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RESEARCH ARTICLE

Dynamic linkages between non-renewable energy, renewable energy and economic growth through nonlinear ARDL approach: evidence from Malaysia

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Abstract
The purpose of this paper is to investigate the links between renewable energy (RE), non-renewable energy (NRE), capital, labour and economic growth, using the nonlinear autoregressive distributive lag (NARDL) model in Malaysia for the period of 1980–2018. The results of NARDL confirm the asymmetric effect of RE and NRE consumption on the economic growth in the long run as well as the short run in Malaysia. The findings also show that in the long and short run, positive shocks of NRE are greater than the positive shocks of RE. It indicates that Malaysia's economic growth is highly dependent on NRE which is not a good indication as NRE consumption increases carbon dioxide (CO_2) emission in the country. Moreover, the empirical results of this study demonstrated that RE consumption reduction accelerates economic growth, whereas NRE consumption reduction decreases economic growth. It can have claimed that in Malaysia, RE is still more expensive than NRE. In conclusion, this study offered a variety of measures to develop RE to reduce the dependency on NRE consumption.

Keywords Economic growth · Malaysia · Renewable energy · NARDL · Asymmetric · Non-renewable energy

1.0 Introduction

Consumption of energy has been shown to be inextricably linked to economic development (Saudi et al. 2019; Abbasi et al. 2021a, 2021b). Renewable energy (RE) consumption is increasing over the world because of availability of this resources, volatile energy prices and environmental pollution. By 2015, RE accounted for 22% of global energy consumption (Balsalobre-Lorente et al. 2018). Many researchers throughout the world have also confirmed that RE can contribute significantly to economic growth (Abbasi et al. 2020a, b), environmental protection (Awodumi and Adewuyi 2020) and employment generation (Bouyghrissi et al. 2021). Malaysia is a developing economy with a gross domestic product (GDP) per capita of 11,414.8 (current US$), based on a 4.3% steady rate of GDP growth in 2019 (World Bank 2020). It is projected that Malaysia's energy demand would increase by 4.8% by 2030 (WEMO, 2017). Non-renewable energy (NRE) originates from sources which will be exhausted or not refilled in our lives—or perhaps in many, many lives. Fossil fuels such as coal, petroleum and natural gas are the main sources of NRE. Malaysia depends largely on fossil fuels, with 53% of its coal, 42% of the natural gas and 5% of hydropower (along with other RE sources) (WEMO, 2017). The country's ultimate energy consumption would triple by 2030 notwithstanding current demand levels (WEMO, 2017). Malaysians have a total resource of 4.73 billion barrels of crude oil in 2017, but we must be aware that one day, this reserve may be depleted if another source of this NRE is not found (Štreimikienė and Baležentis 2015; Ashnani et al. 2014). Although Malaysia is 16th in terms of its natural gas reserves (Central Intelligence Agency, 2011), present natural gas production is reported to be maintained only for around 29 years (Ahmad et al. 2011). Malaysia promised to cut carbon discharges of 40% by 2025 from the base year 2005 at the Copenhagen Conference of the Parties (COP15, 2009). In Malaysia usage of RE for power generation is limited, despite the continuing

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attempts to encourage the use of RE sources. Malaysia has an abundance of RE including forests, leftovers of palm oil, residues of mills, solar, hydropower, municipal garbage, land and rice (Poh and Kong 2002). In 2014, just 1% of total power produced was sourced by RE sources (Commission and (ST) Malaysia. 2017). The results of the 10th Malaysian Plan (2011–2015) demonstrate that Malaysia achieved just 300 MW in 2015 with the expiry of Malaysia's tenth plan, despite its target of 985 MW for the RE (Commission and (ST) Malaysia. 2017). The government has offered electricity providers several types of energy policy such as green financial incentives as well as feed-in tariffs (FiT) and new energy metering (NEM) in order to promote RE consumption. To provide a sustainable approach to RE development in Malaysia, the Malaysian government hence devised an effective plan called the "National Renewable Energy Policy and Action Plan" (Mekhilef et al. 2014; Chachuli et al. 2021). The energy balance in Malaysia was mostly dependent on fossil fuels, as seen in Fig. 1.

In 2015, fossil fuel and water power represented about 78% and 18% of Malaysia's current total consumption, respectively, while RE output looks to be restricted to 4% (Fig. 2A). It is also noted that CO_2 emissions increased from 172,680 to 239,620 Ktoe each year between 2006 and 2018 by 38.8% (Fig. 2B). In the growing process of Malaysia, energy became one of the main aspects in particular to its contribution to the industrial and services efficiency of this nation (Javid and Sharif 2016; Nugraha and Osman, 2019). As seen in Fig. 3, the average annual growth rate for final energy consumption is higher than the average annual increase for primary energy production. The gap in demand and supply of energy is around 35,215ktoe in 2018, with average annual growth rate of GDP, energy supply and consumption of 4.77%, 1.60% and 3.47%, respectively. Thus, in the future, there will be a shortage of energy supply if the energy consumption continuously increases at this rate and known energy sources will be exhausted rapidly. To consider the main cornerstone for sustainable energy future, it is important to highlight the relation among NRE, RE and economic growth in Malaysia.

This research contributes in numerous ways to the energy literature; first, it is found that RE in developing nations has a negative or unbiased influence on economic growth. It is observed that no research has been undertaken in Malaysia to investigate the comparative role of NRE and RE in improving the economic condition of the country (Begum et al. 2015; Tang and Tan 2014; Li and Solaymani 2021a, b). For instance, Begum et al. (2015) showed that energy consumption per capita as well as per capita GDP had a long-term positive impact, but the population growth rate did not have a significant impact on the emission of per capita CO_2. Tang and Tan (2014) reported that energy consumption and GDP affected each other in the short and long run. Very recently, Li and Solaymani (2021a, b) have indicated that overall long-term economic expansion contributed more widely to the growth of energy consumption than in the short term. They concluded that technological innovation improved energy efficiency and reduced energy consumption in the industrial sector. Nurgazina et al. (2021) demonstrated that 1% expansion in energy usage, trade openness and urbanization would worsen the environment by 0.18%, 0.03% and 2.51%, respectively. Second, in addition to capital and labour, this study included two extra variables, such as RE and NRE in the neo-classical production function to address the potentially neglected variable biases. Third, in prior research, it was assumed that energy consumption affected economy of the country in a linear passion. It indicates that they did not consider the variation in the impact of positive and negative shocks of energy consumption on economic growth (Begum et al. 2015; Tang and Tan 2014; Li and Solaymani 2021a, b)). Many economic factors, however, have been proved to exhibit nonlinear features, as evidenced by Ibrahim and Alagidede (2018), Abbasi et al. (2020a) and Ngoc (2020). As a result, the linear regression approach may not be adequate to account for the entire effect of energy use on economic growth. Hence, it is expected that the findings of this study will add some research findings to the current research on energy consumption models, particularly in Malaysia.

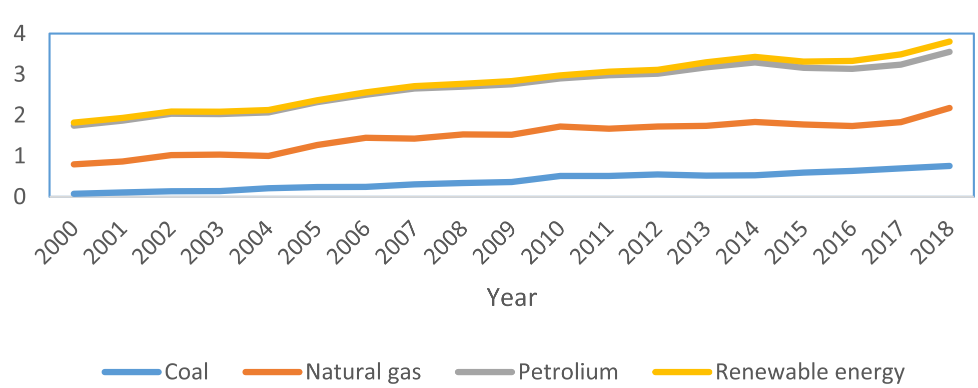


Fig. 1 Malaysian energy mix production from 2000 until 2018 (Energy Commission Malaysia, 2019)

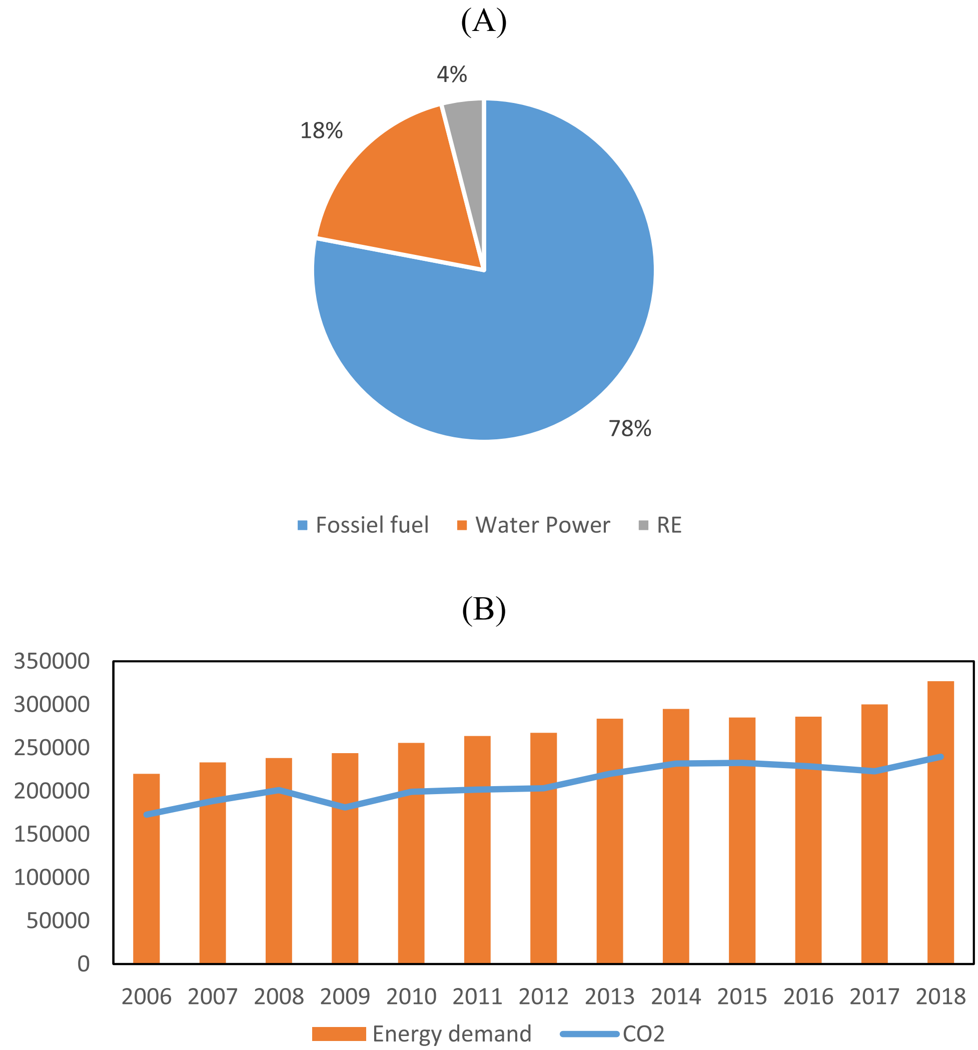


Fig. 2 The production capacity of per energy source in terms of millions of tons of oil is shown in (**A**) and CO_2 emission (kt) and total energy demand (millions of tons) in Malaysia during 2006 to 2018 is shown in (**B**). Source: Authors' own calculations using MS excel based on data retrieved from https://www.worlddata.info/asia/malaysia/energy-consumption.php

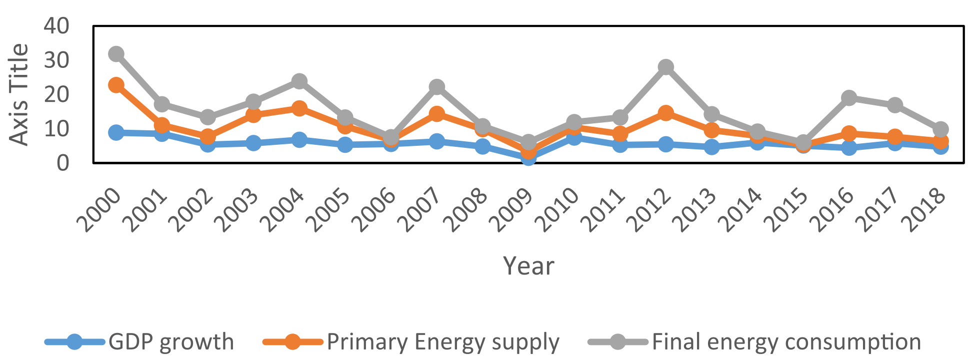


Fig. 3 Average annual growth rate of energy supply and consumption of Malaysia from 2010 to 2017. Source: Energy Commission Malaysia, 2019

A low level of RE usage has a detrimental influence on GDP, according to the research who compared the energy consumption in middle and high-income countries (Cheng et al. 2020; Narayan and Doytch, 2017; Abbasi et al. 2020b, 2021c). In contrast, few research found that RE consumption increased economic growth. However, there was no evidence how RE affects the economy of Malaysia compared to NRE. Hence, Malaysia could benefit from learning more about the effects of RE consumption on economic growth. It is observed that research on the individual influence of RE and NRE on economy of the country is, however, crucial, as the outcomes of this kind of research will allow policymakers to determine what energy consumption should be encouraged to accelerate economic growth. In this context, this study analyses the comparative role of RE and NRE on economic growth. This breakdown allows us to determine which energy sources to invest in based on the relative importance of both forms of energy consumption in the development process. As a result, it will assist policymakers in developing an acceptable energy policy for the country.

Therefore, the objective of this study is to analyse the asymmetrical link between RE, NRE and economic growth in Malaysia as a single country through nonlinear autoregressive distributive lag (NARDL) model which was introduced by Shin et al. (2014a, b). The remainder of the study is that the following section reviews literature and indicates the literature gap to be addressed in this study. The specification of the model, data and estimation procedure are then approached in the methodology section in part three, the empirical results and discussion followed in part four and five, respectively, and the conclusion in part six included the recommendation with brief discussion of important findings of this study. Lastly, the limitation of this study is discussed in part seven.

Literature review

Previous literature established that effective energy generation or use necessitates the financial backing of a healthy economy. Furthermore, the majority of the research concluded that the energy usage of any country has different effects, such as negative, positive and neutral on its economic growth. Ozturk (2010) stated that the use of various sets of data, various estimation approaches, time frame and the analysis of various nations might be the basis of this discrepancy. For instance, few studies have concluded that the association among energy consumption and economic growth is not substantial (Isik et al. 2018; Inglesi and Dogan (2018a, 2018b); Maji et al. 2019). On the other hand, Zafar et al. (2019) discovered that both RE and NRE consumption increased economic growth of Asia–Pacific Economic Cooperation countries using the up to date fully modified ordinary least square (FMOLS) approach. Gozgor et al. (2018) examined the impact of RE and NRE usage on economic development in 29 OECD nations from 1990 to 2013. They employed the autoregressive distributed lag (ARDL) technique, which is supplemented with panel quantile regression. These types of energy sources supported the economy, according to their findings. Similarly, Rafindadi and Ozturk (2017) utilized weekly statistics since 1971Q1 to 2013QIV to investigate the impact of RE on GDP in Germany. Their findings using several model approaches, such as the ARDL bounds test, vector error correction model (VECM) and Granger causality test, revealed that RE usage in Germany increased economic growth. Alper and Oguz (2016) used both ARDL and NARDL models to examine the impact of RE on economic growth for European Union member nations from 1990 to 2009. They demonstrated that RE affected GDP of these countries positively. It is also noticed that most research has adopted the neoclassical production model in which labour and capital are the major components to economic growth. Thus, some research incorporated RE and NRE to analyse their impact on economic growth in addition to capital and labour (Luqman et al. 2019; Chen et al. 2020; Baz et al. 2019; Ali, et al. 2019).

The literature review is broken into three parts for easier comprehension: the first part includes discussions on the association between economic growth and RE consumption, whereas the second part discusses the literature on the association between NRE consumption and economic growth. The literature review on the nonlinear ARDL model is discussed in the "Methodology" section.

RE and economic growth

There is a collection of studies on the effectiveness of RE consumption on economic growth in developed and emerging countries (Rahman and Vu 2020), as well as comparative studies that merged a group of countries with comparable economic status, like the advanced economies (Nguyen and Sato 2019) as well as others (Bhattacharya et al. 2016; Belaid and Zrelli 2019). The effect of RE on economic growth and CO_2 emissions in developing countries was analysed by a recent study conducted by Shah et al. (2020). Their results confirmed that RE had significant favourable influence on GDP. Similar result was found by Abbasi et al. (2020a, b) in case of Pakistan. They concluded that RE usage could bring beneficial impact for the economic growth in Pakistan. In contrast, some studies demonstrated that there was no correlation or neutral relationship between RE usage and economic growth. For instance, Isik et al. (2018) confirmed it for Indonesia. Similarly, for a panel dataset from 1995 to 2012, a neutral relationship between RE and economic growth was discovered in Spain, as well as long-run causation and short-run linkage was found between RE and economic growth in West African States (Inglesi-Lotz and Dogan 2018a, b; Maji et al. 2019). On the other hand, some literature showed that the increment of RE consumption negatively affected economic growth. It is argued that transitioning from old NRE sources to RE necessitated huge initial expenditures (Marques, and Fuinhas, 2012; Ocal and Aslan 2013), which might have a detrimental effect on economic development, for example, in Turkey (Ocal and Aslan, 2013), European countries (Marques, and Fuinhas, 2012) and in India, Ukraine, USA and Israel (Bhattacharya et al. 2016). Furthermore, Chen et al. (2020) established that RE use had a substantial beneficial effect on economic development if and only if developing or non-OECD nations exceeded a particular threshold level of RE consumption.

However, if developing nations used renewables below a certain benchmark, RE use had a detrimental impact on the economy.

NRE and economic growth

According to some research, NRE use is essential for economic development. It is observed from the previous literature that the aggregate role of NRE on economic growth was the main focus of some studies. For instance, Dogan (2015) and Afonso et al. (2017) examined the role of NRE on economic growth in Turkey and 28 countries, respectively, using ARDL model supplemented by various techniques. Their results revealed that NRE had significant and positive effect on economic growth. However, Mohammadi and Parvaresh (2014) also looked at the relationship among NRE consumption and economic growth in 14 oil-producing countries for the period of 1980 to 2007. They found that energy use ultimately led to economic growth. In addition, Abbasi et al. (2021a) explored the factors that influenced Pakistan's economic development from 1972 to 2018. They used ARDL model to examine the influence of positive and negative shocks in energy usage, industrial expansion, urbanization and carbon emissions on Pakistan's economic growth. Their empirical research findings concluded that energy usage and output of the industry had a short- and long-run effect on economic growth. In another study, Abbasi et al. (2021b) identified a long-term causal relationship among electricity usage, price and economic growth in Pakistan's industrial sector, which was the most important determinant of the country's economic transformation. For instance, Ewing et al. (2007) demonstrated that increase in coal, natural gas and fossil fuel power sources had the largest effect on real GDP in the USA. Bloch et al. (2015) used ARDL and VECM Granger causality approaches to explore the individual effect of oil and coal on economic growth of China, and they revealed that these energy sources had positive effect on growth. Similar results were also observed by Caraiani et al. (2015) for oil, gas, coal and renewables among emerging European countries. Moreover, Park and Yoo (2014) and Bhattacharya et al. (2016) found that oil Granger caused growth in Malaysia and coal Granger caused growth in China, while mixed results were noticed for coal by Wolde-Rufael (2010) and Lei et al. (2014) for the biggest coal consuming countries.

NARDL model, energy consumption and economic growth

A limited number of studies examined the possible asymmetric association among energy and economic growth. For instance, Abbasi et al. (2020a) investigated the asymmetric link between RE use, NRE consumption and terrorism's impact on Pakistan's economic growth using the NARDL model. Their empirical findings revealed that positive and negative shocks in RE and terrorism had a strong long-run asymmetric connection on economic development. They also discovered that NRE usage had a negative and considerable impact on economic growth. In comparison to NRE, RE is expensive. Therefore, countries with large populations and extensive energy expansion are benefited from NRE sources for economic reasons. Luqman et al. (2019) examined the nonlinear impact of RE and nuclear-powered energy on economy of the country by expanding neoclassical model in Pakistan, together with labour and capital. Their study utilized annual data from 1990 to 2016 to obtain reliable evidences using NARDL model. The results indicated that the variables were asymmetrically co-integrated. The results showed that RE affected economic growth positively. In addition, the production of capital added to economic growth positively. Shastri et al. (2020) used NARDL model and asymmetric causal test to observe the connection between economic growth, RE and NRE consumption in India covering 1971 to 2017. In the long run, an increase in GDP was found for the positive shocks in NRE and RE consumption in India, but negative shocks in NRE, on the other hand, had a larger negative effect on the GDP. Namahoro et al. (2021) used a NARDL approach to investigate the asymmetric nexus between RE and economic growth, as well as the effect of agricultural production and investment on economic development in Rwanda, during the period of 1990 to 2015. The findings indicate that the use of RE has a positive impact on economic growth. It is highlighted that there is an asymmetrical causation relationship between positive shocks of RE use and economic growth. Furthermore, both positive and negative shocks of RE produced a unidirectional causality moving from agronomy and investment to economic growth. Shahbaz et al. (2017) also examined the unequal relation among energy utilization and economic growth in India using the NARDL model. They found that the negative shocks of energy consumption had negative impact on GDP. Wang et al. (2016) evaluated the connection among energy and economic growth in China during 1978–2012 using linear and NARDL model. Their results revealed that energy consumption affected GDP. On the other hand, their results supported that GDP also affected energy consumption.

Research gap in Malaysian research

There are practically few studies on the dynamic relationship between energy use, economic growth and other factors in Malaysia. For example, Park and Yoo (2014) found that fossil fuels like oil had a positive impact on Malaysia's economic growth. Furthermore, from 1978 to 2018, Li and Solaymani used the ARDL and a dynamic ordinary least square (DOLS) model to examine whether technological innovation, sectoral production and export growth had influence on agriculture and industry in Malaysia. They suggested that overall long-run economic growth is the key driver of higher-than-expected increases in energy demand. However, Rahman et al. (2017) used Toda-Yamamoto (T-Y), a modified Granger causality test, as well as annual disaggregated energy and real GDP growth data from 1971 to 2014 to investigate the long-term relationship between Malaysian economic growth and disaggregated energy usage. They claimed that the economic growth was energy-dependent and energy components were used inconsistently in the Malaysian economy, implying that using more energy resources did not substantially lead to economic development but instead exacerbates environmental pollution. The previous studies have the limitation that most of them did not consider the nonlinearity between the variables in their models. The problem with linear models is that they assume that the parameters remain constant over time (Araç and Hasanov, 2014). However, the link between energy consumption and economic growth cannot be sustained indefinitely due to policy changes and economic and energy crises. As a result, these variations essential be taken into account to avoid incorrect outcome. In addition, according to Bayramoglu and Yildirim (2017), linear models have a symmetric characteristic, which means that shocks in the recessive phase of a cycle are as powerful as shocks in the expansive phase. As a result, linear models have not been able to reflect disparities in macroeconomic circumstances (Koop et al. 1996). Although there are seasonal changes in energy use and economic growth, linear models can be too narrow to discover their relationship. Furthermore, in Malaysia, the relative impact of NRE and RE to economic growth is yet unknown. As a result, in order to close the gap, this study compares the roles of NRE and RE using the NARDL technique in order to highlight their importance, as well as provide an economic evaluation of the Malaysian energy market.

Methodology

Specification of the model

The most popular Neoclassical growth model (Solow, 1956) uses economic growth to recognize mostly the development of the contemporary world. In the neoclassical economic model, goods are produced by capital and labour input as a closed economic system. However, energy together with capital and labour are regarded a critical input in the growing infrastructure process (Baz et al. 2021). Cobb–Douglas is a frequently used production function, known as an easy tool to link production to economic considerations, written as:

$$Y_t = AK_t^{\alpha} L_t^{\beta} \tag{1}$$

where aggregate output at time t represents by Y_t, capital by K_t, labour by L_t, and technology parameter by A. Elasticities of output for capital and labour are represented by α and β, respectively. Current works on economic growth show that capital, labour, technical development and energy are important components of economic growth in industrialized countries. Economic growth models, therefore, are dependent on five variables: production, capital, employment, energy and technical progress (Yuan et al. 2008). Based on previous studies by Rahman and Velayutham (2020), Luqman and Al-Ansari (2020), Baz et al. (2021) and Liao et al. (2010), this study presents a Cobb–Douglas production function which takes energy as an input together with other traditional inputs (labour and capital) in the following mathematical form:

$$Y_t = AK_t^{\beta_1} L_t^{\beta_2} EC_t^{\beta_3} \tag{2}$$

where energy represents by EC_t and the elasticity of output with respect to energy represents by β_3. The conversion into a natural logarithm delivers effective empirical conclusions (Shahbaz et al. 2020; Ummalla and Raghutla, 2015). A more generic strategy is the log-linear transformation of the data set, and all regression coefficients are interpreted as elasticity. The log-linear for the following equation results in the logarithmic form of the production function:

$$LnY_t = C_0 + \beta_1 LnK_t + \beta_2 LnL_t + \beta_3 LnEC_t + \varepsilon_t \tag{3}$$

where Ln is the natural log, C_0 is the intercept, β_s are the coefficients and ε is the error term. Here, LnY_t, LnK_t, LnL_t and $LnEC_t$ represent log of GDP, gross fixed capital formation (K), labour (L) and energy consumption (EC).

Data

Table 1 shows the yearly data that has been used in this study covering 1980 to 2018 for Malaysia. The people who are 15 years old or older denote a country's labour force. In many studies such as Soytas et al. (2007), Soytas and Sari (2009) and Shahbaz et al. (2017) have used labour force to proxy labour. Energy consumption indicates consumption of NRE and RE. NRE comprises of oil, natural gas and coal, and RE includes solar, wind, biomass, hydro, geothermal and tidal wave. The NRE and RE units are measured in millions of tons of oil. Figure 4 outlines the data and workflow of the methodology of this study. Figures 5, 6 and 7 report the trends of RE, NRE and GDP.

Table 1 Data and measurements

Variables	Definition	Acronym	Data source	Scales
Gross domestic product (GDP)	GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products	Y	World Bank Development Indicators	Constant 2015 US$
Gross capital formulation	Gross capital formation (formerly gross domestic investment) consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories	K	World Bank Development Indicators	Constant 2015 US$
Labour force	Labour force comprises people ages 15 and older who supply labour for the production of goods and services during a specified period	L	World Bank Development Indicators	Millions
Non-renewable	Non-renewable energy comprises of oil, natural gas, coal	NRE	BP World Energy Statistical Review 2017	Millions of tons of oil
Renewable energy consumption	Renewable energy includes solar, wind, biomass, hydro, geothermal and tidal wave	RE	BP World Energy Statistical Review 2017	Millions of tons of oil

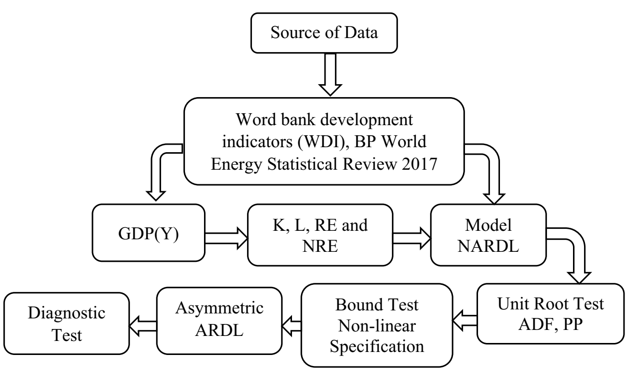


Fig. 4 Workflow and data of the methodology of the study

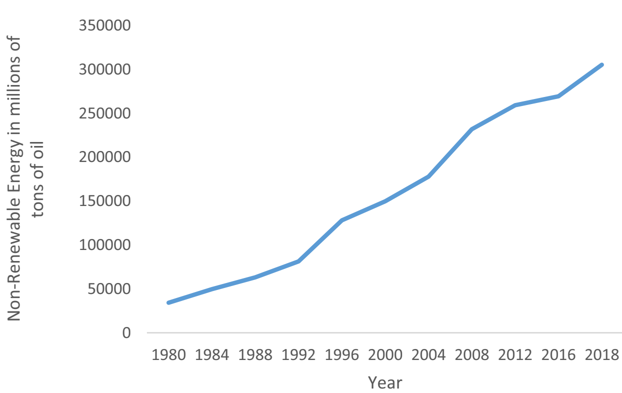


Fig. 5 Non-renewable (NRE) energy in Malaysia during 1980–2018

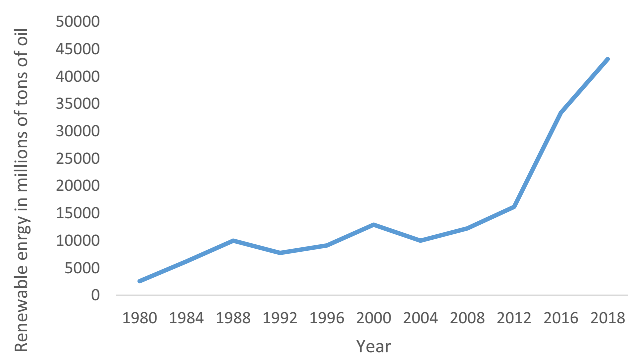


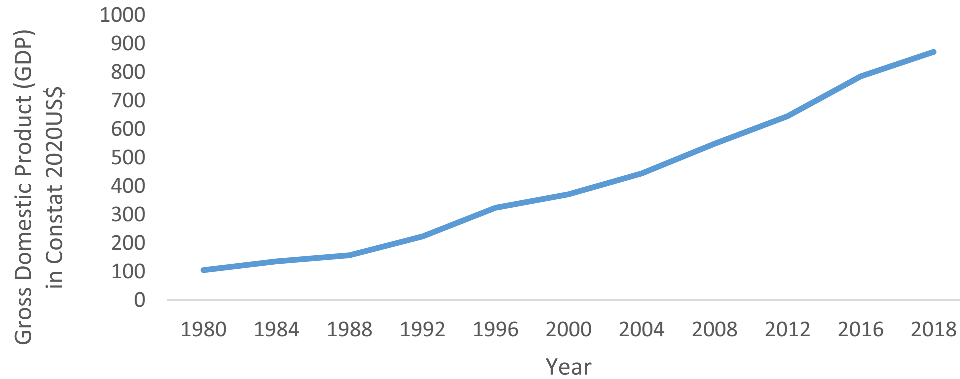
Fig. 6 Renewable energy in Malaysia during 1980–2018

Estimation procedure

The NARDL model introduces nonlinearity by means of partial sum decompositions into the conventional ARDL model which was developed by Pesaran et al. (2001).This model is a single-equation error correction model that allows for asymmetry with respect to positive and negative changes in the explanatory variables (Shin et al. 2014a, b; Romilly et al. 2001; Ahmad and Du, 2017). In order to get exact and accurate findings, NARDL is more versatile in terms of the I(0), I(1) or combination of I(0) and I(1) (Nusair 2016; Hoang et al. 2016).This test takes from the general to the specific framework a number of delays and records data production processes (Laurenceson and Chai, 2003).

A partial technique for integrating variables with increasing and declining asymmetric decomposition is required.

Fig. 7 Gross domestic product (GDP) in Malaysia during 1980–2018



The partial sum procedure can be used to define the increase in energy consumption (EC^{+}) and decrease in energy consumption (EC^{-}), and they can be written as follows:

$$EC_t^{+} = \sum_{j=1}^{t} \Delta EC_j^{+} = \sum_{j=1}^{t} \max(\Delta EC_j, 0) \quad (4)$$

$$EC_t^{-} = \sum_{j=1}^{t} \Delta EC_j^{-} = \sum_{j=1}^{t} \min(\Delta EC_j, 0) \quad (5)$$

The NARDL model which includes the asymmetric dynamics in the short run and long run can be written as follows:

$$\begin{aligned}\Delta LnY = {} & \alpha_0 + \beta_1 \ln Y_{t-1} + \beta_2 \ln L_{t-1} + \beta_3 \ln K_{t-1} \\ & + \beta_4 \ln EC_{t-1}^{+} + \beta_5 \ln EC_{t-1}^{-} \\ & + \sum_{i=1}^{q} \lambda_i \Delta Y_{t-i} + \sum_{i=0}^{q} \lambda_i \Delta L_{t-i} \\ & + \sum_{i=0}^{q} \lambda_i \Delta K_{t-i} + \sum_{i=0}^{q} (\lambda_i^{+} \Delta \ln EC_{t-i}^{+} + \lambda_i^{-} \Delta \ln EC_{t-i}^{-}) + u_i \end{aligned} \quad (6)$$

The null hypothesis ($H_0 : \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5$) denotes the bounds testing procedure by Pesaran et al. (2001). If the null hypothesis cannot be accepted, it will indicate that there is co-integrating association between the variables. Furthermore, long-run parameter are calculated as $\theta^{+} = \frac{\beta_4}{-\beta_1}$ and $\theta^{-} = \frac{\beta_5}{-\beta_1}$. If the hypothesis $\theta^{+} = \theta^{-}$ is rejected, it will confirm the asymmetric long-run influence of RE and NRE on economic growth. Similarly, if the hypothesis $\lambda_i^{+} = \lambda_i^{-}$ is rejected, it will demonstrate the asymmetric adjustment of the variables for the short run.

In order to estimate the NARDL model, Phillips and Perron (1988) and Dickey and Fuller (1979) unit root tests have been applied to check whether all the variables are stationary or not. It is not compulsory for ARDL model to check the stationary. When all variables are basically stationary at I(0) or I(1), or a combination of I(1) and I(0), the ARDL model can be used (Fareed et al. (2018)). To avoid erroneous results, the stationary properties of the variables were checked. The ordinary least-square approach was used in the following step to calculate Eq. (6). In addition, the Schwarz information criterion (SIC) and a general-to-specific strategy (Katrakilidis and Trachanas 2012; Meo et al. 2018) were used. To verify relationship among the variables, the bound test was applied in the next phase. At the last step, the asymmetrical ARDL model was used after verifying for cointegration.

Results

In this part, economic techniques are assessed for the association among NRE, RE and economic growth. Before conducting NARDL model, descriptive information and correlation among the variables were acquired. Table 2 demonstrates that the average consumption of NRE throughout the study period is significantly larger than that of RE consumption. In contrast with RE, however, NRE displays more instability. The correlation coefficients for all pairings of variables show positive correlation. The LnY series is closest to labour followed by NRE, K and RE. Perron (1990) argued that if the time series data has structural change, it can create inaccurate outcome for regression analysis, and the null hypothesis of data stationary cannot be rejected. Hence, Kim and Perron (2009) suggested the breakeven unit root test in order to avoid this kind of ambiguous results. Table 3 presents the breakeven unit root test. The results shown in Table 3 reveal that all the variables are not stationary, and structural break is found in 1984, 1994, 2002 and 1998 for RE, NRE, labour, capital and economic growth, respectively. The reason for this structural break can be happened due to the Asian financial crisis of 1997/1998, as well as the global financial recession of 2007/2008. These two recession slowed economic expansion of the country.

Table 2 Descriptive statistics

	LNY	LNK	LNL	LNNRE	LNRE
Mean	2.506	10.563	7.137	5.100	4.005
Median	2.540	10.628	7.149	5.135	3.984
Maximum	2.940	10.973	7.340	5.485	4.635
Minimum	2.019	10.061	6.895	4.534	3.382
Std. Dev	0.282	0.280	0.140	0.296	0.286
Skewness	−0.221	−0.408	−0.184	−0.437	0.042
Kurtosis	1.782	1.987	1.737	1.886	3.560
Jarque–Bera	2.728	2.751	2.811	3.257	0.521
Probability	0.256	0.253	0.245	0.196	0.771
Sum	97.736	411.966	278.361	198.912	156.185
Sum Sq. Dev	3.028	2.981	0.742	3.335	3.112
Pairwise correlation					
LNGDP	1				
LNK	0.959178	1			
LNL	0.996202	0.933899	1		
LNNRE	0.990738	0.937108	0.991521	1	
LNRE	0.844648	0.798316	0.845221	0.831464	1

Table 3 reports the results of without and with structural breaks unit root test. One of the main advantages of NARDL approaches is that this procedure is accurate regardless of whether all variables are integrated at the level or first difference or display the mixture results I (0) and I (1). The appropriate unit root tests must be applied to confirm none of the variables is integrated into order two I (2) (Pesaran et al. 2001; Demir et al. 2019; Haug and Ucal, 2019; Udeagha and Ngepah 2021). Furthermore, if any variable displays integrated of order two, the estimated F-statistics produced by the Pesaran et al. (2001) bound testing procedure becomes invalid. Moreover, the F-bound test yields two bound values: the upper bound value and the lower bound value; the assumption of stationary at level variables yields the lower bound values, i.e. I (0), and the assignment of the first difference stationary yields the upper bound values, i.e. I (1) (Ahmad et al. 2019; Belloumi 2014; Udeagha and Ngepah 2021). Therefore, in this study, two standard time-series order of integration tests, Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP), are used to verify that the study variables are not integrated into order two, I(2). Table 3 summarizes the results of both the ADF and PP tests to determine the order of integration for LnRE, LnNRE, LnL, LnK and LnY in the case of Malaysia. Here, all the variables are converted into log. Both tests with intercept and trend and intercept restrictions show that LnRE, LnNRE, LnL, LnK and LnY are non-stationary at the level. In contrast, the estimation outputs of both tests with the same restrictions revealed that LnNRE, LnRE, LnL, LnK and LnY are stationary at the first difference. The unit root's null hypotheses are significantly rejected at a 5% level of significance after taking the first differences of the series. As a result, because the significance level of 5% is chosen in this study to decide on the null hypothesis of unit root, both estimation output results of ADF and PP tests show that all variables are integrated into order one I (1). Hence, there is no variable that is integrated into order two (2). Table 4 shows the results of bounds test analysis in nonlinear specification. Asymmetric

Table 3 Unit root test

Variables	Augmented Dickey-Fuller (ADF)				Phillips-Perron (PP)			
	Without structural break							
	Stationarity at level		Stationarity 1st difference		Stationarity at level		Stationarity 1st difference	
	Intercept	Trend and intercept	Intercept	Trend and intercept	Intercept	Trend and intercept	Intercept	Trend and intercept
LnRE	−2.39	0.11	−3.91**	−3.17**	−2.26	0.96	−3.12**	−3.78**
LnNRE	−2.64	−2.08	−5.09**	−5.91**	−1.24	−1.77	−5.03**	−6.10**
LnL	−0.62	−1.89	−5.49**	−5.16**	0.22	−1.19	−3.32**	−3.24**
LnK	−1.54	−2.22	−4.21**	−3.51**	−1.54	−2.22	−4.18**	−4.05**
LnY	−1.07	−1.94	−4.14**	−4.08**	−1.07	−1.94	−4.08**	−4.02
	With structural break							
	Trend and intercept		Break date		Intercept		Break date	
LnRE	−6.19**		2008		-6.05**		1984	
LnNRE	−7.95**		1993		-4.71		1994	
LnL	−5.98**		2002		-1.85		2002	
LnK	−9.93**		1997		-6.85**		1998	
LnY	−5.49**		1988		-7.89**		1998	

(*) and (**) represent 1% and 5% level of significance, respectively cointegration is confirmed by the F-statistic value of 12.11, which is over the critical values of upper boundaries at the 1% significance level. As a result, asymmetric ARDL specifications should be pursued.

Table 5 demonstrates the BDS independence test of nonlinearity. The BDS test is described in Broock, Scheinkman, Dechert and LeBaron (1996). It is a non-parametric test configured primarily to examine the same and independent distribution identical and independent distribution (IID). BDS test is a general test broadly used to check the model specification when used for residuals from fitted models (Kumar, 2017). The findings reveal that all the selected variables have a nonlinear trend in all dimensions. The linearity (null hypothesis) is rejected at a 1% level of significance, while the alternative hypothesis is accepted, suggesting that the included variables are nonlinear. Our outcomes show the accuracy and reliability of the estimated results and validate the model selection (Shahbaz et al. 2017). More specifically, it is worth mentioning that the specified model of economic growth is appropriate for policymaking in Malaysia.

The Wald test results for assessing the equality of positive and negative shocks of NRE and RE are reported in Table 6. The results of Wald test support asymmetry, as it is significant for the long run and short run. Initial literature has shown that both positive and negative shocks have disproportionate short-term and long-term impacts on their respective dependent variables. Table 6 shows overall results for expressing dynamic associations among variables in favour of the NARDL model. The lack of knowledge of asymmetries might lead to an improper modelling in any dynamic model. Table 6 also shows the analysis of diagnostic tests. The results of Breusch-Pagan-Godfrey heteroscedasticity test demonstrate that the null hypothesis of homoscedasticity cannot be rejected because the probability of chi-square value is insignificant. In addition, for serial correlation, the Breusch-Godfrey Serial Correlation LM test and for normality, Jarque–Bera test were conducted. The chi-square tests were shown to be statistically insignificant in both tests. These findings show that there is no serial correlation among the independent variables and the data are normally distributed. The dynamic stability was checked with a cumulative resource residue amount (CUSUM) and a cumulative amount of recursive residual square (CUSUMQ) to further confirm the robustness of our results (Brown et al. 1975). Figure 8A and B show the recursive residuals of CUSUM and CUSUMSQ test statistics, respectively. The results suggest that the test statistics are within critical values at 5% significant, signifying that the series graphical plots are stable. The Durbin-Watson test statistic value of 2.67 for the estimated model also confirms the nonexistence of autocorrelation (Fig. 9). On the basis of Banerjee (1999), the t-statistic (T_{BDM}) authenticates the cointegration among the selected variables at a 1% significance level. Likewise, according to Shin, Yu, and Greenwood-Nimmo (2011), the F-statistics F_{PPS} confirms asymmetric cointegration among LnNRE, LnRE, LnK, LnL and LnY.

Table 7 summarizes the estimation results of NARDL. The results shown in Table 7 report that there is asymmetric long-run relationship among NRE, RE and the NRE. The results of the study demonstrate that the use of energy plays a vital role in the nation's economy. The calculated elasticity of the positive shocks of NRE shows that 1% increase in NRE consumption would increase economic growth by 0.51%. In addition, the coefficient of negative shock of NRE indicates that a 1% decline in NRE would lead to a 0.18% fall in economic growth. Araç and Hasanov (2014) also found similar results in the long run for Thailand, and they indicated that other industrial factors might substitute energy on bad economic terms.

The empirical findings from the NARDL reveal that a positive increase in RE seems to have a positive and

Table 5 Nonlinearity BDS test

Variables	$m=2$	$m=3$	$m=4$	$m=5$	$m=6$
LnNRE	0.1432*	0.2197*	0.2667*	0.3063*	0.3443*
LnRE	0.2037*	0.3439*	0.4456*	0.5734*	0.5646*
LnL	0.2056*	0.3739*	0.4476*	0.3791*	0.5728*
LnK	0.1787*	0.2947*	0.3742*	0.4296*	0.4691*
LnGDP	0.2037*	0.3443*	0.4428*	0.5230*	0.5663*

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

Table 4 Bounds test analysis in nonlinear specification

Model	F-values	Lower bound	Upper bound
$GDP/(LnRE, LnNRE, LnL, LnK)$	12.11		
Critical values			
10%		2.38	3.45
5%		2.69	3.83
2.50%		2.98	4.16
1%		3.31	4.63

Table 6 Wald test and diagnostic test

Variables	Wald test statistics		Diagnostic test	
	Long run	Short run	Tests	Results
LnNRE	−2.76**	5.13**	Heteroscedasticity	6.32 (0.123)
LnRE	−2.28**	4.86**	Serial Correlation	8.43 (0.467)
FPPS	12.42*		Durbin-Watson	2.67
T_{BDM}	−4.32*		Adjusted R^2	0.689

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

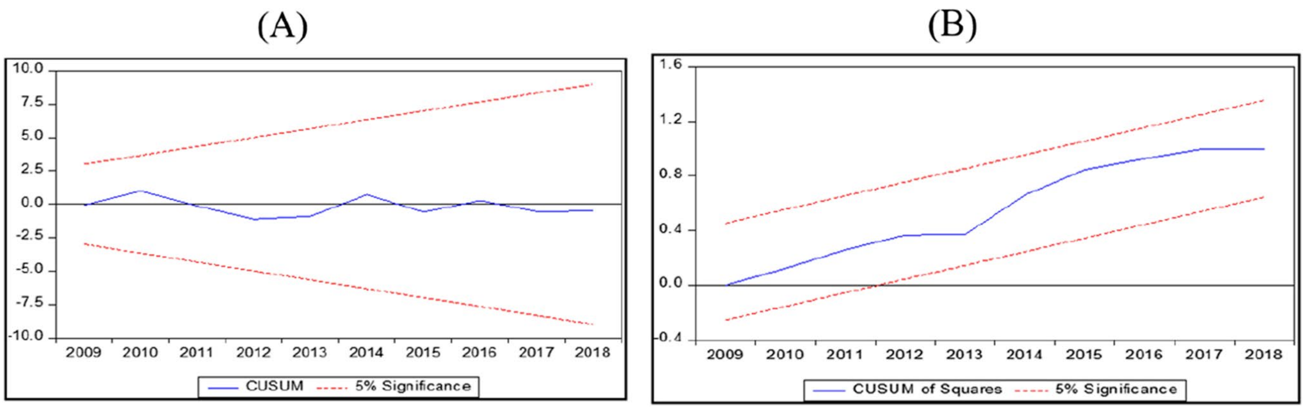


Fig. 8 Cumulative sum of recursive residuals (CUSUM) is shown in (**A**), and cumulative sum of recursive residual square (CUSUMQ) is shown in (**B**)

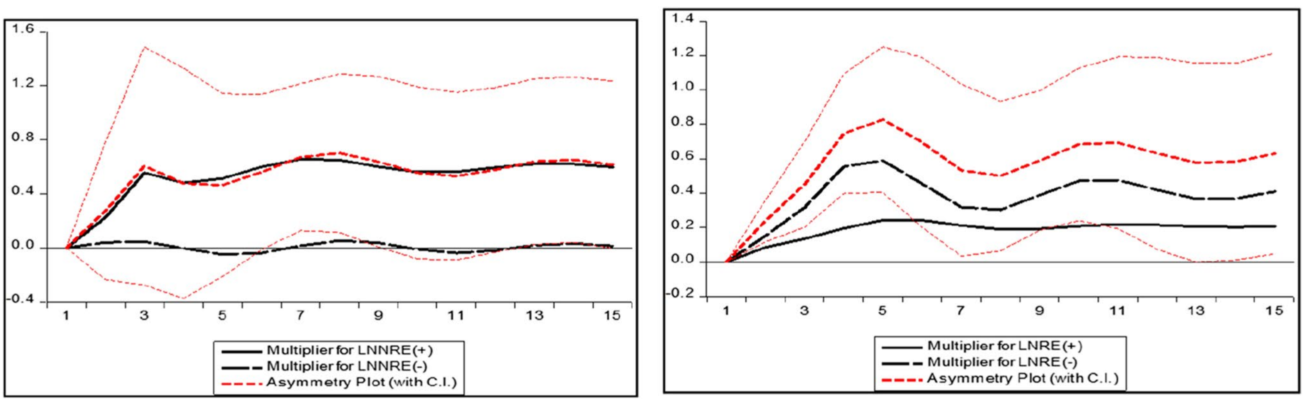


Fig. 9 Cumulative effect of non-renewable energy on economic growth is shown in (**A**), and cumulative effect of renewable energy on economic growth is shown in (**B**)

significant impact on economic growth. This implies that keeping other indicators constant, a 1% increase in RE increases economic growth by 0.20%. Also, a reduction in RE increases economic growth. Thus, a 1% decrease in RE would increase economic growth by 0.42% when other parameters are held constant. However, some literature also showed that the increment of RE consumption negatively affected economic growth because of high investment costs, for example, in Turkey (Ocal, and Aslan (2013)), European countries (Marques and Fuinhas (2012) and in India, Ukraine, the USA, and Israel (Bhattacharya et al. 2016). In contrast, various studies suggested a positive association between RE consumption and economic growth (Abbasi et al. (2020a, b); Alper and Oguz, (2016); Jebli, and Youssef (2017). It is also being discovered that both positive and negative changes in RE consumption boost economic growth, with the magnitude of the effect being greater when negative changes in RE consumption affect economic growth. The findings of NARDL also show that in the long run, labour has a positive and significant impact on economic growth of Malaysia with a coefficient of 2.33. It means that a 1% increase in labour will result in a 2.33% increase in economic growth. The capital coefficient, on the other hand, is positive and significant with a coefficient of 0.33%. This means that a 1% increase in capital will result in a 0.33% increase in economic growth. In the short run, labour shows positive relationship with economic growth, but it is not significant. On other hand, capita shows positive and significant relationship with economic growth. It is consistent with previous research such as Sahoo et al. (2010) for China and Sahoo and Dash (2009) for India, who found that capital formation and labour had a positive effect on economic growth.

Overall, empirical findings of this study imply that NRE and RE consumption in Malaysia has asymmetric long-run effects on economic growth due to different coefficients. On the other hand, the results of this study are consistent with a few studies that found that RE had a significant impact

Table 7 Estimation results of NARDL

Variable	Coefficient	Std. error	t-Statistic	Prob
Panel A: long-run estimates				
LNK	0.333	0.042	7.886	0.000*
LNL	2.338	0.893	2.618	0.026**
LNNRE_POS	0.510	0.140	3.612	0.002**
LNNRE_NEG	0.175	0.399	0.440	0.670
LNRE_POS	0.199	0.063	3.173	0.010**
LNRE_NEG	−0.420	0.115	−3.632	0.005**
Z_{t1998}	−0.033	0.012	−2.628	0.027**
Panel A: short-run estimates				
D(LNGDP(-1))	0.727	0.178	4.080	0.002**
D(LNK)	0.267	0.025	10.777	0.000**
D(LNL)	2.997	2.402	1.248	0.241
D(LNNRE_POS)	0.226	0.065	3.483	0.006**
D(LNRE_POS)	0.085	0.035	2.436	0.035**
D(LNRE_NEG)	−0.154	0.042	−3.696	0.004**

(*) and (**) represent 1% and 5% level of significance, respectively

on economic growth (Abbasi et al. 2020a, b; Luqman et al. 2019; Mohamed et al. 2019; Shahbaz et al. 2013; Shahbaz et al. 2015). These studies have important implications for practitioners and policymakers. First, both NRE and RE have a considerable impact on Malaysia's economic growth. Second, the magnitude of the consequences of increasing and decreasing energy usage may differ. Figure 5A confirms the presence of positive shocks in NRE dominated by negative shocks. In contrast, negative shocks in RE dominates positive shocks (Fig. 5B), which means a negative association between RE and economic growth.

Discussion

This study investigates the links between RE, NRE, capital, labour and economic growth, using the NARDL method in Malaysia for the period of 1980–2018. The sub-sections of this study's outcome are detailed below in order to answer the question, "What is the influence of NRE, RE, capital and labour on economic growth in Malaysia?" using the findings of this study as evidence.

Impact of NRE and RE on economic growth

The results of this study reveal that NRE has a significant and positive influence on GDP, demonstrating that the NRE sector is performing as expected in terms of increased Malaysian economic growth, because energy is the driving force behind all economic activity. Hence, a decrease in NRE consumption will stifle economic activity, resulting in unforeseen and poor economic growth. When it comes to energy use, Malaysia is 34% better than the rest of the world (ETP, 2013). From 1990 to 2013, Malaysia's annual average final energy demand growth rate is projected to be 5.2%. Malaysia relied more on NREs due to its diversification from agriculture to energy-intensive economic activities. Malaysian manufacturing operations are defined by the use of high energy and high energy intensity generation techniques. The term "energy intensity" refers to the efficiency with which energy is used in the economy. Malaysia's energy intensity is higher than that of many developed and emerging nations (Global Energy Statistical Yearbook, 2019). Any initiative to reduce energy must take into account the important implications of NRE for economic development. Malaysia must create ways to improve the quality and quantity of services while reducing the environmental impact of energy use (IEA, 2005). These debates should aid policymakers in deciding whether or not to push for the use of RE to partially replace NRE use. RE is a clean energy source that causes less environmental damage and is thus more crucial for the majority of the country's RE development. Furthermore, the harmful impact of NRE on the environment will also be considered by policymakers. In order to economically harness energy consumption in a range of productive areas, the government must exert tremendous prudence and monitoring.

It is possible that the size of the coefficient of positive energy shocks on economic growth is larger than that of negative energy shocks, implying that an increase in the NRE increases growth by a greater magnitude than a fall in the NRE. In the short term, positive shocks of NRE have a smaller but significant impact on economic growth than in the long term. The findings of this study also suggest that RE use has a detrimental influence on economic growth. It implies that the increased use of RE in Malaysia will stifle the country's economic progress. This is due to incompetence of the energy supply, such as the inability to use important sources as a result of energy plans with incorrect structural and systemic consequences. Furthermore, RE is an expensive energy source. As a result, unless the necessary investments are made, economic growth can be hampered.

Comparative role of NRE and RE

The findings of this study demonstrate that the positive shocks of NRE are larger in the long and short run than that of RE. It indicates that NRE is still playing the vital role for economic growth in Malaysia. In the long term, RE's negative shocks, on the other hand, are larger than NRE's. This finding shows that the use of RE cannot have a beneficial effect on the Malaysian economy. In its production process Malaysia is still unwilling to replace NRE and employ it. In short run, both the positive and negative shocks in the RE have similar relationship with economic growth as they have in the long run and the *t*-values indicate that their coefficients are significant. The negative shocks in RE have a greater and important influence on economic growth in the long run than in the short run. The findings are consistent with the studies conducted in Pakistan (Shahbaz et al. 2015) and in African nations (Apergis & Payne, 2010).

Impact of capital and labour on economic growth

Finally, the importance of labour and capital formation for the economy is shown by their asymmetric impact on economic growth. The findings suggest that economic growth cannot occur without significant capital and labour force investment. Investment is very important in a country's economic development because it is the main source of employment creation and national revenue. It also induces economic prosperity and welfare improvement in general.

Conclusions and actions recommendations

The empirical conclusions of this study showed that reductions in RE consumption speed up economic growth. It can have argued that economic growth might be adversely affected in a developing nation by the usage of RE since RE is costlier than NRE. Moreover, an ongoing rise in the supply of RE will affect the cost of production for most RE sources. Shafie et al. (2011) forecasted that Malaysia faced a growing RE fund scarcity, and, by optimizing feed-in tariff (FiT) payments across different periods, the government could raise its income by increasing electricity rates or cutting its expenditures in order to meet the budget deficit. The governments should thus foster RE sources and enable investors to acquire licenses, enterprises, grids and land. In this respect, Malaysia might focus on the installation of the latest technologies for saving energy. A variety of measures to develop RE are recommended based on the results of the study. The following are:

a) It is recommended that development of RE requires an adequate, strong and efficient regulatory framework, which would solve market failures and encourage companies to enter the RE generating sector. In the legislative framework, FiT should be introduced, a stimulus for the entry into the RE-energy sector, RE industries and research and development (R&D). In addition, RE fund can be developed to reduce the environmental pollution, and society can play a role in contributing to a fund to pay through electricity bills. This is particularly relevant because retail tariffs contain subsidies and are being decreased, and the external expenses are excluded. A technique might be used by including a specified cost into a particular RE fund inside the energy price structure. Consequently, a regulator that would function as a catalyst in the development of RE industries, R&D in RE technology and innovation has a direct spillover impact. These results include the pace of increase in the usage of RE, progressive (or constant) decrease in the consumption of fossil fuels for the conventional generation of electricity and the reduction of CO_2 emissions.
b) It is suggested that incentive package that includes fiscal stimuli and indirect support should be implemented for the reduction of transaction costs and support to small medium enterprises (SMEs) in the RE sector. RE is a novel technology in Malaysia, which requires human resource development in support of RE industry development. A comprehensive R&D plan, which leads to new items and services, must thus be established to accelerate the growth in RE industries. Innovation also helps the spread of RE by making the use of the technology cheaper and easier. Therefore, an R&D strategy to define demand has to be developed, regulations are used to stimulate innovation and R&E activities must be supported.
c) Advocacy programmes should be tailored to specific messages for certain populations. For example, an investment advocacy campaign and a RE market entry must communicate a message significantly different from a common public advocacy programme, aimed to achieve a buy-in to the notion of clean social payments. The common objective of all advocacy programmes is to raise knowledge of the benefits and benefits of utilizing RE and involvement in RE companies by all stakeholders. Once the foundation has been established, the policy mission should be evaluated and (if required) enhanced for time. For example, if the policy is revised in 5 years' time, a suitable regulatory structure would have fulfilled to incorporate the regulation. Nevertheless, as part of the continuous policy vision mission, it might need to be further enhanced or replaced as needed by a fresh impetus.
d) Human capital development is a crucial driving force, because it may be the country's biggest influence. The government of Malaysia acknowledges the importance of human development, as it may increase Malaysian economy's entire productivity and flexibility, which is essential for the transition between the community and the economy, and urges the government to provide the necessary infrastructure. However, given that the proportions of people with university education in the country are modest (about 13.9% in 2001), it is essential to encourage people to join tertiary colleges. This entails determining what motivates a person to receive a high school education and how the government might encourage these people. So, RE experts should be generated simultaneously to promote the development of new skills and capacities for

regular people. However, such procedures are subject to a sunset condition. Institutional preparations to achieve this goal need to be coordinated by the Ministry of Finance, Higher Education, Human Resources Minister and other governmental bodies concerned.

Limitation of the study

Based on the findings of this study, there are several avenues for further investigation. To begin with, rather than separating the effects of RE use on different sectors of the country, this study focused on the impact of RE consumption on economic growth at the national level. The impact of RE on economic growth varies by sector, according to evidence. This impact may be the subject of the next study, which would be great to investigate. Secondly, although the focus of this study was on the influence of RE consumption on economic growth, RE is actually a collection of various categories such as wind energy and hydropower. The next study can look into the impact of each energy type in a variety of areas across the country. Lastly, the next study can look into the impact of RE on the economic development of households. By taking into account alternate energy resources and the consumption capacity of various businesses, all of these future and existing studies may help to promote national economic growth.

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Md Muhibbullah: He wrote the Introduction, Literature review and Methodology.

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Data availability The data sets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval This study did not use any kind of human participants or human data, which require any kind of approval.

Consent to participate Not applicable.

Consent for publication This study did not use any kind of individual data such as video and images.

Conflict of interest The authors declare no competing interests.

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