically, estimation results in a bi-variate setting are more likely to be biased owing to the omission of relevant variables [35]. According to the energy-growth literature, capital stock and foreign direct investment (FDI) are two important variables that affect economic growth and its relationship to energy consumption [29,31,36]. Therefore, omission of capital stock and FDI would cause spurious estimation results. Second, this study borrows the neoclassical Solow's growth theory to construct a theoretical framework to analyse the energy-growth nexus rather than based upon an ad-hoc model specification. Even though estimation with ad-hoc model specification is simple and convenient, the estimation results may be difficult when it comes to the interpretation stage because the analysis is not grounded by the economic theory. Third, apart from the standard DF-GLS and KPSS unit root tests, we also employ the new unit root test with two structural breaks advocated by Narayan and Popp [37] to check the order of integration of each series. On the basis of Monte Carlo experiment, Narayan and Popp [38] found that the new unit root test is superior to the alternative unit root tests [39,40] in the aspect of size and power of the test. Fourth, we used the Bartlett-corrected trace test for small sample proposed by Johansen [41] to examine the presence of long-run equilibrium relationships. Finally, the causality test proposed by Toda and Yamamoto [42] in association with the leveraged bootstrapping simulation approach is used to ascertain the direction of causality between energy consumption and economic growth in Vietnam. It is a well-known fact that the leveraged bootstrapping approach to causality provides robust critical values for small sample [43,44]. Based on our readings on current related literature, the Bartlett-corrected trace test to cointegration and the leveraged bootstrapping approach to causality have not been employed by earlier studies for Vietnam. Based upon the aforementioned modelling and testing procedures, this study provides a comprehensive and robust view of the relationship between energy consumption and economic growth in Vietnam. It is strongly believed that the findings of this study would be a reliable and suitable basis for policymaking.

The rest of this paper is organised as follows. Section 2 discusses the theoretical framework, data and methodology used in this study. The results and conclusion are presented in Section 3 and Section 4, respectively.

2. Methodology and data

2.1. Theoretical framework

In this sub-section, we reveal the association of energy consumption and economic growth within the neoclassical Solow growth framework. Considering the following Cobb–Douglas production function:

$$Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha} \tag{1}$$

where Y is output, K is the stock of capital use to produce output, L is the labour force use to produce output, and A is a labour-augmenting factor indicating the level of technology innovation and efficiency in the economy. According to the neoclassical growth theory, the returns of capital are decreasing, thus $\alpha < 1$. Moreover, labour force and technology innovation are assumed to grow based upon the following function:

$$L_t = L_0 e^{nt} \tag{2}$$

$$A_t = A_0 e^{gt} EC^{\theta} \tag{3}$$

where n is the exogenous rate of growth of the labour force, g is the exogenous rate of technology innovation, EC is the energy consumption and θ is the coefficient with respect to energy consumption. In this study, we extend that variable A depends not only on the constant rate of technology improvement but it also depends on the level of energy consumption in the domestic economy. We believe that this extension is relevant and help to stimulate labour-augmenting technological change because energy serves as a key input to support the development of modern technology. Moreover, Amar [45] documented that energy consumption can speed up the process of re-construction of capital owing the existence of new technologies. Apart from that, he added that the process of "creative destruction" introduced by Schumpeter [46] can also be used to explain the link between energy consumption and economic growth via technology innovation. It is well-known that "creative destruction" will enhance the development of new technologies through the process of re-investment and modernisation in equipment meanwhile energy consumption helps to speed up the innovation process which in turn lead to economic growth.

Table 1
Summary of studies on the energy-growth nexus in ASEAN economies.

No.	Author(s)	Period	Country	Methodology	Variables	Main causality results
Studies with bivariate model:						
1.	Murry and Nan [16]	1970–1990	Indonesia, Malaysia Singapore Philippines	Granger causality – VAR	EC; GDP	EC↔GDP EC→GDP EC↮GDP
2.	Glasure and Lee [17]	1961–1990	Singapore	Engle-Granger; Granger causality	EC; GDP	EC→GDP
3.	Yoo [18]	1971–2002	Indonesia, Thailand Malaysia, Singapore	Engle-Granger; Johansen-Juselius; Granger causality; Hsiao's causality – VAR	EC; GDP	GDP→EC EC↔GDP
4.	Chen et al. [19]	1971–2001	Indonesia, Malaysia, Philippines Singapore, Thailand	Johansen-Juselius; Granger causality – VECM	EC; GDP	GDP→EC EC↮GDP
5.	Chontanawat et al. [5]	1971–2000	Brunei, Myanmar, Philippines, Vietnam Indonesia, Malaysia, Singapore, Thailand	Johansen-Juselius; Granger causality	EC; GDP	EC→GDP EC↛GDP
6.	Chiou-Wei et al. [20]	1954–2006	Indonesia, Malaysia Singapore, Philippines Thailand	Johansen-Juselius; Granger causality – VAR	EC; GDP	EC→GDP GDP→EC
7.	Tang [21]	1972–2003	Malaysia	ECM-based F-test; Granger causality; MWALD	EC; GDP	EC↔GDP
8.	Binh [3]	1976–2010	Vietnam	Engle-Granger; Johansen-Juselius; Gregory-Hansen; Granger causality – VECM	EC; GDP	GDP→EC
9.	Canh [4]	1975-2010	Vietnam	Johansen-Juselius; Granger causality – VAR	EC; GDP	GDP→EC
Studies with multivariate model:						
10.	Masih and Masih [22]	1955–1990	Indonesia Malaysia, Philippines, Singapore	Johansen-Juselius; Granger causality – VECM	CC; P; GDP	GDP→EC EC↮GDP
11.	Masih and Masih [23]	1955–1991	Thailand	Johansen-Juselius; Granger causality – VECM	EC; P; GDP	EC→GDP
12.	Asafu-Adjaye [24]	1971–1995	Indonesia Philippines, Thailand	Johansen-Juselius; Granger causality – VECM	EC; P; GDP	EC→GDP EC↔GDP
13.	Fatai et al. [25]	1960–1999	Indonesia Philippines, Thailand	Johansen; ARDL; Granger causality	EC; Oil; Gas; GDP	EC→GDP EC↔GDP
14.	Mahadevan and Asafu-Adjaye [26]	1971–2002	Indonesia, Malaysia, Singapore Thailand	Johansen-Juselius; Granger causality	EC; GDP; P	EC↔GDP EC→GDP
15.	Ang [27]	1971–1999	Malaysia	Johansen-Juselius, VECM	EC; CO2; GDP	GDP→EC
16.	Lee and Chang [28]	1971–2002	ASEAN-5	Panel cointegration; Granger causality	EC; L; K; GDP	EC→GDP
17.	Tang [29]	1970–2005	Malaysia	ARDL; Granger causality – VECM	EC; POP; FDI; GDP	EC↔GDP
18.	Chandran et al. [30]	1971–2003	Malaysia	ARDL bounds testing; Engle-Granger; Johansen-Juselius; Granger causality – VECM	EC; P; GDP	EC→GDP
19.	Lean and Smyth [31]	1971–2006	Malaysia	ARDL; Johansen-Juselius; MWALD	EC; EX; K, L; GDP	EC↔GDP
20.	Lean and Smyth [32]	1970–2008	Malaysia	ARDL; MWALD	EG, GDP, EX, P	GDP→EG
21.	Lean and Smyth [33]	1980–2006	ASEAN-5	Johansen Fisher Panel Cointegration; Granger causality	EC; CO2; GDP	EC→GDP
22.	Loi [6]	1986–2006	Vietnam	Johansen; Granger causality – VECM	EC; GDP; T	GDP→EC
23.	Islam et al. [34]	1971–2009	Malaysia	ARDL; Granger causality – VECM	EC; POP; FD; GDP	EC↔GDP

Notes: →, ↔, ↛ and ↮ represent uni-directional causality, bi-directional causality, does not Granger-cause and neutral causality, respectively.
Abbreviations are defined as follows: ARDL=autoregressive distributed lag; ECM=error-correction model; GMM=generalised method of moments; MWALD=modified Wald; VAR=vector autoregressive; VECM=vector error-correction model; EC=energy (electricity) consumption; GDP=gross domestic product (or economic growth); C=consumption; CC=coal consumption; EG=electricity generation; EX=exports; FD=financial development; FDI=foreign direct investment; K=capital; L=labour force (employment); P=prices; POP=population; CO_2=carbon dioxide emissions; T=Trade

According to the Solow growth model, the savings ratio is assumed to be exogenously determined either by savers' choices or government policy. Hence, physical capital is accumulated based upon the following function:

$$\frac{\partial K_t}{\partial t} = s_k Y_t - \delta K_t \tag{4}$$

where s_k is the portion of income invested in physical capital and δ is the rate of depreciation of the invested physical capital. Let k and y be the level of physical capital and the level of output in terms of an effective unit of labour, that is $k = K/AL$ and $y = Y/AL$. Hence, the production and accumulation functions can be re-written in terms of an effective unit of labour as follow:

$$y = k^{\alpha} \tag{5}$$

$$\frac{\partial k}{\partial t} = sk - (n+g+\delta)k \tag{6}$$

It is also important to note here that in the steady state, the level of physical capital per effective unit of labour is assumed to be constant. Therefore, k can be defined as:

$$k^* = \left[\frac{k}{(n+g+\delta)}\right]^{\frac{1}{(1-\alpha)}} \tag{7}$$

By substituting Eq. (7) into Eq. (5) and taking the natural logarithm, the steady state per capita income is:

$$\ln\left(\frac{Y_t}{L_t}\right) = \ln A_0 + gt + \theta \ln EC_t + \frac{\alpha}{1-\alpha}\ln k_t - \frac{\alpha}{1-\alpha}\ln (n+g+\delta)_t \tag{8}$$

Since capital (k) is a combination of foreign and domestic investments, we extend the growth model by segregating capital into foreign and domestic to allow us to assess the impact of each capital on economic growth. Apart from that, Mankiw et al. [47] narrated that A_0 not only reflect technological improvement, but also resource endowments, climate, institutions and other, thus $\ln A_0 = \beta_0 + \varepsilon_t$ where β_0 is a constant term and ε_t is the disturbance term or unobservable components. By substituting $\beta_0 + \varepsilon_t$ into the Eq. (8) and segregate k into foreign direct investment (FDI) and domestic investment (DI), the steady state per capita income model is:

$$\ln\left(\frac{Y_t}{L_t}\right) = \beta_0 + gt + \theta \ln EC_t + \frac{\alpha}{1-\alpha}\ln FDI_t + \frac{\alpha}{1-\alpha}\ln DI_t - \frac{\alpha}{1-\alpha}\ln (n+g+\delta)_t + \varepsilon_t \tag{9}$$

Econometrically, the generic form of empirical model that can be used to analyse the long-run relationship between economic growth and its determinants is written below:

$$\ln GDP_t = \beta_0 + \beta_1 T_t + \beta_2 \ln EC_t + \beta_3 \ln FDI_t + \beta_4 \ln DI_t + \beta_5 \ln (n+g+\delta)_t + \varepsilon_t \tag{10}$$

Here ln denotes the natural logarithm and the residual ε_t is assumed to be normally distributed and white noise. $\ln GDP_t$ is the per capita real GDP, T_t is the deterministic time trend variable, $\ln EC_t$ is the per capita energy consumption, $\ln FDI_t$ is the per capita real FDI, $\ln DI_t$ is the per capita real domestic investment, $\ln (n+g+\delta)_t$: n is the labour force growth rate, g is the rate of technology growth and δ is the rate of depreciation. Similar to Mankiw et al. [47], we also set $(g+\delta)$ at the rate of 0.05 because we notice that it is match with the available data in the Vietnamese economy.[1] Finally, β_0 is the constant term whereas $\beta_1, \beta_2, \beta_3$, β_4 and β_5 are the estimated parameters in the model.

[1] Based upon the available data from 1971 to 2011, we notice that the average growth rate of per capita income is approximately 3 percent, indicating that $g=0.03$. However, the average growth rate of capital-output ratio is approximately 2 percent, meaning that the rate of depreciation, $\delta = 0.02$.

2.2. Narayan–Popp unit root test with breaks

Whenever time series data is used, it is necessary to determine ahead the order of integration of each series before any other econometric methods can be applied. In this study, we use DF-GLS and KPSS unit root tests to check the stationarity of each variable. Since these unit root tests are well explained in the existing literature, further discussion on the testing procedures are needless. Apart from using the standard unit root tests, we also employ the new unit root test with two structural breaks proposed by Narayan and Popp [37]. The Monte Carlo simulations by Narayan and Popp [38] suggested that this unit root test has stable power and can accurately identify true the breaks dates. Therefore, we choose to use this unit root test to determine the order of integration of each series. Two types of models have been suggested by the authors to test the order of integration of a series. Model M1 allows for structural breaks in the intercept only, while Model M2 allows for structural breaks in both the intercept and the slope of the trend function.

$$\text{Model M1}: w_t = \kappa + \alpha_1 w_{t-1} + \alpha_2 t + \varphi_1 D(T_B)_{1,t} + \varphi_2 D(T_B)_{2,t} + \phi_1 DU_{1,t-1} + \phi_2 DU_{2,t-1} + \sum_{i=1}^{p} \rho_i \Delta w_{t-i} + e_{1t} \tag{11}$$

$$\text{Model M2}: w_t = \kappa + \alpha_1 w_{t-1} + \alpha_2 t + \varphi_1 D(T_B)_{1,t} + \varphi_2 D(T_B)_{2,t} + \varphi_1 DU_{1,t-1} + \varphi_2 DU_{2,t-1} + \vartheta_1 DT_{1,t-1} + \vartheta_2 DT_{2,t-1} + \sum_{i=1}^{p} \rho_i \Delta w_{t-i} + e_{2t} \tag{12}$$

where w_t is the variables under investigation $[\ln GDP_t, \ln EC_t, \ln FDI_t, \ln DI_t, \ln (n+g+\delta)_t]$, Δ is the first difference operator, $(w_t - w_{t-1})$ and (e_{1t}, e_{2t}) are the disturbances term that assumed to be normally distributed and white noise. The first difference lagged dependent variables $\left(\sum_{i=1}^{p} \Delta w_{t-i}\right)$ are included in the model to correct the serial correlation problem if any. The optimal lag order (p) is selected using the general-to-specific t-significance approach suggested by Hall [48]. According to Ng and Perron [49] and Perron [50], this approach has a more superior performance trend than the information-based methods such as Schwarz Bayesian Criterion (SBC) and Akaike Information Criterion (AIC). $DU_{i,t} = 1(t > T_{B,i})$ and $DT_{i,t} = 1(t > T_{B,i})(t - T_{B,i})$, $i = 1, 2$, represent the dummy variables used to capture the potential structural breaks in the intercept and the slope of the trend function occurring in time T_{B1} and T_{B2}, respectively. The potential break dates (T_{B1}, T_{B2}) are selected based upon the grid searching or sequential procedure discussed in Narayan and Popp [37]. Finally, the null hypothesis of a unit root against the alternative hypothesis of stationary can be tested by the t-statistic of w_{t-1}.

2.3. Multivariate Johansen cointegration test

To determine the presence of long-run equilibrium relationship between economic growth and its determinants, we applied the multivariate Johansen [51] cointegration test. According to Gonzalo [52], the Johansen cointegration test performs better than alternative tests for cointegration such as the two-step Engle and Granger [53] cointegration test. In addition, Pfaff [54] documented that it does not require the same order of integration for testing the presence of cointegration [55,56]. To investigate the Johansen test, we estimated the following vector error-correction model (VECM):

$$\Delta Z_t = \pi Z_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta Z_{t-i} + u_t \tag{13}$$

where Δ is the first difference operator. Z_t is a vector of endogenous variables $[\ln GDP_t, \ln EC_t, \ln FDI_t, \ln DI_t, \ln (n+g+\delta)_t]'$. π is a coefficient matrix which contains information about the long-run relationship between variables in the vector. If the variables are cointegrated, the cointegrating rank, r, is given as $\pi = \alpha\beta'$, where α is the matrix of parameters denoting the speed of convergence to the long-run equilibrium and β represents the matrix of parameters of the cointegrating vector.

Nevertheless, the Monte Carlo study of Cheung and Lai [57] revealed that the Johansen cointegration test is weak in small sample study. Given that our sample size consists of only 39 observations, the Bartlett-corrected trace test for small sample proposed by Johansen [41] will be used to examine the existence of cointegration relationship. The advantage of using the Bartlett-corrected trace test is that it can be used irrespective of whether the test distribution behaviour is non-standard or otherwise [58]. Furthermore, Omtzigt and Fachin [59] discovered that the Bartlett-correction procedure could be an effective procedure to correct the small-sample bias. By and large, the idea of the Bartlett correction procedure is to adjust the LR test statistic $-T\sum \ln\left(1-\hat{\lambda}_i\right)$ by its small sample expectation in a given parameter point θ where T is the total number of observations and $\hat{\lambda}_i$ is the eigenvalue. Johansen [41] documented that the expectation for finite sample is not easy to calculate but it can be replaced by an approximation of the form:

$$E_\theta\left[-T\sum \ln\left(1-\hat{\lambda}_i\right)\right] = f\left(1+T^{-1}B(\theta)\right)+O\left(T^{-3/2}\right) \quad (14)$$

where f represents the expectation of the limit distribution, in particular, the degrees of freedom for a χ^2 distributed test. In this sense, if the expectation takes the form of $f+O\left(T^{-3/2}\right)$, the Bartlett-corrected trace test can be expressed as:

$$LR(\lambda_{Bartlett}) = \frac{-T\sum \ln\left(1-\hat{\lambda}_i\right)}{1+T^{-1}B(\theta)} \quad (15)$$

Owing to the ambit space of this study, interested readers may refer to Johansen [41] and Johansen et al. [60] detailed discussion about the Bartlett-corrected trace test for small samples.

2.4. Granger causality test

This study used the Granger causality approach developed by Toda and Yamamoto [42] to ascertain the direction of causality between energy consumption and economic growth in Vietnam. This is also known as the Modified Wald (MWALD) causality test. This Granger causality test can be conducted by estimating the following augmented vector autoregressive (VAR) system.

$$\begin{aligned} \ln\mathrm{GDP}_t = a_0 &+ \sum_{i=1}^{h} a_{1i}\ln\mathrm{GDP}_{t-i} + \sum_{j=h+1}^{p} a'_{1j}\ln\mathrm{GDP}_{t-j} + \sum_{i=1}^{h} a_{2i}\ln\mathrm{EC}_{t-i} \\ &+ \sum_{j=h+1}^{p} a'_{2j}\ln\mathrm{EC}_{t-j} + \sum_{i=1}^{h} a_{3i}\ln\mathrm{FDI}_{t-i} + \sum_{j=h+1}^{p} a'_{3j}\ln\mathrm{FDI}_{t-j} \\ &+ \sum_{i=1}^{h} a_{4i}\ln\mathrm{DI}_{t-i} + \sum_{j=h+1}^{p} a'_{4j}\ln\mathrm{DI}_{t-j} + \sum_{i=1}^{h} a_{5i}\ln\left(n+g+\delta\right)_{t-i} \\ &+ \sum_{j=h+1}^{p} a'_{5j}\ln\left(n+g+\delta\right)_{t-j} + \upsilon_{1t} \end{aligned} \quad (16)$$

$$\begin{aligned} \ln\mathrm{EC}_t = a_0 &+ \sum_{i=1}^{h} b_{1i}\ln\mathrm{EC}_{t-i} + \sum_{j=h+1}^{p} b'_{1j}\ln\mathrm{EC}_{t-j} + \sum_{i=1}^{h} b_{2i}\ln\mathrm{GDP}_{t-i} \\ &+ \sum_{j=h+1}^{p} b'_{2j}\ln\mathrm{GDP}_{t-j} + \sum_{i=1}^{h} b_{3i}\ln\mathrm{FDI}_{t-i} + \sum_{j=h+1}^{p} b'_{3j}\ln\mathrm{FDI}_{t-j} \\ &+ \sum_{i=1}^{h} b_{4i}\ln\mathrm{DI}_{t-i} + \sum_{j=h+1}^{p} b'_{4j}\ln\mathrm{DI}_{t-j} + \sum_{i=1}^{h} b_{5i}\ln\left(n+g+\delta\right)_{t-i} \\ &+ \sum_{j=h+1}^{p} b'_{5j}\ln\left(n+g+\delta\right)_{t-j} + \upsilon_{2t} \end{aligned} \quad (17)$$

Here ln denotes the natural logarithm and the disturbances term υ_{1t} and υ_{2t} are assumed to be normally distributed and white noise. The optimal lag order h of VAR system is selected by the AIC and the order of lag p is actually $(h+d_{max})$. Toda and Yamamoto [42] suggest that the maximum order of integration for economic series is at most two, i.e. $d_{max}=2$. However, the Monte Carlo simulation results of Dolado and Lütkepohl [61] revealed that $d_{max}=1$ has better properties than other order of d_{max}. Therefore, $d_{max}=1$ was used in this study to construct the augmented-VAR system. From Eq. (16), $a_{2i} \neq 0\ \forall_i$, meaning that energy consumption Granger-cause economic growth, while from Eq. (17), $b_{2i}=0\ \forall_i$, implies that economic growth does not Granger-cause energy consumption.

Given that the sample of this study is small (T=39), there is a probability for the results of MWALD test to be biased and unreliable [44,62]. To overcome this problem, we followed the approach of Hacker and Hatemi-J [43], who recommends incorporating the residual-based leveraged bootstrap approach to the MWALD causality test to derive a new set of critical values for small samples. In doing so, the results of our MWALD causality test are assumed to be more reliable than the earlier studies.

2.5. Data sources

This study used the annual time series data of the Vietnamese economy from 1971 to 2011. Annual data used in this study includes per capita real GDP, per capita energy consumption, per capita real domestic investment, per capita real FDI, working-age population, and the GDP deflator (2005=100). In this study, we measure n as the growth rate of working-age population, i.e. population within the age from 15 to 64. The GDP deflator is used to express monetary variables in real terms and working-age population is used to express the variables in per capita terms. Following Ang [63] and Tan and Tang [64], we construct domestic investment by taking gross fixed capital formation minus FDI. The data of this study are collected from various reliable sources. Specifically, the data of GDP and gross fixed capital formation are extracted from *The United Nations Statistics Division* (UNSD). However, the data of energy consumption, FDI, working-age population and the GDP deflator are taken from the *World Development Indicators* (WDI). Table 2 provides the descriptive statistics of the series used in this study.

Table 2
Descriptive statistics of the variables.

	$\ln\mathrm{GDP}_t$	$\ln\mathrm{EC}_t$	$\ln\mathrm{FDI}_t$	$\ln\mathrm{DI}_t$	$\ln(n+g+\delta)_t$
Mean	16.055	6.3602	10.676	16.519	−2.580
Median	15.918	6.283	12.884	16.089	−2.580
Maximum	16.876	6.898	14.459	17.769	−2.510
Minimum	15.462	6.155	2.369	15.678	−2.721
Std. Dev.	0.444	0.210	3.374	0.774	0.045
Skewness	0.367	1.171	−0.601	0.478	−0.802
Kurtosis	1.823	3.263	2.253	1.560	3.947
Jarque–Bera	3.287	9.502	3.420	5.104	5.924
Probability	0.193	0.009	0.181	0.078	0.052
Sum	658.262	260.770	437.721	677.273	−105.765
Sum Sq. Dev.	7.887	1.772	455.341	23.981	0.084
Observations	41	41	41	41	41

3. Results

3.1. Unit root results

It is well documented in the existing time series econometric literature that regression results may be spurious if the estimated variables are non-stationary and/or not cointegrated [65]. In light of this, testing for a unit root of each series is necessary. To investigate the order of integration, we began by applying the ADF and DF-GLS unit root tests. The results of ADF and DF-GLS tests in the right-hand panel of Table 3 suggested that all variables were integrated of order one, $I(1)$.

To avert Perron's [66] assertion that the standard unit root tests are biased and unreliable when a series confronted with structural break(s) we employed the Narayan and Popp [37] unit root tests with two structural breaks to overcome the problem. The results of Narayan–Popp test statistics reported in left-hand panel of Table 3 cannot reject the null hypothesis of a unit root at the 10 percent significance level. With these results, we confirmed that $\ln GDP_t$, $\ln EC_t$, $\ln FDI_t$, $\ln DI_t$, and $\ln(n+g+\delta)_t$ followed the $I(1)$ process, thus we proceeded to the next step of testing for the presence of long-run equilibrium relationship using the Johansen cointegration test.

3.2. Cointegration results

Given the order of integration of each series are $I(1)$ and there are more than two variables under consideration, the multivariate Johansen cointegration test is superior to single-cointegration approaches. To perform the Johansen cointegration test, we will have to first determine the optimal lag structure of the VAR system. For this purpose, we performed systems-wise AIC to justify the best lag structure because it has superior performance in small sample study. Following the lag structure thought of Enders [69], we set the maximum lag at 3 years which is a sufficiently long time to capture the dynamic structure of annual data. The systems-wise AIC statistics suggest the 3 year lag model, and thus we performed the Johansen cointegration test with this lag structure.

Panel A of Table 4 summarises the results of Johansen cointegration test. At the 10 percent significance level, the standard trace test – $LR(\lambda_{trace})$ rejects the null hypothesis of at most 4 cointegrating vectors ($r \le 4$), implying that there are five cointegrating vectors. This result is inappropriate because there must be at most four cointegrating vectors among the five variables system. This is corroborating to the findings of Cheung and Lai [57] that Johansen cointegration test is biased toward rejecting the null hypothesis of no cointegration. However, a reasonable cointegration result was obtained when we applied the Bartlett-corrected trace test – $LR(\lambda_{Bartlett})$ suggested in Johansen [41]. The LR

Table 4
Cointegration test results.

Panel A: Bartlett-corrected trace test for cointegration			
Hypotheses		Likelihood ratio tests	
H_0	H_A	$LR(\lambda_{trace})$	$LR(\lambda_{Bartlett})$
$r=0$	$r \ge 1$	187.172***	99.721***
$r \le 1$	$r \ge 2$	102.344***	56.046
$r \le 2$	$r \ge 3$	53.310***	17.894
$r \le 3$	$r \ge 4$	24.854*	8.380
$r \le 4$	$r \ge 5$	11.673*	1.758
Panel B: Normalised cointegrating equation			
Variables	Coefficients	Std. errors	*t*-statistics
$\ln GDP_t$	1.0000	–	–
$\ln EC_t$	0.2403	0.0268	8.9521***
$\ln FDI_t$	0.0047	0.0008	5.8750***
$\ln DI_t$	0.1338	0.0167	8.0120***
$\ln(n+g+\delta)_t$	−0.6467	0.1166	−5.5463***
Trend	0.0234	0.0008	30.6856***
Constant	10.1030	–	–
Panel C: Error-correction model (ECM)			
Dependent variable: $\Delta \ln GDP_t$			
Variables	Coefficients	Std. errors	*t*-statistics
$\Delta \ln EC_t$	−0.0688	0.0912	−0.7539
$\Delta \ln FDI_t$	−0.0008	0.0029	−0.2616
$\Delta \ln DI_t$	0.0810	0.0288	2.8148***
$\Delta \ln(n+g+\delta)_t$	−0.4583	0.2667	−1.7180*
ε_{t-1}	−0.7149	0.1238	−5.7766***
Constant	0.0252	0.0067	3.7395***
Panel D: Diagnostic tests			
χ^2_{NORMAL}	2.0788 (0.3537)		
χ^2_{SERIAL}	{1}: 1.1151 (0.2910)	{2}: 1.9604 (0.3752)	
χ^2_{ARCH}	{1}: 0.7958 (0.3724)	{2}: 0.7895 (0.6738)	
χ^2_{RESET}	{2}: 2.7924 (0.2475)		
CUSUM	Stable at the 5% significance level		
CUSUMSQ	Stable at the 5% significance level		

Note: The asterisks *** and * denote statistical significance at the 1 and 10 percent levels, respectively. { } represents the order of the diagnostic test, while ( ) represents the *p*-values. Estima RATS 8.01 and CATS 2.0 were used to perform the Bartlett-corrected trace test for cointegration.

Table 3
Unit root test results.

Variables	ADF	DF-GLS	Narayan–Popp unit root test with two breaks			
			Model: M1		Model: M2	
	Test statistics	Test statistics	Break year	Test statistics	Break year	Test statistics
Levels:						
$\ln GDP_t$	−1.32 (3)	−0.69 (3)	1979; 1986	−2.83 (1)	1978; 1991	−2.91 (1)
$\ln EC_t$	−0.52 (1)	−1.04 (2)	1984; 1988	−2.34 (4)	1988; 2003	−4.31 (0)
$\ln FDI_t$	−2.02 (0)	−1.70 (3)	1991; 1994	−1.24 (0)	1991; 1994	−0.37 (0)
$\ln DI_t$	−2.14 (0)	−2.94 (3)	1984; 1986	−2.23 (0)	1982; 1986	−3.29 (1)
$\ln(n+g+\delta)_t$	−2.83 (1)	−3.12 (1)	1989; 1991	−3.14 (1)	1980; 1989	−1.18 (1)
First differences:			Critical values#			
$\Delta \ln GDP_t$	−6.28 (3)***	−5.14 (3)***	Model: M1		Model: M2	
$\Delta \ln EC_t$	−4.45 (3)***	−4.22 (3)***	1 percent	−5.259	1 percent	−5.949
$\Delta \ln FDI_t$	−6.09 (0)***	−6.17 (0)***	5 percent	−4.514	5 percent	−5.181
$\Delta \ln DI_t$	−5.63 (0)***	−3.61 (3)**	10 percent	−4.143	10 percent	−4.789
$\Delta \ln(n+g+\delta)_t$	−3.86 (3)**	−3.34 (2)**				

Note: The asterisks *** and ** denote significance at the 1 and 5 percent levels, respectively. ADF is the Augmented Dickey–Fuller test and DF-GLS is the Dickey–Fuller generalised least square test. Δ is the first difference operator. The figures in parentheses indicate the optimal lag length for ADF and DF-GLS tests. The optimal lag length for ADF and DF-GLS tests is selected by using the general-to-specific *t*-significance approach suggested by Hall [48]. The critical values for ADF and DF-GLS tests are obtained from MacKinnon [67] and Elliot et al. [68], respectively. The critical values for Narayan–Popp unit root test with two breaks are collected from Narayan and Popp [37]. All the variables are trended. The selection of deterministic components is based on visual inspection of the plot.

$(\lambda_{Bartlett})$ statistics suggests that at the 1 percent significance level there are at most one cointegrating vectors. In contrast to Chontanawat et al. [5] and Binh [3], we confirm that economic growth, energy consumption and other determinants in Vietnam are moving together in the long-run (i.e. cointegrated). Clearly, testing for cointegration with a multivariate model is superior to the commonly used bi-variate model.

As the interest of this study is to find the response of economic growth to energy consumption, FDI, domestic investment and the growth rate of labour force in Vietnam, the cointegrating vectors will be normalised by economic growth. The normalised cointegrating vectors are revealed in Panel B of Table 4. From the estimated results, we find that in the long-run energy consumption, FDI and domestic investment are positively related to economic growth in Vietnam, while economic growth seems to respond negatively to $\ln\,(n+g+\delta)_t$. In addition, all the explanatory variables turn out to be statistically significant at 1 percent level. With the exception of energy consumption and FDI, the vector error-correction model (VECM) shows that the sign of short-run coefficients are consistent with the long-run, but only domestic investment, $\Delta\ln\,(n+g+\delta)_t$ and the one period lagged error-correction term (ε_{t-1}) are statistically significant at the 10 percent level. These results imply that energy consumption, foreign direct investment and domestic investment are the main drivers of long-term economic growth in Vietnam.

3.3. Granger causality results

Even though we find that the economic growth and energy consumption in Vietnam are cointegrated in the neoclassical Solow growth framework, it does not confirm the direction of causality. For this reason, we implemented the MWALD causality test proposed by Toda and Yamamoto [42] to verify the direction of causality between energy consumption and economic growth in Vietnam. As mentioned in the previous section, the leveraged bootstrap approach will be adopted to improve the robustness of the MWALD test. Table 5 summarises the results of MWALD causality tests together with the leveraged bootstrap critical values for small samples.

The MWALD causality test statistics in Table 5 suggests that the null hypothesis of energy consumption does not Granger-cause economic growth can be rejected at the 5 percent significance level. However, the calculated MWALD statistics for the null hypothesis of economic growth does not Granger-cause energy consumption is less than the 10 percent leveraged bootstrap critical values. Therefore, the null hypothesis cannot be rejected. With these findings, we can surmise that there is uni-directional Granger causality running from energy consumption to economic growth in Vietnam. This result is contrary to the findings of Binh [3], Canh [4] and Loi [6], but consistent with most of the studies such as Glasure and Lee [17], Masih and Masih [23], Asafu-Asjaye [24], Fatai et al. [25], Chontanawat et al. [5], Lee and Chang [28], Chandran et al. [30] and Lean and Smyth [33], which articulated that energy consumption is Granger-causes economic growth. As a result, we confirm that the energy-led growth hypothesis is valid and Vietnam is an energy-dependent country. For this reason, any environmental policies that attempt to conserve energy consumption will stagger and retard the process of economic growth in Vietnam.

Table 5
Multivariate MWALD causality test results.

Null hypotheses	Estimated MWALD tests	Leveraged bootstrap critical values		
		1%	5%	10%
$\ln EC_t \nrightarrow \ln GDP_t$	22.1277**	25.2877	15.6562	10.8104
$\ln GDP_t \nrightarrow \ln EC_t$	8.6382	25.6147	14.9268	11.4695

Note: The asterisk ** denotes statistical significance at the 5 percent level. The optimal lag length of VAR is determined by Akaike's Information Criterion (AIC). The leveraged bootstrap critical values are based upon 1000 times of replications.

4. Conclusion and policy recommendations

We have investigated the relationship between energy consumption and economic growth in Vietnam using the neoclassical Solow growth model by using the cointegration and Granger causality test for the period of 1971–2011. The results revealed that there exists a stable and long-run equilibrium relationship between economic growth and its determinants (i.e. energy consumption, FDI, capital stock, etc). We found that generally energy consumption, FDI and capital stock positively affect economic growth in Vietnam. Given the strong positive association among these variables, any negative shock to these variables, such as impact of energy conservation policies or deterioration of FDI inflows, will have a negative influence on economic growth in Vietnam. As far as our concerned, available literature in Vietnam economy [3–6] provide little or no persuasive empirical evidences in support of the magnitude of this effect. Furthermore, the Granger causality test showed uni-directional causality running from energy consumption to economic growth in Vietnam and not vice-versa. It is clearly evident in this study that energy is an important source of economic growth in Vietnam. Given the fact that Vietnam is an energy-dependent country, any energy or environmental policy initiative aimed at conserving energy consumption will retard the process of economic growth and development in Vietnam.

Based on the findings of this study, there are several issues and challenges that Vietnamese policymakers may need to exercise caution when designing energy or environment policies to combat global warming and/or to stimulate economic growth. Firstly, energy conservation policies are not suitable to combat global warming because our finding suggests that Vietnam is an energy-dependent country. Hence, we suggest policymakers to increase the usage of energy from renewable resources which able to reduce global warming and ignite economic growth at the same time. Apart from that, the renewable energy policy has vital implication in promoting technological development and innovation for job creation and regional development. The market competitiveness of renewable energies could be achieved by propagating investment in research and development (R&D). For instance, to ensure the R&D on developing alternative sources of energy or renewable energy such as hydropower, forest and biomass power, wind and solar power, and geothermal power could be useful to reduce CO_2 emissions without deleterious side effects on the Vietnamese economic growth and development. This suggestion is in line with the National Plan for Environment and Sustainable Development which aims to develop an eco-friendly energy sector in Vietnam. Secondly, our estimation results suggest that FDI has a positive effect on economic growth in Vietnam. It is needless to say that FDI is one of the main channels for technology transfer from the host to the recipient economy [70]. Hence, FDI inflows are expected to bring in more efficient and eco-friendly technologies to the recipient economy. For this reason, we suggest that the Vietnamese government should devote resources and launch policies to attract more FDI inflows, particularly in the energy and high technology sectors. By doing so, more efficient and low carbon technologies can be developed and applied in all sectors and thus stimulates economic growth in Vietnam.

Finally, the government should go on an awareness campaign to communicate and educate the public about the importance of using energy-saving equipment. The awareness-raising campaign should starts with pre-schooling education and run through all learning fields into the higher education system, where the Ministry of Education eases an appropriate education system on energy-saving in the curriculum. Moreover, special attention needs to be given to R&D in order to successfully implement this policy. R&D on energy-saving technologies could be achieving by promoting the creation or development of new energy-saving products and investment. At the same time, government should also emphasise the collaboration between academic institutions and industry sectors (public/private partnerships) as a means to merge basic and applied research in order to enhance knowledge dissemination regarding R&D on energy-saving technologies. Furthermore, the governments and the Department of Energy must make grant funds to support the renewable and efficient energy research and development as well as variety of research programme of advancing energy efficiency. In summary, as far as global warming is concerned, renewable energy and energy-saving technologies should be used to support the development of the Vietnamese economy. Therefore, economic growth in Vietnam can be sustained and the quality of environment can be controlled.

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