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Examining the impact of oil use on the relationship between GDP growth and life expectancy in Malaysia

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Abstract
Life expectancy reflects a population's overall health and prosperity. This study applies the Auto-Regressive Distributed Lag (ARDL) method to analyze how oil use influences the link between GDP growth and life expectancy in Malaysia from 1980 to 2020. The results show that while GDP growth boosts life expectancy in both the short and long term, dependence on oil negatively affects it. Wealth accumulation positively contributes to longevity, whereas healthcare budget distribution surprisingly reduces life expectancy. These findings highlight the complex relationship between economic development and environmental conditions, suggesting the need for policies that support both growth and environmental sustainability to improve public health outcomes.

Keywords Oil consumption · Economic expansion · Life expectancy · Financial development · Health outcomes

1 Introduction

Life expectancy refers to the predicted number of years an individual is expected to live. According to data from the World Health Organization (WHO), the global average lifespan increased from 66.8 years in 2000 to 73.4 years in 2019 [1]. However, research by Heuveline [2] at the California Center for Population Research (CCPR) indicates that life expectancy declined by 0.92 years from 2019 to 2020 and by another 0.72 years from 2020 to 2021. This decline was largely attributed to the COVID-19 pandemic, but the trend appears to have stabilized by the end of 2021. Various factors influence life expectancy, including socioeconomic status, medical advancements, nutrition, lifestyle choices, and living conditions [3]. Among these, economic expansion is considered the primary driver that enables improvements in healthcare infrastructure, access to basic necessities, and overall living standards [4]. The strong correlation between economic growth and life expectancy is widely recognized, as higher incomes allow individuals to invest in better healthcare,

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education, and overall well-being. Moreover, economic prosperity enables governments to allocate more resources toward healthcare systems and research, leading to improved public health outcomes.

Despite the widely accepted link between economic growth and life expectancy, the role of oil consumption in shaping this relationship remains unclear. As highlighted by Shaari et al. [5], the majority of economic sectors depend on oil as a key production input. However, studies by Lim et al. [6] and Alkhathlan and Javid [7] have established a direct link between oil consumption and rising carbon emissions, which pose significant environmental and health risks. Carbon dioxide (CO2), a major greenhouse gas, is released through the combustion of oil in industries, transportation, and power generation, contributing to climate change and air pollution. These environmental changes, in turn, lead to adverse health effects such as respiratory diseases, cardiovascular disorders, and increased mortality rates. Moreover, rising temperatures and extreme weather events linked to climate change can exacerbate food insecurity, malnutrition, and disease outbreaks, all of which negatively impact life expectancy. While economic growth typically improves public health, reliance on oil as a primary energy source may introduce risks that counteract these benefits.

Although extensive research has examined the direct relationship between economic growth and life expectancy, limited attention has been given to how oil consumption influences this dynamic. Prior studies have primarily focused on the positive effects of economic expansion on public health [6, 7], overlooking how economic dependency on oil may alter these benefits. Given that many economic sectors rely heavily on oil [5], it is crucial to assess whether its consumption offsets the expected health improvements associated with economic growth. Additionally, while some studies have explored the direct link between oil consumption and life expectancy, the indirect effects of oil use through its role in economic growth remain underexplored. This study aims to address these gaps by investigating how oil consumption affects the relationship between GDP growth and life expectancy in Malaysia. Specifically, the research seeks to answer the following questions: How does oil consumption affect life expectancy in Malaysia? How does oil consumption influence the relationship between GDP growth and life expectancy?

By answering these questions, this study provides a comprehensive analysis of the intersection between economic development, energy dependency, and public health using data from 1980 to 2020 and applying the Auto Regressive Distributive Lag (ARDL) approach. For robustness checks, we also employ Fully Modified Ordinary Least Squares (FMOLS) and the Dynamic Ordinary Least Squares (DOLS) methods, and confirm the findings using Granger causality tests. Understanding these relationships is essential for designing policies that promote sustainable economic growth while mitigating the negative health effects associated with oil consumption. Given Malaysia's reliance on oil as a major energy source, evaluating its impact on life expectancy is crucial for ensuring long-term public health sustainability.

2 Overviews of life expectancy and oil consumption in Malaysia

In the context of Malaysia, the pattern of life expectancy is keep increasing as life expectancy at birth in 2016 is 74.7 years compared to 72.2 years in 2000 [8]. Moreover, the government has long recognized the issue of extending life expectancy and has addressed it by implementing retirement age policies. Figure 1 represents the ascending pattern of life expectancy in Malaysia since 1960–2021. Several sectors play a significant role in driving Malaysia's economic expansion, including agriculture, mining, construction, manufacturing, and services. Each of these sectors brings unique contributions to the country's overall economic development.

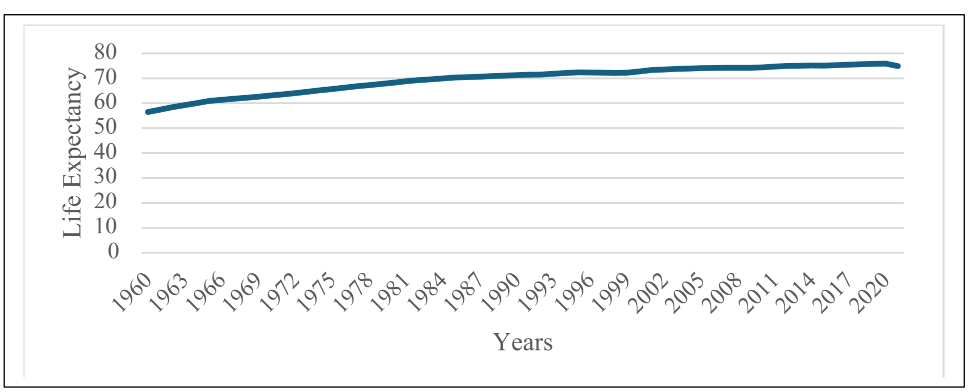

Fig. 1 Life Expectancy in Malaysia (1960–2021). Source: World Bank [9]

Agriculture provides essential food products and raw materials, while mining supplies valuable minerals and fuels. Construction drives infrastructure development, creating jobs and stimulating related industries. Manufacturing transforms raw materials into finished goods, adding significant value and fostering industrial expansion. The services sector, encompassing a wide range of activities such as finance, retail, tourism, and professional services, stands out as the most substantial contributor to economic expansion. According to a report by the Economic Planning Unit [10], the services sector contributed the largest share to Malaysia's economic expansion, accounting for approximately 58.3%. This sector's broad scope and dynamic nature enable it to drive substantial economic activity and innovation. Following the services sector, the manufacturing sector contributes 24.5% to the nation's economic expansion. This sector's focus on production and export of goods supports a robust industrial base and enhances Malaysia's position in the global market.

Figure 2 reflects the usage of oil in Malaysia since 1980–2021. The usage of oil is increasing over time. Oil price shocks such as the 1997–1998 Asian Financial Crisis, 2008 Global Financial Crisis, and 2014–2015 oil price crash likely affected oil consumption due to economic slowdowns and shifts in energy policies. Similarly, government actions like fuel subsidy removals, tax incentives for renewable energy, or investments in alternative energy sources could explain changes in oil demand over time.

3 Theoretical background

The Grossman Model, is a key economic framework in health economics that explains the relationship between health and economic behavior [12]. It views health as a capital stock that individuals invest in to enhance well-being and productivity. While health naturally deteriorates over time, it can be maintained or improved through investments such as medical care, healthy behaviors, and education. Individuals must allocate their time and resources between health-related investments and other activities, balancing the trade-off between health, work, and leisure. The model explains why healthier individuals have higher earnings and why health investments become more important with age. Expanding on this perspective, Smith and Dunt [13] introduced the health production function, which considers both health expenditures and non-health inputs as key determinants of health outcomes. More recently, Shaari et al. [14] incorporated health investments into their model, highlighting their role in improving life expectancy. Similarly, Anwar et al. [15] found that increased health expenditures positively impact life expectancy, further supporting the link between health investments and long-term well-being.

Existing literature has largely examined the impact of total energy consumption on life expectancy, with some studies distinguishing between clean and non-clean energy sources. Additionally, previous research has explored the influence of financial development, health expenditure, and economic growth on life expectancy.

3.1 Energy use, economic expansion and life expectancy

A number of studies have looked at the correlation between energy use and longevity and have found it in many nations [e.g., Hendrawaty et al. [16]; Osei-Kusi et al. [17]; Weitensfelder et al. [18]; Wang et al. [19]]. Rather than studying energy use in its whole, several studies have concentrated on clean energy research [Wang et al. [20]; Liu and Zhong, [21]; Caruso et al. [22]; Yılmaz and Şensoy, [23]]. This approach has been confirmed by further study. The amount of energy consumed significantly affects the average life expectancy, according to strong data that remains consistent across numerous methods. A study by Hendrawaty et al. [16] examined the linkage between economic development rate,

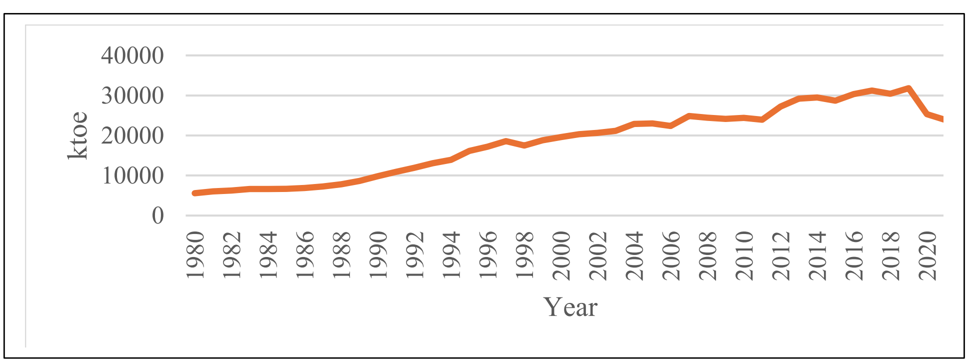

Fig. 2 Oil consumption in Malaysia (1980–2021) (ktoe). Source: Malaysia Energy Commission [11]

energy consumption, and average life expectancy in ASEAN countries from 1988 to 2018. Using the panel ARDL method, they observed varied short- and long-term outcomes. Increased energy consumption may be associated with longer life expectancy in the short term, but not necessarily in the long run. Economic development may have limited initial effects, but its long-term impacts include a considerable increase in life expectancy. Osei-Kusi and colleagues [17] studied several locations, including Europe, Central Asia, North Africa, the Middle East, and Sub-Saharan Africa, to determine the correlation between economic expansion, energy consumption, and mortality rates. The study found that economic expansion, even in regions with higher carbon emissions, could increase life expectancy, according to 1990 data analysis.

According to research by Weitensfelder et al. [18], there is a cutoff point beyond which increasing energy consumption would only have a marginal positive effect on life expectancy. When this point is achieved, there are no additional repercussions for increasing energy consumption. Researchers identified this threshold by analyzing data from 1972 to 2014 across numerous nations using non-linear models, taking distributional inconsistencies into account. This cutoff point evolves with time, as shown by the varying effect of energy consumption on longevity among studies. Wang et al. [20] investigated the correlation between home energy use and average life expectancy in China between 1990, 2000, and 2010. The investigation produced findings that differed among provinces and areas. The researchers employed OLS and geographically weighted regression (GWR) models. Life expectancy of rural Chinese families using coal for heating was lower than those using electricity as the primary energy source. Based on the GWR investigation, western regions were negatively affected by coal, while east to west regions were positively affected by electricity. This study provides insights into complex, site-specific energy consumption patterns and their effects on public health.

3.2 Clean energy usage, economic expansion and life expectancy

Using non-linear panel threshold and linear fixed-effect methods, Wang et al. [19] examined the effect of clean energy use and economic expansion on life expectancy in 121 nations with varying degrees of wealth. A higher average lifespan was consistently associated with clean energy use, according to data from 2002 to 2018. The researchers also found that the positive correlation between economic expansion and life expectancy is amplified when clean energy sources are used. Liu and Zhong [21] analyzed quarterly data from 2000 to 2020 using the Vector Error Correction Model (VECM) to determine how healthcare spending and clean energy use affect average longevity in China. They found that increasing healthcare spending and switching to clean energy sources both substantially impact people's longevity.

Using data from 12 European nations between 1990 and 2015, Caruso et al. [22] examined the correlation between energy consumption and health using the Panel Vector Auto Regression (PVAR) technique. Their research shows that stringent regulations encouraging clean energy usage are required to solve numerous societal problems. Concerns covered include minimizing foreign energy import dependence, public awareness, market dynamics, and government policy. However, no conclusive causal linkages between clean energy use and health evaluation outcomes were found. The study highlighted how clean energy policies affect the broader social and environmental framework, potentially impacting health outcomes in the European countries studied. The potential causal association between clean energy usage and life expectancy in Turkey was examined by Yılmaz and Şensoy [23] using the Toda-Yamamoto causality test. They examined data from 1990 to 2019. Their findings showed no causal linkage between the two, directly contradicting the idea that clean energy usage is positively associated with longer life expectancy.

In a study on 55 economies, Majeed et al. [24] analyzed the correlation between clean energy and public health using multiple panel techniques. The methodologies included pooled ordinary least squares, random effects, fixed effects, two-stage least squares, and extended technique of moments. Their empirical investigation found that using clean energy sources improved health outcomes, resulting in longer life expectancy and lower mortality rates. It is reasonable to assume that clean energy reduces the prevalence of chronic diseases, thereby increasing life expectancy, given the positive association between these variables.

3.3 Financial development, CO2 emissions, health expenditure and life expectancy

Murthy et al. [25] shifted attention from energy use to carbon dioxide emissions as a potential driver of life expectancy. Using panel ARDL methodology, they examined 1992–2017 data for D-8 member states. They found that rising populations, GDP, and healthcare expenditure contributed to higher life expectancy in the region. This method raises questions about basic mechanisms and cause-and-effect development. The research highlights key factors increasing longevity but ignores potential drawbacks of carbon dioxide emissions, commonly associated with health issues and environmental damage. Prempeh et al. [26] and Uddin et al. [27] examined factors that influence health, including the role of financial development. Prempeh et al. [26] examined 11 ECOWAS countries from 1990 to 2019, exploring the relationship between health and its key determinants. Their findings, using advanced statistical methods, show economic growth and financial development improve health, while pollution harms it. However, these factors' impact varies across countries. The study found bidirectional causality, meaning financial and environmental factors influence health, and health affects them. Meanwhile, Uddin et al. [27] studied Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka from 2002 to 2020, examining institutional quality and environmental degradation alongside financial development. Using CIPS, CS-ARDL, FMOLS, and DOLS methods, they found that strong institutions, a developed financial sector, and higher health spending contribute to longer life expectancy. Conversely, pollution, environmental damage, high birth and mortality rates, and rapid population growth reduced life expectancy.

Despite extensive research linking energy use to longevity, most studies have focused on clean energy's positive effects, leaving oil use's impact largely unexplored. While studies confirm increased energy consumption and economic expansion can enhance life expectancy, they often overlook oil consumption's role, a key factor in many developing economies. Existing literature lacks detailed examination of how oil dependence affects the relationship between GDP growth and life expectancy. This study addresses these gaps by investigating the interaction between oil use, economic development, and life expectancy.

4 Methodology

4.1 Theory and model

Grossman's health investment model [12] provides a foundation by emphasizing how individuals make rational decisions regarding health investments to maximize well-being over their lifetime. This model posits that individuals allocate resources toward healthcare and preventive measures to reduce illness and mortality risks, improving productivity and extending lifespan. Key determinants like education, income, and health behaviors influence these outcomes, highlighting individual agencies and medical interventions in shaping well-being. However, Grossman's model does not account for environmental consequences of economic activities, particularly adverse health effects of oil consumption. To address this gap, we can incorporate insights from environmental economics, specifically the pollution-health nexus, which posits that exposure to air pollution from fossil fuel combustion contributes to respiratory diseases, cardiovascular conditions, and premature mortality.

In Malaysia, rapid GDP growth driven by oil consumption may increase pollution, negatively affecting public health and life expectancy. By integrating Grossman's model with this environmental perspective, our framework better explains how oil consumption, GDP growth, and health outcomes are interconnected. Economic expansion improves healthcare access and living standards, but excessive oil reliance may counteract these benefits by increasing environmental and health risks. This dual perspective highlights the need for policies balancing economic growth with sustainable energy transitions to protect long-term public health and life expectancy.

4.2 Model specification

The objective of the study will be achieved by the following model (Eq. (1)):

$$\mathrm{LE_t} = \alpha_0 + \alpha_1 \mathrm{LNHE_t} + \alpha_2 \mathrm{LNGDP_t} + \alpha_3 \mathrm{LNFD_t} + \alpha_4 \mathrm{LNO_t} + \varepsilon_t \tag{1}$$

Life expectancy (LE) is the average number of years a person is expected to live, indicating a population's overall lifespan. Health expenditure (HE) refers to resources allocated to health care, measured as a percentage of gross domestic product (GDP). Gross domestic products, calculated in constant US dollars, indicate economic expansion. Oil consumption is the total oil a country utilizes, measured in barrels or metric tons, gauging energy consumption patterns. Financial development may be measured by the percentage of a country's GDP consisting of domestic credit supplied by the financial sector. These variables were selected based on considerations validated by previous studies. The proxy for financial development follows Meniago et al. [28] and Adusei [1], who used GDP and domestic credit supplied by the financial sector as a preferred measure. This selection is supported by reliable World Bank data. Meanwhile, the proxies for health expenditure and GDP are consistent with the study by Sulong et al. [29]. The proxy for life expectancy (LE) aligns with the approaches of Veerman et al. [30], Steel [31], and Chen et al. [32]. The time index is represented by t. The intercept is represented by α_0, whereas the parameters that need estimation are marked by $\alpha_1 \ldots \alpha_4$.

Data from 1980 to 2020 is used to examine the impact of oil consumption on GDP growth and life expectancy in Malaysia. During this period, Malaysia experienced significant economic, energy, and healthcare changes. The transition from an agriculture-based economy to an industrialized nation altered energy consumption and economic growth [33]. Malaysia faced oil price shocks, including the 1980s, the 1997–98 Asian financial crisis, and the 2008 global financial crisis, affecting oil dependence, economic performance, and policies [3]. Structural changes like energy diversification, fuel subsidy adjustments, and industrialization shaped GDP growth and life expectancy trends. While higher GDP improved healthcare infrastructure, urbanization, and increased oil consumption posed environmental and health challenges, affecting life expectancy.

$$LE_t = \beta_0 + \beta_1 LNHE_t + \beta_2 LNGDP_t + \beta_3 LNFD_t + \beta_4\, LN\left(GDP * O_t\right) + \varepsilon_t \tag{2}$$

Calculated by multiplying the two variables, the expression LN(GDP*O) in Eq. (2) illustrates the interaction between economic expansion and oil consumption. This interaction is represented by the term. In order to comprehend the manner in which these factors collectively affect life expectancy, it is essential to comprehend this interaction term. To be more specific, if the coefficient of LNO (β_1) is positive (that is, β_1 is greater than zero) and the coefficient of the interaction term (β_4) is negative (that is, β_4 is less than zero), then this signifies that the positive influence of economic expansion (LNGDP) on life expectancy is mitigated by the negative impact of oil consumption. If, on the other hand, the coefficient of LNO (β_1) is negative (that is, β_1 is less than zero) and the coefficient of the interaction term (β_4) is positive (that is, β_4 is more than zero), then it can be shown that the use of oil exacerbates the negative impact that economic expansion has on life expectancy.

The interaction term makes it possible to calculate the marginal influence of GDP on life expectancy at different levels of oil consumption. This is accomplished by calculating the partial derivative of Eq. (2) with respect to GDP, as shown in the Eq. (3):

$$\frac{\partial LNLE_t}{\partial LNO_t} = \beta_3 + \beta_4 LNGDP \tag{3}$$

A positive marginal effect indicates that an increase in both GDP and oil consumption negatively impacts life expectancy, whereas a negative marginal effect suggests an opposite outcome.

4.3 Descriptive statistics and unit root test

Before performing the ARDL test, descriptive statistics are conducted as an essential preliminary step. Descriptive statistics play a fundamental role in research by providing a comprehensive overview of data distribution and key attributes, thereby laying a solid foundation for further analysis. This work utilizes the Augmented Dickey-Fuller (ADF) unit root test to evaluate the stationarity of the data, based on the approaches of Hassan et al. [34], Ulucak et al. [35], and Ilkay et al. [36]. The ADF test is often used in time series analysis because to its capacity to address autocorrelation and provide crucial insights for model construction. If the value of the test statistic is insignificant ($\delta = 0$), the null hypothesis is accepted, suggesting that the data is not stationary or includes a unit root. On the other hand, if the null hypothesis is not supported ($\delta > 0$), the alternative hypothesis is accepted, indicating that the data is stationary. In order for the ARDL limits test to be valid, it is necessary that each variable be integrated of order I(0) or I(1), but not I(2). Although it is often expected that I(1) is necessary for the dependent variable, some research, including De Vita et al. [37], have discovered cases where this criterion does not apply.

4.4 ARDL analysis

The ARDL, sometimes referred to as the bound test for cointegration, is used with diagnostic tests to achieve the objectives of this research. The ARDL limits test is very suitable for evaluating cointegration, especially in cases when the dataset is severely limited. Pesaran et al. [38] proposed the bound test as an alternative to the cointegration test created by Johansen and Juselius [39]. The limits test is suitable for smaller samples, unlike the cointegration test which requires a large dataset.

The ARDL technique takes into consideration both short-term autoregressive effects and long-term distribution lag effects, capturing the interdependencies between variables across time. ARDL models are useful for analyzing long-term interactions in non-stationary time series data, providing dynamic insights into changeable interactions within a system. The ARDL model is more beneficial compared to other time series models such as the Ordinary Least Squares (OLS) regression, the Engle and Granger co-integration method and Johansen's approach. The ARDL model offers a number of advantages that these other models do not possess [25]. By enabling the concurrent evaluation of both enduring and immediate outcomes, it guarantees the acquisition of a more extensive comprehension of the interplay between factors. In addition, it utilizes delayed and control variables to tackle issues of endogeneity and collinearity, hence improving the reliability of the estimate [40].

Furthermore, Norehan et al. [41]assert that the ARDL model exhibits adaptability in determining the optimal lag duration based on economic theory and the dataset. Using panel ARDL with adequate lags helps deal the issue of endogeneity [3, 38]. In addition, the Johansen Co-integration technique focuses largely on establishing long-term equilibrium linkages, as shown by Elias et al. [42]. This strategy necessitates the integration of variables in the same sequence. According to Majekodunmi et al. [43], the OLS approach is susceptible to endogeneity and omitted variable bias, and it has limitations in capturing long-term trends.

The ARDL model utilizes the Wald test, sometimes referred to as the F-statistic, to ascertain the presence of a causal linkage across time. A long-term linkage is indicated when the F-statistic exceeds the upper critical value. Conversely, if the F-statistic falls below the lower critical value, it is suggested that there is no long-term connection. If the F-statistic falls within the specified range of important values, the outcome is deemed inconclusive [22]. As a result, the equation may be written in the following equation:

$$\Delta lnLE_t = \gamma_0 + \sum_{i=1}^{o} \delta_i \Delta \mathrm{lnLE}_{t-i} + \sum_{j=1}^{p} \mu_1{\prime} \Delta \mathrm{lnHE}_{t-i} + \sum_{k=1}^{q} \mu_2{\prime} \Delta \mathrm{lnGDP}_{t-i} + \sum_{l=1}^{r} \mu_3{\prime} \Delta \mathrm{lnFD}_{t-i} + \sum_{m=1}^{s} \mu_4{\prime} \Delta \mathrm{lnO}_{t-i} + \vartheta \mathrm{ECT}_{t-1} + \varepsilon_t \tag{4}$$

$$\mathrm{X} lnLE_t = a_0 + \sum_{i}^{o} \delta_i \Delta \mathrm{lnLE}_{t-i} + \sum_{j}^{p} k_1{\prime} \Delta \mathrm{lnHE}_{t-i} + \sum_{k}^{q} k_2{\prime} \Delta \mathrm{lnGDP}_{t-i} + \sum_{l}^{r} k_3{\prime} \Delta \mathrm{lnFD}_{t-j} + \sum_{m}^{s} k_4{\prime} \Delta \mathrm{ln}(\mathrm{GDP}^{*}\mathrm{O})_{t-i} + \vartheta \mathrm{ECT}_{t-1} + \varepsilon_t \tag{5}$$

The ARDL equation for the ECM, as denoted by Eqs. (4) and (5), is employed to compute short-term coefficients and the rate of adjustment. In this equation, the difference between the dependent and independent variables, known as ECT_{t-1}, is assessed one period after the long-term expression in Eqs. (4) and (5). A negative value of ECT_{t-1} signifies the presence of cointegration or long-term linkages, along with indicating the pace of adjustment towards equilibrium. In line with the proposition by Pesaran et al. [38], negative ECT_{t-1} values suggest model stability, implying that any temporary deviations from equilibrium will gradually be rectified over time. This underscores the capacity of error correction models to reveal enduring correlations and cointegration among variables, thereby mitigating concerns about spurious regression.

5 Findings

Table 1 shows variability and distribution characteristics of the variables. LNGDP, with a mean of 25.6277, has the largest central tendency, indicating it is significantly higher than other variables. LNHE, with a mean of 0.4097, is the lowest, indicating a smaller central value. The standard deviation values reflect dispersion around the mean, with LNGDP showing the highest variability (0.6722) and LNLE the lowest (0.0292). LNO is the most negatively skewed (− 0.1075), with a longer left tail. LNHE's skewness is nearly neutral (− 0.0316), suggesting a more symmetric distribution. Kurtosis values show distribution peaks, with LNLE's kurtosis (2.1253) indicating a more peaked distribution, suggesting heavier tails.

Table 2 shows the unit root test results, performed with a constant and with a constant and trend. All variables (LNLE, LNO, LNFD, LNGDP, and LNHE) are non-stationary at levels but stationary at initial differences when considering a constant. With a constant and trend, all variables except LNHE are non-stationary at levels but stationary at initial differences. The results indicate that all variables are integrated of order I(1), except LNHE under the constant and trend condition, which is stationary at the level. This integration order supports the ARDL approach, suitable for models with I(0) or I(1) variables but not I(2), justifying its use for further analysis.

With regard to both models, the results of the bound tests are presented in Table 3. The determination of a co-integrating connection becomes unclear when F-statistics are measured inside the upper and lower boundaries

Table 1 Descriptive statistics

	LNHE	LNGDP	LNO	LNFD	LNLE
Mean	0.4097	25.6277	6.7629	5.1910	4.2873
Median	0.4055	25.7223	6.7405	5.2605	4.2873
Maximum	0.7275	26.6221	7.6976	5.6354	4.3299
Minimum	0.0678	24.4552	5.5053	4.6994	4.2231
Std. Dev	0.1992	0.6722	0.6237	0.2554	0.0292
Skewness	− 0.0316	− 0.2365	− 0.1075	− 0.3768	− 0.3904
Kurtosis	1.7324	1.7921	1.7057	1.9035	2.1253

Table 2 Unit root test results

Variable	Constant		Constant and trend	
	Level	1st difference	Level	1st difference
LNLE	− 1.995	− 3.934***	− 2.818	− 4.129**
LNO	− 1.300	− 6.359***	− 1.387	− 3.967**
LNFD	− 0.643	− 7.041***	− 2.341	− 7.014***
LNGDP	− 1.131	− 4.761***	− 1.563	− 4.762***
LNHE	− 1.582	− 6.987***	− 3.993**	− 6.915***

*** and ** denote significance level in the range of 1% and 5%

Table 3 Bound tests results

Model 1				
			Lower bound	Upper bound
F-statistic	8.4630	10%	2.2	3.09
		5%	2.56	3.49
		1%	3.29	4.37
Model 2				
			Lower Bound	Upper Bound
F-statistic	8.4630	10%	2.2	3.09
		5%	2.56	3.49
		1%	3.29	4.37

of the distribution. If F-statistics are lower than the lower limits, we can reject the alternative hypothesis, indicating no co-integrating connection. However, our investigation shows that F-statistics for both models are higher than the upper limits, statistically significant at the 1% level. This indicates a co-integrating link between the variables: life expectancy in Malaysia, health spending, economic expansion, financial development, oil consumption, and the interaction variable.

5.1 Estimations results

Table 4 depicts the results of the ARDL short-run estimations for both models. The analysis reveals insightful linkages between factors and life expectancy. Health expenditure exhibits a significant negative impact on life expectancy in the short run, with a 1% increase resulting in a 0.0109% decrease. Conversely, economic expansion and financial development show significant positive effects, with a 1% rise in each leading to increases of 0.0258% and 0.0124%, respectively. The study uncovers a noteworthy finding regarding oil consumption, indicating a significant negative impact on life expectancy. A 1% increase in oil consumption correlates with a 0.0017% decrease in life expectancy. Equation 2, which includes the interaction variable, suggests that economic expansion coupled with oil consumption may diminish life expectancy, implying a potential trade-off between economic expansion and public health. This underscores the

Table 4 ARDL shot-run estimations

Variable	Model 1 Coefficient	Model 1 Prob.*	Model 2 Coefficient	Model 2 Prob.*
LNHE	− 0.0109	0.0008	− 0.0109	0.0008
LNGDP	0.0258	0.0005	0.0274	0.0003
LNFD	0.0124	0.0414	0.0124	0.0414
LNO	− 0.0017	0.0001	–	–
LNGDP*O	–	–	− 0.0017	0.0001
C	0.8479	0.0022	0.8479	0.0022

importance of considering sustainable economic strategies to safeguard life expectancy, particularly in contexts like Malaysia, where reliance on oil consumption for economic expansion poses risks to public health.

Table 5 provides a comprehensive overview of the results derived from the ARDL long-run estimations for both models. These findings illuminate significant linkages between key variables and life expectancy over extended periods. Firstly, the analysis reveals a noteworthy negative association between health expenditure and life expectancy in the long run. A 1% increase in health expenditure is linked to a considerable long-term decrease of 0.0597% in life expectancy. This observation indicates the complex interplay between healthcare investment and population health outcomes, suggesting potential areas for further investigation or policy intervention to optimize healthcare resource allocation.

Economic expansion and financial development are key factors positively impacting life expectancy. A 1% rise in these areas corresponds to long-term increases of 0.0398% and 0.0394%, respectively, in life expectancy. This underscores the role of economic prosperity and financial stability in health outcomes, reflecting broader socioeconomic health determinants. However, the interaction variable, oil consumption, adds complexity to the analysis. Prolonged reliance on oil for economic growth may adversely affect life expectancy over time. This highlights the trade-offs between economic development and public health, emphasizing the need for sustainable practices to safeguard long-term health outcomes.

In summary, the findings underscore the multifaceted nature of the linkage between key socioeconomic variables and life expectancy. They emphasize the significance of holistic policy approaches that integrate considerations of healthcare investment, economic expansion, and environmental sustainability to promote enduring improvements in public health outcomes.

Table 6 presents the outcomes of diagnostic tests for normality, serial correlation, heteroskedasticity, and the Ramsey RESET test. The results indicate that neither model exhibits diagnostic issues, suggesting their robustness for analyzing the interaction effect of oil consumption on life expectancy. A lack of diagnostic problems signifies that the models meet assumptions required for reliable inference. Normality tests ensure residuals follow a normal distribution, serial correlation tests assess correlation among residuals, heteroskedasticity tests examine whether residual variance is constant, and the Ramsey RESET test checks for potential model misspecification. The absence of these issues instills confidence in the

Table 5 ARDL long-run estimations

Variable	Model 1 Coefficient	Model 1 Prob.	Model 2 Coefficient	Model 2 Prob.
LNHE	− 0.0597	0.0213	− 0.0597	0.0213
LNGDP	0.0398	0.0010	0.0460	0.0005
LNFD	0.0394	0.0432	0.0394	0.0432
LNO	− 0.0062	0.0013	–	–
LNGDP*O	–	–	− 0.0062	0.0013
C	3.1329	0.0000	3.1329	0.0000

Table 6 Diagnostic tests results

	Model 1		Model 2	
Normality	1.982	0.371	1.982	0.371
Serial Correlation	2.064	0.149	2.064	0.149
Heteroskedasticity	1.372	0.244	1.372	0.244
Ramsey RESET	1.094	0.285	1.094	0.285

validity of the models' results, affirming their capability to accurately capture the linkage between oil consumption and life expectancy. This strengthens the credibility of the findings and indicates the models' utility in informing policymaking and further research in this domain.

Figure 3 presents the outcomes of Cumulative Sum (CUSUM) and CUSUM of Squares analyses. The blue lines representing both models are contained within the red lines, indicating the stability of the model. CUSUM and CUSUM of Square are statistical tools used to assess the stability of a regression model over time. These techniques help detect structural changes or instability in the parameters of the model. When the plotted lines remain within certain bounds, it suggests that the coefficients in the model remain relatively stable over time. The fact that the blue lines for both models fall within the bounds set by the red lines indicates that the coefficients in the models are stable. This implies that the linkages between the variables remain consistent throughout the period under consideration. Consequently, researchers can have confidence in the robustness of the model's estimations and conclusions drawn from it. The stability depicted in Fig. 3 lends credibility to the reliability of the models in analyzing the linkage between the variables studied. It provides assurance that any observed effects or linkages are likely genuine and consistent patterns within the data.

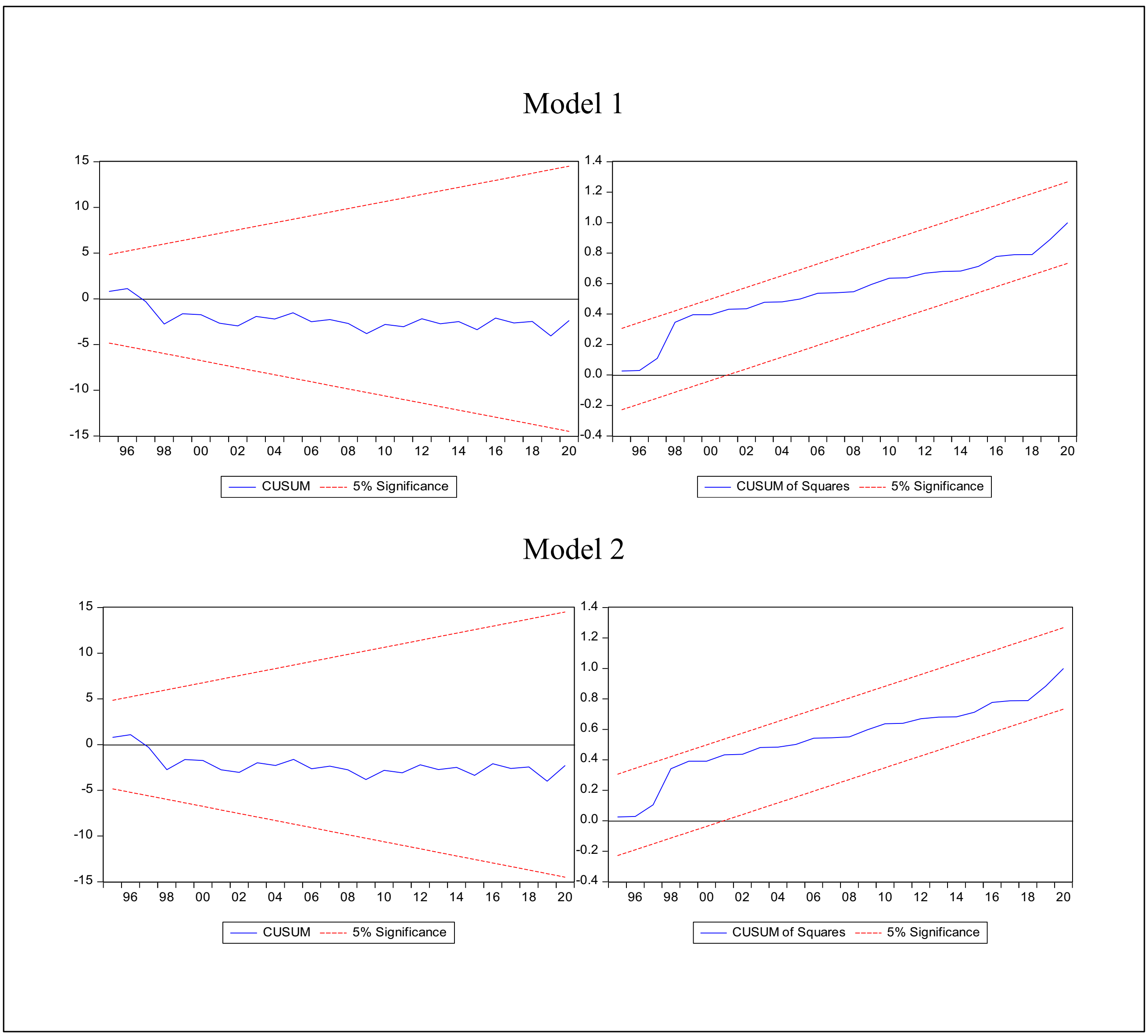

Fig. 3 CUSUM and CUSUM of squares

Table 7 Robustness Check Results (FMOLS and DOLS)

	Model 1				Model 2			
	FMOLSS		DOLS		FMOLSS		DOLS	
	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.
LNGDP	0.0251	0.0000	0.0210	0.0076	0.0280	0.0000	0.0255	0.0014
LNO	– 0.0029	0.0116	– 0.0045	0.0003	–	–	–	–
LNFD	0.0531	0.0001	0.0696	0.0002	0.0531	0.0001	0.0696	0.0002
LNHE	– 0.0082	0.3384	– 0.0158	0.1370	– 0.0082	0.3384	– 0.0158	0.1370
LNGDP*O	–	–	–	–	– 0.0029	0.0116	– 0.0045	0.0003
C	3.3918	0.0000	3.4189	0.0000	3.3918	0.0000	3.4189	0.0000

Table 8 Granger Causality Results

Model 1					
	Dependent variables				
Independent Variables	LNLE	LNGDP	LNO	LNFD	LNHE
LNGDP	3.3018 (0.0200)	–	1.0626 (0.4044)	1.9051 (0.1293)	2.3054 (0.0747)
LNO	4.7757 (0.0034)	0.0603 (0.9973)	–	0.3370 (0.8856)	0.1262 (0.9851)
LNFD	0.7247 (0.6113)	1.0380 (0.4174)	1.3954 (0.2599)	–	1.6501 (0.1836)
LNHE	0.7347 (0.6044)	2.4395 (0.0623)	1.0452 (0.4135)	0.3448 (0.8807)	
LNLE	–	3.7961 (0.0108)	2.3409 (0.0712)	1.4654 (0.2364)	1.0232 (0.4253)
Model 2					
	Dependent variables				
Independent variables	LNLE	LNGDP	LNFD	LNHE	LNGDP*O
LNGDP	3.3018 (0.0200)	–	1.9051 (0.1293)	2.3054 (0.0747)	0.6089 (0.6938)
LNFD	0.7247 (0.6113)	1.0380 (0.4174)	–	1.6501 (0.1836)	0.6947 (0.6323)
LNHE	0.8484 (0.5287)	2.4395 (0.0623)	0.3448 (0.8807)	–	0.5441 (0.7411)
LNGDP*O	4.7757 (0.0034)	0.0603 (0.9973)	0.3328 (0.8883)	0.1432 (0.9803)	
LNLE	–	3.7961 (0.0108)	1.4654 (0.2364)	0.4201 (0.8303)	2.3409 (0.0712)

The values in brackets represent the probabilities

5.2 Robustness check

The robustness check results from FMOLS and DOLS models in Table 7 show economic growth and financial development positively impact life expectancy, as indicated by significant coefficients across all models. However, health expenditure lacks a significant effect, reflected in high p-values. In Model 1, oil consumption significantly negatively impacts, suggesting higher pollution worsens health outcomes. In Model 2, the interaction term (LNGDP*O) also shows a negative effect, indicating the combined influence of economic growth and oil consumption may reduce life expectancy.

The Granger Causality results in Table 8 show a bidirectional relationship between economic growth and life expectancy, both statistically significant at the 5% level. Oil consumption influences life expectancy, but the reverse is weakly significant. Financial development and healthcare expenditure do not significantly impact life expectancy, nor does life expectancy affect them. No significant causal relationship exists between oil consumption and economic growth, financial development, or healthcare expenditure. For Model 2, economic growth and life expectancy continue to significantly influence each other. Economic growth interacting with oil consumption affects life expectancy, though the reverse is weak. Financial development and healthcare expenditure do not Granger-cause life expectancy, nor does life expectancy affect them. Lastly, there is no causal link between the interaction term (economic growth and oil consumption) and economic growth, financial development, or healthcare expenditure.

6 Discussion

Our study reveals a significant negative relationship between increased healthcare expenditures and life expectancy, both in the short and long term, particularly in the Malaysian context. This finding contradicts much of the existing literature, which generally suggests that higher healthcare spending leads to improved health outcomes. However, similar results have been observed in other studies. For instance, Anwar et al. (34) found that increased healthcare spending was associated with a decline in infant mortality. Using the Generalized Method of Moments (GMM) to analyze data from OECD nations, their study highlighted the complex relationship between healthcare investment and public health outcomes.

One possible explanation for the negative relationship is inefficiency in resource allocation, where funds may not be directed toward the most critical areas, such as preventive care, rural healthcare access, or essential medical infrastructure. Ahmed et al. [3] found that many Asian countries struggle with inefficient use of healthcare resources, which may reduce the benefits of increased expenditure. Additionally, our findings are consistent with research in the United States. Kim and Lane [44] identified a negative relationship between healthcare spending and life expectancy across 17 states, suggesting that factors beyond spending levels, such as how funds are allocated and managed, play a crucial role in shaping health outcomes. Healthcare spending may reach a threshold where additional investments yield diminishing returns. Initial increases in expenditures can improve healthcare access, infrastructure, and services, but further spending may not proportionally enhance health outcomes. This pattern may stem from inefficiencies in delivery, resource misallocation, or declining marginal benefits of certain interventions.

In addition, our study's findings highlight a positive link between economic expansion and increased life expectancy in Malaysia, observable in both short and long term. Wang et al. [40] support our findings with an alternate methodology and wider scope of inquiry, demonstrating that economic expansion can increase life expectancy. This conclusion highlights the potential advantages of socioeconomic development in enhancing population well-being and indicates the effect of economic expansion on public health outcomes. Several factors can affect this identified link. Firstly, economic expansion typically leads to improved living standards, healthcare accessibility, and overall quality of life. These improvements can positively influence health behaviors, illness prevention, and healthcare service usage. Furthermore, increased economic prosperity may enable governments to dedicate more resources towards healthcare infrastructure, public health programs, and social services, enhancing overall health outcomes. Additionally, the association between economic expansion and life expectancy aligns with principles and empirical evidence in development economics and public health. According to the "health transition" idea, as societies advance economically, they experience shifts in illness costs, healthcare priorities, and health results, leading to increased life expectancy. Our research findings provide empirical data supporting this theoretical framework, particularly in the Malaysian context.

Furthermore, our study suggests a clear connection between financial development in Malaysia and average population longevity. Nica et al. [45] also provide evidence that financial development is key in improving life expectancy in Eastern European countries. Given this connection's significance, it's reasonable to assume financial sector expansion contributes to improved population health outcomes. This has significant repercussions for economic and public health policies. One probable explanation for this connection lies in the interlinkages between financial system development, economic stability, and healthcare accessibility. A sophisticated financial sector encourages efficient resource allocation, investment, and money mobilization, stimulating economic expansion and generating revenue. Consequently, people and families can access superior healthcare services, prescriptions, and other health-related costs due to greater incomes and improved financial stability. This ultimately leads to improved overall health outcomes and increased life expectancy.

The results of our investigation reveal a critical discovery: economic expansion, particularly when heavily reliant on oil use, may negatively affect average lifespan. This unforeseen association prompts a more comprehensive examination of the intricate linkage between economic development, energy use patterns, and public health repercussions. Hendrawaty et al. [16] found a clear connection between energy use and average life expectancy in ASEAN nations. Additionally, Majeed et al. [24] demonstrated that clean energy utilization led to an increase in average lifespan. The conclusions of our study, on the other hand, differ from those of earlier research since we focus on determining whether or not there is a connection between oil consumption and life expectancy.

In addition, we investigate the linkage between the use of oil and the connection between economic expansion and life expectancy, so offering a significant contribution to the currently available body of research. The consumption of oil, which is a significant driver of economic expansion in a variety of contexts, frequently results in elevated levels of air pollution, emissions of greenhouse gases, and harm to the environment. It is well acknowledged that these pollutants have detrimental effects on respiratory health, cardiovascular function, and general well-being. As a consequence, the rates of disease and mortality among those who are affected by them are significantly greater. Our study highlights that high oil consumption impacts the positive relationship between economic growth and life expectancy due to its harmful health effects. Oil-related pollution contributes to respiratory diseases, cardiovascular conditions, neurological disorders, and cancer through exposure to pollutants like PM2.5, NO_x, and benzene. These physiological pathways provide biological plausibility for our findings, explaining how Malaysia's reliance on oil negatively impacts public health despite economic progress. Policymakers should consider cleaner energy alternatives to mitigate these health risks and ensure sustainable improvements in life expectancy.

7 Conclusion and policy recommendation

The purpose of this study is to evaluate the link between oil use, Malaysia's economic expansion, and average life expectancy. An analysis of data from 1980 to 2020 will be conducted using the ARDL methodology. Initially, we find an inverse link between health spending and life expectancy, suggesting increased healthcare investments may not necessarily improve health outcomes in Malaysia. Our analysis reveals several important insights. Additionally, the region's life expectancy is positively influenced by economic expansion and global financial system development. This supports the idea that broader socioeconomic issues play a significant role in determining population health outcomes.

Our findings indicate a considerable impact of oil consumption on the link between economic expansion and life expectancy. The use of oil directly affects this link, according to our data. As a result, the connection changes from positive to negative. However, substantial oil consumption may negate the advantages of economic expansion, highlighting the complex nature of the connection between energy consumption, economic progress, and public health outcomes. This implies that although economic expansion is typically linked to improved life expectancy, substantial oil consumption may negate these advantages.

Our discoveries motivate legislators and healthcare practitioners to implement a comprehensive plan for allocating resources and money in the healthcare sector. The association between economic expansion and increased life expectancy has significant implications for policymakers and stakeholders involved in public health and economic development governance. This underlines the necessity of encouraging sustainable economic expansion strategies prioritizing investments in human capital, healthcare infrastructure, and social determinants of health. By leveraging links between economic expansion and health improvement, Malaysian policymakers can work toward achieving comprehensive and equitable improvements in population health outcomes nationwide.

The findings, which support the hypothesis that financial development contributes to an increase in life expectancy, highlight the necessity of lobbying for changes in the financial sector, regulatory frameworks, and institutional structures that allow fair and sustainable financial expansion. There is a possibility that policymakers in Malaysia would develop an atmosphere that is conducive to the promotion of financial innovation, market competition, and consumer protection. Because of this, they will be able to make use of the transformational force of financial development in order to improve the results of both public health and economic success. Based on the findings, it can be concluded that the use of oil has a negative influence on the correlation between economic expansion and life expectancy in Malaysia. Therefore, it is of the utmost importance to encourage the spread of energy sources beyond fossil fuels and towards alternatives that are clean and responsible for the environment.

To reduce Malaysia's reliance on oil and its negative impact on life expectancy, a multi-faceted policy approach is essential. The government should establish financial incentives like tax credits, subsidies, and low-interest loans to encourage investments in clean energy sources such as solar, wind, and hydroelectric power. Phasing out fossil fuel subsidies and introducing a carbon tax would redirect resources toward sustainable alternatives. Strengthening renewable energy infrastructure is crucial, including expanding the national grid, investing in battery storage, and enhancing clean energy integration. Industries should transition to renewable energy through tax incentives and regulatory measures to meet sustainability targets. Germany's Energiewende (Energy Transition) policy, with subsidies, feed-in tariffs, and wind and solar power investments, increased its renewable energy share and reduced fossil fuel reliance. Despite initial costs, this transition led to economic benefits, including job creation in the renewable sector and improved public health. Similarly, Denmark successfully integrated wind power into its grid, ensuring energy security and economic stability. The Danish government supported this shift with financial incentives for renewable energy adoption and energy-efficient infrastructure investments. Today, wind energy accounts for nearly half of Denmark's electricity generation, showing that a strong commitment to clean energy can coexist with economic prosperity.

8 Limitations and suggestions for future research

A key limitation of this study is its focus on a single country (Malaysia), restricting the generalizability of findings to similar economies. The cross-sectional approach limits establishing causal relationships between GDP growth, oil use, and life expectancy, as unobserved factors may influence results. Another concern is potential measurement issues in life expectancy data. Changes in data collection methods or reporting accuracy could introduce inconsistencies, affecting the reliability of findings. Similarly, the definition of oil consumption may have evolved, altering how energy use is recorded and potentially influencing results. A more critical examination of these data limitations would strengthen the analysis by addressing how such inconsistencies might impact the study's conclusions.

Moreover, this study does not account for key socioeconomic and structural factors, such as education levels, urbanization rates, and technological advancements, which could independently affect both economic growth and life expectancy. Education influences health awareness, healthcare access, and economic opportunities, while urbanization affects healthcare accessibility, pollution exposure, and lifestyle choices. Technological advancements in medical care and infrastructure can significantly improve life expectancy, regardless of economic growth or oil consumption. The omission of these variables may introduce omitted variable bias, limiting the results' robustness. Finally, this study is constrained by data from 1980 to 2020, which may not fully capture long-term structural shifts in the economy, healthcare system, or energy consumption patterns. Future research could benefit from exploring longer time frames or incorporating additional variables for a more comprehensive analysis.

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Data availability The data is available upon request.

Declarations

Ethics approval and consent to participate This study does not involve any human participants or animals, and therefore, no ethical approval was required. The research adheres to ethical guidelines in the analysis of secondary data. All data used in this study were publicly available, and no personal or confidential information was included. The findings of this study reflect the relationship between economic and environmental factors and life expectancy in Malaysia, without any conflicts of interest from the authors.

Competing interests The authors declare no competing interests.

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