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The Impact of Renewable Energy Consumption on GDP and the Three Key Economic Sectors' Growth in Malaysia

Sze May Ng, Mui Yin Chin*, Christine Siew Pyng Chong, Lee Peng Foo

Tunku Abdul Rahman University of Management and Technology, Malaysia. *Email: chinmy@tarc.edu.my

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ABSTRACT

Despite Malaysia's long-standing efforts to diversify its energy sources and increase renewable energy consumption since 1980, the progress has been hindered by inefficiencies and technological limitations, while the economic impact of these changes remains unmeasured. This study, using annual World Bank data from 1990 to 2022, examines the relationship and impact of renewable energy consumption on Malaysia's economic and industry, service, and agriculture sectors' growth. The findings suggest that the renewable energy sector is cointegrated and has a significant positive impact on the overall economy, and the industry and service sectors in the long run. Furthermore, the Granger causality Wald test results support the growth, neutrality, and conservation hypotheses for the overall economy, industry, agriculture, and service sectors, respectively, in the short run. Overall, the results suggest that renewable energy could benefit Malaysia's economy in varying degrees across the three important sectors. Therefore, prioritizing investments in renewable energy consumption within the industry and service sectors is crucial, as they offer the largest positive impact on economic growth. Additionally, the adoption of technologies in agricultural sector is low, thus efforts to enhance access to modern farming techniques using renewable energy should be promoted to improve the performance of the agricultural sector.

Keywords: Renewable Energy Consumption, Economic Growth, CO_2 Emission, Economic Sectors, ARDL Model
JEL Classifications: C22, O44, Q43

1. INTRODUCTION

The International Energy Agency (IEA) revealed that the global demand for energy had increased by 1.3%, with natural gas consumption increase by 4.5 million TJ (IEA, 2023). The COVID-19 Pandemic and the adverse weather condition exacerbated the Global Energy Crisis particularly in countries faced with winter season, specifically in Europe, China, USA and Russia (Mišík, 2022; IEA, 2024; Ghiles, 2022). The crisis is further aggravated by the Russia-Ukraine Invasion event that impacting the energy supply chain resulting in global energy supply inefficiency. This drove up the fossil fuel cost of the countries that were highly dependent on Russia fossil fuel supply (Khudaykulova et al., 2022; Liadze et al., 2022; Orhan, 2022). Other than the susceptibility to global price fluctuations, fossil fuel energy use causes environmental issues such as GHG pollution, climate change, natural disaster and health (Haines et al., 2008; Kabir et al., 2023; Kong, 2000; National Institute of Environmental Health Science, 2022; West et al., 2017; WHO, 2023). The depletion of fossil fuel sources, environmental and health concern increases the urgency of government globally to shift to cleaner energy (Gautam et al., 2019).

Malaysia has been adopting renewable energy notably solar, geothermal and biomass due to the richness of solar, hydro and geothermal resources (Afrouzi et al., 2022). Although the Malaysian government has long pursued energy diversification since 1980 and the overall percentage of renewable energy use has increased in the general energy market, the progress of its adoption has been slow and hindered by inefficiencies and technological limitations, resulting in Malaysia's less competitive position in the energy market (Liew et al., 2014). Furthermore, the detailed impact brought by this change on Malaysia's economy is yet to be measured (Afroz and Muhibbullah, 2022; Paramati et al., 2018).

Despite the extensive body of research examining the nexus between renewable energy growth and economic development in various countries (Apergis and Payne, 2010a; Apergis and Payne, 2010b; Aslan et al., 2022; Gyimah et al., 2022; Kahia et al., 2016; Pao et al., 2014; Raihan and Tuspekova, 2022; Sadorsky, 2009), the findings on cointegration and causality, which are influenced by various economic factors and conditions, remain inconsistent and limited, particularly in the context of Malaysia. Moreover, prior studies have largely focused on the overall trajectory of Malaysia's GDP growth (Afroz and Muhibbullah, 2022), often overlooking the distinct reactions within different sectors of the economy. Given that each sector exhibits unique energy consumption patterns, it is essential to consider these sectoral variations in order to gain a more comprehensive understanding of the role of renewable energy in driving economic growth.

Therefore, this study, utilizing annual data from the World Bank spanning from 1990 to 2022, aims to investigate the impact of renewable energy consumption on the growth of key economic sectors in Malaysia, specifically the industry, service, and agriculture sectors. Furthermore, it seeks to explore the short-run relationship between renewable energy consumption and economic growth within these sectors. The findings of this study offer a more nuanced understanding of how renewable energy influences sectoral economic performance. This could provide valuable insights for policymakers, enabling the development of targeted and sector-specific policies that promote sustainable economic growth while considering the unique energy needs of each sector.

2. LITERATURE REVIEW

Early studies on energy and economic growth tend to focus on the non-renewable energy sources and economic growth relationship (Humphrey and Stanislaw, 1979; Riaz, 1987; Stern, 1993). Subsequent studies on energy and economic growth emphasized examining the cointegration relationship and causality over both the short term and long term across various countries during a specific time frame. Most studies on impact and cointegration relationship had found positive impact relationship (Al-Mulali, 2014; Munir et al., 2020; Shahbaz and Lean, 2012; Stjepanovic, 2018; Taasim et al., 2021). In recent years, studies of renewable energy and economic growth have increased as researchers have become more interested in discovering the linkage of their relationship and causality (Susilo et al., 2024; Pratomo et al., 2023; Rusiadi et al., 2024; Ahmad et al., 2024; Satrianto et al., 2024; Seriram et al., 2024).

Findings on the short- and long-term relationship and causality between renewable energy and economic growth are mixed. Countries which have been ahead in implementing renewable energy use were found to have a positive and sizable effect on economic growth (Alam et al., 2017; Belaïd and Zrelli, 2019; Ghazouani et al., 2020; Raza et al., 2020; Shahbaz et al., 2020; Hieu et al., 2021; Ivanovski et al., 2020; Salari et al., 2021; Afroz and Muhibbullah, 2022; Le, 2022; Hieu and Mai, 2023). In contrast, renewable energy was found to be negative and has no long run significant impact on economic growth in some countries (Shahbaz et al. 2020; Raza et al., 2020; Can and Korkmaz, 2019; Kayani, 2021; Nyoni and Phiri, 2020). Furthermore, literature on renewable energy and economic growth has not been able to establish the direction of causality relationship in the short term and long term (Apergis and Payne, 2010a; Apergis and Payne, 2010b; Alam et al., 2017; Belaïd and Zrelli, 2019; Salari et al., 2021).

The literature and studies on the causality relationship direction with energy consumption and economic growth were found to be inconclusive. The causality relationship has been categorized by Ozturk (2010) into four hypotheses with distinct directions carry in between energy consumption and energy growth, namely neutrality hypothesis, conservation hypothesis, growth hypothesis and feedback hypothesis. The *Neutrality hypothesis* argued that energy consumption and GDP have no causality relationship; thus, implementing energy conservation policies targeted at affecting energy consumption will not impact and affect a country's economy. *Conservation hypothesis* stated that the economic growth and energy consumption have a unidirectional causality and runs from economic growth towards energy consumption. Consequently, economic growth will receive modest negative effects by the energy conservation policies. *Growth hypothesis* assumes a unidirectional causality runs from energy consumption to energy growth inferring that energy is a prerequisite for production process, complementing factor of production direct and indirectly. Thus, any energy supply shocks will exhibit economic growth. *Feedback hypothesis* asserted a bidirectional causality exists between energy consumption and energy growth suggesting that the two variables are mutually interdependent and jointly determined simultaneously (Ozturk, 2010; Hajko et al., 2018). Amongst these four hypotheses, studies on economic-growth nexus mostly found first and foremost, the growth hypothesis, followed by conservation and feedback hypothesis. Neutrality hypothesis was the least supported by the literature's findings (Mutumba et al., 2021).

Research that explored the renewable energy at various sectors of economies remains limited (Paramati et al., 2018). Findings from studies that examined the sector of economics' causality and relationship have also not been able to reach a consensus on the results in the short run and long run. Salim et al. (2014) centered on one of the sectors of economies, by looking into the dynamic relationship between both renewable and non-renewable energy consumption on the industrial sector from 1980 to 2011 in OECD countries. They found evidence of a long run equilibrium relationship and bidirectional causality running towards each other between industrial output and renewable energy consumption in both the short run and long run. Similarly, Marques et al. (2016) adopted industrial production index as a proxy for manufacturing sector and found no significant long run result from electricity generated from renewable energy sources on the industrial sector in Greece. Distinctly, Paramati et al. (2018) explored the impact of renewable energy on three sectors, namely agriculture, industry, and services of the G20 economies from 1980 to 2012 and found renewable energy consumption has more impact on the 3 sectors compared to non-renewable energy and unidirectional causality runs from renewable energy consumption to the service industry.

To date, there are limited studies that investigate the relationship and causality between energy and GDP contributed by sector (Paramati et al., 2018). Paramati et al. (2018) argued that studies on energy should emphasize their impact on sectoral economic activities for policy makers and governments, as the consumption of renewable energy will not adversely affect the environment and the economy of different sectors. The impact of renewable energy and economic growth in the industry, service, and agriculture sectors in Malaysia, even though imperative, has yet to be examined and confirmed. Thus, the goal of this study is to elucidate the capacity to formulate strategies for potential gains or losses within different sectors resulting from the uptake of renewable energy. While the Malaysian government has implemented a large number of strategies to foster renewable energy development, the expansion of the market, remains relatively small and less impactful compared to traditional non-renewable energy sources (Afroz and Muhibbullah, 2022). Consequently, businesses across different sectors find it challenging to track and align with the evolving trends. This study, therefore, endeavors to offer a comprehensive understanding and interpretation of the possible short and long-term dynamics between energy and the economy, information that is crucial for businesses to adapt to. Furthermore, it provides valuable insights into potential strategic planning in anticipation of future changes within diverse sectors offering guidance in assessing the possibility of developing of the future renewable energy market. This, in turn, may contribute to promoting and generalizing the adoption and application of renewable energy among diverse groups in society, contributing to the maintenance of a healthy environment and fostering a sustainable future for both human and natural habitats.

3. DATA AND METHODOLOGY

This study utilized the World Bank data from the year 1990 to 2022. Table 1 defines the variable and lists the source of data used in this study.

4. METHODOLOGY

4.1. Theoretical Framework

This study applies and employs the Cobb-Douglas production function, initially introduced by Cobb and Douglas (1928), as the theoretical framework. Cobb-Douglas Production Function has been widely embraced as the theoretical framework in various studies exploring the determinants of GDP across different countries (Apergis and Payne, 2010a; Apergis and Payne, 2010b; Omri et al., 2015; Alper and Oguz, 2016; Kahia et al., 2017; Haseeb et al., 2019; Nepal and Musibau, 2021). Based on their studies, the framework has been augmented by many researchers to incorporate additional variables.

The Cobb-Douglas production function (1928) is stated as the equation below:

$$Y_t = AL_t^{\propto} K_t^{1-\propto} \quad (1)$$

Where,
Y = Gross Domestic Product,
L = Labor,
K = Capital,
A = Efficiency parameter,
α = Output elasticity for labor,
β = Output elasticity for capital and
t = Time representative.

Ozturk (2010) postulated that the multivariate model performs better in obtaining a more accurate result. As such, more

Table 1: Data and measurements

Variables	Definition	Acronym	Data Source	Scales
GDP Constant LCU	The sum of total gross value added by the resident producer within an economy.	GDP	World Bank	Malaysian Ringgit (MYR)
Industry Constant LCU	The net output of the economic sector includes mining, manufacturing, construction, electricity, water and gas.	Industry	World Bank	Malaysian Ringgit (MYR)
Service Constant LCU	The net output of the economic sector includes wholesale and retail, transport, government, financial, education, health care and real estate service.	Service	World Bank	Malaysian Ringgit (MYR)
Agriculture Constant LCU	The net output of the economic sector includes forestry, agriculture, fishing, and the cultivation of crops and the production of livestock.	Agriculture	World Bank	Malaysian Ringgit (MYR)
Renewable Energy Consumption	The percentage of renewable energy in the total final energy consumption.	REC	World Bank	% of Total Final Energy Consumption
Labour	The production force of the employed people in the production of goods and services.	L	World Bank	Total Labour Force
Capital	Gross capital formation, including the fixed assets of the economy such as land improvements, purchases of plants and machinery, and construction.	K	World Bank	Malaysian Ringgit (MYR)
Carbon Dioxide Emission	The carbon dioxide emission that is produced from fossil fuels energy source and cement manufacture.	CO_2	World Bank	Kiloton (kt)

LCU: Local Currency. Source: World Bank Group (2024). Country, Malaysia. Retrieved from https://data.worldbank.org/country/malaysia determinants of GDP are integrated into the production function, shaping it into an augmented production function. Incorporating the essential variables, the augmented Cobb-Douglas production function for this study is formed as follows:

$$Y_t = AL_t^{\propto} K_t^{1-\propto} REC_t^{\beta} CO2_t^{\gamma} \quad (2)$$

Where,
Y = Gross domestic product (GDP),
A = Efficiency parameter,
REC = Renewable energy consumption,
L = Labor force,
K = Gross capital formation,
CO_2 = Total carbon dioxide emissions,
$\propto, 1-\propto, \beta, \gamma$ = Output elasticity and
t = Time representative.

The impact of renewable energy consumption on economic growth is being tested by using GDP as the proxy for measuring economic growth, along with other determinants including the labor force, capital and total carbon dioxide emissions. Based on the framework formed in Equation (2), an empirical model for this study is as stated below:

$$GPD_t = \beta_0 + \beta_1 REC_t + \beta_2 L_t + \beta_3 K_t + \beta_4 \mathrm{CO}_{2t} + \varepsilon_1 \quad (3)$$

Where $\beta_1 \ldots \beta_4$ = Coefficient of the variable, and ε_1 = Error correction term.

Additionally, Afroz and Muhibbullah (2022) concluded that most of the previous studies had narrowed their focuses on the overall economy in renewable energy-growth nexus; research that uncovers the effects and causality relationship of renewable energy and economic *sector*s was limited, particularly in Malaysia. In order to further bridge the research gap and provide more detailed findings, this study disaggregates the GDP into three different economic sectors, namely industry, service and agriculture. As such, the overall and three empirical models following Afroz and Muhibbullah (2022) will be formed and transformed into a log model to linearize the model (Shabaz et al., 2015) as follows:

$$LnGPD_t = \beta_0 + \beta_1 LnREC_t + \beta_2 LnL_t + \beta_3 LnK_t + \beta_4 Ln\mathrm{CO}_{2t} + \varepsilon_1 \quad (4)$$

$$LnIndustry_t = \beta_0 + \beta_1 LnREC_t + \beta_2 LnL_t + \beta_3 LnK_t + \beta_4 Ln\mathrm{CO}_{2t} + \varepsilon_1 \quad (5)$$

$$LnService_t = \beta_0 + \beta_1 LnREC_t + \beta_2 LnL_t + \beta_3 LnK_t + \beta_4 Ln\mathrm{CO}_{2t} + \varepsilon_1 \quad (6)$$

$$LnAgriculture_t = \beta_0 + \beta_1 LnREC_t + \beta_2 LnL_t + \beta_3 LnK_t + \beta_4 Ln\mathrm{CO}_{2t} + \varepsilon_1 \quad (7)$$

Where Ln denotes the logarithmic transformation. *LnGDP*, *LnIndustry*, *LnService* and *LnAgriculture* represent the GDP contributions from the overall economy, the industry sector, the service sector, and the agriculture sector, respectively, t represents the period of time series data, β_0 represents the constant of the model effect, $\beta_1, \beta_2, \beta_3, \beta_4$ represent the coefficient of the variables, and ε represent the error term.

4.2. Method of Estimation

This study applies two testing methods, namely the ARDL bound test and the Granger causality Wald test. Prior to undergoing the cointegration testing, the stationary test is performed for a time series cointegration assumption. The ARDL bound testing was first developed by Pesaran et al. (2001), which is widely adopted for cointegration of variables testing. The ARDL bound test is applied because it is able to test the regression used in the model regardless of its purely stationary I(0), first I(1) or mixed level. Furthermore, it performs better in a small sample set (Shahbaz and Lean, 2012). Unit root test such as Augmented Dickey Fuller test (Dickey and Fuller, 1979) and Phillips-Perron test (Phillips and Perron, 1988) will be carried out to identify if a data set is stationary. The PP test is also able to identify the heteroscedasticity in the test model (Afriyie et al., 2020). If the result indicates that there is no unit root, the model's data that applied in the research is regarded as stationary.

After the model passes both stationary tests, a cointegration test will be carried out. The cointegration test is being applied to identify the cointegrated long-run relationship among the variables in many studies that focusing on the relationship between energy and economy (Can and Korkmaz, 2019; Haseeb et al., 2019; Kayani, 2021; Nyoni and Phiri, 2020; Shahbaz and Lean, 2012). The unrestricted error correction model for the ARDL bound test can be formed as follows:

$$\begin{aligned}\Delta LnGDP_t &= \beta_1 + \beta_2 LnGDP_{t-1} + \beta_3 LnREC_{t-1} \\ &+ \beta_4 LnL_{t-1} + \beta_5 LnK_{t-1} + \beta_6 LnCO_{2t-1} \\ &+ \sum_{i=1}^{p} \alpha_{1i} \Delta LnGDP_{t-i} + \sum_{i=0}^{p} \alpha_{2i} \Delta LnREC_{t-i} + \sum_{i=0}^{p} \alpha_{3i} \Delta LnL_{t-i} \\ &+ \sum_{i=0}^{p} \alpha_{4i} \Delta LnK_{t-i} + \sum_{i=0}^{p} \alpha_{5i} \Delta LnCO_{2t-i} + \varepsilon_{1t} \quad (8)\end{aligned}$$

The ARDL bound model for the Industry, Service and Agriculture is formed as follows:

$$\begin{aligned}\Delta LnIndustry_t &= \beta_1 + \beta_2 LnIndustry_{t-1} + \beta_3 LnREC_{t-1} \\ &+ \beta_4 LnL_{t-1} + \beta_5 LnK_{t-1} + \beta_6 LnCO_{2t-1} + \sum_{i=1}^{p} \alpha_{1i} \Delta LnGDP_{t-i} \\ &+ \sum_{i=0}^{p} \alpha_{2i} \Delta LnREC_{t-i} + \sum_{i=0}^{p} \alpha_{3i} \Delta LnL_{t-i} + \sum_{i=0}^{p} \alpha_{4i} \Delta LnK_{t-i} \\ &+ \sum_{i=0}^{p} \alpha_{5i} \Delta LnCO_{2t-i} + \varepsilon_{1t} \quad (9)\end{aligned}$$

$$\begin{aligned}\Delta LnService_t &= \beta_1 + \beta_2 LnService_{t-1} + \beta_3 LnREC_{t-1} \\ &+ \beta_4 LnL_{t-1} + \beta_5 LnK_{t-1} + \beta_6 LnCO_{2t-1} + \sum_{i=1}^{p} \alpha_{1i} \Delta LnGDP_{t-i} \\ &+ \sum_{i=0}^{p} \alpha_{2i} \Delta LnREC_{t-i} + \sum_{i=0}^{p} \alpha_{3i} \Delta LnL_{t-i} + \sum_{i=0}^{p} \alpha_{4i} \Delta LnK_{t-i} \\ &+ \sum_{i=0}^{p} \alpha_{5i} \Delta LnCO_{2t-i} + \varepsilon_{1t} \quad (10)\end{aligned}$$

$$\Delta LnAgriculture_t = \beta_1 + \beta_2 LnAgriculture_{t-1} + \beta_3 LnREC_{t-1} + \beta_4 LnL_{t-1} + \beta_5 LnK_{t-1} + \beta_6 LnCO_{2t-1} + \sum_{i=1}^{p}\alpha_{1i}\Delta LnGDP_{t-i} + \sum_{i=0}^{p}\alpha_{2i}\Delta LnREC_{t-i} + \sum_{i=0}^{p}\alpha_{3i}\Delta LnL_{t-i} + \sum_{i=0}^{p}\alpha_{4i}\Delta LnK_{t-i} + \sum_{i=0}^{p}\alpha_{5i}\Delta LnCO_{2t-i} + \varepsilon_{1t} \quad (11)$$

If the test statistic is larger than the upper limit of the critical value, the variables in the model is cointegrated.

Next, to identify the lag for each of the variables used in the test model, the Akaike's Information Criteria (AIC) is being applied to be a reference for identifying the lag (Danish et al., 2018). The long-run estimation model is as formed below:

$$LnGDP_t = \alpha_0 + \sum_{i=1}^{p}\beta_0 LnGDP_{t-i} + \sum_{t=1}^{k}\beta_1 LnREC_{t-i} + \sum_{t=1}^{k}\beta_2 LnL_{t-i} + \sum_{t=1}^{k}\beta_3 LnK_{t-i} + \sum_{t=1}^{k}\beta_4 LnCO_{2t-i} + \varepsilon_t \quad (12)$$

$$LnIndustry_t = \alpha_0 + \sum_{i=1}^{p}\beta_0 LnIndustry_{t-i} + \sum_{t=1}^{k}\beta_1 LnREC_{t-i} + \sum_{t=1}^{k}\beta_2 LnL_{t-i} + \sum_{t=1}^{k}\beta_3 LnK_{t-i} + \sum_{t=1}^{k}\beta_4 LnCO_{2t-i} + \varepsilon_t \quad (13)$$

$$LnService_t = \alpha_0 + \sum_{i=1}^{p}\beta_0 LnService_{t-i} + \sum_{t=1}^{k}\beta_1 LnREC_{t-i} + \sum_{t=1}^{k}\beta_2 LnL_{t-i} + \sum_{t=1}^{k}\beta_3 LnK_{t-i} + \sum_{t=1}^{k}\beta_4 LnCO_{2t-i} + \varepsilon_t \quad (14)$$

$$LnAgriculture_t = \alpha_0 + \sum_{i=1}^{p}\beta_0 LnAgriculture_{t-i} + \sum_{t=1}^{k}\beta_1 LnREC_{t-i} + \sum_{t=1}^{k}\beta_2 LnL_{t-i} + \sum_{t=1}^{k}\beta_3 LnK_{t-i} + \sum_{t=1}^{k}\beta_4 LnCO_{2t-i} + \varepsilon_t \quad (15)$$

The direction of the causation for the relationship of variables will be tested using a causality test (Sadorsky, 2009; Apergis and Payne 2010a; Al-Mulali, 2014; Pao et al., 2014; Jebli and Youssef, 2015; Kahia et al., 2017). The Granger Causality Wald test (Granger, 1969) will be adopted to determine if there is a unidirectional, bidirectional causality or no causality between two variables. The short run dynamic between variables is being identified within the cointegrated model (Engle and Granger, 1987). The estimated model is formed as follows:

$$\Delta LnX_t = \alpha_1 + \sum_{i=1}^{n}\beta_1\Delta X_{t-1} + \sum_{i=1}^{n}\beta_2\Delta LnREC_{t-1} + \sum_{i=1}^{n}\beta_3\Delta CO_{2t-1} + \sum_{i=1}^{n}\beta_4\Delta K_{t-1} + \sum_{i=1}^{n}\beta_5\Delta L_{t-1} + \varepsilon_t \quad (16)$$

$$\Delta LnREC_t = \alpha_0 + \sum_{i=1}^{n}\beta_1\Delta REC_{t-1} + \sum_{i=1}^{n}\beta_2\Delta LnX_{t-1} + \sum_{i=1}^{n}\beta_3\Delta CO_{2t-1} + \sum_{i=1}^{n}\beta_4\Delta K_{t-1} + \sum_{i=1}^{n}\beta_5\Delta L_{t-1} + \varepsilon_t \quad (17)$$

$$\Delta LnCO_{2t} = \alpha_0 + \sum_{i=1}^{n}\beta_1\Delta CO_{2t-1} + \sum_{i=1}^{n}\beta_2\Delta LnX_{t-1} + \sum_{i=1}^{n}\beta_3\Delta REC_{t-1} + \sum_{i=1}^{n}\beta_4\Delta K_{t-1} + \sum_{i=1}^{n}\beta_5\Delta L_{t-1} + \varepsilon_t \quad (18)$$

$$\Delta LnK_t = \alpha_0 + \sum_{i=1}^{n}\beta_1\Delta K_{t-1} + \sum_{i=1}^{n}\beta_2\Delta LnX_{t-1} + \sum_{i=1}^{n}\beta_3\Delta REC_{t-1} + \sum_{i=1}^{n}\beta_4\Delta CO_{2t-1} + \sum_{i=1}^{n}\beta_5\Delta L_{t-1} + \varepsilon_t \quad (19)$$

$$\Delta LnL_t = \alpha_0 + \sum_{i=1}^{n}\beta_1\Delta L_{t-1} + \sum_{i=1}^{n}\beta_2\Delta LnX_{t-1} + \sum_{i=1}^{n}\beta_3\Delta REC_{t-1} + \sum_{i=1}^{n}\beta_4\Delta CO_{2t-1} + \sum_{i=1}^{n}\beta_5\Delta K_{t-1} + \varepsilon_t \quad (20)$$

The LnX in the equations represents *LnGDP*, *LnIndustry*, *LnService* and *LnAgriculture* to investigate the causality of the overall economy in Malaysia and the GDP contributed by the industry, service and agriculture sectors. The β represents the short run parameters, α equals to a constant, ε represent disturbance term, n represents the number of lags and t equals to the time subscript.

The diagnostic testing involves a range of statistical assessments, including the Breusch-Godfrey serial correlation LM test, Ramsey Regression Equation Specification Error (RESET) test, JB test, Breusch-Pagan-Godfrey test and CUSUM test. This study implements these diagnostic tests to validate the proper specification and robustness of the model across the sample period ranging from the year 1990 to 2022. Such thorough evaluation is essential for ensuring the integrity of the model as a Best Linear Unbiased Estimator (BLUE), thereby enhancing the reliability and validity of the results obtained.

5. EMPIRICAL RESULTS AND DISCUSSION

Table 2 presents the descriptive information of all the variables in log form. The mean growth value of the industry

Table 2: Descriptive statistics of the variables (after logarithm)

Variables	Mean	Median	Max.	Min.	Std. Dev.
LnGDP	27.037	27.899	28.041	25.818	0.6904
LnIndustry	26.241	26.417	27.041	25.092	0.6021
LnService	26.103	26.172	27.458	24.445	0.9537
LnAgriculture	24.968	24.885	25.344	24.482	0.2596
LnREC	1.6584	1.6525	2.4510	0.6729	0.5290
LnCO_2	4.7234	4.8744	5.6735	3.3333	0.7461
LnL	16.048	16.080	16.667	15.388	0.4193
LnK	24.391	24.542	25.166	23.219	0.6005

(26.241) and service (26.103) sectors is higher than the agricultural (24.968) sector. The result suggests that the GDP contributed by the agriculture sector has lower variability compared to the overall economy and the GDP contributed by industry and service sectors. The minimum values of overall economy (25.818), GDP contributed by industry (25.092), service (24.445) and GDP from agriculture (24.482) sectors, with maximum values of 28.041, 27.041, 27.458 and 25.344 respectively, suggest that the overall economy, GDP contributed by industry, service sector and agriculture fluctuated within a concentration around the mean value. The mean value of renewable energy is 1.7, with a standard deviation of 0.5290, suggesting moderate variability. Similarly, renewable energy's minimum and maximum values suggest a concentrated fluctuation around the mean. The mean of carbon dioxide emission (LnCO_2) is 4.7, with a standard deviation of 0.7461, and minimum and maximum values of 5.6735 and 3.3333. This suggests a smaller variability, with a slightly skewed concentration above the mean value as the median value is 4.8744. Capital (24.391) has a higher mean value than labor (16.048), and a higher standard deviation (0.6005) compared to labor (0.4193). This suggests that capital has a relatively higher variability than labor. The minimum and maximum values of capital are 23.219 and 25.166 respectively, while the labor has minimum and maximum value of 15.388 and 16.667. Both variables' results suggest a concentrated fluctuation around the mean value.

Table 3 shows the ADF and the PP test results. For the first specification (intercept), all variables were found to be insignificant at level. Contrarily, both ADF and the PP test results rejected the null hypothesis at a 1% level of significance. Thus, all variables are stationary at the first difference. As such, the model is fit for the ARDL bounds test.

The models for the overall economy and key economic sectors (industry, service, and agriculture) were assessed for long-run cointegration using the ARDL approach (Table 4). For the overall economy model (*LnGDP*), the optimal lag combination, determined by the AIC, was ARDL (3, 4, 2, 0, 3) with a maximum lag order of 4. The F-statistic value of 8.0676 exceeded both the lower bound value of 3.29 and the upper bound value of 4.37 at the 1% significance level, confirming the presence of a long-run cointegration relationship. Similarly, the model for GDP contributed by the industry (*LnIndustry*) had the optimal lag combination ARDL (4, 0, 3, 0, 1), with an F-statistic value of 11.557, also surpassing the critical bounds at the 1% significance level, indicating long-run cointegration.

For the service sector (*LnService*), the optimal lag order was ARDL (1, 5, 4, 5, 2), with a maximum lag of 5. The F-statistic value of 5.8071 was above the critical values of 3.29 and 4.37 at the 1% significance level, suggesting cointegration in the long run. The agricultural sector (*LnAgriculture*) optimal lag combination was identified as ARDL (2, 0, 0, 3, 0), with a maximum lag order of 4. The F-statistic result of 7.9363 exceeded the critical bounds at the 1% significance level, indicating a long-run cointegration relationship. Thus, all four models exhibit long-run cointegration at the 1% significance level.

Based on the results in Table 5, the regression analysis for *LnGDP* model revealed that renewable energy consumption has a positive and significant impact on Malaysia's overall economy. Specifically, a 1% increase in renewable energy consumption is associated with a 0.14% increase in economic growth. This finding aligns with studies by Paramati et al. (2018) and Haseeb et al. (2019) in Malaysia and the G20 nations. Additionally, CO_2 emissions (LnCO_2) show a positive and highly significant effect on Malaysia's GDP, with a 1% increase in CO_2 emissions resulting in a 0.84% increase in economic growth. This is consistent with Mirza and Kanwal (2017) and Rahman et al. (2020) findings, who argued that high economic activities, such as manufacturing and industrial expansion, drive this relationship. However, the results of the factors of production were mixed. Labor (LnL) was found to positively and significantly affect economic growth, with a 1% increase in labor leading to a 0.32% increase in GDP. Conversely, capital (LnK) exhibited a negative sign and was insignificant.

In the *LnIndustry* model, renewable energy consumption was found to have a positive and significant impact on industrial GDP at the 10% significance level. A 1% increase in renewable energy consumption corresponds to a 0.230% increase in industrial GDP. This validates that renewable energy consumption positively contributes to industrial growth, akin to the effects of non-renewable energy (Taasim et al., 2021). CO_2 emissions also positively impact industrial GDP, with a 1% increase in CO_2 emissions leading to a 0.8806% rise in industrial output. In the *LnService* model, renewable energy consumption was found to positively impact GDP contributed by the service sector at the 10% significance level, with a 1% increase in renewable energy consumption linked to a 0.2917% increase in service sector GDP. This positive effect is consistent with the significant share of renewable energy in Malaysia's total energy consumption (50.93% in 2022, Statista, 2023). CO_2 emissions were also found to have a strong positive impact on service sector GDP, with a 1% increase in CO_2 emissions contributing to a 1.5182% increase in service sector output, the largest impact among the three sectors. The high energy consumption in the service sector, driven by urbanization, likely contributes to this relationship (Sikder et al., 2022). While capital (LnK) exhibited a negative impact in *LnIndustry* model, labor (LnL) had a positive but

Table 3: Unit root test result

Variables	ADF		PP		Stationary
	Level	1st Difference	Level	1st Difference	
LnGDP	−1.7001	−5.1485***	−1.7001	−5.1485***	I (1)
LnIndustry	−2.1478	−5.3640***	−2.3747	−5.3763***	I (1)
LnService	−1.4812	−4.1896***	−1.2469	−4.2655***	I (1)
LnAgriculture	−1.3759	−6.3107***	−1.4673	−6.6805***	I (1)
LnCO$_2$	−1.8450	−7.1774***	−1.8450	−7.1324***	I (1)
LnREC	−1.2451	−3.8264***	−1.1626	−3.8207***	I (1)
LnK	−1.4854	−8.6891***	−1.6336	−9.1068***	I (1)
LnL	−2.1624	−6.8888***	−0.6202	−8.0948***	I (1)

The ***/**/* represents stationary at 1%, 5% and 10% significance level respectively.

Table 4: Result of F-bound test

Dependent variable	F-statistic	Level of significance (%)	Lower bound	Upper bound	Long-run relationship
LnGDP	8.0676	10	2.20	3.09	Present
		5	2.56	3.49	
		2.5	2.88	3.87	
		1	3.29	4.37	
LnIndustry	11.557	10	2.20	3.09	Present
		5	2.56	3.49	
		2.5	2.88	3.87	
		1	3.29	4.37	
LnService	5.8071	10	2.20	3.09	Present
		5	2.56	3.49	
		2.5	2.88	3.87	
		1	3.29	4.37	
LnAgriculture	7.9363	10	2.20	3.09	Present
		5	2.56	3.49	
		2.5	2.88	3.87	
		1	3.29	4.37	

Table 5: ARDL test results for overall economy, *LnIndustry, LnService* and *LnAgriculture* Model

Variables	*LnGDP*	*LnIndustry*	*LnService*	*LnAgriculture*
LnREC	0.1434**	0.2299*	0.2917*	0.0143
	(0.0116)	(0.0544)	(0.0767)	(0.7561)
LnCO$_2$	0.8390***	0.8806***	1.5182**	−0.0555
	(0.000)	(0.0054)	(0.0345)	(0.5507)
LnK	−0.0549	0.2208**	−0.3677	0.0863**
	(0.3444)	(0.0342)	(0.1254)	(0.0268)
LnL	0.3204**	0.2373	0.3417	−0.3795
	(0.0389)	(0.2996)	(0.6465)	(0.3522)
C	19.212***	−0.0220	22.013	0.0318**
	(0.000)	(0.3877)	(0.1246)	(0.0256)

The ***/**/* represents long run significance at 1%, 5% and 10% significance level respectively.

insignificant impact. These results were similar to those of Ciobanu (2020) and Solarin and Bello (2015) findings on labour and capital, respectively.

Finally, the *LnAgriculture* model revealed that renewable energy consumption has a positive but insignificant impact on agricultural GDP. This may be due to the agriculture sector's minimal energy consumption of 1.1% of total energy consumption in Malaysia (Suruhanjaya Tenaga, 2021), suggesting that renewable energy might not significantly affect sector productivity. CO2 emissions had a negative but insignificant impact on agricultural GDP, in line with Raihan et al. (2022), who argued that energy use and CO_2 emissions in sectors like industry, transportation, and electricity are more critical to overall energy consumption than agriculture. However, capital (LnK) had a significant positive impact on agricultural GDP, with a 1% increase in capital leading to a 0.0863% increase in agricultural output. In contrast, labor (LnL) had a negative but insignificant impact on agricultural GDP at the 10% significance level.

Overall, while renewable energy consumption and CO_2 emissions have varying degrees of influence across sectors, having the largest positive impact on the service sector and an insignificant impact on the agriculture sector, the results highlight sector-specific dynamics and underline the need for tailored energy policies to foster sustainable growth in Malaysia's diverse economic sectors.

The results from Table 6 indicate that the LnGDP model shows an insignificant causal relationship from economic growth (LnGDP) to renewable energy consumption (LnREC). However, LnREC demonstrates a significant causal relationship with economic growth (LnGDP) at the 5% significance level. This suggests a unidirectional causality running from renewable energy consumption to economic growth. The findings provide evidence supporting the growth hypothesis proposed by Ozturk (2010), indicating that renewable energy consumption contributes to overall economic growth.

Table 6: VEC Granger Causality/Block Exogeneity Wald Tests

Dependent Variable	Excluded				
Overall economy					
	LnGDP	LnREC	$LnCO_2$	LnK	LnL
LnGDP	-	11.292** (0.0102)	18.563*** (0.003)	12.341*** (0.0063)	9.6206** (0.0221)
LnREC	1.5160 (0.6786)	-	7.8681** (0.0488)	4.6226 (0.2016)	5.1219 (0.1631)
$LnCO_2$	7.0753* (0.0695)	3.5619 (0.3128)	-	3.4938 (0.3216)	10.532** (0.0145)
LnK	17.291*** (0.0006)	8.6684** (0.0340)	7.1470* (0.0674)	-	12.452*** (0.0060)
LnL	12.679*** (0.0054)	2.9419 (0.4007)	4.2315 (0.2375)	2.3904 (0.4954)	-
***LnIndustry* Model**					
Dependent Variable	**Excluded**				
	LnIndustry	*LnREC*	*$LnCO_2$*	*LnK*	*LnL*
LnIndustry	-	2.1918 (0.1387)	4.9489** (0.0261)	0.2121 (0.6451)	0.2142 (0.6435)
LnREC	0.0023 (0.9618)	-	6.9323*** (0.0085)	4.1101** (0.0426)	18.228*** (0.0001)
$LnCO_2$	1.8750 (0.1709)	0.8562 (0.3548)	-	0.3222 (0.5703)	3.5013* (0.0613)
LnK	3.3961* (0.0654)	0.1850 (0.6671)	2.7281* (0.0986)	-	0.7563 (0.3845)
LnL	0.1985 (0.6559)	0.5692 (0.4506)	0.5689 (0.4507)	0.1125 (0.7373)	-
***LnService* Model**					
Dependent Variable	**Excluded**				
	LnService	*LnREC*	*$LnCO_2$*	*LnK*	*LnL*
LnService	-	2.2060 (0.3319)	7.2630** (0.0265)	2.0072 (0.3666)	0.8273 (0.6612)
LnREC	5.2910* (0.0710)	-	15.045*** (0.0005)	9.4960*** (0.0087)	10.034*** (0.0066)
$LnCO_2$	1.6848 (0.4307)	0.2561 (0.8794)	-	0.7623 (0.6831)	4.3560 (0.1133)
LnK	2.7400 (0.2541)	1.8704 (0.3925)	0.3339 (0.8462)	-	1.0577 (0.5893)
LnL	9.9150*** (0.0070)	3.3661 (0.1858)	1.6496 (0.4383)	2.3865 (0.3032)	-
***LnAgriculture* Model**					
Dependent Variable	**Excluded**				
	LnAgriculture	*LnREC*	*$LnCO_2$*	*LnK*	*LnL*
LnAgriculture	-	1.1856 (0.2762)	0.1006 (0.7512)	4.5097** (0.0337)	3.7646* (0.0523)
LnREC	1.0303 (0.3101)	-	15.907*** (0.0001)	4.4775** (0.0343)	9.0879*** (0.0026)
$LnCO_2$	0.0362 (0.8490)	0.4527 (0.5011)	-	0.3383 (0.5608)	1.9273 (0.1651)
LnK	0.7612 (0.3829)	0.0462 (0.8298)	0.1614 (0.5879)	-	1.4540 (0.2279)
LnL	7.0889*** (0.0078)	0.2058 (0.6500)	3.2382* (0.0719)	0.2924 (0.5887)	-

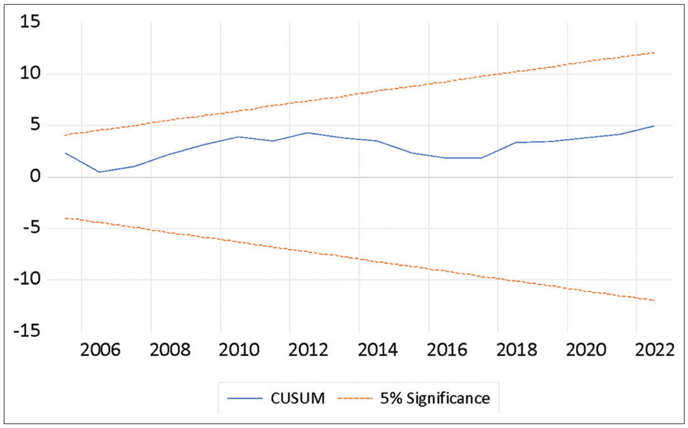
The ***/**/* represents significant causality at 1%, 5% and 10% significance level respectively.

In the *LnIndustry* model, the results indicate that no causality relationship exists between renewable energy consumption (LnREC) and industrial GDP (*LnIndustry*). However, a unidirectional causality runs from CO_2 emissions to industrial GDP (*LnIndustry*) at the 5% significance level. These findings support the neutrality hypothesis by Ozturk (2010), as there is no causal link between renewable energy consumption and industrial output.

The *LnService* model shows a significant causality relationship from service sector output (*LnService*) to renewable energy consumption (LnREC) at the 10% significance level, indicating a unidirectional causality from service sector output to renewable energy consumption. This result aligns with the conservation hypothesis proposed by Ozturk (2010), suggesting that the service sector's output drives renewable energy consumption.

Finally, the *LnAgriculture* model reveals no causal relationship between renewable energy consumption (LnREC) and agricultural GDP (*LnAgriculture*), nor does agricultural GDP influence renewable energy consumption. These findings further support the neutrality hypothesis by Ozturk (2010), indicating that renewable energy consumption does not have a causal effect on agricultural output.

Figure 1: CUSUM test for overall economy model



Similar to the ARDL findings, the results highlight that the relationships between the variables differ across the overall economy and sectoral models, reinforcing the importance of developing targeted policies for each economic sector.

To ensure that the models used are a reasonable fit and free from robustness issues, a series of diagnostic tests were conducted to examine autocorrelation, specification errors, heteroskedasticity, and the stability of the models. These diagnostic tests were applied to the four models representing the overall economy, industry, services, and agriculture sectors. The results of the diagnostic tests are presented in Table 7 and Figures 1-4. The findings show that all four models fall within the acceptable range for the Durbin-Watson test (1.5 to 2.5). Additionally, the models meet the 5% significance level criterion for the CUSUM test. The results also support the acceptance of the null hypothesis for the Ramsey RESET test, Jarque-Bera test, LM test, and BPG test. These outcomes indicate that the models are free from issues such as autocorrelation, structural breaks, specification errors, non-normality, serial correlation, and heteroskedasticity, thereby confirming that the results are robust and reliable.

Table 7: Diagnostic tests results

LM test			
Dependent variables	**F-statistic**	**P-value**	**Result**
Overall Economy Model	0.8097	0.5394	No serial correlation
Industry Model	0.0450	0.9561	No serial correlation
Service Model	0.5250	0.4826	No serial correlation
Agriculture Model	0.0405	0.9604	No serial correlation
Durbin Watson test			
Dependent variable	**Statistic**		**Result**
Overall Economy Model	1.5<2.4145<2.5		Within range
Industry Model	1.5<1.8894<2.5		Within range
Service Model	1.5<2.1544<2.5		Within range
Agriculture Model	1.5<2.0038<2.5		Within range
Ramsey RESET test			
Dependent variable	**F-statistic**	**P-value**	**Result**
Overall Economy Model	0.8422	0.4114	No specification error
Industry Model	2.6374	0.1193	No specification error
Service Model	0.8905	0.3639	No specification error
Agriculture Model	0.0460	0.8318	No specification error
Jarque Bera test			
Dependent variable	**F-Statistic**	**P-value**	**Result**
Overall Economy Model	3.5597	0.1687	Normally Distributed
Industry Model	0.2927	0.8638	Normally Distributed
Service Model	1.7926	0.4081	Normally Distributed
Agriculture Model	0.9115	0.6340	Normally Distributed
Breusch-Pagan-Godfrey test			
Dependent variables	**F-statistic**	**P-value**	**Result**
Overall Economy Model	0.8166	0.6555	Homoskedasticity
Industry Model	1.2338	0.3221	Homoskedasticity
Service Model	0.7815	0.7316	Homoskedasticity
Agriculture Model	1.0319	0.4401	Homoskedasticity

Figure 2: CUSUM test for industry model

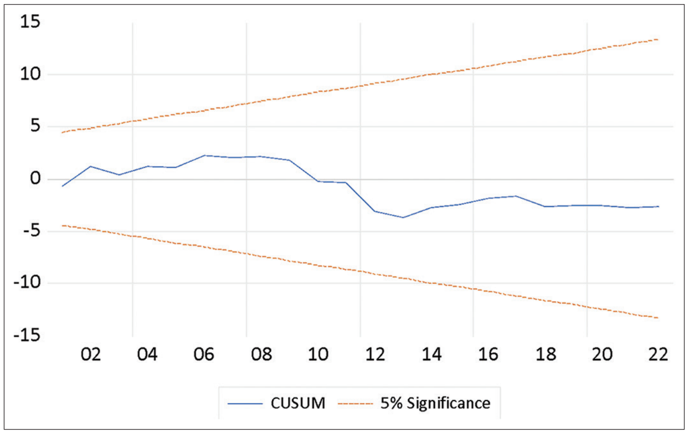


Figure 3: CUSUM test for service model

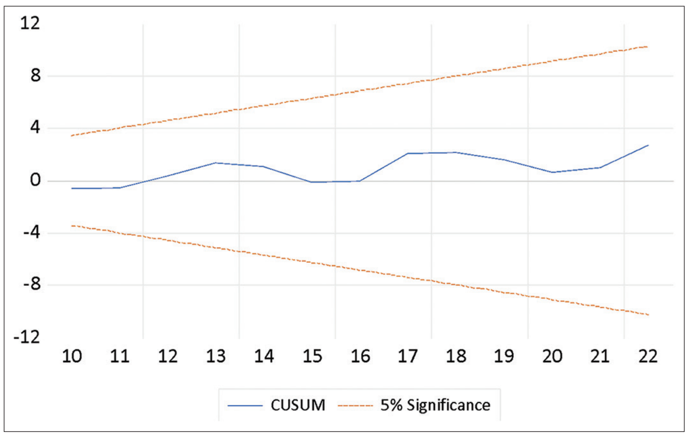
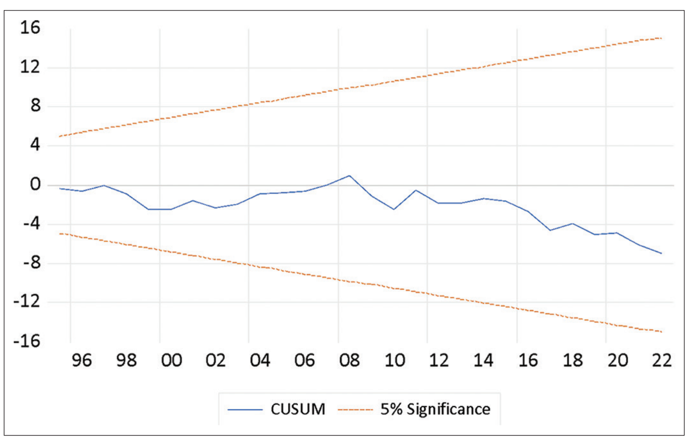


Figure 4: CUSUM test for agriculture model



6. CONCLUSION AND POLICY IMPLICATIONS

This study examined the impact of the renewable energy consumption long-term impact on Malaysia's economy, both at the overall economic level (GDP) and at the sectoral level, encompassing industry, service and agriculture. The ARDL results revealed a significant and positive long-run impact of renewable energy consumption on the overall Malaysia's economy, which supports the proposition of using renewable energy as an alternative to replace non-renewable energy, even if it is more expensive (Afroz and Muhibbullah 2022; Saidi and Omri 2020). The long-term positive effect of the renewable energy consumption aligns with Paramati et al. (2018) and Haseeb et al. (2019) findings in Malaysia and the G20 nations. Hence, it is proven that renewable energy improves both environmental quality and contributes to economic growth. In addition, this study also investigates the relationship between the variables in the short run using the Granger Causality test. The findings revealed a unidirectional causal relationship running from the direction of renewable energy consumption towards the Malaysia's economy, supporting the growth hypothesis, which indicated that the renewable energy consumption's growth and development can positively impact Malaysia's economy (Hasanove et al., 2017; Ozcan and Ozturk. 2019; Chontanawat, 2020; Aslan et al., 2022).

Nevertheless, the results from the three economic sectors provided varies results relative to the overall economy. Firstly, the findings from ARDL test signified that renewable energy consumption impose a positive and significant impact on industrial and service sectors output but has not significant impact on agricultural sector output. The insignificant impact on the agricultural sector might be due to the low energy consumption in the agricultural sector, which accounts for only 1.1% of total energy consumption (Suruhanjaya Tenaga, 2021).

Besides, the Granger causality Wald test shows that there is no causality between renewable energy consumption and industrial GDP contributed by the industry, supporting the neutrality hypothesis (Omri et al., 2015; Alper and Oguz, 2016; Ozcan and Ozturk, 2019; Aslan et al., 2022). Meanwhile, the regression found a unidirectional causality running from the direction of the service sector output to renewable energy consumption, supporting the conservation hypothesis (Kahia et al., 2016; Alper and Oguz, 2016; Raihan and Tuspekova, 2022). Finally, the Wald test implied that there is no causality between renewable energy consumption and GDP contributed by the agricultural sector, supporting neutrality hypothesis (Omri et al., 2015; Alper and Oguz, 2016; Ozcan and Ozturk, 2019; Aslan et al., 2022).

The findings from this study across various economic sectors highlight several key policy implications that are vital for Malaysia's transition towards renewable energy. Notably, the industry and service sectors were found to benefit more significantly from renewable energy consumption than the agricultural sector. As a result, the Malaysian government must take a proactive approach to developing the renewable energy industry to facilitate energy transition. This should include prioritizing investment in research and development, enhancing financing mechanisms, and formulating policies that foster the expansion of renewable energy-related infrastructure, particularly in the industry and service sectors, which are among the largest consumers of energy in the country. The current policies, including the National Energy Policy 2022-2050 (DTN), the Twelfth Malaysia Plan 2021-2025 and the National Energy Transition Roadmap (NETR) 2023, are insufficient to fully lay out and execute a comprehensive energy transition strategy (Ministry of Economy, 2023). There is a pressing need for these policies to be more robust and targeted to support renewable energy growth across the key sectors of the economy.

Furthermore, the unidirectional causality observed from the service sector output to renewable energy consumption underscores the important role that economic activities in sectors such as retail businesses, tourism, banking, and finance play in driving renewable energy development. This indicates that the expansion of economic activities in these areas is closely tied to an increase in renewable energy consumption. The Granger causality results also revealed that capital in the industry, service, and agricultural sectors is crucial for fostering renewable energy consumption, highlighting the importance of capital investment in supporting energy transition. Therefore, the Malaysian government should implement programs and policies designed to attract and ensure sufficient capital investment in these sectors, while simultaneously encouraging technological advancements. Such investments will create new opportunities for employment and business growth, improve renewable energy infrastructure, and contribute to reducing Malaysia's carbon footprint.

In the agricultural sector, which is still largely dependent on traditional farming methods, there is an urgent need to invest in modern technologies and more efficient agricultural practices (Ministry of Agriculture and Food Industry, 2021). The government's focus should be on providing targeted training programs and subsidies to improve the sector's technological adoption and productivity. This will not only increase the sector's competitiveness but will also support the broader goal of reducing the carbon footprint and enhancing sustainability. Additionally, investments in agricultural capital, such as machinery, automated systems, and improved crop management technologies, are essential for boosting productivity and ensuring long-term growth in the agricultural sector. The ARDL findings reinforce the importance of capital investments in this sector, highlighting its potential to significantly enhance the sector's performance in the long term.

Additionally, to support the growth of both the economy and the renewable energy industry, the Malaysian government should focus on increasing the employment rate and ensuring better compensation for workers in these sectors. According to the NETR (2023), the transition from traditional energy sources to renewable energy is expected to generate significant job opportunities. To fully capitalize on this, the government must invest in developing a highly skilled workforce by enhancing training programs that are aligned with the emerging needs of various sectors, particularly those related to renewable energy technologies. Policies aimed at enhancing the skills and mobility of labor across sectors will be crucial for maintaining economic competitiveness, especially in energy-intensive industries. Furthermore, offering competitive wages and improving labor market conditions will help retain skilled workers and reduce the risk of brain drain, particularly in the context of the service sector and industries reliant on specialized knowledge.

In conclusion, the formulation and implementation of targeted policies that cater to the specific needs of key economic sectors, namely, industry, service, and agriculture, will not only contribute to environmental preservation but will also drive Malaysia's long-term economic growth. By fostering a sustainable energy transition through strategic investments, skill development, and robust policy frameworks, Malaysia can achieve a balanced approach to economic development, renewable energy adoption, and environmental sustainability. These efforts will ensure that Malaysia remains competitive in the global economy while advancing towards a greener, more sustainable future.

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