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Exploring the nexus of electricity consumption, economic growth, energy prices and technology innovation in Malaysia

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HIGHLIGHTS

- ▶ The electricity-economic growth nexus in Malaysia is examined.
- ▶ Enhanced technology innovation could reduce electricity consumption.
- ▶ Technology innovation Granger-causes electricity consumption and economic growth.
- ▶ Technology innovation could curb wastage of electricity.
- ▶ Technology innovation could also stimulate Malaysia's long-term economic growth.

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ABSTRACT

This study principally attempts to investigate the relationship between electricity consumption on the one hand and economic growth, energy prices and technology innovation in Malaysia on the other over the period, 1970–2009. The results of this study indicate that electricity consumption and its determinants are cointegrated. Specifically, the empirical results show that income positively affects electricity consumption, while energy prices and technology innovation negatively affect it in Malaysia over a long run. The Granger causality results reveal that technology innovation Granger-cause economic growth and electricity consumption in Malaysia. Moreover, we find that electricity consumption and economic growth Granger-cause each other both in the short and in the long run. Therefore, policymakers should increase investment in electricity infrastructure to ensure that electricity supply is sufficient for economic growth and development and at the same time encourage technology innovation to minimise the usage of fossil fuels. This could strike a balance between environmental quality and economic growth in Malaysia.

1. Introduction

Over the past decades, many empirical studies on energy-growth nexus have been published. Generally, they all involved the use of conventional variables with mere changes in the data span. Karanfil [1] emphasised that changing the data span is an insufficient contribution to literatures and effective policymaking. Ozturk [2] and Payne [3] highlighted that omission of relevant variable(s) and methodological flaws are two major factors that cause conflicting estimation results. Instead of using a bi-variate model, research on the energy-growth nexus should consider other potential variable(s) that affect energy consumption and economic growth. In addition, more robust econometric approaches should be employed to reduce the possibility of producing inaccurate results. Karanfil [1] and Ozturk [2] suggested that the fairly new bounds testing approach to cointegration should be used to avoid conflicting and unrealistic results for policymaking.

Motivated by the above studies, the goal of this study is to re-investigate the electricity-growth nexus in Malaysia by accommodating technology innovation as a new control variable. To the best of our knowledge, technology innovation has not been considered by other electricity-growth studies, particularly in the case of Malaysia. Technology innovation could stimulate long-term economic growth as emphasised by the neoclassical and the endogenous growth theories [4,5]. More green energy and energy savings products could also be created through technology innovation. Greater technology innovation could reduce fossil fuel consumption which in turn leads to a better quality of the environment and economic growth. In this context, technology innovation is considered a very important variable affecting energy consumption and its relationship with economic growth.

Malaysia is the choice of this study because of its impressive economic growth record, with rapid development in the informa-

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tion and communication technologies (ICTs) and other infrastructures that require large inputs of electricity [6,7]. Since 1980s, Malaysia has been one of the popular destinations of foreign direct investment (FDI). Such influx of FDI has brought about large volumes of technology transfer to Malaysia because FDI is a main channel of foreign technology transfer. Therefore, it is important to investigate the relationship between electricity consumption, economic growth, energy prices, and technology innovation in Malaysia.

This study employs a set of econometric techniques to achieve the objective of this study. First, apart from using the standard Phillips–Perron (PP) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) unit root tests, we also apply the Zivot and Andrews [8] and Narayan and Popp [9] unit root tests with one and two structural breaks to verify the order of integration of each series. This is because according to Perron [10], standard unit root tests have low power when there are structural breaks in the data series. On the basis of Monte Carlo experiments, Narayan and Popp [11] found that the two-break unit root test proposed by Narayan and Popp [9] has better size and power than the other unit root tests (e.g. [12,13]). Second, we follow the recommendations of Karanfil [1] and Ozturk [2] in using the bounds testing approach to cointegration to examine the presence of a long run equilibrium relationship between electricity consumption and its determinants in Malaysia. This approach is superior for small samples and is able to handle variables with mixed orders of integration. Finally, the Granger causality test will be conducted within an error-correction model (ECM) to ascertain the direction of causality among electricity consumption, economic growth, energy prices, and technology innovation in Malaysia to yield valuable lessons for future policy direction. One of the advantages of using the ECM-based Granger causality test is that it allows us to differentiate between short and long run causal relationships, if any.

The rest of this paper will be organised as follows. A concise review of the power sector in Malaysia is presented in the next section. Section 3 then discusses the past empirical studies on Malaysia and Section 4 will describe the methodology used in this study. The empirical results will be discussed in Section 5. Finally, Section 6 will present the conclusion and policy recommendations.

2. An overview of power sector in Malaysia

Malaysia which gained independence from Britain in 1957 is one of the more advanced developing countries in the Association of Southeast Asia Nation (ASEAN). As a result of rapid development, there was a sharp increase in energy consumption. For example, electricity sold in 1955 was only 919 million kilowatt per hour (kWh), and it increased markedly to 21,889 million kWh in 1989 and to more than 89,000 million kWh in 2007 [14].

Historically, the main power supply in Malaysia was managed by the Central Electricity Broad (CEB) which was renamed as the National Electricity Broad (NEB) in June 1965. However, in the mid-1980s, the privatisation policy has been implemented to improve the power sector's efficiency and productivity. Under the Privatisation Master Plan [15], Tenaga National Berhad (TNB) was established on 1st September 1990 to replace the NEB. Currently, electricity in Malaysia is supplied, transmitted and distributed by three main utility companies namely, TNB, Sabah Electricity Private Limited (SESB), and Sarawak Electricity Supply Corporation (SESCO). TNB remains the largest power supply utility company in Malaysia and Southeast Asia. It is responsible for supplying electricity throughout Peninsula Malaysia and Sabah while SESB and SESCO are responsible for supplies to East Malaysia.

Fig. 1 shows that oil was previously the main resources used for generating electricity in Malaysia. However, it was gradually re-

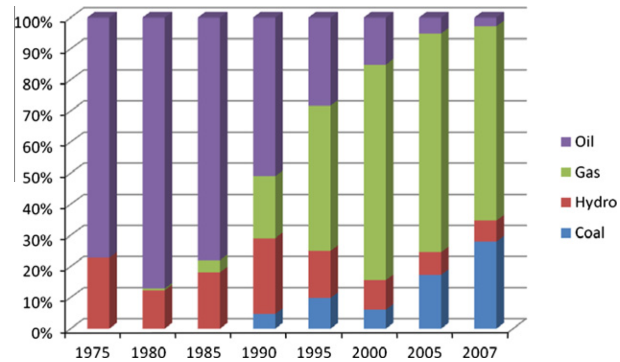

Fig. 1. The sources of electricity in Malaysia. Source: World Development Indicators (WDI).

placed by natural gas and coal due to the implementation of the Four-Fuel Diversification Policy in 1981. Following that, electricity in Malaysia was generated by four main resources such as oil, natural gas, hydropower, and coal. Before 1980, nearly 90% of the electricity in Malaysia was generated by oil, while hydropower supplied the remainder (see Fig. 1). In 1990, the contribution of natural gas to electricity generation in Malaysia was approximately 20% compared to approximately 51% contribution from oil. Nevertheless, the contribution of natural gas grew tremendously to approximately 70% in 2005, while the contribution of oil dropped to approximately 5%. Apart from natural gas, another important fossil fuel for generating electricity in Malaysia is coal and it becomes more prominent after 2000. In 1990, coal contributed 4.7% of total electricity generation in Malaysia and this has increased to 28% in 2007. According to Energy Information Administration [16], coal accounted for 42% of world electricity generation in 2007. It is expected to continue contributing to a large portion of worldwide electricity generation until 2035 as it is the world's most abundant fossil fuel and is cheaper compared with the other fossil fuel.

3. Review of studies on Malaysia

Economists and environmentalists have been investigating the nexus between energy consumption and economic growth because it has important policy implications. Basically, they attempt to determine whether energy consumption Granger-causes economic growth or economic growth Granger-causes energy consumption or both. Understanding the direction of causality is very important for policymakers to formulate appropriate energy and economic growth and development policies to ensure sustainable economic development. Thus, knowing the direction of causal relationship between energy consumption and economic growth is needed even though it is not a new area of exploration. There are many existing studies on this topic were published using either a bi-variate or a multivariate framework. A major limitation of bi-variate studies is that they are prone to suffer from the omitted variable bias problem. In other words, biased estimates of the actual causal relationship between two variables of interest could result from a bi-variate model. Recently, Ozturk [2] and Payne [3] have published two comprehensive literature surveys on the energy-growth nexus. To conserve space, our literature review only focuses on the empirical studies related to Malaysia (see Table 1). Generally, the Malaysian empirical studies can be divided into two major groups. The first group involved bi-variate framework, while the second involved multivariate framework.

We begin our discussion with the findings of the bi-variate framework studies. Masih and Masih [17] used annual data from

1955 to 1990 to analyse the relationship between energy consumption and economic growth in 6 Asian countries (namely, India, Indonesia, Pakistan, Malaysia, the Philippines, and Singapore). For the case of Malaysia, they found that the variables are not cointegrated, and they then used the first difference vector autoregressive (VAR) model to ascertain the direction of Granger causality between energy consumption and economic growth. The Granger causality results suggest that energy consumption and economic growth in Malaysia is neutral. Murry and Nan [18] investigated the causal relationship between electricity consumption and economic growth in 15 countries using the Granger causality test on a first difference VAR framework. Unlike Masih and Masih [17], they found that electricity consumption and economic growth in Malaysia has a bi-directional causality. Similarly, Yoo [19] found that electricity consumption and economic growth in Malaysia have a bi-directional relationship, but failed to find any evidence of cointegration as Masih and Masih [17]. Chen et al. [20] employed the Johansen cointegration test to determine the presence of long run relationship between electricity consumption and economic growth in 10 Asian countries. Similar to the findings of Yoo [19], they cannot find evidence to support the presence of long run relationship in Malaysia. Nevertheless, they found unidirectional Granger causality running from economic growth to electricity consumption. Chiou-Wei et al. [21] employed the Johansen cointegration and the Granger causality tests to examine the relationship between energy consumption and economic growth in 8 newly industrialised Asian countries as well as the United States. For the case of Malaysia, the Johansen cointegration results suggested that energy consumption and economic growth are not cointegrated, but the Granger causality test showed that the variables Granger-cause each other. Chontanawat et al. [22] used the Johansen cointegration and Hsiao's [23] version of Granger causality tests to examine the causal relationship between energy consumption and economic growth over 100 countries in the world. Overall, the cointegration and causality results varied among the selected countries. For the case of Malaysia, they found that energy consumption and economic growth are not cointegrated. Similar to the findings of Masih and Masih [17], they found that energy consumption and economic growth in Malaysia do not Granger-cause each other. Tang [6] employed the recently developed cointegration advocated by Kanioura and Turner [24] to examine the presence of cointegration between electricity consumption and economic growth in Malaysia. He found that the variables are not cointegrated, but electricity consumption and economic growth Granger-cause each other in the short and long run.

Turning to the multivariate framework studies, Tang [25] conducted a study on the relationship between electricity consumption and economic growth in Malaysia using a multivariate framework by taking into account FDI and population. He employed the bounds testing approach to cointegration to ascertain the presence of a cointegration relationship. Interestingly, the study found that the variables are cointegrated. Moreover, the results of Granger causality test within a vector error-correction model (VECM) show that electricity consumption and economic growth in Malaysia have a bi-directional causality with each other. Chandran et al. [26] included energy prices in the electricity-growth model as a control variable. Similarly, they also found that the variables are cointegrated and their Granger causality results show unidirectional causality running from electricity consumption to economic growth in Malaysia. Thus, they surmised that Malaysia is an energy-dependent country. Lean and Smyth [7] analysed the multivariate Granger causality between economic growth, electricity consumption, exports, capital, and labour in Malaysia using cointegration and Granger causality tests. The cointegration results indicate that the variables are cointegrated. Moreover, they showed that electricity consumption and economic growth have a bi-directional Granger causality with each other in Malaysia. The most recent study on Malaysia – Lean and Smyth [27] examined the causal relationship between electricity generation, economic growth, prices and exports in Malaysia using the bounds testing approach to cointegration and the TYDL Granger causality test developed by Toda and Yamamoto [28] and Dolado and Lütkepohl [29]. Similarly, the variables are found to be cointegrated. In addition, the TYDL causality results suggest unidirectional causality running from economic growth to electricity generation in Malaysia, rather than a reverse causation.

As a summary, at least two interesting conclusions could be drawn from this literature survey. First, electricity consumption and economic growth in Malaysia are not cointegrated when using bi-variate model, while the variables become cointegrated when additional variables are included in the system. Hence, a bi-variate model specification may not appropriate for examining the energy-growth nexus. This is in line with the argument of Ozturk [2] and Payne [3] that omissions of relevant variables are the main factor that cause biased results. Second, although many empirical works have contributed to the energy-growth literature, no study has considered the effect of technology innovation on energy-growth nexus. Therefore, it is essential for us to attempt this study. Technological innovation could have a bearing on the energy-growth nexus. It could affect the energy used per unit of economic output. Stern [30] observed that energy used per unit of economic output has fallen not only in developed but in some developing countries as well. Technological innovation could affect the relationship between energy consumption and economic growth via a change in the product composition (the substitution of energy-saving for energy-guzzling products), a switch in the production technique to a more energy-efficient and a replacement of a poorer quality by a higher quality fuel (see also [31]).

4. Model, data and methodology

4.1. Empirical model and data

Theoretically, the demand for electricity is related to income and energy prices. This is the basic demand function proposed in many economic textbooks. Therefore, the theoretical electricity consumption function can be written as follows:

$$EC_t = f(Y_t, P_t) \quad (1)$$

where EC_t is electricity consumption, Y_t is income or economic growth and P_t is the energy prices. In line with the objective of this study, we include technology innovation into the electricity consumption function as a new control variable. Hence, the new empirical model for electricity consumption in Malaysia is given below:

$$\ln EC_t = \beta_0 + \beta_1 \ln Y_t + \beta_2 \ln P_t + \beta_3 \ln TE_t + \varepsilon_t \quad (2)$$

Here ln denotes the natural logarithm, $\ln EC_t$ is per capita electricity consumption, $\ln Y_t$ is per capita real income, $\ln P_t$ is the energy price, and $\ln TE_t$ is technology innovation. The error term ε_t is assumed to be spherically distributed and white noise. The expected signs for the parameters of real income, energy price and technology innovation are $\beta_1 > 0$, $\beta_2 < 0$, and $\beta_3 < 0$, respectively.

This study uses secondary data of per capita electricity consumption, per capita real GDP, energy prices, and technology innovation extracted from the World Bank's, *World Development Indicators* (WDIs) and the United States Patent and Trademark Office. Energy price data is unavailable in most developing countries as well as Malaysia. In addition, Mahadevan and Asafu-Adjaye [32] noted that government subsidised the energy-intensive industries, thus energy prices will deviate among industries. Given this reason, the consumer price index (CPI) has been extensively used as a proxy for energy prices. From the literature survey, many studies used CPI as a proxy for either electricity or energy prices (e.g. [26,27,32–36]). Therefore, the CPI data will also be used as a proxy for energy prices in this study. Likewise, it is also very difficult to obtain a complete dataset for technology innovation. Based upon Grupp [37], direct quantitative measures for technology innovation is non-existent because technology is complex and is usually measured through a proxy measurement. With regard to this, some studies used research and development (R&D) expenditure as a proxy for technology innovation, but the data span for R&D expenditure in Malaysia is available only from 1996 onwards. Kortum [38], Kumaresan and Miyazaki [39] and Thomas [40] suggested that the amount of patenting activities can be used as a proxy for technology innovation because patents are the codified part of technology and increase in patents would imply the interest of industries and private organisation in exploiting a new technology. Moreover, Schmoch [41] also documented that technology innovation can be measured by a quantitative indicator such as the number of patents. In practice, ample empirical studies (e.g. [42–44]) used the number of patents as a proxy for technology innovation. In the context of Malaysia, Wong and Goh [45,46], Zeufack et al. [47] and Chandran and Wong [48] also measured the level of technology innovation in Malaysia with the number of patents. The more new patents are registered or trademarked, the more new technologies are invented. Therefore, this study uses the number of patents as the measure for technology innovation. In estimating the impact of new technologies on energy consumption, Popp [49] also relied upon patent data.

Lastly, all variables will be transformed to natural logarithm to induce stationarity in the variance–covariance matrix (see [50,51]). Therefore, the first differences of the variables can be interpreted as growth rates. Table 2 provides a summary of descriptive statistics of the variables under investigation. The standard deviations for all variables range from 0.287 to 0.803. Unlike technology innovation, the descriptive statistics reveal that energy consumption, GDP, and energy price are spherically distributed (Jarque–Bera, Skewness and Kurtosis statistics).

Table 2
Summary of descriptive statistics for each series.

Statistics	$\ln EC_t$	$\ln Y_t$	$\ln P_t$	$\ln TE_t$
Mean	7.096	9.205	4.136	4.802
Median	7.033	9.172	4.157	4.640
Maximum	8.207	9.882	4.719	5.553
Minimum	5.739	8.378	3.281	4.605
Standard deviation	0.803	0.454	0.417	0.287
Skewness	−0.135	−0.163	−0.508	1.593
Kurtosis	1.685	1.794	2.254	4.284
Jarque–Bera	3.002	2.600	2.645	19.656
(Probability)	(0.223)	(0.272)	(0.266)	(0.000)
Observations	40	40	40	40

4.2. Unit root tests

Perron [10] argued that the standard unit root tests may be inappropriate when a series has structural breaks. To circumvent this problem, we use the Zivot and Andrew [8] one-break unit root test and the Narayan and Popp [9] two-break unit root test to determine the order of integration of each series. One of the main advantages of these unit root tests is that they do not require a priori knowledge about the possible timing of structural breaks because the break dates are endogenously determined within the model. This study uses two versions of Zivot–Andrew sequential trend break model to determine the order of integration of each series. Model A allows for a change in intercept, while Model C allows for a change in both the intercept and slope. Model A and Model C take the following regression forms:

$$\text{Model A}: \Delta y_t = a_0 + a_1 t + a_2 DU_t + b_1 y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + e_{1t} \quad (3)$$

$$\text{Model C}: \Delta y_t = a_0 + a_1 t + a_2 DU_t + a_3 DT_t + b_1 y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + e_{2t} \quad (4)$$

Table 1
Summary of past studies related to Malaysia.

No.	Authors	Research period	Econometric methods	Major findings of the direction of causality			
				EC → GDP	GDP → EC	EC ↔ GDP	EC ⇹ GDP
1	Masih and Masih [17]	1955–1990	Johansen [53]; Granger causality – VAR				✓
2	Murry and Nan [18]	1970–1990	Granger causality – VAR			✓	
3	Yoo [19]	1971–2002	Engle and Granger [52]; Hsiao [23] version of Granger causality – VAR			✓	
4	Chen et al. [20]	1971–2001	Johansen [53]; Granger causality – VAR		✓		
5	Ang [67]	1971–1999	Johansen [53]; Granger causality – VECM		✓		
6	Chiou-Wei et al. [21]	1971–2003	Granger causality – VAR			✓	
7	Chontanawat et al. [22]	1971–2000	Johansen [53]; Hsiao [23] version of Granger causality – VAR				✓
8	Tang [6]	1971:1–2003:4	Kanioura and Turner [24]; Granger causality – VAR; Toda and Yamamoto [28] – augmented VAR			✓	
9	Tang [25]	1970–2005	Pesaran et al. [58]; Granger causality – VECM			✓	
10	Chandran et al. [26]	1971–2003	Pesaran et al. [58]; Engle and Granger [52]; Johansen [53]; Granger causality – VECM	✓			
11	Lean and Smyth [7]	1971–20 $\ln TE_t (\ln Y_t$ 06	Johansen [53]; Pesaran et al. [58]; Toda and Yamamoto [28] and Dolado and Lütkepohl [29] – augmented VAR; Granger [65] – VECM			✓	
12	Lean and Smyth [27]	1970–2008	Pesaran et al. [58]; Toda and Yamamoto [28] and Dolado and Lütkepohl [29] – augmented VAR		✓		

Notes: EC → GDP represents the unilateral causality running from electricity (energy) consumption to economic growth; GDP → EC represents the unilateral causality running from economic growth to electricity (energy) consumption; EC ↔ GDP represents the bilateral causality; EC ⇹ GDP represents neutral causality.

Here Δ is the first difference operator, k is the optimal lag length, and the residuals e_{it} are assumed to be normally distributed and white noise. DU_t and DT_t are dummy variables for a level shift and trend shift, where $DU_t = 1$ if $t > T_B$ and 0 otherwise; $DT_t = t - TB$ if $t > T_B$ and 0 otherwise. The potential break date is selected at which the t-statistic for y_{t-1} is minimised.

It is true that the Zivot–Andrew test is designed for one break, while the test may lose power when confronted with two or more breaks. To overcome this problem, we also employ the two break unit root test proposed by Narayan and Popp [9]. They suggested two versions of the endogenous break unit root model. Model M1 allows for two changes in the intercept, while Model M2 allows for two changes in both the intercept and the slope. The testing models are as follows:

$$\text{Model M1}: \Delta y_t = a_1 + a_2 t + b_1 y_{t-1} + \varphi_1 D(T_B)_{1,t} + \varphi_2 D(T_B)_{2,t} + \kappa_1 DU_{2,t-1} + \kappa_2 DU_{2,t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + e_{1t} \quad (5)$$

$$\text{Model M2}: \Delta y_t = a_1 + a_2 t + b_1 y_{t-1} + \varphi_1 D(T_B)_{1,t} + \varphi_2 D(T_B)_{2,t} + \kappa_1 DU_{2,t-1} + \kappa_2 DU_{2,t-1} + \varphi_1 DT_{1,t-1} + \varphi_2 DT_{2,t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + e_{2t} \quad (6)$$

where $DU_{i,t} = 1(t > T_{B,i})$ and $DT_{i,t} = 1(t > T_{B,i})(t - T_{B,i})$, $i = 1,2$, represent the dummy variables for breaks in the intercept and slope occurring at time T_{B1} and T_{B2}, respectively. The potential break dates can be determined based on the grid search procedure discussed in Narayan and Popp [9]. Finally, the t-statistic for y_{t-1} can be used to test the null hypothesis of a unit root against the alternative hypothesis of stationary.

4.3. Bounds testing approach to cointegration

To examine the presence of a long run equilibrium relationship between electricity consumption and its determinants, we employ the bounds testing approach to cointegration with an autoregressive distributed lag (ARDL) model. This cointegration approach is the choice of this study because it has several advantages over the conventional cointegration tests such as the two-step residuals-based test for cointegration proposed by Engle and Granger [52] and the system-wide cointegration test suggested by Johansen [53] and Johansen and Juselius [54]. The first advantage of the bounds testing approach to cointegration is that it is applicable irrespective of whether the explanatory variables are purely $I(0)$, purely $I(1)$, or mutually cointegrated. Second, Banerjee et al. [55,56] pointed out that unlike the Engle–Granger cointegration test, the bounds testing approach to cointegration with an ARDL framework does not push the short run dynamics into the residuals terms. Thus, it has better statistical properties in testing for the presence of cointegration. Third, on the basis of Monte Carlo experiment, Pesaran and Shin [57] found that the bounds testing approach is more efficient in small samples. Following Pesaran et al's. [58] suggestion, we estimate Eq. (7) with the Ordinary Least Squares (OLS) estimator as follows:

$$\Delta \ln EC_t = \alpha_0 + \delta_1 \ln EC_{t-1} + \delta_2 \ln Y_{t-1} + \delta_3 \ln P_{t-1} + \delta_4 \ln TE_{t-1} + \sum_{i=1}^{p} \phi_i \Delta \ln EC_{t-i} + \sum_{i=0}^{q} \theta_i \Delta \ln Y_{t-i} + \sum_{i=0}^{r} \vartheta_i \Delta \ln P_{t-i} + \sum_{i=0}^{s} \varphi_i \Delta \ln TE_{t-i} + \mu_t \quad (7)$$

where Δ is the first difference operator and μ_i is the errors term. p, q, r and s are the optimal lag orders determined by the Akaike's Information Criterion (AIC). To ascertain the presence of cointegration, we use the joint significance F-test on the lagged level explanatory variables ($\ln EC_{t-1}$, $\ln Y_{t-1}$, $\ln P_{t-1}$, $\ln TE_{t-1}$). Pesaran et al. [58] provided two sets of asymptotic critical values that are lower and upper bound critical values. The lower bound of critical values assumes that all explanatory variables are $I(0)$, while the upper bound of critical values assumes that all explanatory variables are $I(1)$. Given that the sample size of this study is relatively small ($T = 40$), the critical values tabulated in Pesaran et al. [58] are inappropriate. With regard to this, Narayan [59] simulated a new set of critical values for small samples. For making decisions, if the computed F-statistic is greater than the upper bound critical value, we reject the null hypothesis of no cointegration. Otherwise the variables are not cointegrated. If the variables are cointegrated and since the interest of this study is to analyse the effects of economic growth, energy prices and technology innovation on electricity consumption, we derive the long run coefficients from Eq. (2) with the procedure suggested by Bardsen [60]. The long run coefficients for economic growth, energy prices and technology innovation are $-(\delta_2/\delta_1)$, $-(\delta_3/\delta_1)$, and $-(\delta_4/\delta_1)$, respectively.

4.4. Granger causality test

This study employs the Granger causality test to examine the causal relationship between electricity consumption, economic growth, energy prices and technology innovation in Malaysia. To ascertain the direction of causality between the variables of interest, we estimate the following vector error-correction model (VECM):

$$\Delta \ln EC_t = \upsilon_1 + \sum_{i=1}^{k} \gamma_{1i} \Delta \ln EC_{t-i} + \sum_{i=0}^{k} \kappa_{1i} \Delta \ln Y_{t-i} + \sum_{i=0}^{k} \lambda_{1i} \Delta \ln P_{t-i} + \sum_{i=0}^{k} \omega_{1i} \Delta \ln TE_{t-i} + \psi_1 \varepsilon_{t-1} + \zeta_{1t} \quad (8)$$

$$\Delta \ln Y_t = \upsilon_2 + \sum_{i=1}^{k} \kappa_{2i} \Delta \ln Y_{t-i} + \sum_{i=0}^{k} \gamma_{2i} \Delta \ln EC_{t-i} + \sum_{i=0}^{k} \lambda_{2i} \Delta \ln P_{t-i} + \sum_{i=0}^{k} \omega_{2i} \Delta \ln TE_{t-i} + \psi_2 \varepsilon_{t-1} + \zeta_{2t} \quad (9)$$

$$\Delta \ln P_t = \upsilon_3 + \sum_{i=1}^{k} \lambda_{3i} \Delta \ln P_{t-i} + \sum_{i=0}^{k} \kappa_{3i} \Delta \ln Y_{t-i} + \sum_{i=0}^{k} \gamma_{3i} \Delta \ln EC_{t-i} + \sum_{i=0}^{k} \omega_{3i} \Delta \ln TE_{t-i} + \psi_3 \varepsilon_{t-1} + \zeta_{3t} \quad (10)$$

$$\Delta \ln TE_t = \upsilon_4 + \sum_{i=1}^{k} \omega_{4i} \Delta \ln TE_{t-i} + \sum_{i=0}^{k} \lambda_{4i} \Delta \ln P_{t-i} + \sum_{i=0}^{k} \kappa_{4i} \Delta \ln Y_{t-i} + \sum_{i=0}^{k} \gamma_{4i} \Delta \ln EC_{t-i} + \psi_4 \varepsilon_{t-1} + \zeta_{4t} \quad (11)$$

Here Δ is the first difference operator and k is the optimal lag order determined by the AIC statistics. The error terms (ζ_{1t}, ζ_{2t}, ζ_{3t}, ζ_{4t}) are assumed to be spherically distributed and white noise. $\varepsilon_{t-1} = \ln EC_{t-1} + (\alpha_0/\delta_1) + (\delta_2/\delta_1) \ln Y_{t-1} + (\delta_3/\delta_1) \ln P_{t-1} + (\delta_4/\delta_1) \ln TE_{t-1}$ is the one period lagged error-correction term derived from the normalised cointegrating equation. The significance of ε_{t-1} is normally used to examine the direction of long run Granger causality and the rate of convergence to the long run equilibrium. However, ε_{t-1} must be excluded from the models if the variables

Table 3
The results of unit root tests with break(s).

	ln EC_t		ln Y_t		ln P_t		ln TE_t	
	Model A	Model C	Model A	Model C	Model A	Model C	Model A	Model C
Panel A: Zivot–Andrews test for unit roots with one break								
TB1	2003	1993	2000	1992	2000	1980	2003	1996
$t(\hat{\lambda}_{inf})$	−3.02	−4.38	−2.79	−3.57	−4.08	−4.58	−2.73	−4.37
Lag order	3	3	1	1	2	1	3	0
Critical values								
1%	−5.340	−5.570						
5%	−4.800	−5.080						
	ln EC_t		ln Y_t		ln P_t		ln TE_t	
	Model M1	Model M2	Model M1	Model M2	Model M1	Model M2	Model M1	Model M2
Panel B: Narayan–Popp test for unit roots with two breaks								
TB1	1993	1979	1984	1984	1980	1981	1991	1990
TB2	1998	1993	1997	1997	1984	1984	1993	1996
$t(\hat{\lambda}_{inf})$	−0.92	−3.34	−0.19	−4.94	−1.11	−2.62	−0.30	−3.83
Lag order	0	3	0	0	0	3	0	3
Critical values								
1%	−5.259	−5.949						
5%	−4.154	−5.181						

Notes: The optimal lag order is determined by the Akaike Information Criterion (AIC). The critical values for one and two breaks are obtained from Zivot and Andrews [8] and Narayan and Popp [9], respectively.

are not cointegrated, thus, the first difference vector autoregression (VAR) model will be used to test for Granger causality. In testing the short run Granger causality between electricity consumption and its determinants, we apply the F-test on the first difference lagged explanatory variables. For the short run Granger causality, we examine the following hypotheses:

$H_{01}:\kappa_{1i}=0\forall_k$, implying that $\Delta \ln Y$ does not Granger-cause $\Delta \ln EC$.
$H_{02}:\gamma_{2i}=0\forall_k$, implying that $\Delta \ln EC$ does not Granger-cause $\Delta \ln Y$.
$H_{03}:\lambda_{1i}=0\forall_k$, implying that $\Delta \ln P$ does not Granger-cause $\Delta \ln EC$.
$H_{04}:\omega_{1i}=0\forall_k$, implying that $\Delta \ln TE$ does not Granger-cause $\Delta \ln EC$.

and so on for the rest of variables.

5. Empirical results

5.1. Unit root results

According to Granger and Newbold [61] and Phillips [62], regression results with time series data may be spurious if the variables are non-stationary and/or non-cointegrated. In addition, Masih and Masih [63] maintained that the Granger causality test is just a predictability test if the variables are not cointegrated. Therefore, testing the order of integration and the presence of cointegration are necessary to obtain robust and realistic results. Prior to cointegration test, we perform the PP and KPSS unit root tests to ascertain the order of integration of each series.[1] The results of both unit root tests consistently reveal that all variables are non-stationary at levels, but they are stationary at the first differences. Therefore, these unit root tests suggest that electricity consumption, real income, energy prices and technology innovation are integrated of order one, $I(1)$ which means that they are difference rather than trend stationary. These results are consistent with the assertion that most of the macroeconomic variables are non-stationary at levels, but are stationary after first difference (see [64]).

In addition, we also implement the Zivot–Andrews and the Narayan–Popp unit root tests with structural breaks to confirm the order of integration of each series. The results of the Zivot–Andrews and the Narayan–Popp unit root tests are reported in Panel A and B of Table 3, respectively. Overall, both unit root tests cannot reject the null hypothesis of a unit root for the levels. Therefore, both unit root tests with structural breaks find no additional evidence against the PP and KPSS unit root tests. For this reason, we confidently surmise that the variables are integrated of order one. As all the variables are integrated of the same order, i.e. one, the cointegration test may be performed on this set of variables to see if they bear any long-run relationship with each other.

5.2. Cointegration and long-run equilibrium relationship

Given that the sample size of this study is relatively small and that none of the variables is integrated of an order higher than $I(1)$, the application of the bounds testing approach to cointegration is suitable. The calculated F-statistic for the bounds testing approach and a number of diagnostic tests are reported in Table 4 and Fig. 2.

In terms of diagnostic tests, we find that the Jarque–Bera (JB) normality test cannot reject the null hypothesis of normality, implying that the error terms are normally distributed. Therefore, the standard R-squared, t-statistics and F-statistics can be used for statistical inferences. Furthermore, the Breusch–Godfrey LM test for serial correlation and the Autoregressive Conditional Heteroskedasticity (ARCH) LM test consistently suggest that the errors term are free from serial correlation and heteroskedasticity problem up to order two. Moreover, the model is also correctly specified because the Ramsey RESET test cannot reject the null hypothesis of no general specification error at the 10% significance level. The plots of CUSUM and CUSUM of squares statistics also fluctuate within the 5% critical bounds (see Fig. 2). Therefore, the estimated coefficients are stable over the sample period from 1970 to 2009.

Next, the calculated F-statistic for the bounds test (9.742) is greater than the 1% upper bounds critical value provided by Nara-

[1] To save space, the full results of the PP and KPSS unit root tests will not be reported here, but they are available upon request from the authors.

Table 4
The results of the ARDL cointegration test.

Calculated F-statistic for bounds test		
F_{EC} (EC|Y, P, TE)		9.742***
Optimal lag		[3, 0, 2, 3]
Significance level	Lower $I(0)$	Upper $I(1)$
#Critical values bounds (F-test)		
1%	5.018	6.610
5%	3.558	4.803
10%	2.933	4.020
Conclusion	Cointegrated	

Notes: R-squared: 0.811; Adjusted R-squared: 0.670;
F-Statistic: 5.727 (0.000); Jarque–Bera: 0.577 (0.749);
Breusch–Godfrey LM test [1]: 0.178 (0.673), [2]: 1.322 (0.516);
ARCH test [1]: 0.483 (0.487), [2]: 0.719 (0.698);
Ramsey RESET [1]: 0.684 (0.408);
[ ] refers to the diagnostics tests order; () refers to the p-values.
*** Significance at the 1% level.
# Unrestricted intercept and no trend (k = 3, T = 40) critical values are obtained from Narayan [59].

Table 5
The summary of the cointegrating equation.

Dependent variable: ln EC_t Explanatory variables	Coefficients	Std. error	t-Statistics
Constant	−10.595	1.633	−6.486***
ln Y_t	3.165	0.497	6.369***
ln P_t	−1.685	0.576	−2.924***
ln TE_t	−0.872	0.240	−3.634***

*** Significance at the 1% level.

yan [59]. Therefore, electricity consumption, real income, energy prices and technology innovation in Malaysia are cointegrated, implying that electricity consumption bears a long run relationship with these variables. This finding is contradictory with Tang [6], Yoo [19], and Chen et al. [20], but consistent with Tang [25], Lean and Smyth [7] and Chandran et al. [26]. The results of this study are however more convincing as it includes energy prices and technology innovation.

As the variables are cointegrated, we derive the long run coefficients of real income, energy prices and technology innovation in the electricity consumption equation. Table 5 shows the long run coefficients and the t-statistics. We find that real income is positively related to electricity consumption in the long run with an estimated long run elasticity of 3.2. However, energy prices and technology innovation have negative effects on electricity consumption in Malaysia with estimated long run elasticities of −1.69 and −0.87 respectively. All the estimated coefficients are statistically significant at the 1% level. Therefore, increases in technology innovation and energy prices play an important role in reducing energy consumption, and hence could make economic growth more environmentally sustainable.

5.3. Granger causality

The presence of cointegration between electricity consumption, economic growth, energy prices and technology innovation implies that there must be at least one way of Granger causality, but it does not indicate the direction of causality. Hence, Granger [65] suggests estimating a VECM to test the direction of causality between electricity consumption, economic growth, energy prices and technology innovation in Malaysia. Table 6 exhibits the short and long run Granger causality results.

Beginning with the long run causal effects, the one period lagged error-correction term (ε_{t-1}) is statistically significant at the 5% level in all the VECM equations. This shows that electricity consumption, economic growth, energy prices and technology innovation in Malaysia have bi-directional Granger causality in the long run. In addition, the significance of ε_{t-1} also indicates that the estimated variables are moving together in the long run (see [66]), meaning that the findings of cointegration with the bounds testing approach are valid.

Turning to the short run causal effects, we find that electricity consumption, economic growth, energy prices and technology innovation in Malaysia have bi-directional short run Granger causality. Particularly the finding of bi-directional causality between electricity consumption and economic growth implies that Malaysia is an energy-dependent country. Thus, energy conservation policies unaccompanied by new environment friendly sources of energy or machinery via technology innovation will be detrimental to Malaysia's economic growth and development. Furthermore, we also find that technology innovation Granger-causes economic growth in Malaysia. This result supports the neoclassical and the endogenous growth theories that technology innovation is an important determinant of economic growth (see [4,5]). Thus promoting technology innovation will not only minimise usage of electricity and improve environmental quality but will also stimulate the process of economic growth and development of Malaysia.

6. Conclusion and policy recommendations

This study attempts to analyse the energy-growth nexus in Malaysia using annual data from 1970 to 2009. Unlike the earlier

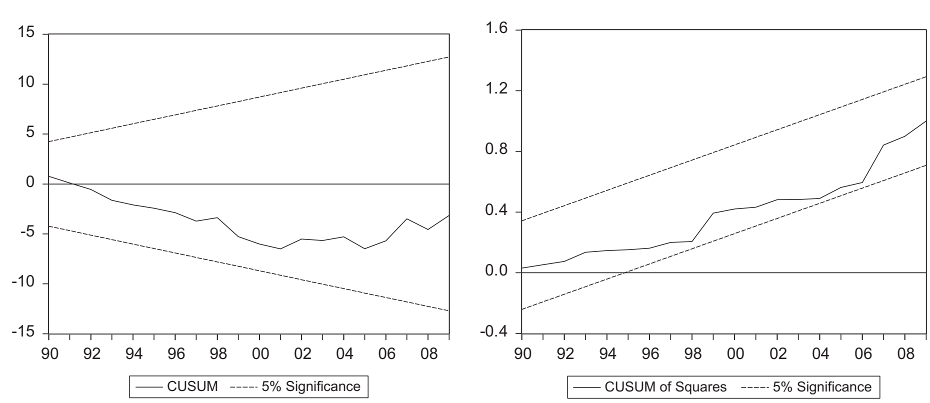

Fig. 2. The plots of CUSUM and CUSUM of square statistics.

Table 6
The results of Granger causality tests.

Dependent variable	F-statistics [p-values]				ε_{t-1} [t-statistics]
	$\Delta \ln EC_t$	$\Delta \ln Y_t$	$\Delta \ln P_t$	$\Delta \ln TE_t$	
$\Delta \ln EC_t$	–	9.590*** [0.0009]	8.527*** [0.0005]	3.939** [0.0141]	−0.264 [−4.761]***
$\Delta \ln Y_t$	6.537*** [0.0014]	–	7.497*** [0.0014]	6.767*** [0.0012]	0.332 [4.954]***
$\Delta \ln P_t$	7.099*** [0.0015]	10.522*** [0.0006]	–	6.683*** [0.0010]	−0.196 [−5.632]***
$\Delta \ln TE_t$	4.181** [0.0135]	3.259** [0.0340]	3.006** [0.0444]	–	−0.383 [−2.279]**

Notes: * Statistical significance at 10% level. The optimal lag order is determined by the Akaike Information Criterion (AIC). The selected lag lengths for $\Delta \ln EC_t$ = [2, 1, 2, 3], $\Delta \ln Y_t$ = [3, 2, 2, 3], $\Delta \ln P_t$ = [2, 1, 2, 3] and $\Delta \ln TE_t$ = [3, 3, 3, 3].
** Statistical significance at 5% level.
*** Statistical significance at 1% level.

studies on this subject, we contribute to the existing literature by including technology innovation in the energy-growth relationship in order to enhance the robustness and reliability of estimates. This study uses the bounds testing approach to cointegration to examine the presence of a long run equilibrium relationship between electricity consumption, real income, energy prices and technology innovation in Malaysia. The Granger causality test is then applied to examine the direction of causality between the variables of interest. We find that electricity consumption and its determinants are cointegrated in Malaysia. In the long run, real income positively contributes to electricity consumption, while energy prices and technology innovation negatively influence electricity consumption in Malaysia. The negative effect of technology innovation on electricity consumption implies that products of research and development (R&D) could contribute to efficient utilisation of electricity in Malaysia. In addition, we also find that electricity consumption has a bi-directional Granger causality with economic growth, energy prices and technology innovation in the short and in the long run. With these findings, we are clear that Malaysia is an energy-dependent country. Hence energy conservation policies will adversely affect its process of economic growth and development unless there is sufficient technology innovation. Though these results are consistent with some of the earlier studies on Malaysia, this study is more conclusive as it factors in the potentially important role technological innovation in the energy consumption-economic growth nexus apart from the use of more sophisticated econometric techniques.

At least two important policies recommendations can be drawn from the findings of this study. First, as the Ganger causality test results suggest that causal relationship between electricity consumption and economic growth is bi-directional, Malaysia needs to strike a balance between environmental protection and economic growth. While the government should increase investment in electricity infrastructure to enhance power supply for generating economic growth, it should also implement electricity conservation policies to reduce inefficiency or unnecessary wastage of electricity consumption. Over the past decades, a series of energy policies have been implemented by the Malaysian government to promote efficient utilisation of energy and to minimise the wastage. Among them are the National Energy Policy in 1979, the National Depletion Policy in 1980 and the Four-Fuel Diversification Policy in 1981 and 1999. Second, in order to make these policies more effective, policymakers should encourage technology innovation in areas of green energy and energy savings products as our results show that technology innovation negatively influences electricity consumption and Granger-causes economic growth. Therefore, technology innovation could simultaneously boost long-term economic growth and minimise environmental degradation. The consumption of fossil fuels could be reduced without slowing down the process of economic growth.

In fact the New Economic Model (NEM) of Malaysia which was launched in 2011 underscores the need for the country to pursue green growth and development in the quest for attaining the status of a high-income nation. Currently by World Bank's classification, Malaysia is only an upper middle-income economy (UMC). The NEM sets out plans for Malaysia to adopt the "Polluter Pays" principle in order to preserve the environment and to rationalise subsidies and removal of price controls on energy so that producers and consumers are forced to pay a price closer to the social cost of energy consumption. It is envisaged that this will encourage the adoption of renewable and green technologies.

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