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The Impact of Low-Carbon Fuel Consumption on Public Debt in Malaysia

(Kesan Penggunaan Bahan Bakar Rendah Karbon Terhadap Hutang Awam di Malaysia)

Amri Sulong
Politeknik Seberang Perai

Mohd Shahidan Shaari
Universiti Malaysia Sarawak

Noorazeela Zainol Abidin
Universiti Malaysia Perlis

Zulkefly Abdul Karim
Universiti Kebangsaan Malaysia

ABSTRACT

Low-carbon fuel consumption is essential for reducing greenhouse gas emissions, combating climate change, and preserving the planet's natural resources for future generations. Any country that seeks to achieve this goal requires strong financial capability. However, due to financing constraints and the fiscal demands of other sectors, countries often have to rely on debt sources. Thus, using the two-gap model, this study investigated the impact of low-carbon fuel consumption on public debt in Malaysia from 1980 to 2021. The Autoregressive Distributed Lag (ARDL) approach was employed for both long-run and short-run analyses of two models. The first model included trade openness, investment, foreign direct investment, domestic savings, low-carbon fuel consumption, and exchange rate, while the second model incorporated exchange rate, foreign direct investment, investment, renewable energy, and trade openness. Findings from the first model indicated that low-carbon fuel consumption does not significantly affect public debt in the long run but has a significant positive impact in the short run. In the second model, it was found that renewable energy significantly increases public debt in the long run. In the short run, the exchange rate and foreign direct investment exhibit significant positive and negative effects on public debt, respectively. The results highlight the varying impacts of different types of energy consumption and economic variables on public debt over different time horizons. The policy implications point to the necessity to enhance low-carbon and renewable energy policies, balance fiscal and environmental policies, encourage energy efficiency and green technology investments, and investigate innovative financing options like public-private partnerships and green bonds. Additionally, cost-benefit analysis, long-term planning, constant observation, and international collaboration are essential to ensure sustainable energy transition can be achieved without exacerbating the public debt burden and compromising national fiscal stability.

Keywords: Low-carbon fuel; public debt; investment; savings; foreign direct investment

ABSTRAK

Penggunaan bahan bakar rendah karbon adalah penting untuk mengurangkan pelepasan gas rumah hijau, menangani perubahan iklim, serta memelihara sumber semula jadi bumi untuk generasi akan datang. Mana-mana negara yang ingin mencapai matlamat ini memerlukan keupayaan kewangan yang kukuh. Namun begitu, disebabkan oleh kekangan pembiayaan dan keperluan perbelanjaan sektor lain, negara sering terpaksa bergantung pada sumber hutang. Oleh itu, dengan menggunakan model dua jurang (two-gap model), kajian ini meneliti kesan penggunaan bahan bakar rendah karbon terhadap hutang awam di Malaysia dari tahun 1980 hingga 2021. Pendekatan autoregresif lag tertabur (autoregressive distributed lag, ARDL) telah digunakan untuk analisis jangka panjang dan jangka pendek bagi dua model. Model pertama merangkumi keterbukaan perdagangan, pelaburan, pelaburan langsung asing, simpanan domestik kasar, penggunaan bahan bakar rendah karbon, dan kadar pertukaran, manakala model kedua melibatkan kadar pertukaran, pelaburan langsung asing, pelaburan, tenaga boleh diperbaharui dan keterbukaan perdagangan. Penemuan daripada model pertama menunjukkan bahawa penggunaan bahan bakar rendah karbon tidak mempengaruhi hutang awam dengan signifikan dalam jangka panjang, namun mempunyai kesan positif yang signifikan dalam jangka pendek. Dalam model kedua, didapati bahawa tenaga boleh diperbaharui meningkatkan hutang awam dengan signifikan dalam jangka panjang. Dalam jangka pendek, kadar pertukaran dan pelaburan langsung asing masing-masing menunjukkan kesan positif dan negatif yang signifikan terhadap hutang awam. Keputusan ini mengetengahkan kesan berbeza oleh pelbagai jenis pembolehubah tenaga dan ekonomi terhadap hutang awam mengikut tempoh masa yang berlainan. Implikasi dasar menekankan keperluan untuk memperkukuh dasar rendah karbon dan tenaga boleh diperbaharui, menyelaras dasar fiskal dengan dasar alam sekitar, menggalakkan pelaburan dalam kecekapan tenaga dan teknologi hijau, dan meneroka

pembiayaan inovatif seperti perkongsian awam-swasta dan bon hijau. Selain itu, analisis kos-faedah, perancangan jangka panjang, berterusan, dan kerjasama antarabangsa adalah penting bagi memastikan peralihan tenaga lestari dapat dicapai tanpa meningkatkan beban hutang awam dan menjejaskan kestabilan fiskal negara.

Kata kunci: Bahan bakar rendah karbon; hutang awam; pelaburan; simpanan; pelaburan langsung asing

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INTRODUCTION

Public debt has become a concern for countries worldwide. The United Nations Conference on Trade and Development (2023) reported that global public debt has surged to over four times its level in 2000 and far surpassed global GDP growth, reaching a record $92 trillion in 2022. High public debt can harm a country in many ways. For example, it slows economic growth and worsens inequality, as more money is spent on interest while less is left for vital services like healthcare and education. Excessive debt can also make borrowing more expensive and limit a government's ability to respond to crises, risking the country's financial stability. In Malaysia, the significant issue of public debt has attracted attention from academia, politics, and the media. Data from the Ministry of Finance shows a substantial debt increase over the past five decades, from RM5 billion in 1970 to RM1 trillion in 2023. The rising proportion of public debt as a percentage of GDP (see Figure 1) further signals a growing burden relative to economic output. This underlines the necessity for Malaysia to enact prudent fiscal policies and effective debt management practices for long-term financial stability and sustainable economic growth.

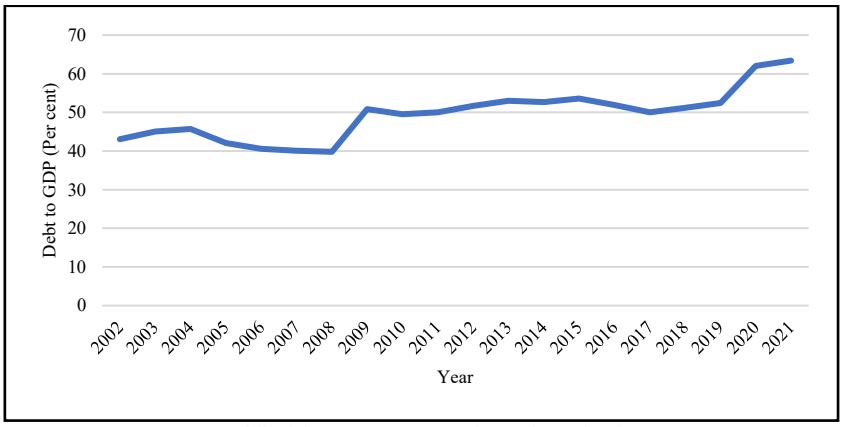

FIGURE 1. Public debt as a percentage of GDP in Malaysia

Shifting to renewable low-carbon energy systems can foster economic recovery and fiscal resilience, especially considering that Malaysia's fuel reserves may be depleted by 2035. In 2017 alone, Malaysia's transportation sector consumed 873,072 terajoules of energy, largely from non-renewable sources. By producing less carbon emissions than traditional fossil fuels like coal and oil (International Energy Forum 2023), low-carbon fuels can reduce energy costs, revitalize sectors, combat climate change, boost profitability, and trim government spending. Correspondingly, efforts are underway in Malaysia to promote low-carbon fuel consumption and explore renewable diesel, aiming to enhance environmental conditions and safety (Chia et al. 2022). Specifically, the country has implemented four diversification strategies involving oil, gas, coal, and hydro resources (Rahim & Liwan 2012). Figure 2 illustrates Malaysia's energy consumption trends for fuel, coal, and gas from 1980 to 2020, measured in thousands of tons of oil equivalent (ktoe). Fuel consumption steadily increased until 2000, then decreased with some fluctuation. The post-2000 decline can be attributed to factors like enhanced energy efficiency and a shift to cleaner sources. Meanwhile, coal consumption rose until the early 1990s, stabilized, then decreased. Gas consumption grew steadily until the mid-2000s, with a sharp rise from 2016 to 2018. Thus, natural gas serves as a practical and effective means to reduce overall carbon intensity in energy systems.

Notwithstanding its long-term benefits, shifting to low-carbon fuel consumption demands hefty investments in new infrastructure and technology (Bulkot et al. 2024), along with generous subsidies for cleaner energy initiatives (International Energy Agency 2021). This initial financial burden can strain short-term fiscal concerns, as governments must juggle funding for green initiatives with other priorities. They often resort to borrowing, which escalates public debt. Case in point, the Malaysian Investment Development Authority (MIDA) projected energy transition costs to reach RM 637 billion in 2023. Amid ongoing economic uncertainties and previous fiscal deficits, such large-scale investments would elevate public debt. It is thus likely that the growth trends in gas consumption and public debt are interconnected. Specifically, gas consumption increases public debt by compelling governments to borrow more to fund energy subsidies,

infrastructure projects, and pro-environmental efforts. This potential correlation makes it is imperative to examine the impact of low-carbon fuel consumption on public debt in the Malaysian setting.

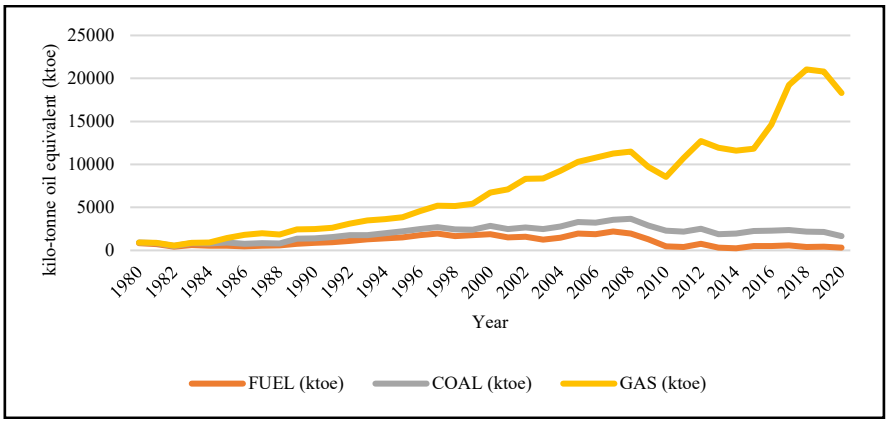

FIGURE 2. Gas, coal, and oil consumption in Malaysia

Prior research has primarily focused on national factors or specific country categories as predictors of public debt. For instance, Briceño and Perote (2020) studied factors like gross domestic product (GDP), interest rates, and unemployment, while Dawood et al. (2021) analyzed exchange rates and government expenditure. In Greece, Badarkas et al. (2022) explored public debt in relation to annual budgets and military spending, whereas Soh et al. (2021) investigated government efficiency and corruption as determinants of public debt across various economies. In the case of Malaysia, Zulkifli et al. (2022) reported that increasing public debt stems from development financing needs, despite the country's tendency to strictly avoid seeking financial assistance from the International Monetary Fund (IMF), even in the face of severe financial crises like that of 1997.

However, scholars have largely overlooked the influence of low-carbon fuel consumption on public debt, revealing a gap in the literature. Among the few that exist, Zhou et al. (2021) examined this relationship in the UK, finding a debt cost increase from 1.5% to 7.5%. In China, Bei and Wang (2023) highlighted the high initial outlay required to adopt low-carbon fuel. This raises a question mark for Malaysia, which has been in a budget deficit for over a decade (Hashemi-Nabi et al. 2021). In light of the crucial role played by energy consumption in effective debt management and environmental policy, this study contributes to the public debt analytical discourse by addressing how low-carbon fuel consumption impacts debt levels. Understanding this link is vital in the context of climate change commitments and fiscal responsibility. Moreover, assessing the long-term fiscal consequences of low-carbon fuel policies is essential because its consumption can stimulate renewable energy sectors, support job creation and economic growth, and potentially reduce deficit spending. At the global level, insights into the broader impact of low-carbon fuel consumption can inform policy formulation and international cooperation towards climate change mitigation, thus allowing countries to achieve sustainable development while managing public finances responsibly.

THEORETICAL BACKGROUND AND LITERATURE REVIEW

THEORETICAL BACKGROUND

Three main theories generally arise in public debt discourse, with the suitability of each depending on the context being discussed. First, there is the two-gap model, originally proposed by Chenery and Strout in 1966. This model underscores two critical gaps hindering the development of less developed nations: (i) the disparity between a country's savings and the necessary investment for growth; and (ii) the imbalance between a nation's earnings from exports and its expenditure on imports. The latter is known as the trade gap, which can lead to borrowing due to insufficient funds for essential imports. This model considers both internal factors (e.g., savings and investment) and external factors (e.g., trade openness), all of which collectively shape a nation's debt accumulation and development trajectory.

The debt overhang theory, on the other hand, was introduced by Myers (1977) to describe the negative effect of debt as "overhang." The theory explains that excessive borrowing can harm a country's economy by obstructing investments in critical sectors that are essential for growth, such as education, healthcare, and infrastructure. When a nation's debt becomes burdensome, allocating resources to repay old debts limits funds available for new projects, consequently slowing economic progress. Additionally, concerns about repayment can lead to higher interest rates, exacerbating the debt challenge. Essentially, this theory emphasizes that while borrowing can be beneficial, excessive debt can impede a country's development, akin to carrying a heavy burden on the path to economic growth.

Third, the crowding-out theory, developed by John Maynard Keynes in 1936, explains how extensive government borrowing and high public debt levels impact an economy. The more heavily a government borrows, the less the funds

available for individuals and businesses, leading to "crowding out." The competition for funds raises interest rates, hindering business investments and consumer spending. In short, this theory suggests that government borrowing can limit opportunities for others, resulting in higher interest rates and slower economic growth.

LITERATURE REVIEW

Existing literature has identified several factors that influence the level of public debt in a country, including exchange rates, foreign direct investment (FDI), gross domestic savings (GDS), investment, and trade openness. For example, Silva and Vernengo's (2007) study in Latin America focused on interest rates and foreign exchange as determinants of public debt, revealing a negative correlation between the exchange rate and public debt. This finding is consistent with that of Eichengreen and Luengnaruemitchai (2004), who identified that an appreciated exchange rate boosts profits in other sectors, reducing the nation's reliance on debt; consequently, they concluded that there is a negative relationship between the exchange rate and public debt. However, Forslund et al. (2011) found contradictory results, as they observed no significant relationship between exchange rates and public debt in the case of emerging and developing economies. They also included GDP and inflation as other variables in their study. Meanwhile, Özata (2017) and Wahyuni et al. (2019) indicated that exchange rates positively affect countries' public debt.

Other research endeavors on public debt have delved into the driving role of GDS, characterized by Khan et al. (2017) as the aggregate savings of the public, private, and household sectors. However, the literature on this relationship is marked by divergent findings. Luke and Joanna (2008) found that private savings decrease state debt across multiple nations. In the context of Pakistan, Chaudhry et al. (2009) revealed how the close nexus between savings and income jointly mitigates the reliance on public debt, while Rais and Anwar (2012) postulated that augmented private savings can amplify revenue streams and diminish public debt. Likewise, Onafowora and Owoye's (2019) exploration of the Caribbean context identified that savings can bolster human capital and profitability, thus decreasing public debt. The negative savings-debt link has been corroborated by evidence from Arize et al. (2014) in the USA, Aliyu and Usman (2013) in Nigeria, Bhatta and Mishra (2020) in Nepal, Soares et al. (2020) in Europe, Chigeto (2017) in Ethiopia, Ngangchi et al. (2022) in Cameroon, Obeidat et al. (2022) in Jordan, and Peterman and Sager (2018) in select countries. Notably, studies employing the Autoregressive Distributed Lag (ARDL) methodology, including those authored by Jagadeesh (2015), Adamu and Rasiah (2016), and Ozata (2017), consistently unveiled an inverse relationship between GDS and state debt. On the other hand, Akram (2011) stated that savings heighten the imperative for public debt by compounding the budget deficit, while Saungweme and Odhiambo (2019) uncovered no association between savings and governmental debt in Zambia.

Apart from exchange rates and savings, scholarly investigations by researchers like Asghar et al. (2022), Danish et al. (2022), Hilton (2021), Fatás et al. (2019), and Tiruneh (2004) have contributed unique insights into the interplay between public debt and investment. Employing the Generalized Method of Moments technique, Veiga and Veiga (2014) reported a positive correlation between investment and public debt, while Mendonca and Brito (2021), Dawood et al. (2021), and Sulong et al. (2024) observed a contrasting negative association using the same technique. In a parallel vein, several studies have established a negative relationship between investment and public debt by utilizing the panel fixed effect regression method. Among them, Salotti (2012) scrutinized 20 economies under the Organization for Economic Co-operation and Development (OECD), Babu et al. (2014) delved into the East Africa community, Abbas and Wizarat (2018) focused on South Asia, Alzahrani (2018) extended their examination to ASEAN and G7 nations, and Anyanwu (2021) conducted a comprehensive inquiry spanning 16 developing Asia Pacific countries.

Turning to the ARDL method, Saungweme and Odhiambo (2019) conducted an exhaustive study of 54 African nations, concluding that heightened investments reduce the public debt burden. Getinet and Ersumo's (2020) study in Ethiopia and Haughton's (2020) research in Mozambique encountered congruous outcomes. Conversely, Kharusi and Ada (2018) in Oman, Jarju (2021) in Gambia, and Yoong et al. (2020) uncovered a positive correlation between investment and debt in their respective studies. Using panel autoregression analysis across 127 countries, Liaqat (2019) confirmed a negative association between investment and public debt, consistent with parallel investigations by Melesse (2020) in Ethiopia, Kamau (2021) in Kenya, and Toth et al. (2022) in the European Union.

Moreover, scholarly discourse posits that trade openness wields a significant influence on public debt dynamics. Zafar et al. (2008) unveiled the compelling positive impact of trade openness on public debt in Pakistan via an extensive 36-year analysis spanning from 1972 to 2007. Building upon this line of inquiry, Kizilgol and Ipek (2014) analyzed data from Turkey between 1990 and 2012. Their results echoed the preceding study, revealing a clear positive correlation between trade openness and the evolution of state debt, both in the short term and over an extended horizon. Research conducted by Mahara and Dhakal (2020) in Nepal also affirmed a discernible positive correlation between trade openness and public debt. This convergence of empirical outcomes across different national contexts underscores that trade openness can notably impact public debt trajectory.

In the context of FDI and its implications for public debt, Swamy's (2015) extensive research involving 148 countries revealed an inverse relationship between FDI and debt levels. This trend was supported by Kudla's (2018) research, which additionally emphasized how the absence of FDI can lead other sectors to rely more on public debt for financing. Sinha et al.'s (2011) study incorporated FDI alongside variables like current account balance, government expenditure, interest rates, GDP, and inflation; however, their findings showed that none of these factors significantly impact public debt. Jarju's

(2021) examination in Gambia presented a similar perspective, as it found no substantial correlation between FDI and public debt. These divergent outcomes highlight the complex and context-specific relationship between FDI and public debt. They further underscore the importance of nuanced evaluations that consider specific regional and national variables.

Omer (2017) conducted a comprehensive literature analysis to explore strategies for ensuring consistent human prosperity and economic growth. The study found that relying on low-carbon fuel sources or renewable energy significantly reduces the risk of greenhouse gas emissions. Omer (2017) thus advocated for a preventative approach rather than a control-based strategy. The rationale is that as dependence on fossil fuels diminishes in favor of renewable energy sources, pollution levels will decrease, ultimately leading to substantial cost savings for countries. This shift not only mitigates environmental damage but also promotes sustainable economic development. Nurgazina et al. (2023) conducted an in-depth study on the adoption of low-carbon fuel consumption in China, using the ARDL model to elicit robust insights into the long-term effects of sustainable energy practices. Their findings indicate that while positive environmental and economic impacts are achievable, these benefits only materialize over time. Their study also highlights that transitioning to eco-friendly energy sources can reduce environmental expenditure. Correspondingly, Bei and Wang (2023) confirmed that an initial outlay is required for the implementation of low-carbon fuel consumption in China. Although this incurs a cost in the short run, it ultimately fosters the development of a green economy in the long run.

Shaari et al. (2023) defined low-carbon fuels as energy sources that emit substantially less carbon dioxide than conventional fossil fuels such as coal and oil. In the Malaysian context, natural gas is recognized as a crucial "bridge fuel" that enables the transition from coal-based energy systems to near-zero emission alternatives, while also facilitating the short- and medium-term integration of renewable energy sources. This perspective is consistent with that of Majekodunmi et al. (2023) and Safari et al. (2019), who similarly emphasized the importance of natural gas in reducing carbon intensity and advancing sustainable energy transitions. Methodologically, a robust analytical approach involves quantifying the ratio of natural gas consumption (a relatively lower-carbon fossil fuel) to the combined consumption of coal and oil, which are higher carbon fossil fuels (Wu 2024). This metric effectively represents the degree to which carbon intensive fuels are being replaced by cleaner alternatives such as natural gas, thereby serving as an indicator of progress toward a more sustainable and low carbon energy system (Chang 2023).

Bertrand (2021) highlighted numerous risks linked to high carbon fuel consumption, such as extreme weather events, sea level elevation, plastic pollution, air pollution, oil spills, health issues, and ocean acidification. These risks entail substantial costs for nations. When confronted with insufficient resources to tackle these risks, countries might resort to augmenting their public debt burden. It is therefore imperative to explore the potential ramifications of low-carbon fuel consumption on public debt. Notably, to date, there exists no comprehensive study investigating this correlation in Malaysia, which is in a fiscal deficit. Moreover, although the two-gap model has been widely adopted to examine public debt, previous studies have not applied it using renewable energy or environmental factors. This presents a reasonable opportunity to use this model to explain, in detail, whether low-carbon fuel consumption can influence public debt in Malaysia.

METHODOLOGY

This quantitative study employed a rigorous methodology to investigate the relationship between low-carbon fuel consumption and public debt. The details of the variables and their sources are presented in Table 1. Data for the study's dependent variable, public debt, was meticulously sourced from authoritative government financial reports and central bank data. Concurrently, data for the set of independent variables, namely exchange rate, low-carbon fuel consumption, trade openness, GDS, FDI, and investment, were gathered from various reliable sources. All data covered the period from 1980 to 2021, resulting in 41 observations.

TABLE 1. Summary of data sources and proxies

Variables	Proxy	Symbol	Unit of Measurement
Public Debt	Total annual public debt	PD	Ringgit
Exchange Rates	Official exchange rate (LCU per US$, period average)	ER	Ringgit
FDI	FDI, net inflows (BoP, current US$)	FDI	US dollars
GDS	GDS (% of GDP)	GDS	Per centage
Trade Openness	Net trade in goods and services (BoP, current US$)	TO	US dollars
Investment	Gross capital formation (current US$)	INV	US dollars
Low-carbon fuel	Ratio of gas to the combined sum of coal and oil (United Nations Framework Convention on Climate Change, 2014) (Yu. A. Izrael Institute of Global Climate and Ecology,2023), International Energy Forum (2023), Wu (2024), Chang (2023)	LCF	Percentage
Renewable Energy	Total renewable energy supplied	RENR	Kilo tons (Ktoe)

Two separate models were developed to distinguish between low-carbon fuel and renewable energy. Low-carbon fuel reduces carbon emissions but is typically derived from fossil sources such as natural gas, whereas renewable energy is generated from naturally replenished sources like solar and wind, which produce little to no emissions (Oshilalu & Iboh 2025). The models are as follows:

$$LNPD_t = \alpha + \beta_1 LNER_t + \beta_2 LNTO_t + \beta_3 LNGDS_t + \beta_4 LNFDI_t + \beta_5 LNINV_t + \beta_6 LNLCF_t + \varepsilon_t \quad (1)$$

$$LNPDt = \alpha + \beta_1 LNER_t + \beta_2 LNFDI_t + \beta_3 LNINV_t + \beta_4 LNRENR_t + \beta_5 LNTO_t + \varepsilon_t \quad (2)$$

These equations delineate the natural logarithm of public debt (LNPDt) at time *t*, represented as a function of several explanatory variables. Each model includes an intercept term, α, which denotes the fundamental level of public debt when all explanatory variables are valued at zero. The coefficients β_1, β_2, β_3, β_4, β_5, and β_6 represent the extent of influence exerted by variations in the corresponding explanatory variables, namely the exchange rate (LNERt), trade openness (LNTOt), GDS (LNGDSt), FDI (LNFDIt), investment (LNINVt), and low-carbon fuel consumption (LNLCFt). In Equation (2), LNRENRt refers to renewable energy as a separate determinant of public debt. The use of natural logarithms allows for the characterization of variable relationships in terms of percentage changes, thereby providing insights into the sensitivity of public debt to these factors. The error term ε_t captures unexplained fluctuations or stochastic influences affecting public debt at time *t*.

It is crucial to establish the stationarity status of all variables in Equation (1) as either I(1) for first-difference or I(0) for original level, while excluding I(2) or second-order stationarity. This assessment involved applying the Augmented Dickey-Fuller (ADF) unit root test, as outlined below:

$$\Delta Y_t = \beta_1 + \beta_{2t} + \delta y_{t-1} + \alpha_i \Sigma \Delta Y_{t-1} + \varepsilon_t \quad (3)$$

In this equation, ΔY_t denotes the initial change in the variable Y_t, β_1 represents the constant term, β_2 signifies the coefficient reflecting the impact of time *t* on ΔY_t, and the coefficient δ is a parameter indicating the effect of the lagged dependent variable Y_{t-1}. The parameter α_i corresponds to the coefficients associated with previous changes in Y_t, summarized as $\Sigma\Delta Y_{t-1}$, which in turn represents the accumulation of earlier changes in Y_t. Finally, ε_t is the error term encompassing the unexplained variability in ΔY_t that is not accounted for by the independent variables.

The hypotheses for the ADF unit root test are as follows:

Null Hypothesis (H0): $\delta = 0$ (4)
Alternative Hypothesis (H1): $\delta \neq 0$ (5)

The null hypothesis suggests that the data possesses a unit root and lacks stationarity, while the alternative hypothesis argues against the presence of a unit root, implying stationary data. When the test supports the null hypothesis (H_0 accepted or δ is insignificant), it indicates the data has a unit root and is not stationary. Conversely, if the results favor the alternative hypothesis (H_1) and demonstrate statistical significance ($\delta \neq 0$), the data is stationary and lacks a unit root. Subsequently, a bound test assesses whether the variables are cointegrated. If the F-statistic exceeds a certain threshold of the upper bound critical value, it signifies a significant co-integration relationship between the variables. This leads to rejection of the null hypothesis and allows the estimation of a long-term relationship between the variables.

Accordingly, the long-term ARDL estimations for this study are as follows:

$$\begin{aligned} \ln PD_t = {} & \beta_0 + \beta_1 \ln PD_{t-1} + \beta_2 \ln ER_{t-1} + \beta_3 \ln FDI_{t-1} + \beta_4 \ln GDS_{t-1} + \beta_5 \ln INV_{t-1} + \beta_6 \ln TO_{t-1} + \beta_7 \ln LCF_{t-1} + \beta_{8,}i \\ & \sum_{i=0}^{q1} \Delta \ln PD_{t-i} + \beta_9,i \sum_{i=0}^{q2} \Delta \ln ER_{t-i} + \beta_{10},i \sum_{i=0}^{q3} \Delta \ln FDI_{t-i} + \beta_{11},i \sum_{i=0}^{q4} \Delta \ln GDS_{t-i} + \beta_{12},i \sum_{i=0}^{q5} \Delta \ln INV_{t-i} \\ & + \beta_{12},i \sum_{i=0}^{q6} \Delta \ln TO_{t-i} + \beta_{13},i \sum_{i=0}^{q7} \Delta \ln LCF_{t-i} + \mu_t \end{aligned} \quad (6)$$

and

$$\begin{aligned} \ln PD_t = {} & \beta_0 + \beta_1 \ln PD_{t-1} + \beta_2 \ln ER_{t-1} + \beta_3 \ln FDI_{t-1} + \beta_4 \ln INV_{t-1} + \beta_5 \ln RENR_{t-1} + \beta_6 \ln TO_{t-1} + \beta_{8,}i \\ & \sum_{i=0}^{q1} \Delta \ln PD_{t-i} + \beta_9,i \sum_{i=0}^{q2} \Delta \ln ER_{t-i} + \beta_{10},i \sum_{i=0}^{q3} \Delta \ln FDI_{t-i} + \beta_{11},i \sum_{i=0}^{q4} \Delta \ln INV_{t-i} + \beta_{12},i \\ & \sum_{i=0}^{q5} \Delta \ln RENR_{t-i} + \beta_{12},i \sum_{i=0}^{q6} \Delta \ln TO_{t-i} + \mu_t \end{aligned} \quad (7)$$

In these equations, Δ denotes the first difference operator, t-1 signifies a one-period lag, and $\Sigma_{(i=1)}$ represents the accumulation of past values of $\ln PD_t$. Parameters q_1 to q_3 determine the most suitable lag lengths. Lastly, μ_t stands for the error term, which encompasses the portion of the change in the dependent variable ($\Delta \ln PD_t$) not explained by the independent variables.

Moreover, to investigate the immediate relationship between the independent variables and public debt, an error correction model (ECM) test was employed. The following equation illustrates the ECM model:

$$\begin{aligned} \Delta \ln PD_t = {} & \mu + \sum_{i=1}^{p} \delta \Delta \ln PD_{t-i} + \sum_{i=0}^{q1} \delta_2 \Delta \ln ER_{t-i} + \sum_{i=0}^{q2} \delta_3 \Delta \ln FDI_{t-i} + \sum_{i=0}^{q3} \delta_4 \Delta \ln GDS_{t-i} + \\ & \sum_{i=0}^{q4} \delta_5 \Delta \ln INV_{t-i} + \sum_{i=0}^{q5} \delta_6 \Delta \ln TO_{t-i} + \sum_{i=0}^{q6} \delta_7 \Delta \ln LCF_{t-i} + \theta_1 ECT_{t-1} + \mu_t \end{aligned} \quad (8)$$

In Equation (8), δ_1 through δ_4 represent short-term dynamic coefficients, while θ_1 signifies the speed at which adjustments occur towards the long-term equilibrium. ECT_{t-1} represents the error correction term lagged by one period.

Diagnostic tests were also conducted to ensure the accuracy and suitability of the baseline model, confirming that the model satisfied the necessary criteria. These diagnostic tests include the Normality Test, Breusch-Godfrey Serial Correlation LM Test, Breusch-Pagan-Godfrey Heteroskedasticity Test, and Ramsey RESET Test. Moreover, the stability of the model was evaluated using the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of the square of recursive residuals (CUSUMSQ). The CUSUM and CUSUMSQ lines were inspected to ascertain whether they fall within the 5% significance line. If the lines remain within this range, the model is considered stable.

FINDINGS

The ARDL approach was used for analysis, yielding results on detailed short and long-run interactions. Table 2 summarizes the descriptive statistics for public debt (dependent variable) and the seven independent variables: low-carbon fuel consumption, exchange rate, FDI, GDS, investment, renewable energy consumption, and trade openness. Public debt recorded a mean of 18.9391 with low variability. Among the independent variables, trade openness showed the highest variability while GDS had the lowest. Most variables were fairly symmetric, except for exchange rate and trade openness, which were negatively skewed and deviated from normality per the Jarque-Bera test. The sum, squared deviations, central tendencies, variability, skewness, and kurtosis of the 41 observations are also presented in Table 2.

TABLE 2. Descriptive statistics

	LNPD	LNLCF	LNER	LNFDI	LNGDS	LNINV	LNRENR	LNTO
Mean	18.9391	4.8828	1.1360	21.8813	3.6117	24.0562	6.3695	15.5434
Median	18.6488	4.9381	1.1477	22.1242	3.6033	24.0821	6.2166	23.5306
Maximum	20.5949	6.9000	1.4587	23.4393	3.8851	25.1746	8.2137	24.6612
Minimum	16.9700	1.3592	0.7779	18.5575	3.2607	22.6983	4.7875	-21.9711
Std. Dev.	0.9694	1.3671	0.2098	1.1326	0.1535	0.8102	0.8636	16.8001
Skewness	0.1237	-1.0358	-0.0433	-0.8604	-0.2155	-0.1720	0.5331	-1.7285
Kurtosis	2.0123	3.8416	1.5321	3.1866	2.2834	1.7968	3.0416	4.0360
Jarque-Bera	1.7711	8.5417	3.6939	5.1176	1.1945	2.6752	1.9450	22.2493
Probability	0.4125	0.0140	0.1577	0.0774	0.5503	0.2625	0.3781	0.0000
Sum	776.5032	200.1958	46.5759	897.1336	148.0806	986.3057	261.1481	637.2775
Sum Sq. Dev.	37.5858	74.7587	1.7607	51.3150	0.9426	26.2583	29.8314	11289.6800

Table 3 shows unit root test results for the variables in both level and first difference forms. In level form, variables like trade openness, FDI, investment, GDS, low-carbon fuel, and renewable energy exhibited non-stationarity, indicating a unit root and persistent trends. However, in the first difference form, the variables' t-statistics increased and probabilities approached zero, indicating stationarity. This means that after differencing, all variables were stationary and suitable for time series analysis.

TABLE 3. Unit root test results

	Level		1st Difference	
Variable	t-statistic	Prob*	t-statistic	Prob*
LNPD	0.2596	0.9730	-3.1071	0.0342**
LNTO	-3.3436	0.0193	-9.3303	0.0000***
LNER	-1.2977	0.6214	-5.0938	0.0002***
LNFDI	-3.6443	0.0090	-6.9459	0.0000***
	-1.3149			
LNINV		0.6133	-5.2365	0.0001***
LNGDS	-0.3714	0.9044	-5.3988	0.0001***
LNLCF	-2.4074	0.1462	-4.7545	0.0004***
LNRENR	-0.3087	0.9146	-4.8851	0.0003***

Note: ** is significant at 5% and *** is significant at 1%.

The lag length selection results reported in Table 4 provided insights into determining the appropriate lag structure for the ARDL modeling approach for Model 1. We aimed to strike a balance between model fit and complexity by employing information criteria such as the Akaike Information Criterion (AIC) and Hannan-Quinn Criterion (HQ). As observed in the table, the AIC value decreased steadily from Lag 0 to Lag 3, indicating an improvement in model fit with the inclusion of additional lags. Based on the AIC criterion, the results suggest that a lag length of 3 could offer the best compromise between model fit and complexity.

TABLE 4. Lag Length Selection (Model 1)

Lag	AIC	HQ
0	11.5387	11.646
1	0.2881	1.1467
2	-0.3370	1.2729
3	-1.6274*	0.7339*

Table 5 reports the bound test results, which assessed whether there are stable, long-term connections among the variables. The critical values at different significance levels (1%, 2.50%, 5%, and 10%) were compared against the F-

statistic. We found that the F-statistic value of 14.2052 was greater than all the critical values, indicating significant long-term relationships among the variables. In simple terms, the bound test results revealed that the variables have important and lasting effects on each other over an extended time period.

TABLE 5. Bound test results (Model 1)

F-Bounds Test		Lag order	Null Hypothesis: No level of relationship		
Test Statistic	Value	(1,1,3,3,3,3,2)	Sig.	I(0)	I(1)
F-statistic	14.2052		10%	1.99	2.94
k	6		5%	2.27	3.28
			2.50%	2.55	3.61
			1%	2.88	3.99

Table 6 presents the long-term ARDL results, shedding light on the direct relationships between the explanatory factors and public debt in Malaysia. The analysis revealed that trade openness, investment, and GDS play significant roles in shaping public debt, each at the 1% significance level. In the long run, trade openness and investment positively affect public debt; a 1% increase in trade openness corresponds to a 0.0270% increase in public debt, while a similar increase in investment leads to a substantial 0.7349% rise in public debt. This finding is consistent with prior research conducted by Zafar et al. (2008) and Kizigol and Ipek (2014).

With regard to trade openness, the government's adoption of a more open stance towards international trade by reducing trade barriers can increase public debt for several reasons. First, trade liberalization policies can diminish government revenue through tariff collections. Second, the government may be compelled to allocate substantial funds to develop trade-related infrastructure and facilities. Third, domestic industries might encounter heightened competition from foreign counterparts, resulting in reduced taxable income for the government. Altogether, these phenomena underscore the profound impact of trade liberalization on the dynamics of the local economy.

Concerning investment, the finding parallels that of Americo et al. (2023) and Were and Mandete (2022). To develop low-carbon fuel initiatives, the government must incur substantial initial investments. Such expenditures are normally financed by debt due to public fund shortages. As a result, investments in low-carbon fuels contribute to debt accumulation, particularly during the initial stages when returns on investment take time (Poszwa 2021). In the Malaysian context, this connection can further be attributed to the government's substantial infrastructure investments and financial aid packages, which increase borrowing requirements and, consequently, public debt levels.

Conversely, the significant negative relationship between GDS and public debt is in line with Chaudhry et al. (2009), pointing to how long-term fiscal dynamics are affected by savings. We found that for every 1% increase in GDS, there is a corresponding 1.2395% decrease in public debt levels, indicating a robust and multifaceted mechanism through which higher savings contribute to reduced public debt. First, when individuals, businesses, and institutions within a nation save more, they effectively divert a larger proportion of their income towards savings rather than immediate consumption. This accumulation of funds creates a financial buffer or reserve that can be tapped into to cover future expenses, thus reducing the need for governments to resort to borrowing to finance public expenditures. Correspondingly, when energy costs borne by individuals, corporations, and the government decline, the surplus funds previously spent on energy are channeled into savings. As a result, higher domestic savings serve as a source of internal financing, alleviating pressure on government budgets and limiting reliance on external borrowing to meet fiscal obligations.

Moreover, increased domestic savings can exert downward pressure on interest rates in financial markets. As savings accumulate within the economy, the demand for loanable funds diminishes, leading to a surplus of available capital. In response to this increased supply, lenders may lower interest rates to incentivize borrowing and investment. The resulting decline in interest rates reduces the cost of borrowing for the government when issuing bonds to finance public expenditures. Consequently, governments can access cheaper financing options, leading to more cost-effective debt management strategies and potentially lower debt servicing costs over time.

Notably, higher levels of domestic savings can enhance the overall stability and resilience of the economy, which can indirectly influence public debt dynamics. A robust savings base provides a cushion against external shocks or economic downturns, reducing the likelihood of fiscal crises that may necessitate emergency borrowing or bailouts. Additionally, a financially secure population with ample savings is better equipped to weather economic uncertainties, thereby reducing the likelihood of demands for government intervention or stimulus measures that could exacerbate public debt burdens. Ultimately, it is evident that the vital role played by low-carbon fuel consumption contributes to cost reductions that later translate into lower debt reliance.

However, referring to the two-gap model by Chenery and Strout (1966), the long-term ARDL analysis for Malaysia indicated no significant effect of low-carbon fuel consumption, FDI, and exchange rates on public debt. Consistent with Hariyani et al. (2020), these insignificant findings highlight the complexity of public debt dynamics.

TABLE 6. Long-run ARDL model estimates (Model 1)

Case 2: Restricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNTO	0.0270	0.0032	8.4337	0.0002***
LNINV	0.7349	0.1185	6.2009	0.0008***
LNGDS	-1.2395	0.1562	-7.9354	0.0002***
LNLCF	0.1346	0.0836	1.6101	0.1585

LNFDI	0.0022	0.0708	0.0311	0.9762
LNER	0.3384	0.1840	1.8393	0.1155

Note: *** is significant at 1%.

Table 7 provides insights into the short-term ARDL analysis outcomes, revealing which variables significantly influence public debt in the short run. Specifically, trade openness and investment positively affect public debt at the 10% significance level, with a 10% increase in trade openness causing a 0.0009% rise in public debt. FDI is negative and significant at the 5% level, where a 5% increase in FDI reduces public debt by approximately 0.0208%. This suggests that FDI helps alleviate short-term debt pressures, consistent with Kudla (2018) and Jarju (2021). Low-carbon fuel consumption also significantly increases public debt in the short run, with a 1% increase leading to a 0.1317% rise in public debt. Governments may increase spending to invest in green energy projects, subsidies, and infrastructure, leading to higher public debt. At the same time, such initiatives can create jobs and stimulate economic activity, potentially boosting short-term economic growth. Thus, while fuel-switching benefits the environment, it may increase public debt in the short term due to upfront government spending and potential tax incentives that reduce revenue (Poszwa 2021).

TABLE 7. Short-run ARDL model estimates (Model 1)

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
ECT	-0.3375	0.0720	-4.6892	0.0034**
LNTO	0.0009	0.0005	1.9848	0.0944*
LNINV	0.0618	0.0697	0.8863	0.4096
LNGDS	-0.1026	0.0926	-1.1082	0.3102
LNLCF	0.1317	0.0342	3.8468	0.0085***
LNFDI	-0.0208	0.0085	-2.4445	0.0502**
LNER	-0.1289	0.1340	-0.9616	0.3734
C	1.4682	0.5043	2.9116	0.0269**

Note: * is significant at 10%, ** is significant at 5% and *** is significant at 1%.

Table 8 presents the diagnostic test results for assessing the model's validity. The F-statistics for serial correlation (0.96147) and heteroscedasticity (1.22190) reported high p-values (0.34350 and 0.35030), indicating no significant evidence of these issues. The Jarque-Bera statistic (0.01755), with a high p-value of 0.99127, suggests that the residuals followed a normal distribution. The Ramsey RESET test (0.00285) also had a high p-value of 0.95820, indicating no omitted variable bias. These results support the model's reliability and adherence to key statistical assumptions.

TABLE 8. Diagnostic test results (Model 1)

Diagnostic test	F Statistic	Probability
Serial Correlation	0.9615	0.3435
Heteroscedasticity	1.2219	0.3503
Jarque-Bera	0.0176	0.9913
Ramsey RESET	0.0029	0.9582

Note: ** is significant at 5% and *** is significant at 1%.

A CUSUM test was conducted to verify the model's stability. If the analyzed graph stays within critical boundaries, the model can be deemed stable at a 5% significance level. In this study, the CUSUM graph fell within the critical range, confirming stability in both long-run and short-run estimations (see Figure 3). This suggests that the estimated relationships between the variables were consistent and reliable over the examined period.

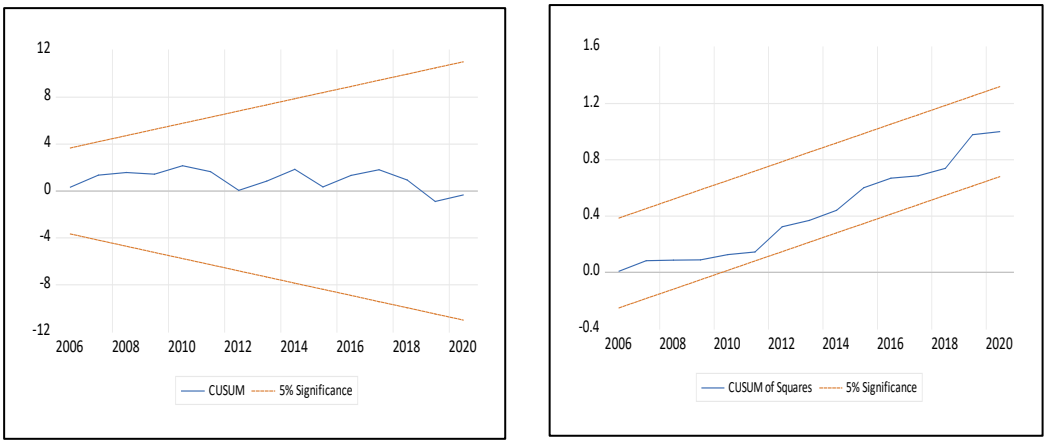

FIGURE 3. CUSUM and CUSUM SQ results (Model 1)

Model 2, which included renewable energy, showed relatively different findings than Model 1. Table 9 presents the lag length selection using AIC and HQ. For Lags 0, 1, and 2, the lowest AIC and HQ values indicated the best fit. Lag 2 was optimal, with an AIC of 2.7173 and HQ of 3.9110, suggesting it provides the best balance between fit and complexity.

TABLE 9. Lag length selection (Model 2)

Lag	AIC	HQ
0	13.1965	13.2883
1	3.4164	4.0592
2	2.7173*	3.9110*

Table 10 shows the bound test results for Model 2. The F-statistic of 13.1647 exceeded critical values at all significance levels, indicating strong evidence against the null hypothesis of "no level relationship."

TABLE 10. Bound test results (Model 2)

F-Bounds Test		Lag order	Null Hypothesis: No levels relationship		
Test Statistic	Value	(1,0,0,0,1,0)	Sig.	I(0)	I(1)
F-statistic	13.1647		10%	2.08	3
k	5		5%	2.39	3.38
			2.50%	2.7	3.73
			1%	3.06	4.15

The long-run ARDL results in Table 11 show that among the independent variables in Model 2, only renewable energy has a significant positive impact on public debt at the 5% level. This finding is consistent with Abbas et al. (2024). Meanwhile, the exchange rate, FDI, investment, and trade openness do not significantly affect public debt in the long run, consistent with Hariyani et al. (2020).

TABLE 11. Long-run ARDL model estimates (Model 2)

Case 2: Restricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNER	-2.5058	2.0459	-1.2248	0.2296
LNFDI	0.3513	0.3098	1.1338	0.2653
LNINV	0.3606	0.4255	0.8473	0.4031
LNRENR	1.2623	0.5883	2.1456	0.0396**
LNTO	0.0166	0.0115	1.4478	0.1574

Note: ** is significant at 5%

Based on the short-run ARDL results in Table 12, the ECT is significant, indicating adjustment toward the long-run equilibrium. The exchange rate also demonstrated a significant positive impact on public debt. However, FDI, investment, renewable energy, and trade openness did not show significant effects on public debt in the short run.

TABLE 12. Short-run ARDL model estimates (Model 2)

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
ECT	-0.0791	0.0388	-2.0369	0.0520*
LNER	0.1812	0.0796	2.2772	0.0296**
LNFDI	-0.0254	0.0143	-1.7819	0.0843*
LNINV	-0.0261	0.0395	-0.6599	0.5140
LNRENR	-0.0071	0.0545	-0.1294	0.8979
LNTO	-0.0012	0.0008	-1.4956	0.1445
C	0.2977	0.4298	0.6926	0.4935

* is significant at 10%, ** is significant at 5% and *** is significant at 1*

Next, the diagnostic test results in Table 13 confirm no significant issues with serial correlation, heteroscedasticity, or normality, as indicated by the high p-values (all above 0.1).

TABLE 13. Diagnostic test results (Model 2)

Diagnostic test	F Statistic	Probability
Serial correlation	2.3459	0.1204
Heteroscedasticity	1.7655	0.1130
Jarque-Bera	0.6029	0.7397

Finally, the CUSUM test was conducted to evaluate the model's stability. Figure 4 shows that the graph remains within the critical boundaries at a 5% significance level. This stability suggests consistent and reliable estimated relationships between the variables in Model 2.

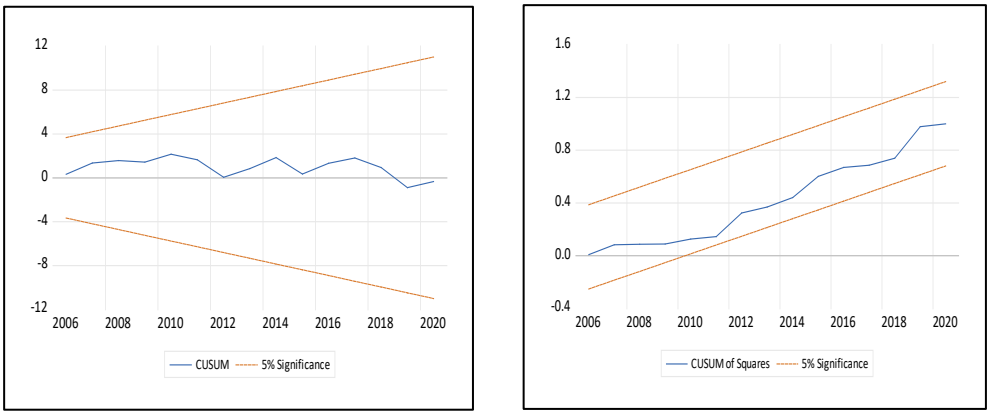

FIGURE 4. CUSUM and CUSUM SQ results (Model 2)

SUMMARY AND CONCLUSIONS

In summary, our analysis of the factors influencing public debt in Malaysia reveals several significant predictors based on the two-gap model. Notably, low-carbon fuel consumption and renewable energy adoption are key drivers, showing pronounced correlations with public debt levels due to their high initial costs (Bei & Wang 2023; Fan et al. 2020). Given Malaysia's prolonged budget deficit, these costs contribute to increased government expenditure, which then elevate public debt. Therefore, close monitoring of fiscal impacts is crucial in environmental or energy-related initiatives. This highlights the need to explore how environmental policies affect public debt dynamics, considering their implications for fiscal sustainability and economic resilience. Indeed, Chia et al. (2022) emphasized the need for the adoption of low-carbon fuel to ensure environmental sustainability, so that environmental degradation does not later impose additional costs on other sectors through ecological rehabilitation and protection programs.

This study's findings can guide policymakers in developing effective and sustainable economic and energy policies to manage public debt effectively. To support the transition to cleaner energy sources while minimizing debt impacts, governmental strategies must be tailored by considering potential costs and exploring international collaborations. Moreover, policymakers must prioritize investments in energy efficiency and renewable energy sources to reduce environmental risks and government expenditure. Innovative financing approaches, such as public-private partnerships and green bonds, can also be leveraged to fund this transition without significantly increasing public debt. Apart from that, thorough cost-benefit analyses and long-term planning must be conducted to ensure that cleaner energy adoption delivers economic benefits and eases public financing burdens. Finally, implementing robust monitoring and evaluation frameworks is important for assessing energy policies' effectiveness, particularly in contributing to sustainable growth and managing public debt. By integrating these strategies, policymakers can advance towards a more sustainable energy landscape while maintaining long-term fiscal stability and resilience.

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Amri Sulong
Commerce Department
Politeknik Seberang Perai
Jln Permatang Pauh,13500 Pulau Pinang, MALAYSIA.
E-mail: amri.sulong@psp.edu.my

Mohd Shahidan Shaari
Faculty of Economics and Business
Universiti Malaysia Sarawak
94300 Kota Samarahan, Sarawak, MALAYSIA.
E-mail: smshahidan@unimas.my

Noorazeela Zainol Abidin
Faculty of Business & Communication
Universiti Malaysia Perlis
02600 Arau, Perlis, MALAYSIA.
E-mail: noorazeela@unimap.edu.my

Zulkefly Abdul Karim*
Faculty of Economics and Management
Universiti Kebangsaan Malaysia
43600 UKM, Bangi Selangor, MALAYSIA
E-mail: zak1972@ukm.edu.my

* Corresponding author