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Article

# Unlocking the Path to Sustainable Energy: An Analysis of Factors Influencing Renewable Energy Consumption in Malaysia

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## Abstract

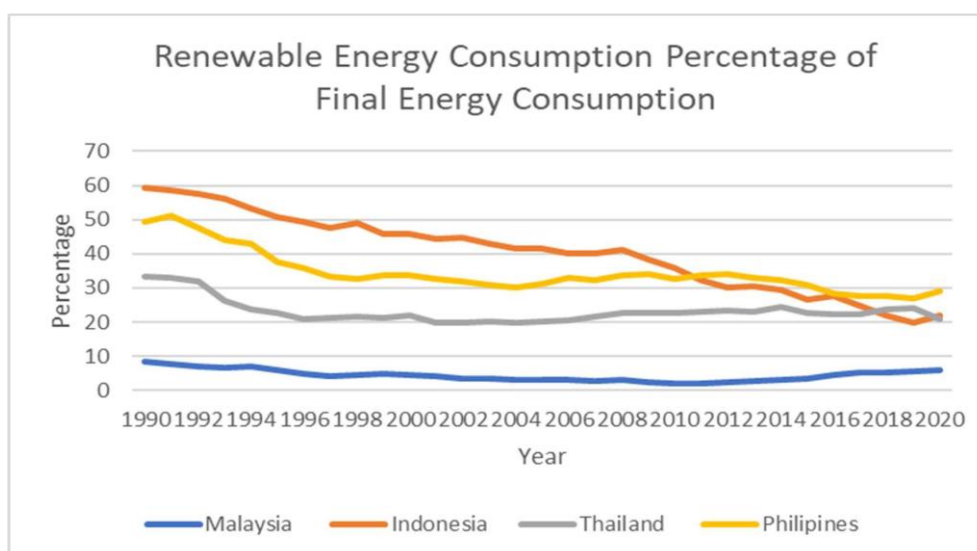
The paper seeks to determine whether renewable energy is a future pathway for society or rather a temporary stage leading towards sustainable sources of energy. It evaluates the factors that affect the use of renewable energy in Malaysia through modeling their long-term relationship and short-term causalities. Time series data collected from 1970 to 2020 is used in the Johansen cointegration test and Vector Error Correction Model (VECM) to determine the association among renewable energy consumption, per capita GDP, foreign direct investments (FDI), carbon dioxide (CO<sub>2</sub>) emissions, oil prices, trade openness, and urbanization. There is evidence of a strong positive long-term association between renewable energy consumption and per capita GDP. However, there is evidence of a negative long-term relationship between renewable energy and FDI, CO<sub>2</sub> emissions, oil prices, and urbanization. There is a positive relationship between renewable energy consumption and trade openness in the long term. In addition, short-term causality analysis shows the existence of a feedback loop between renewable energy consumption, economic growth, and FDI. Overall, the paper provides empirical evidence for the carbon-neutral target set by Malaysia in 2050.

**Keywords:** renewable energy consumption; carbon emissions; macroeconomic determinants; urbanization; Malaysia

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## 1. Introduction

Tackling the pressing issue of global warming is of paramount importance because it directly affects the well-being of humanity. Global warming is responsible for the irreversible loss of crucial resources, the occurrence of droughts and floods, disruptions in ecosystems, and threats to human lives (Calleja-Agius, England, & Calleja, 2021; Solaun & Cerdá, 2019). Despite its detrimental effects, many countries continue to heavily depend on fossil fuels and coal due to their cost-effectiveness (Shaari et al., 2022; Shaari et al., 2021; Ridzuan et al., 2022). Utilizing natural resources including hydropower, sun, wind, bioenergy, waves, geothermal, and tide power, renewable energy (Olabi & Abdelkareem, 2022), is considered by some experts to be a potent solution for curbing carbon emissions and mitigating environmental pollution (Ergün et al., 2019; Kumaran et al., 2020).



**Figure 1.** Renewable Energy Consumption as Percentage of Final Energy Consumption Year 1990-2020 (Source: WDI).

According to Figure 1, Malaysia has the lowest renewable energy consumption among the ASEAN-4 countries, which includes Indonesia, the Philippines, and Thailand. The comparison among these four developing nations, including Malaysia, is pertinent due to their geographical proximity and competitive nature. Malaysia experiences competition due to other countries around them that show greater per capita use of renewable energy. However, Malaysia's per capita use of renewable energy stands at 5.84% compared to 28% for the Philippines, even after implementing various policies and incentives to increase renewable energy usage (Kumaran et al., 2020). Malaysia encounters many challenges in shifting to renewable energy sources. While the Malaysian government's objectives remain intact, the utilization rate of renewable energy as part of the country's energy mix remains unchanged at 7.24% between 2015 and 2018 (Sayed et al., 2021).

Furthermore, Malaysia's heavy reliance on foreign energy is a significant threat to its energy security and economic stability due to expectations of increased costs of energy globally—specifically crude oil, natural gas, and coal (U.S. Energy Information Administration). The threat is further complicated by the likelihood of political instability such as the Iran crisis of 2026, which resulted in the closure of the Strait of Hormuz, affecting about 20% of the world's oil supply and leading to increased inflation worldwide by up to 0.8% (Wikipedia, 2026). As illustrated by the figures found in Malaysia Energy Statistical Handbook 2023, Malaysia's dependency on foreign energy in 2019 was 100% for coal and coke, 55.2% for petroleum products, 38.1% for crude oil, 16.3% for piped natural gas, and 4% for liquefied natural gas (LNG). Therefore, developing renewable energy capacity is crucial in reducing Malaysia's dependency on non-renewable energy sources.

Resources of Crude Oil and Condensates By Region					Resources of Natural Gas by Region										
Year	PENINSULAR MALAYSIA				TOTAL	PENINSULAR			SABAH			SARAWAK			Grand Total
	Associated	Non Associated	Total	Associated		Non Associated	Total	Associated	Non Associated	Total					
1990	2.943	0.000	0.000	2.943	6.080	21.350	27.430	1.030	1.320	2.350	3.310	23.840	27.150	56.930	
1991	3.045	0.000	0.000	3.045	6.200	21.320	27.520	0.980	1.380	2.360	3.400	25.770	29.170	59.050	
1992	3.743	0.604	1.267	5.614	6.700	22.500	29.200	1.100	1.800	2.900	3.800	31.900	35.700	67.800	
1993	4.279	0.631	1.205	6.115	7.800	23.900	31.700	1.700	3.000	4.700	3.800	36.600	40.400	76.800	
1994	2.500	0.600	1.200	4.300	7.900	26.600	34.500	1.200	2.900	4.100	4.200	37.900	42.100	80.700	
1995	2.455	0.590	1.067	4.112	8.200	28.000	36.200	1.300	6.000	7.300	4.200	37.000	41.200	84.700	
1996	2.500	0.600	0.900	4.000	8.300	28.300	36.600	1.200	4.900	6.100	4.300	33.200	37.500	80.200	
1997	2.700	0.470	0.680	3.850	8.900	29.400	38.300	1.200	4.800	6.000	3.000	32.500	35.500	79.800	
1998	2.440	0.580	0.860	3.880	8.900	27.700	36.600	1.200	4.900	6.100	3.700	40.600	44.300	87.000	
1999	2.080	0.510	0.830	3.420	8.500	25.900	34.400	1.100	6.600	7.700	3.800	39.900	43.700	85.800	
2000	1.920	0.620	0.850	3.390	8.400	25.300	33.700	1.300	6.700	8.000	3.400	37.400	40.800	82.500	
2001	1.920	0.620	0.850	3.390	8.400	25.300	33.700	1.300	6.700	8.000	3.400	37.400	40.800	82.500	
2002	2.100	0.780	1.340	4.230	8.400	24.900	33.300	1.200	6.800	8.000	3.400	42.600	46.000	87.300	
2003	2.040	1.210	1.300	4.550	8.500	23.900	32.400	1.800	8.100	9.900	4.000	42.700	46.700	89.000	
2004	1.980	1.430	1.420	4.830	9.520	21.740	31.260	1.880	7.750	9.630	3.380	42.750	46.130	87.020	
2005	1.770	1.970	1.560	5.300	9.200	21.590	30.790	2.500	8.230	10.730	3.130	40.540	43.670	85.190	
2006	1.791	2.129	1.334	5.254	9.650	23.170	32.820	2.750	8.210	10.960	2.930	41.240	44.170	87.950	
2007	1.452	1.975	0.889	4.316	9.440	24.030	33.470	3.137	8.461	11.598	3.008	40.850	43.858	88.926	
2008	1.719	2.424	1.315	5.458	9.269	24.190	33.459	3.584	9.132	12.716	2.861	38.974	41.835	88.010	
2009	1.781	2.348	1.388	5.517	9.153	24.079	33.232	3.523	8.578	12.101	2.908	39.727	42.635	87.968	
2010	2.061	2.376	1.362	5.799	9.280	25.139	34.419	3.787	8.681	12.468	2.513	39.187	41.700	88.587	
2011	2.374	1.992	1.492	5.858	9.797	25.337	35.134	3.327	8.638	11.965	3.033	39.856	42.889	89.988	
2012	2.413	1.941	1.600	5.954	9.594	26.144	35.738	3.502	9.801	13.303	3.180	39.901	43.081	92.122	
2013	2.335	1.923	1.592	5.850	9.325	25.649	34.974	3.764	9.454	13.218	3.330	46.798	50.128	98.320	
2014	2.341	1.855	1.566	5.762	9.688	25.242	34.930	3.724	10.029	13.753	3.024	48.955	51.979	100.662	
2015	2.205	2.009	1.693	5.907	8.471	24.022	32.493	3.149	11.884	15.033	2.853	50.034	52.887	100.413	
2016	1.735	1.925	1.370	5.030	6.793	20.428	27.221	2.521	10.915	13.436	1.770	45.336	47.106	87.763	
2017	1.669	1.767	1.290	4.726	6.333	19.327	25.660	1.487	11.060	12.547	1.508	43.184	44.692	82.899	
2018	1.612	1.637	1.304	4.553	6.422	17.266	23.688	2.078	10.504	12.582	1.507	41.754	43.261	79.531	
2019	1.476	1.497	1.702	4.675	6.428	15.219	21.647	2.054	9.611	11.665	1.419	44.436	45.855	79.167	
2020	1.306	1.451	1.770	4.527	5.701	14.612	20.313	1.605	8.945	10.550	1.151	43.248	44.399	75.262	
2021	1.292	1.342	1.796	4.430	5.885	14.362	20.247	1.518	8.157	9.675	1.971	44.139	46.110	76.032	

**Figure 2.** Crude Oil and Natural Gas Reserve in Malaysia (Source: Malaysia Energy Statistical Handbook 2023 pg.9&10).

Figure 2 depicts the reserves of crude oil and natural gas. As can be seen from Figure 2, both reserves demonstrate a downward trend during the observed period. It should be noted that there is a short-term increase in the reserves of non-renewable energy sources, namely crude oil and natural gas, from 2018 to 2019. However, this temporary increase cannot offset the general depletion trend and, therefore, raises questions regarding energy security. The decrease in the reserves of crude oil (2015–2021) and natural gas (2014–2020), depicted in Figure 2, are critical indicators for encouraging Malaysia to think about renewable energy.

This study enhances the existing literature in multiple significant aspects. Empirically, it offers extensive long-term time-series evidence (1970–2020) about the factors influencing renewable energy use in Malaysia, rectifying discrepancies in previous research and presenting novel insights into energy transition dynamics within the ASEAN framework. Methodologically, the study utilizes a Vector Error Correction Model (VECM) to concurrently identify long-term equilibrium linkages and short-term causal dynamics, facilitating a more robust and dynamic evaluation of the energy-growth nexus than traditional single-equation methods. The findings of the study theoretically disclose intricate and unconventional relationships, notably the adverse effects of foreign direct investment and the influence of structural factors like urbanisation and oil prices, thereby contesting the presumption that economic integration and growth inherently facilitate the adoption of renewable energy. Overall, the study offers policy-relevant evidence on how emerging economies, such as Malaysia, might strategically transition to renewable energy amidst present geopolitical threats and structural hurdles to attain long-term energy sustainability and carbon neutrality goals.

## 2. Literature Review

In the past few decades, extensive studies have examined the interrelationship between renewable energy use and various determinants, such as gross domestic product per capita, foreign direct investments (FDI), carbon dioxide (CO<sub>2</sub>) emissions, crude oil prices, trade openness, and urbanization. The empirical findings, however, have been inconsistent in terms of geographical location and methodology employed. As an illustration, Hoa, Xuan, and Thu (2023) found a positive link between renewable energy consumption and GDP for Japan, Korea, Singapore, Hong Kong, Israel, and China, implying that the respective nations focus on the efficient utilization of energy resources and the increasing use of renewables during their development process to minimize the

reliance on fossil fuels. Conversely, Li et al. (2020) noted that high income levels were associated with increased use of non-renewable energy in OECD countries through the CS-ARDL model for the period from 1990 to 2017. Likewise, Oluoch et al. (2021) discovered that income constraints limited renewable energy uptake among 23 Sub-Saharan African countries because fossil fuels were relatively cheaper than renewable energy. On the other hand, Wang et al. (2022) identified an inverted-U shape in Pakistan, which means that renewable energy consumption first decreases with economic growth and later increases with the importance of sustainability.

Besides the income effect, other dimensions of the role played by foreign direct investments (FDI) in renewable energy consumption have been widely discussed in scientific literature. Hoa, Xuan, and Thu (2023) confirm the positive impact of renewable energy consumption on FDI because, in their opinion, foreign investments make it possible for investors to gain access to financial capital, innovations, and international markets. The same pattern was found by Tiwari et al. (2022), who confirmed that the effect of FDI on renewable energy adoption is evident in 16 Asian countries, especially under circumstances when countries lack financial resources. On the contrary, in the study of Mohamed Yusoff et al. (2023), FDI leads to negative results in Malaysia due to the fact that the majority of funds received from foreign investors goes into fossil fuels industry. Finally, Shahbaz et al. (2022) discovered a U-shaped effect in 39 countries around the world.

The link between renewable energy usage and environmental quality with regard to CO<sub>2</sub> emissions is ambiguous. According to Nguyen and Kakinaka (2019), there exists a positive long-term connection between the two variables in developing and emerging economies, which shows the continuous use of fossil fuels at the early stage of development. On the other hand, da Silva et al. (2018) and Assi, Isiksal, and Türsoy (2021) found a negative correlation between the use of renewable energy and CO<sub>2</sub> emissions in Sub-Saharan Africa and ASEAN+3 nations, respectively, highlighting the advantage of reducing emissions from renewable energy usage. Conversely, Karacan et al. (2021) found no correlation in Russia, indicating that the environmental effect of renewable energy might be different depending on the specific energy system of individual nations.

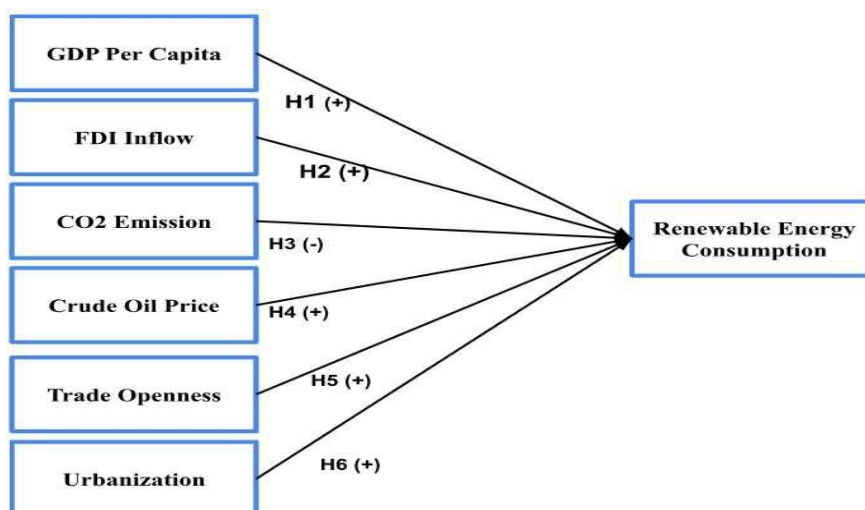
Likewise, energy price factors play a crucial role in the consumption of renewable energy sources. For instance, Li et al. (2020) found that oil prices and renewable energy consumption were positively correlated in the OECD economies, while according to Zaghdoudi et al. (2023), an increase in oil prices positively influenced renewable energy consumption in China. However, higher oil prices could negatively affect renewable energy consumption, as observed in Russia and Azerbaijan by Karacan et al. (2021) and Mukhtarov et al. (2020).

Trade openness, another important determiner, also shows mixed results in various studies. Nabaweesi et al. (2023) prove that more trade openness encourages technology transfers and ensures better availability of renewable energy technologies; thus, it leads to an increase in renewable energy use among the East African Community. On the contrary, Kumaran et al. (2020) find a negative impact of trade openness on the demand for renewable energy for the selected Asian economies like Indonesia, Malaysia, Philippines, and Thailand due to their dependence on pollution-inducing energy resources for industrial development.

Finally, the impact of urbanization on renewable energy use is still not well-defined. According to Kumaran et al. (2020), there exists a positive correlation between renewable energy consumption and urbanization, implying that urbanization promotes the use of efficient and renewable forms of energy. However, according to Huang et al. (2022) and Dingru et al. (2023), there exist negative correlations because urbanization leads to an increase in energy demands, which are usually met using traditional energy sources since renewable energy sources are relatively expensive.

### 3. Data and Methodology

#### 3.1. Framework



#### 3.2. Hypothesis Development

**Table 1.** Hypothesis Testing and Reference.

Hypothesis	References
H1: Long-term GDP per capita and renewable energy consumption are positively correlated.	Oluoch et al. (2021), da Silva et al. (2018), Manni & Mansur (2024), Assi, Isiksal, & Türsoy (2021), Hoa, Xuan, & Thu (2023), Chen et al. (2021), Li et al. (2020), Ergün & Rivas (2023)
H2: Long-term FDI and renewable energy consumption are positively correlated.	Nabaweesi et al. (2023), Huang, Ahmad, and Ali (2022), Hoa, Xuan, and Thu (2023), Ergün et al. (2019), Tiwari et al. (2022), Dingru et al. (2023), Shahbaz et al. (2022)
H3: Long-term CO2 and renewable energy consumption are negatively correlated.	Manni and Mansur (2024), Oluoch et al. (2021), da Silva et al. (2018), Gözgör et al. (2020), Mohamed Yusoff et al. (2023), Olanrewaju et al. (2019), Karacan et al. (2021), Mukhtarov et al. (2020), Deniz (2019)
H4: Long-term Crude Oil and renewable energy consumption are positively correlated.	Chen et al. (2021), Gözgör et al. (2020), Zaghdoudi et al. (2023), Zhou et al. (2023), Deniz (2019)
H5: Long-term Trade Openness and renewable energy consumption are positively correlated.	Kumaran et al. (2020), Nabaweesi et al. (2023), Chen et al. (2021), Yahya and Rafiq (2019), Deniz (2019), Mohamed Yusoff et al. (2023), Tiwari et al. (2022), Dingru et al. (2023)
H6: Long-term Urbanization and renewable energy consumption are positively correlated.	Nabaweesi et al. (2023), Kumaran et al. (2020), Mohamed Yusoff et al. (2023), Akintande et al. (2020)

#### 3.3. Data Description

In this empirical research, we used secondary data which is time series data to examine the relationship between GDP per Capita, FDI Inflows, CO2 Emission, Crude Oil Price, Trade Openness, Urbanization between renewable energy consumption. The data is collected from World Bank Indicator and Our World In Data from Year 1970 to 2020 which is 51 year on annual basic.

**Table 2.** Data Sources.

Variables	Abbreviation	Description	Source
Renewable Energy Consumption	REC	Primary renewable energy consumption is measured in terawatt-hours (TWh)	Our World In Data
Gross Domestic Product Per Capita	GDP	GDP per capita (current US\$)	World Bank Indicator
Foreign Direct Investment Inflows	FDI	Foreign direct investment, net inflows (BoP, current US\$)	World Bank Indicator
CO2 Emission	CO2	CO2 emissions (metric tons per capita)	World Bank Indicator
Crude Oil Price	OP	Crude oil prices (current US\$ per cubic meter)	World Bank Indicator
Trade Openness	TO	Trade (% of GDP)	World Bank Indicator
Urbanization	UG	Urban population growth (Population %)	World Bank Indicator

### 3.4. Estimation of the Model

$$\ln \text{REC}_t = \beta_0 + \beta_1 \ln \text{GDP}_t + \beta_2 \ln \text{FDI}_t + \beta_3 \ln \text{CO2}_t + \beta_4 \ln \text{OP}_t + \beta_5 \ln \text{TO}_t + \beta_6 \ln \text{UG}_t + \epsilon_t \quad (1)$$

where

$\ln \text{REC}$  = Renewable Energy Consumption (in natural logarithmic form)

$\ln \text{GDP}$  = GDP per capita (in natural logarithmic form)

$\ln \text{FDI}$  = Foreign Direct Investment Inflows (in natural logarithmic form)

$\ln \text{CO2}$  = CO2 Emission per capita (in natural logarithmic form)

$\ln \text{OP}$  = Crude Oil Price (in natural logarithmic form)

$\ln \text{TO}$  = Trade Openness (in natural logarithmic form)

$\ln \text{UG}$  = Urbanization (in natural logarithmic form)

$\beta_0$  = Constant/ Intercept

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$  = Parameters of the estimate

$\epsilon_t$  = Error term

### 3.5. Empirical Model

The REC, GDP, FDI, CO2, OP, TO, and UG variables' stationarity is evaluated using the Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests. It is essential for these variables to exhibit non-stationarity in levels and stationarity at first differences,  $I(1)$ , as a prerequisite before proceeding with the Johansen and Juselius multivariate cointegration test. Cointegration exists when the variables are integrated of the same order and there is a stationary linear combination of them.

#### 3.5.1. Johansen and Juselius Multivariate Cointegration Test

The Johansen and Juselius (1990) Multivariate cointegration test is utilised to examine whether there is a long-run relationship between the dependent variable ( $\ln \text{REC}$ ) and independent variables ( $\ln \text{GDP}$ ,  $\ln \text{FDI}$ ,  $\ln \text{CO2}$ ,  $\ln \text{OP}$ ,  $\ln \text{TO}$  and  $\ln \text{UG}$ ) using trace and maximum eigenvalue statistics.

#### 3.5.2. Granger-Causality test within Vectors Error-Correction Modelling (VECM)

Upon establishing the cointegration of the variables, the Vector Error Correction Model (VECM) can be employed. Granger causality tests within the VECM framework are then used to study the causal relationships among the variables as below:

$$\begin{aligned} \Delta \ln REC_t = & a_1 + \sum_{i=1}^k \varphi_{1i} \Delta \ln REC_{t-1} + \sum_{i=1}^k \theta_{1i} \Delta \ln GDP_{t-1} + \sum_{i=1}^k \delta_{1i} \Delta \ln FDI_{t-1} \quad (2) \\ & + \sum_{i=1}^k \gamma_{1i} \Delta \ln CO2_{t-1} + \sum_{i=1}^k \omega_{1i} \Delta \ln OP_{t-1} + \sum_{i=1}^k \beta_{1i} \Delta \ln TO_{t-1} \\ & + \sum_{i=1}^k \vartheta_{1i} \Delta \ln UG_{t-1} + \lambda_{1\epsilon t-1} + \mu_{1t} \end{aligned}$$

$$\begin{aligned} \Delta \ln GDP_t = & a_2 + \sum_{i=1}^k \varphi_{2i} \Delta \ln REC_{t-1} + \sum_{i=1}^k \theta_{2i} \Delta \ln GDP_{t-1} + \sum_{i=1}^k \delta_{2i} \Delta \ln FDI_{t-1} \quad (3) \\ & + \sum_{i=1}^k \gamma_{2i} \Delta \ln CO2_{t-1} + \sum_{i=1}^k \omega_{2i} \Delta \ln OP_{t-1} + \sum_{i=1}^k \beta_{2i} \Delta \ln TO_{t-1} \\ & + \sum_{i=1}^k \vartheta_{2i} \Delta \ln UG_{t-1} + \lambda_{2\epsilon t-1} + \mu_{2t} \end{aligned}$$

$$\begin{aligned} \Delta \ln FDI_t = & a_3 + \sum_{i=1}^k \varphi_{3i} \Delta \ln REC_{t-1} + \sum_{i=1}^k \theta_{3i} \Delta \ln GDP_{t-1} + \sum_{i=1}^k \delta_{3i} \Delta \ln FDI_{t-1} \quad (4) \\ & + \sum_{i=1}^k \gamma_{3i} \Delta \ln CO2_{t-1} + \sum_{i=1}^k \omega_{3i} \Delta \ln OP_{t-1} + \sum_{i=1}^k \beta_{3i} \Delta \ln TO_{t-1} \\ & + \sum_{i=1}^k \vartheta_{3i} \Delta \ln UG_{t-1} + \lambda_{3\epsilon t-1} + \mu_{3t} \end{aligned}$$

$$\begin{aligned} \Delta \ln CO2_t = & a_4 + \sum_{i=1}^k \varphi_{4i} \Delta \ln REC_{t-1} + \sum_{i=1}^k \theta_{4i} \Delta \ln GDP_{t-1} + \sum_{i=1}^k \delta_{4i} \Delta \ln FDI_{t-1} \quad (5) \\ & + \sum_{i=1}^k \gamma_{4i} \Delta \ln CO2_{t-1} + \sum_{i=1}^k \omega_{4i} \Delta \ln OP_{t-1} + \sum_{i=1}^k \beta_{4i} \Delta \ln TO_{t-1} \\ & + \sum_{i=1}^k \vartheta_{4i} \Delta \ln UG_{t-1} + \lambda_{4\epsilon t-1} + \mu_{4t} \end{aligned}$$

$$\begin{aligned} \Delta \ln OP_t = & a_5 + \sum_{i=1}^k \varphi_{5i} \Delta \ln REC_{t-1} + \sum_{i=1}^k \theta_{5i} \Delta \ln GDP_{t-1} + \sum_{i=1}^k \delta_{5i} \Delta \ln FDI_{t-1} \\ & + \sum_{i=1}^k \gamma_{5i} \Delta \ln CO2_{t-1} + \sum_{i=1}^k \omega_{5i} \Delta \ln OP_{t-1} + \sum_{i=1}^k \beta_{5i} \Delta \ln TO_{t-1} \\ & + \sum_{i=1}^k \vartheta_{5i} \Delta \ln UG_{t-1} + \lambda_{5\epsilon t-1} + \mu_{5t} \end{aligned} \quad (6)$$

$$\begin{aligned} \Delta \ln TO_t = & a_6 + \sum_{i=1}^k \varphi_{6i} \Delta \ln REC_{t-1} + \sum_{i=1}^k \theta_{6i} \Delta \ln GDP_{t-1} + \sum_{i=1}^k \delta_{6i} \Delta \ln FDI_{t-1} \\ & + \sum_{i=1}^k \gamma_{6i} \Delta \ln CO2_{t-1} + \sum_{i=1}^k \omega_{6i} \Delta \ln OP_{t-1} + \sum_{i=1}^k \beta_{6i} \Delta \ln TO_{t-1} \\ & + \sum_{i=1}^k \vartheta_{6i} \Delta \ln UG_{t-1} + \lambda_{6\epsilon t-1} + \mu_{6t} \end{aligned} \quad (7)$$

$$\begin{aligned} \Delta \ln UG_t = & a_7 + \sum_{i=1}^k \varphi_{7i} \Delta \ln REC_{t-1} + \sum_{i=1}^k \theta_{7i} \Delta \ln GDP_{t-1} + \sum_{i=1}^k \delta_{7i} \Delta \ln FDI_{t-1} \\ & + \sum_{i=1}^k \gamma_{7i} \Delta \ln CO2_{t-1} + \sum_{i=1}^k \omega_{7i} \Delta \ln OP_{t-1} + \sum_{i=1}^k \beta_{7i} \Delta \ln TO_{t-1} \\ & + \sum_{i=1}^k \vartheta_{7i} \Delta \ln UG_{t-1} + \lambda_{7\epsilon t-1} + \mu_{7t} \end{aligned} \quad (8)$$

where  $\ln REC_t$  is the logarithmic form of renewable energy consumption in Malaysia at time  $t$ ,  $\ln GDP_t$  is the logarithmic form of GDP per capita of Malaysia (a proxy of Malaysian economic growth) at time  $t$ ,  $\ln FDI_t$  is the logarithmic form of foreign direct investment inflows of Malaysia at time  $t$ ,  $\ln CO2_t$  is the logarithmic form of CO2 emission of Malaysia at time  $t$ ,  $\ln OP_t$  is the logarithmic form of oil price at time  $t$ ,  $\ln TO_t$  is the logarithmic form of trade openness of Malaysia at time  $t$ ,  $\ln UG_t$  is the logarithmic form of urbanisation in Malaysia at time  $t$ ,  $\alpha$  is the intercept,  $\varphi$ ,  $\theta$ ,  $\delta$ ,  $\gamma$ ,  $\omega$ ,  $\beta$  and  $\vartheta$  are the coefficients of the independent variables of the regression,  $\lambda$  is the error correction coefficient,  $\epsilon_{t-1}$  is the error correction term and  $\mu$  is an error term of the regression.

#### 4. Result and Discussion

Table 3. Unit Root Test Results.

	Augmented Dickey-Fuller (ADF) Test			
	Levels		First Difference	
	Intercept	Trend & Intercept	Intercept	Trend & Intercept
$\ln REC$	0.2555 (0)	-1.8903 (0)	-5.5882 (1)***	-5.6199 (1)***

<b>lnGDP</b>	-2.5336 (1)	-2.7065 (0)	-5.4924 (0)***	-5.8583 (0)***
<b>lnFDI</b>	-2.3576 (1)	-3.1313 (4)	-7.7922 (1)***	-7.7737 (1)***
<b>lnCO2</b>	-1.4019 (0)	-1.7342 (0)	-9.0266 (0)***	-9.1181 (0)***
<b>lnOP</b>	-1.5190 (4)	-2.8244 (0)	-6.5498 (0)***	-6.6612 (0)***
<b>lnTO</b>	-1.9679 (1)	-0.4522 (0)	-5.2737 (0)***	-5.6884 (0)***
<b>lnUG</b>	1.8249 (1)	-0.3385 (0)	-5.0910 (0)***	-6.0375 (0)***
<b>Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Test</b>				
	<b>Levels</b>		<b>First Difference</b>	
	<b>Intercept</b>	<b>Trend&amp; Intercept</b>	<b>Intercept</b>	<b>Trend&amp; Intercept</b>
<b>lnREC</b>	0.8913 (5)***	0.1977 (1)**	0.1308 (4)	0.0824 (5)
<b>lnGDP</b>	0.9438 (5)***	0.1369 (5)*	0.3332 (4)	0.0773 (2)
<b>lnFDI</b>	0.8779 (5)***	0.1275 (3)*	0.1941 (15)	0.0243 (1)
<b>lnCO2</b>	0.9454 (5)***	0.1853 (5)**	0.2176 (2)	0.0658 (4)
<b>lnOP</b>	0.7275 (5)**	0.1549 (1)**	0.2234 (0)	0.0977 (1)
<b>lnTO</b>	0.5288 (5)**	0.2233 (5)**	0.5360 (0)	0.1113 (1)
<b>lnUG</b>	0.7569 (5)***	0.2406 (5)***	0.3462 (20)	0.0765 (1)

Notes: Asterisk (\*\*\*), (\*\*) and (\*) denote significant at 1%, 5% and 10% levels, respectively.

Based on the results shown in Table 3, both Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests indicate that all the time series variables employed in the study are non-stationary at their levels but stationary at their first difference, or I(1) variables. Since all the time series variables are integrated in the same order of 1, I(1), the study proceeds to analyse the cointegration between the variables using Johansen and Julius Cointegration Test.

**Table 4.** Johansen-Juselius Cointegration Test.

Trace Test: lnREC, lnGDP, lnFDI, lnCO2, lnOP, lnTO, lnUG (k = 2, r = 1)			
H <sub>0</sub>	H <sub>1</sub>	$\lambda$ -trace	95% CV
r = 0	r ≥ 1	181.8353**	125.6154
r ≤ 1	r ≥ 2	42.62581	47.85613
r ≤ 2	r ≥ 3	23.61112	29.79707
r ≤ 3	r ≥ 4	6.879682	15.49471
Maximum Eigenvalue Test: lnREC, lnGDP, lnFDI, lnCO2, lnOP, lnTO, lnUG (k = 2, r = 1)			
H <sub>0</sub>	H <sub>1</sub>	$\lambda$ -max	95% CV
r = 0	r = 1	52.05042**	46.23142
r ≤ 1	r = 2	19.01469	27.58434
r ≤ 2	r = 3	16.73144	21.13162
r ≤ 3	r = 4	6.874316	14.26460

Notes: Asterisk (\*\*) denotes significant at 5% level, k is the number of lag and r is the number of cointegration vector. The null hypothesis of r = 0 is rejected at 5% significant level against its alternative r = 1, However, the hypothesis of r < 1 cannot be rejected at the same level of significance.

Table 4 presents the results of the Johansen-Juselius Cointegration test, indicating that there is only one cointegrated relationship between renewable energy consumption and its influencing variables, as evidenced by both Trace and Max-Eigen test statistics. This implies that renewable energy consumption and the identified factors move together in the long run, reflecting a long-run linear equilibrium.

$$\ln \text{REC}_t = -15.3476 + 2.7360 \ln \text{GDP}_t - 0.2773 \ln \text{FDI}_t - 3.8058 \ln \text{CO2}_t - 1.2243 \ln \text{OP}_t + 4.0522 \ln \text{TO}_t - 4.9145 \ln \text{UG}_t \quad (9)$$

<i>t-stat</i>	[7.6812]***	[-4.1228] ***	[-6.3912]***	[-8.9790]***
[8.3149]***	[-10.1878]***			

Note: Asterisks (\*\*\*) denote significance at 1% level.

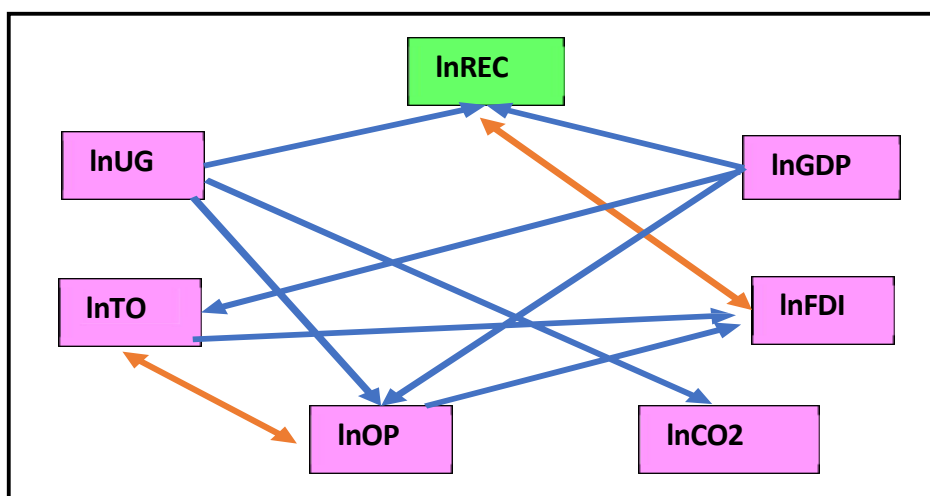
The long-run estimates presented in Eq. (9) reveal statistically significant relationships at the 1% level between renewable energy consumption (REC) and its key determinants. GDP exerts a positive effect on REC, where a 1% increase in GDP leads to a 2.736% rise in REC. The result concurs with previous research studies by Assi et al. (2021); Chen et al. (2021); da Silva et al. (2018); Dingru et al. (2023); Gozgor et al. (2020); Hoa et al., 2023; Li et al., 2020; Manni & Hj. Md. Mansur, 2024; Mohamed Yusoff et al. (2023), which show that economic growth is a critical factor in increasing energy consumption and promoting investment in renewable energy. On the other hand, foreign direct investment (FDI) has a negative and significant influence on the REC because a 1% increment in FDI lowers the REC by 0.2773%. The trend is supported by previous studies by Assi et al. (2021); da Silva et al. (2018); Manni & Hj. Md. Mansur, 2024; Nguyen & Kakinaka (2019); Raihan & Tuspekova (2022) as investors are often attracted by traditional energy sectors due to the lack of motivation to invest in renewable energy technologies. In addition, CO<sub>2</sub> emissions have a negative impact on the REC because a 1% decline in the level of CO<sub>2</sub> emissions increases REC by 3.8058%, which shows that renewable energy has the potential to minimize environmental degradation. Oil prices (lnOP) also exert a negative and significant impact on renewable energy, with a 1% increment in oil prices decreasing REC by 1.2243%, in line with Karacan et al. (2021); Mukhtarov et al. (2020); and Deniz (2019). Such findings can possibly be explained by the existence of various government subsidies that decrease the motivation to switch from fossil fuels to renewable energy.

Apart from this, another determinant that influences the REC positively is trade openness (lnTO). Consistent with the studies of Chen et al. (2021) and Nabaweesi et al. (2023), when there is a 1% increase in trade openness, there is a 4.0522% increase in REC. Such an outcome can be attributed to the fact that trade enables individuals to access advanced renewable energy technologies and save on costs. At the same time, urbanisation (lnUG) is another important determinant that has a negative and significant impact on the level of REC. With a 1% increase in urbanisation, REC is reduced by 4.9145% due to increased expenses and difficulties in implementing such technologies in cities that mainly depend on conventional energy sources.

**Table 5.** Granger Causality Test based on Vector Error Correction Model (VECM).

Dependent Variables	2-statistic (p-value)							ECTs	
	$\Delta$ REC	$\Delta$ LGDP	$\Delta$ FDI	$\Delta$ CO <sub>2</sub>	$\Delta$ LOP	$\Delta$ LTO	$\Delta$ LUG	Coefficient	t-statistic
$\Delta$ REC	-	2.904 (0.088)*	4.169 (0.041)**	0.947 (0.330)	0.099 (0.753)	0.301 (0.583)	3.714 (0.054)*	-0.150	-1.723**
$\Delta$ LGDP	0.008 (0.927)	-	0.165 (0.685)	0.702 (0.402)	2.661 (0.103)	0.184 (0.668)	1.123 (0.289)	-0.111	-1.858**
$\Delta$ FDI	2.787 (0.095)*	1.405 (0.236)	-	0.255 (0.613)	3.820 (0.051)*	2.784 (0.095)*	0.103 (0.749)	-0.914	-2.009**
$\Delta$ CO <sub>2</sub>	0.050 (0.824)	0.628 (0.428)	0.235 (0.628)	-	0.063 (0.801)	0.118 (0.731)	3.953 (0.047)**	-0.041	-1.084
$\Delta$ LOP	1.374 (0.241)	8.344 (0.004)***	0.072 (0.789)	0.914 (0.339)	-	3.156 (0.076)*	3.386 (0.066)*	-0.599	-4.530***
$\Delta$ LTO	1.166 (0.280)	5.543 (0.019)**	0.666 (0.415)	2.236 (0.135)	7.776 (0.005)***	-	0.313 (0.576)	0.018	0.565
$\Delta$ LUG	0.255 (0.614)	0.650 (0.420)	0.297 (0.586)	0.418 (0.518)	1.752 (0.186)	2.102 (0.147)	-	0.006	0.293

Notes: Asterisk (\*\*\*) , (\*\* ) and ( \* ) denote significant at 1% , 5% and 10% levels, respectively.  $\Delta$  is the first different operator.



**Figure 3.** The Short-run Granger Causality Effect.

Notes:

→ represents one-way direction of Granger causality effect among the variables in the short run.

↔ represents two-way direction of Granger causality effect among the variables in the short run.

Boxes in green color is dependent variable (DV) and Pink Color is independent variable (IVs)

Further complementing the long-term perspective, Table 5 provides information on the Granger causality between the variables under investigation, thus providing some additional insight regarding their dynamic interaction. According to the results presented in Figure 3, InGDP Granger-causes InREC, InTO, and InOP, thus confirming its significant impact on the formation of both energy demand and economic environment. Additionally, InFDI Granger-causes InREC, whereas InOP and InTO Granger-cause InFDI, suggesting interdependence between foreign capital flows and economic conditions. Moreover, InUG Granger-causes InREC, InCO<sub>2</sub>, and InOP. Mutual (bidirectional) causality exists between InREC and InFDI, as well as between InTO and InOP, thus proving the existence of short-term feedback mechanisms.

Bidirectional causality between REC and FDI implies that these two factors are interdependent. On the one hand, high REC levels might facilitate an inflow of FDI as a result of environmental sustainability and compliance with ESG principles (Chen et al., 2023). On the other hand, FDI can stimulate the use of renewable energy due to policy measures and incentives, such as Malaysia's Renewable Energy Roadmap (MyRER), as well as the Green Investment Tax Allowance (GITA) and Green Income Tax Exemption (GITE) (ShineWing TY TEOH, 2024). Unidirectional causality between GDP per capita and REC confirms the importance of economic growth for increasing the share of renewable energy, which is consistent with the findings of Mohamed Yusoff et al. (2023) and Manni and Mansur (2024). Finally, causality between urbanisation and REC proves that urbanisation patterns affect energy preferences, albeit negatively in the long run. This highlights the importance of strengthening green urban policies, such as sustainable building standards and low-carbon initiatives, to support Malaysia's transition towards carbon neutrality by 2050 (Kumaran et al., 2020; Kaur, 2023; AQ Energy, 2024).

## 5. Conclusion

This paper investigates the determinants of renewable energy consumption in Malaysia using a Vector Error Correction Model (VECM) to examine both long-run relationships and short-run causal dynamics. The results indicate that GDP per capita and renewable energy consumption have a positive long-run relationship, as well as short-run causality. In contrast, foreign direct investment (FDI) and renewable energy consumption are negatively related to each other in the long-run while exhibiting bidirectional short-run causality. Besides, while trade openness is found to have a significant positive long-run impact on renewable energy consumption, CO<sub>2</sub> emissions and oil prices are found to have a negative long-run relationship. Lastly, the variable of urbanisation is positively associated with a negative long-run relationship and short-run causality for renewable energy consumption.

On the basis of the results of empirical analysis, it would be useful to consider a set of policy recommendations to help Malaysia achieve its aim of becoming carbon-neutral by 2050. Specifically, since FDI and renewable energy consumption have a bidirectional short-run causality, the Malaysian government should develop an incentive mechanism to attract FDI in green technologies, as exemplified in 2023 through collaboration of YTL Power International and NVIDIA. Secondly, the importance of integrating renewable energy technologies in urban areas in Malaysia must be considered in line with Malaysia's national standards of green buildings, for instance, the Green Building Index (GBI) and GreenRE. Thirdly, the influence of GDP per capita implies the need for economic growth as well as strong fiscal capacity. Consequently, efficient collection of taxes is crucial to support renewable energy generation. Fourthly, increased trade openness will allow for a smoother process of transferring technologies.

Despite its contributions, it would be necessary to mention a number of limitations associated with the study. In particular, the country-specific focus of the research in Malaysia may restrict the generalisability and robustness of the results. Additionally, there may be omitted variable bias as some of the factors have not been incorporated into the model (e.g., technological innovation, policy incentives), and the VECM model relies on a linear assumption that might not hold true in reality. Moreover, structural breaks and shocks were not controlled for. Therefore, further research in this area could benefit from incorporating more variables, applying non-linear models, and comparing results across countries to provide more comprehensive insights into the determinants of renewable energy consumption.

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