



Investigation of the driving factors of ecological footprint in Malaysia

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Abstract

Malaysia's growing trends in energy production-related emissions throw doubt on the country's possibility of meeting the Paris Climate Change Agreement and SDG obligations. Taking into account Malaysia's current growth pattern and climatic circumstances, this study evaluates the association between ecological footprint and its potential determinants: economic growth, oil consumption, renewable energy and domestic capital investment for the period between 1965 and 2017. The stationary nature of the parameters is investigated using the conventional unit root approach (ADF and PP unit root) and structural break unit root (ZA unit root). The bounds approach in combination with the critical approximation p-values of Kripfganz and Schneider (2018) established a cointegration association between the observed parameters. The ARDL approach uncovered that economic growth and oil consumption contribute to ecological footprint. Furthermore, renewable energy consumption and gross capital formation reduce the ecological footprint. The FMOLS and DOLS estimators were applied as the sensitivity analysis of the ARDL estimators. Furthermore, the spectral BC causality approach was also utilized to investigate the causal association between ecological footprint and its determinants.

Keywords Economic growth · Malaysia · Ecological footprint · Capital investment · Energy consumption

Introduction

There has been an improvement in human living standards and well-being in the last several decades, accompanied by an increasing concern for both scientists and policy makers on the environmental damage resulting from the increased economic growth at global level (Adebayo and Acheampong 2021). Industrial revolution brought about the transformation of global economy from human- and animal power-based organic production into large-scale industries based on the mass use of non-renewable resources such as fossil fuels (Shrinkhal 2019;

Dogan et al. 2019; Miao et al. 2022). The reason behind the increasing concern is due to not only the generation of greenhouse gases (GHG) contributing to global warming but also the environmental degradation and resource depletion generating obscurity in sustainable economic growth. To be able to decrease or prevent the harmful effects of human activities on the environment, several governmental and intergovernmental environmental policies are put into action such as Kyoto Protocol and Paris Agreement aiming to reduce GHGs and CO₂ emissions to control global warming. Since energy is the fundamental source for human economic activities, thus for economic growth (Khan et al. 2021a; Xu et al. 2022), there has been a tremendous increase in global energy demand (Khan et al. 2021b).

There are two main effects of energy consumption on human economic activities through opposite dimensions. First, energy consumption promotes economic growth by increasing the production of goods and services and creating jobs; while second, it interferes with economic growth by deteriorating the environmental quality as a result of the overuse or misallocation of energy sources (Majeed and Mazhar 2019; He et al. 2021). In other words, increasing economic human activities promote human living standards, while the accumulative use of factors of production leads to the depletion of resources used for energy production,

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which in turn negatively impacts the sustainability of economic growth. Main energy sources are divided into two main categories as renewable and non-renewable sources. Renewable sources include biological and flow sources which can regenerate itself over time, while non-renewable sources include sources which exist in fixed amounts or renewable at a geological timescale which is considered to have zero regenerative capacity, such as fossil fuels which are the main source of energy production at the global level (Hussen 2004).

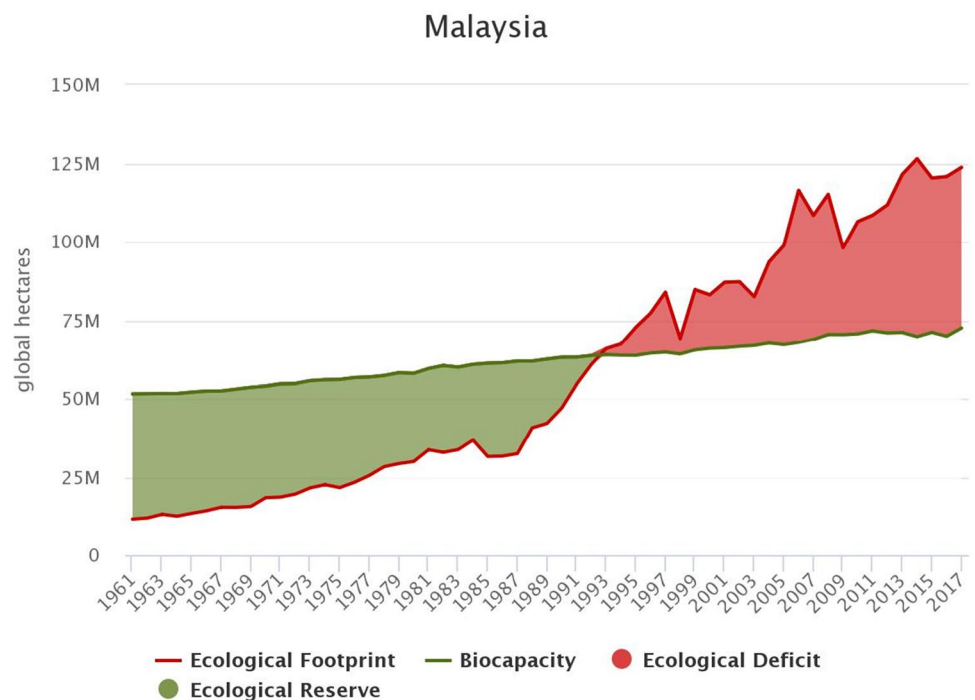
In Malaysia, as in other emerging economies, environmental issues have turned to receive considerable attention from the policy makers and scientists and became one of the main concerns of the government, since the use of fossil fuel and biomass as an energy source impacts the environment negatively. The major source for energy production in Malaysia depends on non-renewable energy sources such as coal, oil, and gas. However, the increase in oil and gas prices accompanied by the risk of depletion of the resources ascends the solution for energy supply reduction to support sustainable economic growth. Therefore, there is an urgent need to find an alternative energy source that is renewable for energy production (Petinrin and Shaaban 2015).

Malaysia is characterized as an emerging economy with USD 336,664 billion gross domestic product (GDP) and USD 10,401 per capita GDP in 2020 (World Bank 2021). Since the 1970s, sustainable development has been at the center of Malaysia’s development approach. The four main targets of sustainable development include eliminating

poverty, improving living standards of citizens, delivering higher quality education, and considering environmental quality. The New Economic Model (NEM) is formulated in 2009, based on three key features, which are high income, inclusivity, and sustainability, signifying three components of Sustainable Development Goals (SDG) of Malaysia, namely economy, society, and environment (Economic Planning Unit 2021). The 2030 Agenda for Sustainable Development is adopted by the United Nations in 2015 including 194 nations. Malaysia committed to the Agenda with the other 193 nations to promote her economic, social, and environmental status. According to the SDG index and report, Malaysia ranked 68th out of 162 countries and 4th among the members of the Association of Southeast Asian Nations (ASEAN) following Thailand, Vietnam, and Singapore (Economic Planning Unit 2021). Yet, according to the Living Planet Report of 2016, per capita consumption of Malaysia is 4.2 global hectares which is higher than the global average, while the global hectares that everyone should live has to be within the 1.7 range. This is an indication that Malaysia is borrowing earth’s resources generating shortchange for future generations. Figure 1, presented below illustrates the biocapacity, ecological footprint, ecological reserve, and ecological deficit of Malaysia over the years covering the period from 1961 to 2017.

As seen in Fig. 1, Malaysia has been experiencing an increasing ecological deficit since the early 1990s. Environmental issues in Malaysia are stated to have arisen mostly as a result of having underdeveloped economic frameworks and improper economic activity. As a result, the explanatory

Fig. 1 Ecological footprint of Malaysia



Global Footprint Network, 2021 National Footprint and Biocapacity Accounts

factors investigated in this study are likely to impact the quality of the environment coupled with causes of environmental hardships suffered by Malaysia. Malaysia depends heavily on fossil fuels to satisfy their energy demands. For example, oil consumption is the largest chunk of energy sources in Malaysia, accounting for around 36.83% of the total energy consumption. Malaysia environmental quality is likely to have deteriorated as a result of their severe reliance on fossil fuels. However, since the renewable energy of Malaysia is relatively low, it is possible that the low quantity of renewable could lead to the deterioration of environmental quality in Malaysia. There is a need to obtain a better insight regarding the opposing viewpoints of many research on what may be the source of the increase in the level of ecological footprint and whether any of the parameters used might also assist to minimize the increasing level in ecological footprint generated by other parameters. Thus, this current study aims to examine the role of economic growth, gross capital formation, oil consumption, and renewable energy on the ecological footprint in Malaysia by utilizing newly developed econometric techniques employing time series data covering the years from 1967 to 2017. The main contribution of this study is to investigate the role of gross capital formation on ecological footprint and the role of oil consumption on ecological footprint. There is only a limited number of studies that examine the isolated position of some of these macroeconomic variables on ecological footprint, for emerging economies like Malaysia (Bello et al. 2018; Khan et al. 2021a; Ahmed et al. 2019), however, no studies have combined these variables for the case of Malaysia. Second, the current research examines the potential influence of renewable energy and economic growth on ecological footprint. However, these variables act as the control variables, which helps to alleviate the risks of omitted-variable distortion in the estimated models. Third, the current study examines a possible structural break in the dependent variable in the computed models. Fourth, it makes use of the bounds approach combining the critical values of Kripfganz and Schneider (2018) to determine the cointegration association of the observed parameters, while the ARDL estimator is used to detect the long-term effect of these regressors on ecological footprint. Fifth, the sensitivity of the ARDL approach is also examined using the DOLS and FMOLS estimator. Sixth, this study proceeds to analyze the causal interconnection by applying the spectral BC causality approach, which is useful in detecting the causal connection between ecological footprint and its determinants at different frequencies. Finally, the initiative of combating climate change is projected to be pushed significantly through the policy suggested in this current study and emulated in other emerging nations with poor policy standards.

This study follows with a brief literature review with the “Literature review” section. The “Data and methodology” section provides information on the data and methodology used, while the “Empirical results and discussion” section represents the empirical findings. Finally, the “Conclusion and policy implications” section concludes the study.

Literature review

Environmental issues started to receive increasing attention from both policy makers and academics in the field since the beginning of the 1990s. The overuse and misallocation of resources to generate energy which is crucial for economic growth lead to a decrease in environmental quality which is expressed mostly by carbon emissions (Grossman and Krueger 2002; Ramzan et al. 2021; Kalmaz and Kirikkaleli 2019; Mata et al. 2022; Panait et al. 2021; Yuping et al. 2021; Katircioglu 2021; Katircioglu et al. 2018), and recently by ecological footprint in the academic literature. The ecological footprint is considered to be a stronger proxy for environmental quality, since it does not include only the emission level generated by human activities but also expresses the impact of human activities on the natural ecosystem (Zafar et al. 2019). Therefore, this study takes ecological footprint as an indicator of environmental quality. Thus, the literature review focuses on the outcomes of the research taking ecological footprint into consideration. Studies in the literature investigating the relationship between ecological footprint and economic growth are examined by the application of either the cross-country panel (Saud et al. 2020; Sabir and Gorus 2019; Pata and Yilanci 2020; Liu and Kim 2018; Charfeddine and Mrabet 2017; Ulucak and Bilgili 2018; Bagliani et al. 2008) or country-specific time-series (Godil et al. 2020; Hassan et al. 2019; Ahmed et al. 2021; Zafar et al. 2019; Khan et al. 2021a; Majeed et al. 2021; Koksall et al. 2020) analysis which follow two main strands. The first strand of these studies analyses the validity of the Environmental Kuznets Curve (EKC) hypothesis to investigate the impact of economic growth on environmental quality which is determined by ecological footprint (Sharif et al. 2020; Sabir and Gorus 2019; Liu et al. 2018; Charfeddine and Mrabet 2017; Ulucak and Bilgili 2018; Al-mulali et al. 2015; Koksall et al. 2020), while the second strand aims to investigate the main determinants of ecological footprint by the application of different methods and targets to explore the link between economic growth and ecological footprint by mostly utilizing cointegration and causality tests (Majeed et al. 2021; Kirikkaleli et al. 2021; Ahmed et al. 2021; Hassan et al. 2019; Bello et al. 2018). There are studies in the literature, some taking ecological footprint and the rest carbon emissions as a proxy for environmental degradation, while others include gross capital formation in their analysis as a control variable since capital formation promotes both economic growth and energy use, hence

deteriorating environmental quality (Abbas et al. 2020; Rahman and Ahmad 2019; Adebayo 2020; Narayan and Smyth 2008). Some of those studies focus on Malaysia as a case study to investigate the determinants of environmental degradation (Khan et al. 2021a; Anastasia 2015; Borhan and Ahmed 2012; Aeknarajindawat et al. 2020; Bekhet et al. 2017; Saboori and Sualiman 2013; Saboori et al. 2012, Suki et al. 2022; Ahmed et al. 2019). Nonetheless, to the best of the authors' knowledge, there is no study that takes capital formation into account while considering ecological footprint as an indicator for environmental degradation. Furthermore, the outcomes of the studies in the literature demonstrated varying results depending on different variables included in estimations, varying time period data covers, econometric tools employed, and specific features of the country or regions such as characteristics of the non-renewable energy resources, cultures, political foundations, and energy policies. Thus, the relationship between environmental quality and economic indicators is still unconvincing deserving further research. Table 1 summarizes some of the most recent studies in the literature, providing information about the country or region under consideration, economic indicators focused, econometric tools employed, and the results achieved.

Data and methodology

Several studies in the literature aimed to explore the determinants of environmental degradation, since environmental concerns started to gain more importance in recent years. According to the previous studies, the overuse of resources to generate energy to promote economic growth is considered to be the main determinant of the reduction of environmental quality (Grossman and Krueger 2002; Khan et al. 2021a; Zafar et al. 2019; Katircioglu et al. 2017; Bekun et al. 2021; Lean and Smyth 2010). This study reinvestigates the main determinants of environmental degradation in the case of Malaysia, utilizing the time series data covering the years from 1965 to 2017 by employing Eq. (1) given below:

$$EF_t = f(EG_t, REN_t, OC_t, GCF_t) \quad (1)$$

Furthermore, this study employs also the impact of incorporating a dummy parameter into the model, which helps to generate the model (2) as given below;

$$EF_t = f(EG_t, REN_t, OC_t, GCF_t, DUM) \quad (2)$$

where EF denotes ecological footprint, EG stands for economic growth which is proxied from per capita Gross Domestic Product (GDP), REN represents renewable energy consumption per capita, while OC, GCF, and DUM symbolize oil consumption, gross capital formation as percentage of GDP, and dummy parameter respectively.

Thus, the econometric model for models (1) and (2) is denoted as:

$$EF_t = \beta_0 + \beta_1 \ln EG_t + \beta_2 \ln REN_t + \beta_3 \ln OC_t + \beta_4 GCF_t + \varepsilon_t \quad (3)$$

$$EF_t = \beta_0 + \beta_1 \ln EG_t + \beta_2 \ln REN_t + \beta_3 \ln OC_t + \beta_4 GCF_t + DUM + \varepsilon_t \quad (4)$$

β_0 refers to the intercept and the estimated long-term coefficients attached to associated independent variables are expressed by β_1, \dots, β_5 whereas ε represents the error term while t stands for the time. To be able to capture the growth impact of the variables under consideration, logarithmic forms of the series are taken as denoted with (\ln). Our perspectives regarding the impact of these determinants of ecological footprints are as follows: Between EG and EF, a positive interconnection is expected. i.e., $(\beta_1 = \frac{\delta EF}{\delta EG} > 0)$. Our viewpoint is derived from the conclusion of Akinsola et al. (2021) and Kirikkaleli et al. (2021). For REN and EF, a negative interconnection should be established $(\beta_2 = \frac{\delta EF}{\delta REN} < 0)$, which is based on the findings of Yuping et al. (2021); Zhang et al. (2021), and Coelho et al. (2021). Moreover, a positive interconnection should be detected between OC and EF, i.e. $(\beta_3 = \frac{\delta EF}{\delta OC} > 0)$. Lastly, between GCF and EF, our expectation regarding the association is either positive or negative, i.e., $(\beta_4 = 0 < \frac{\delta EF}{\delta OC} > 0)$.

The main innovation of this study is to investigate the role of gross capital formation and oil consumption on ecological footprint, using renewable energy and economic growth as a control variable, which helps to fill this gap in the literature where the model is summarized in Fig. 2.

Table 2 provides information about the description of the series used and the sources from which the data for each indicator is gathered. The data for ecological footprint is collected from Global Footprint Network (2018) and GDP per capita and Gross Domestic Formation are gathered from the World Bank Database Indicators (2021), while renewable energy consumption per capita and oil consumption are obtained from the British Petroleum database.

Econometric method

Since it is well known that non-stationary time series data might generate a spurious regression problem (Granger and Newbold 1974), conventional unit root tests such as augmented Dickey Fuller (ADF) and Phillips-Perron (PP) followed by the structural unit root test are applied to test for the stationarity of the series. It is confirmed that all series are integrated at the first difference I(1); the Pesaran Bounds test approach is applied to check for the long-run cointegration among the series. Critical values used for the bounds test are based on the bounds test developed by Kripfganz

Table 1 Literature review

Authors	Country	Indicators	Model	Years covered	Result
Ahmed et al. (2019)	Malaysia	EG, EC, GLOB, FD, POP	Bayer- Hanck cointegration test and the ARDL bound test	1971–2014	EG → EF POP → EF EC → EF FD → EF
Ahmed et al. (2021)	Japan	POP, FD, EC, GLOB, EG	Non-linear ARDL	1971–2016	FD → EF
Al-mulali et al. (2015)	93 countries	EG, EC, TO, FD, UR	GMM	1980–2008	EKC is valid for upper, middle, and high-income countries but not for low and lower-middle-income
Bagliani et al. (2008)	141 Selected countries	EG, EF	OLS, Weighted OLS	Cross-Country analysis	Results do not show evidence of de-linking
Bello et al. (2018)	Malaysia	EG, EC	VECM Granger causality	1971–2016	EKC is valid EC → EF EC → EG EG ↔ EF
Charfeddine and Mrabet (2017)	MENA	UR, EC	Pedroni Cointegration, DOLS, FMOLS, Granger Causality	1975–2007	EKC is valid EC → EF
Godil et al (2020)	China	GLOB, FD, TU	QARDL	1986–2018	FD → EF GLOB → EF TU → EF
Hassan et al (2019)	Pakistan	EG, HD, UR	Bayer-Hanck cointegration, ARDL	1971–2014	EG → EF
Khan et al. (2021a)	Malaysia	FD, NR, EG	DARDL	1980–2019	EKC is valid FD → EF NR → EF EG → EF
Kirikkaleli et al. (2021)	Turkey	TO, EC, GLOB, EG	Dual Adjustment Approach	1985–2017	EG → EF GLOB → EF TO → EF EC → EF
Koksal et al. (2020)	Turkey	Shadow Economies	Johansen Cointegration,	1961–2014	Shadow Economies → EF
Liu et al. (2018)	Japan, Korea, China	EG	Johansen cointegration, VECM	1990–2013	EKC is valid for Japan and Korea but not for China
Liu and Kim (2018)	BRI Countries	FDI, EG	PVAR, VECM, Granger Causality	1990–2016	EF → FDI Varying results
Majeed et al. (2021)	Pakistan	EC, EG, GCF, OC, CC, ELC	NARDL	1971–2014	OC → EF EC → EF CC → EF
Pata and Yilanci (2020)	G7 Countries	FD, EG, GLOB, EC	Fourier Toda-Yamamoto Causality Test	1980–2015	FD → EF GLOB → EF EG → EF EC → EF
Sabir and Gorus (2019)	South Asian Countries	FDI, TO, GLOB, TECH,	Westerlund, ARDL	1975–2017	EKC is valid FDI → EF TO → EF GLOB → EF
Saud et al. (2020)	OBORI Nations	FD, GLOB, EG, EC	PARDL, Granger Causality	1990–2015	FD ↔ EF GLOB ↔ EF EG → EF EC → EF

Table 1 (continued)

Authors	Country	Indicators	Model	Years covered	Result
Sharif et al. (2020)	Turkey	NE, RE, EG	QARDL, Granger Causality	1965Q-2017Q	EKC is valid NE ↔ EF RE ↔ EF EG ↔ EF
Ulucak and Bilgili (2018)	Malaysia	EG, TO, HD	Second Generation Panel Techniques	1961–2013	EKC is valid HD → EF TO → EF
Zafar et al. (2019)	US	EG, EC, NR, FDI	ARDL, Granger Causality	1970–2015	EC ↔ EF EG ↔ EF

ARDL, autoregressive distributed lag; BRI, belt and road initiative; CC, coal consumption; DARDL, dynamic simulated ARDL; DOLS, dynamic ordinary least squares; EC, energy consumption; EF, ecological footprint; EG, economic growth; EKC, environmental Kuznets curve; FD, financial development; FDI, foreign direct investment; FMOLS, fully modified ordinary least squares; GLOB, globalization; GMM, generalized method of movements; HD, human development; MENA, Middle East and North African; NARDL, non-linear ARDL; NE, non-renewable energy; NR, natural resources; OBORI, One Belt One Road Initiative; OC, oil consumption; PARDL, Panel ARDL; POP, population density; PVAR, vector autoregression; QARDL, quantile ARDL; RE, renewable energy; TECH, technological changes; TO, trade openness; TU, tourism; UR, urbanization; VECM, vector error correction model

and Schneider (2018), which follows F and t distribution stating the null hypothesis that there is no long-run cointegration between the variables. Furthermore, the Breusch-Godfrey test, Ramsey’s RESET, Jarque Berra, and LM tests are conducted to test for serial correlation, misspecification of the data, normality, and heteroscedasticity respectively as a diagnostic check for regression. Moreover, CUSUM and CUSUM-SQ tests are employed to confirm the long-run stability of the coefficients of both models used in econometric analysis. The utilization of the error correction model (ECM) aims to introduce an error correction term into the long run estimation model which serves as a mechanism to correct the short-term imbalances (Engle and Granger 1987). Furthermore, fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) are employed for a robustness check. Finally, this study also explores the causality effect of the regressors on ecological footprint using the spectral BC causality approach, which helps to probe into the period when the causal association is established. Figure 3 provides a graphical insight into the study’s procedure of analysis.

Empirical results and discussion

This section of the study focuses on interpreting the empirical outcomes of the econometric estimations. We presented an overview that encompasses the assessment of central tendencies and dispersion of the defined parameters in the previous section, which is demonstrated in Table 3.

EG is ranked as the highest average followed by OC, GCF, OC, and REN with ecological footprint having the lowest average. Coincidentally, a similar ranking is also confirmed with respect to the median. This indicates that EG is on the upsurge in Malaysia. With respect to symmetry, all series display negative skewness with the exception of GCF; however, all series indicate a low tail peakedness of less than 3. Moreover, the Jarque–Bera test and its probability value also demonstrate that all series are normally distributed. In addition, the RADAR chart is depicted as illustrated in Fig. 4 to showcase the descriptive statistics of the observed variables.

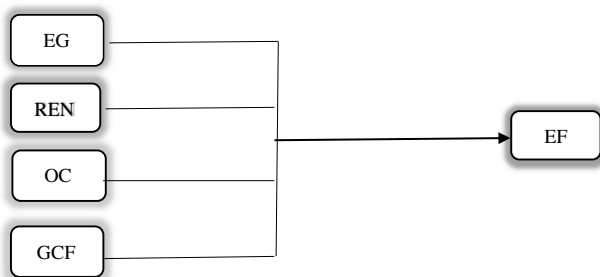


Fig. 2 Determinants of EF

Table 2 Description of the variables

Indicators	Description	Sourced
EF	Ecological footprint	Global footprint network (GFN 2018)
EG	GDP per capita (constant 2010 US\$)	World Bank Database indicators
REN	Renewable energy consumption per capita	British Petroleum database
OC	Oil consumption (million tons)	British Petroleum database
GCF	Gross capital formation (% of GDP)	World Bank Database indicators

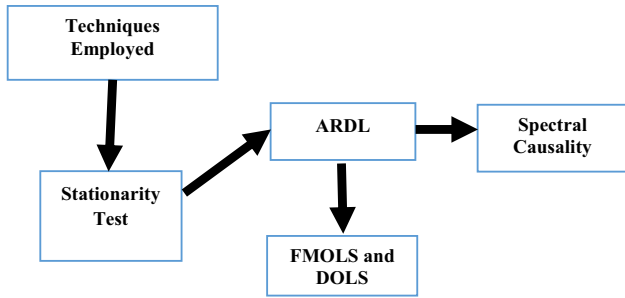


Fig. 3 Graphical flow of analysis

Furthermore, the matrix of Pearson correlation exhibiting the pairwise association amongst the underlined series is investigated in Table 4. We discovered a positive and significant association between OC and ecological footprint, indicating the nature of oil consumption towards environmental degradation in Malaysia. An akin positive association is evident between the ecological footprint and these

variables (EG, REN, and GCF). Correlation analysis, on the other hand, is insufficient to reach a resolution in the empirical literature. Hence, this research will conduct additional econometric analysis to either disprove or validate the stated association.

Subsequently, this research proceeds to investigate the stationarity properties of the series as a crucial requirement in econometrics modeling in order to avoid erroneous analysis and inappropriate policy prescribed. The stationarity nature of the observed variables is summarized in Table 5 and Table 6.

The conventional unit roots test (ADF and PP) reveal that all series are integrated at the first level. Also, the structural break unit also reveals that ecological footprint, EG, REN, OC, and GCF are integrated at the first level with the break level of 1988, 1998, 1989, 1981, and 1998 respectively. Hence, permitting to discover for a long run equilibrium association between the variables, as stated by the Pesaran Bounds testing approach expressed in Table 7. The bounds test using the Kripfganz and Schneider critical values

Table 3 Descriptive statistics

	EP	EG	REN	OC	GCF
Mean	0.429568	3.671707	1.082526	2.719100	1.412765
Median	0.468457	3.684712	1.133569	2.820074	1.405248
Maximum	0.648165	4.069551	1.558652	3.351352	1.639884
Minimum	0.148443	3.208584	0.358878	2.222753	1.133354
Std. Dev	0.154999	0.255716	0.378162	0.282122	0.114614
Skewness	-0.291196	-0.228872	-0.422492	-0.178690	0.108502
Kurtosis	1.626879	1.840436	1.836996	2.073032	2.791088
Jarque – Bera	4.912753	3.432009	4.563690	2.179602	0.200372
Probability	0.085745	0.179783	0.102096	0.336283	0.904669
Observations	53	53	53	53	53

Fig. 4 Radar chart

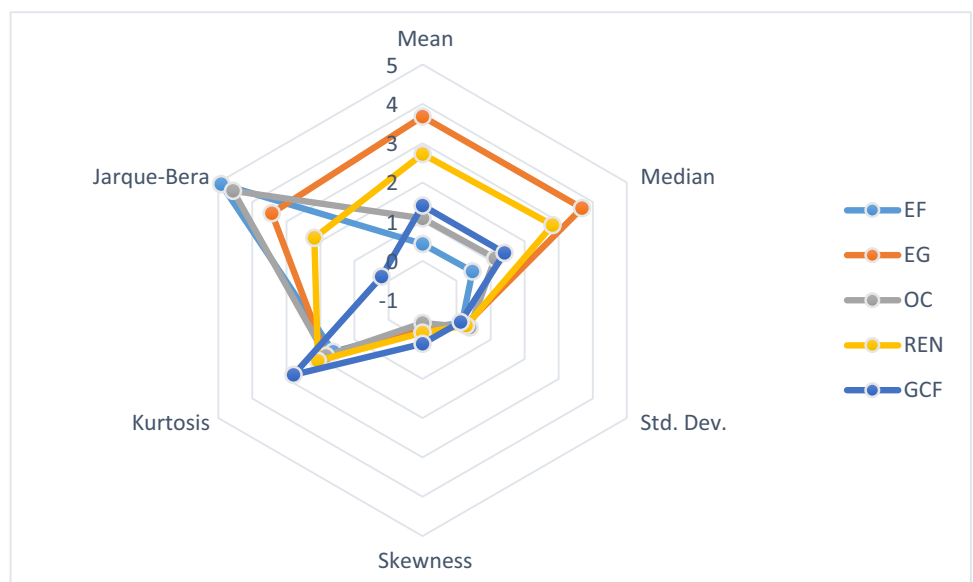


Table 4 Pearson correlation analysis

Observations	EF	EG	REN	OC	GCF
EF	1				
EG	0.9724*	1			
OC	0.9769	0.9931	1		
REN	0.8115*	0.8728*	0.8611*		
GCF	0.3624*	0.3029**	0.3425**	0.272429	1

* and ** portrays 0.01 and 0.05 significance level

establishes an equilibrium association between the observed series. This is asserted by the F-statistics and t-statistics having a greater value than both critical values (lower and upper value) at a 5% statistically significant level, implying convergence between the observed variables during the period of study. Therefore, this suggests a long-term association between ecological footprint and its determinants for an effective policy architecture in Malaysia.

For the ARDL model’s goodness of fit, we conducted several post-estimation tests as mentioned in the previous section of our study. These diagnostics tests are showcased in Table 7, which reveals that the residual of these models does not have heteroscedasticity, misspecification, and serial correlation issue. The residual of these models is also normally distributed. Furthermore, the CUSUM and CUSUMSQ tests indicate that the models are stable at a 5% level of significance, which is illustrated in Figs. 5 and 6.

To examine the magnitude and effect of the long-run association of the ecological footprint and its determinants, the coefficient for the long- and short-term analysis is computed as summarized in Table 8. Moreover, the long-run association is corroborated by the error correction model, which demonstrates a negative and significant with its coefficient as 0.5105 for model 1 and 0.5041 for model 2. This suggests that the rate of convergence in the place of short shock is 51.05% for model 1 and 50.41% for model 2.

As illustrated in Table 8, economic growth, renewable energy consumption, and oil consumption are the underlying factors of ecological footprint in the long run. According

Table 5 Conventional unit-roots outcome

	ADF		PP	
	I(0)	I(1)	I(0)	I(1)
EF	-2.4365	-9.3475*	-2.4365	-9.3814*
EG	-1.7810	-6.3093*	-1.8863	-6.3141*
REN	-2.3978	-5.5976*	-2.0937	-5.4584*
OC	-0.5615	-7.3020*	-0.6018	-7.3062*
GCF	-1.9341	-6.5675*	-2.0143	-6.5661*

* and ** depicts significance level of 0.01 and 0.05

Table 6 Structural break unit-roots outcome

	I(0)	I(1)
EF	-4.7740 (1991)	-10.4139* (1988)
EG	-2.9782 (1992)	-7.1217* (1998)
REN	-3.5593 (1983)	-6.3504* (1989)
OC	-2.8461 (1993)	-8.0196* (1981)
GCF	-4.5064 (1998)	-7.1311* (1998)

* depicts significance level of 0.01; structural breaks are in parentheses

to the estimation results, economic growth exhibits a positive and significant association with the ecological footprint in Malaysia not just in the long-term, but also in the short-term. This indicates that a 1.40% and 1.29% upsurge in ecological footprint is triggered by a 1% increase in EG as reported in model 1 and model 2 respectively. This is consistent with the previous research by Alola et al. (2021) in China, Kirikkaleli et al. (2021) in Turkey, Awosusi et al. 2022 in BRICS economies, and Kihombo et al. (2021) in WAME economies, which establishes a positive interaction between EG and ecological footprints. Economic expansion is unattainable unless goods and services are produced and consumed. Consequently, as income levels continue to expand, there will be an upsurge in the consumption of resources (such as water, food, and energy), residential sector, generation waste in the construction sector, transportation sector, industrial sector, and land use, among others. Thus, as the ecological footprint becomes more intense, environmental degradation worsens. Furthermore, this outcome is understandable given Malaysia’s transition from an agrarian to an industrial and service-based economy with a heavy reliance on energy. Malaysia’s average energy consumption growth rate in the industrial, transportation, and residential sectors has been between 6 and 7% during the last four decades.

Furthermore, with respect to Malaysia’s energy mix, the consumption of oil has a significant and positive interconnection with the ecological footprint only in the long run, suggesting that the increase in oil consumption intensifies ecological footprint, thereby contributing to environmental degradation in both models. This conclusion suggests that increased oil consumption for other energy-intensive economic operations underpins the association between economic growth and ecological footprint. Although this energy resource promotes and boosts economic growth, its usage raises the ecological footprint. This conclusion backs up the findings of earlier empirical research conducted on Pakistan by Majeed et al. (2021). Furthermore, the research by Adebayo et al. (2021) confirmed a similar interconnection between CO₂ emission and oil consumption in Japan. Oil consumption is the largest chunk of energy sources in Malaysia, accounting for around 36.83% of the total energy

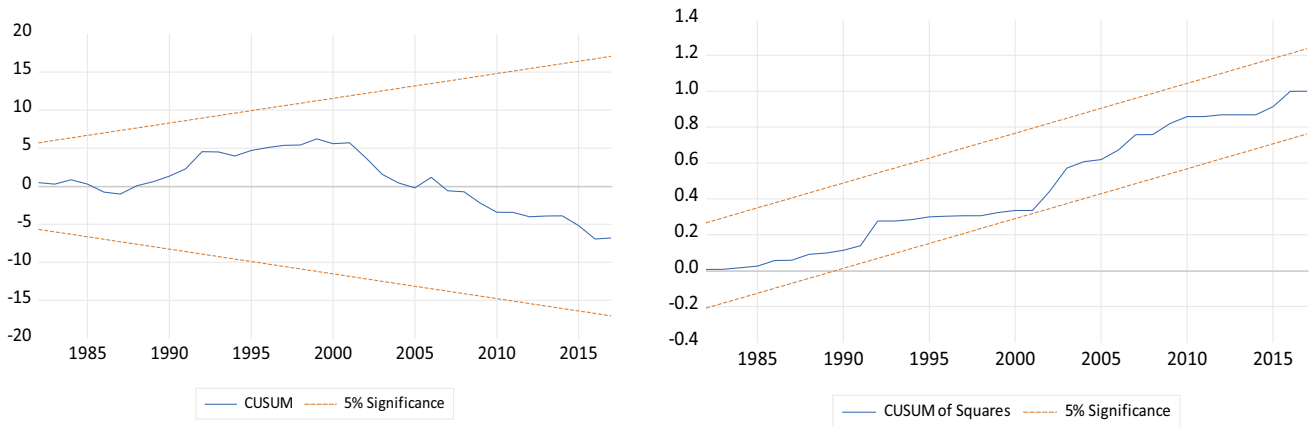


Fig. 5 Stability test for model 1

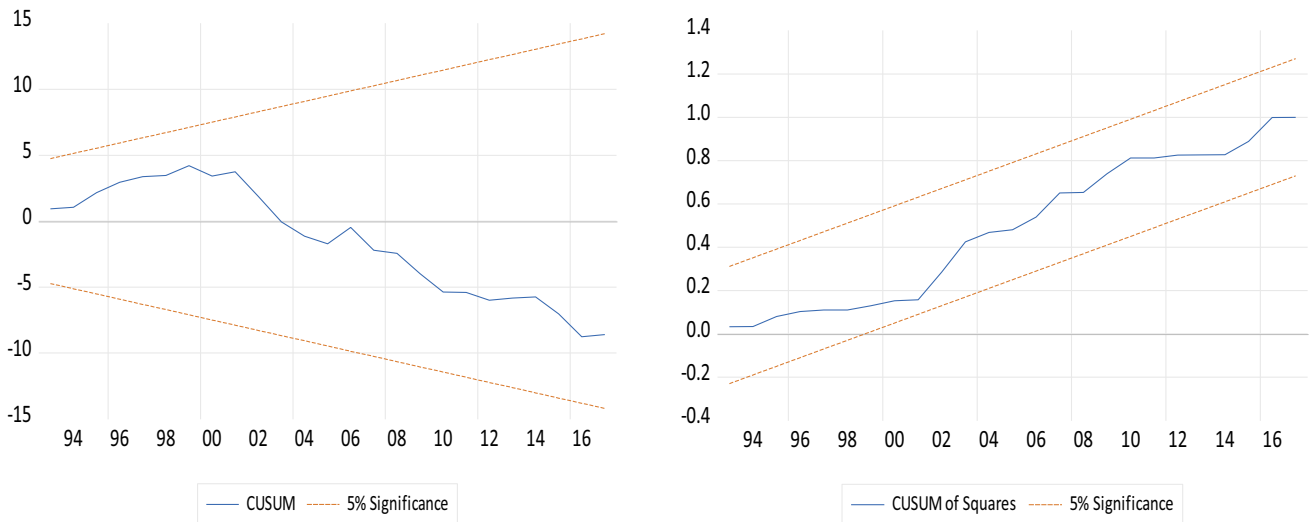


Fig. 6 Stability test for model 2

Table 7 ARDL approach to cointegration.

	Model 1		Model 2			
F-statistic	4.6785*		4.3395*			
T-statistic	−5.0982*		−5.4549*			
Kripfganz and Schneider critical values						
	1%		5%		10%	
	LB	HB	LB	HB	LB	HB
F-statistic	3.74	5.06	2.86	4.01	2.45	3.52
T-statistic	−3.43	−4.60	−2.86	−3.99	−2.57	−3.66
Diagnostic check						
	Model 1		Model 2			
χ^2 Normality	0.7618 (0.6832)		0.9632 (0.6177)			
χ^2 LM	0.1912 (0.8268)		0.0432 (0.9578)			
χ^2 Heteroscedasticity	1.1683 (0.3401)		1.0305 (0.4479)			
χ^2 Ramsey	0.3076 (0.7602)		0.1814 (0.8571)			

* depicts significance level of 0.05; *p* value in parentheses

Table 8 ARDL estimators outcome

Variable	Model 1		Model 2	
	Coefficients	T-statistics	Coefficients	T-statistics
EG	1.4070*	3.8542	1.2948*	3.5114
OC	0.3579*	3.6956	0.3418*	3.5528
REN	-0.1575**	3.6956	-0.1758**	-2.4462
GCF	-0.0233	-0.2397	-0.2757**	-2.3069
DUM			0.0325	1.4130
ΔEG	1.4070*	4.3307	1.2948*	4.1208
ΔREN	-0.0775	-1.8343	-0.0865**	-2.1205
ΔGCF	-0.0233	-0.2709	-0.1908**	-2.5943
ECT(-1)	-0.5105	-5.0982	-0.5041*	-5.4549

* and ** depict a significance level of 0.01 and 0.05; p-value in parentheses

consumption. However, owing to the advent and development of renewable energy sources, as well as the transition of other fossil energy, Malaysia’s reliance on oil consumption has gradually decreased in recent years. This assists the economy in reducing its ecological footprint produced by the excessive consumption of oil.

Moreover, renewable energy has a significant and negative interconnection with ecological footprint not just in the long term but also in the short term. The reduction in ecological footprint by 0.16% can be realized by the increase in renewable energy by 1% in model 1; whereas, in model 2, the ecological footprint will decrease by 0.18%. This seems plausible given that numerous prior research shows that RN reduces EF, thereby promoting environmental quality; for example, Akinsola et al. (2021) for Brazil; Rafique et al. (2021) for selected ten economies; and Iorember et al. (2021) for South Africa. Energy consumption is required to maintain continuous economic expansion; although, only clean energy sources such as geothermal, tidal, wind, sun, and hydropower could assist in achieving long-term sustainability in terms of growth. Moreover, using these energy sources will not only promote a sustainable ecosystem

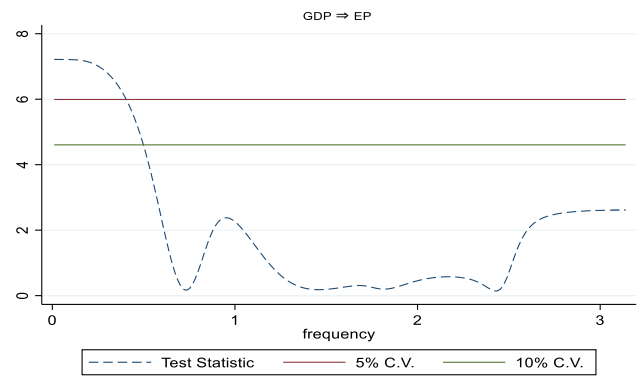


Fig. 7 Spectral BC causality from EG to EF

without impeding economic growth but can also assist governments in meeting their environmental goals.

However, it is evident that the adverse effect of oil consumption on the ecosystem outmatches the positive effect of renewable energy on the environment. By discovering this, we concluded that the present manufacturing processes are insufficient to satisfy the standards for carbon intensity and energy efficiency. This condition is undesirable for long-term sustainable growth. Hence, Malaysia needs to re-engineer its long-term economic policy to ensure the extensive use of cleaner energy in the industrial and residential sectors. To ensure a cleaner ecosystem, policymakers must pinpoint pollution-intense industries where the use of clean energy resources like biomass, water, air, solar, and wind can be expanded.

Also, as depicted in Table 8, gross capital formation exerts an insignificant effect on ecological footprint not just in the long term, but in the short term as well. Although, having incorporated the dummy variable in model 2, it is evident that there is a negative and significant association between gross capital formation and ecological footprint not just in the long term, but in the short term as well, which is in conformity with the study of Majeed et al. (2021) in Pakistan. This indicates that the gross capital formation of Malaysia is effective in decreasing the ecological footprint, suggesting thus investment is channeled

Table 9 Robustness estimator outcome

Variable	FMOLS		FMOLS with breaks		DOLS		DOLS with breaks	
	Coefficients	T-statistics	Coefficients	T-statistics	Coefficients	T-statistics	Coefficients	T-statistics
EG	1.2252*	2.9630	1.1954*	3.0820	1.1138*	2.3982	1.1041*	2.4126
REN	-0.0783***	-1.9907	-0.0778**	-2.1071	-0.0742***	-1.6800	-0.0759*	-1.7418
OC	0.3678**	2.6667	0.3518*	2.7133	0.3427**	2.2113	0.3344*	2.1861
GCF	0.0009	0.0163	0.0277	0.5051	0.0156	0.2429	0.0570	0.8979
DUM			0.0421	1.1065			0.0348	0.7913

* and ** depict a significance level of 0.01 and 0.05

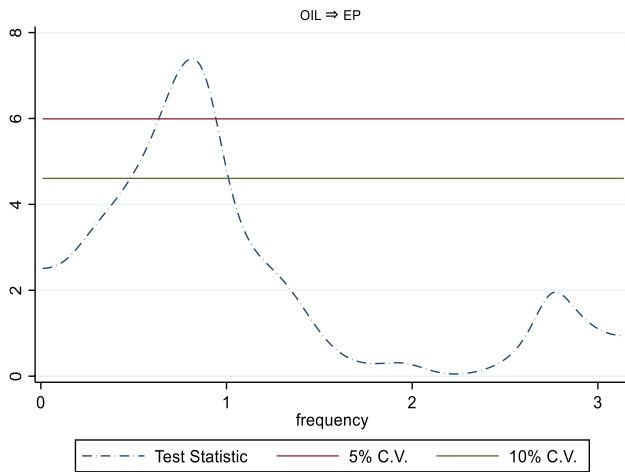


Fig. 8 Spectral BC causality from OC to EF

towards eco-friendly technologies for the production of goods. Finally, the dummy variables have a positive and insignificant effect on ecological footprint not only in the long run but also in the short run. This positive linkage could be possible owing to the increase in GDP, which in turn increases oil consumption, which results in environmental degradation.

The robustness analysis for models 1 and 2 is summarized in Table 9. The findings reveal that economic growth and oil consumption significantly impact ecological footprint, but renewable energy exhibits a negative effect on ecological footprint. Conversely, between domestic capital investment and ecological footprint, an insignificant association was reported. These outcomes are in accordance with the outcomes of the ARDL estimators.

Having established the long-run effect of ecological determinants, this current study proceeded to examine the causal interconnection by applying the spectral BC causality approach, which is useful in detecting the causal connection between ecological footprint and its determinants at different frequencies. However, the conventional Granger causality

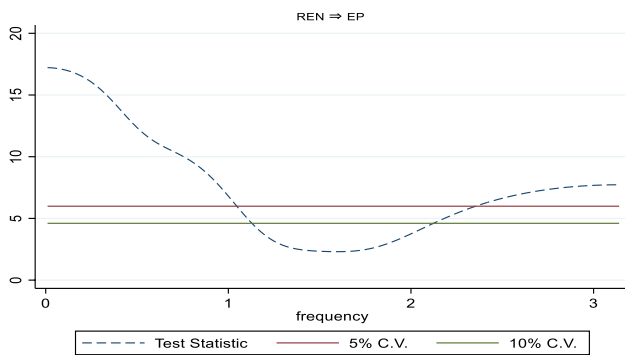


Fig. 9 Spectral BC causality from REN to EF

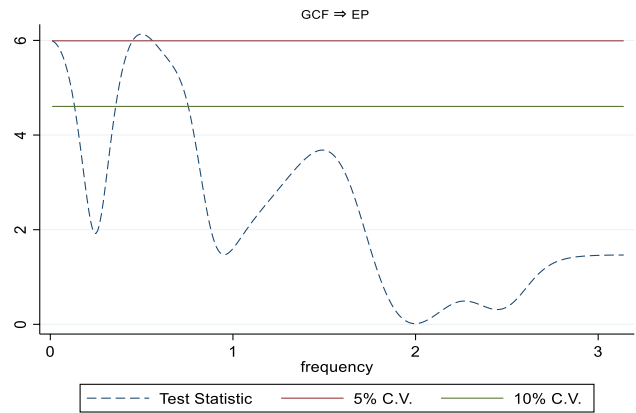


Fig. 10 Spectral BC causality from GCF to EF

method is incapable of performing this operation. Figures 7, 8, 9, and 10 display the outcomes of the causality interconnection of ecological footprint with its determinants. In Figs. 7, 8, 9, and 10, the green and red plain lines represent the 10% and 5% level of significance and the t-statistics of the BC causality approach is represented by the dash-line. Figure 7 indicates the unidirectional causal connection from economic growth to ecological footprint is evident only in the short run, signifying that only in the short run economic growth is a predictor of ecological footprint. A similar finding is seen between oil consumption and ecological footprint in Fig. 8, where the unidirectional causal connection from oil consumption to ecological footprint is evident only in the short run. Thus, oil consumption is a predictor of ecological footprint in the short term. Also, Fig. 9 displays the causality association between renewable energy and ecological footprint. The unidirectional causal connection from renewable energy to ecological footprint is evident in the medium and long term. Hence, renewable energy is a predictor of ecological footprint in the medium and long term. Finally, Fig. 10 indicates the unidirectional causal connection from

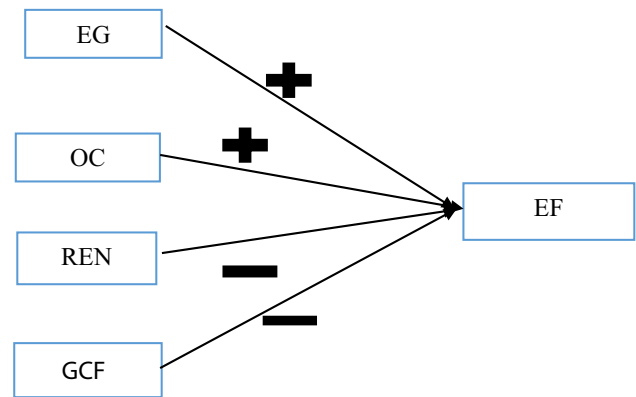


Fig. 11 Graphical illustration of the study

domestic capital investment to ecological footprint is evident only in the short run; signifying that only in the short run domestic capital investment is a predictor of ecological footprint. Based on these outcomes, it is obvious that economic growth, oil consumption, renewable energy, and domestic capital investment are the predictive factors of the ecological footprint in Malaysia. Hence, any initiatives aimed at enhancing economic growth, oil consumption, renewable energy, and domestic capital investment will have a significant impact on the ecological footprint.

Conclusion and policy implications

Malaysia's industrial and residential sector is heavily dependent on the use of fossil fuels to generate energy (Fig. 11). Despite the many major fossil fuels used in the production process, oil generates the lion's share of Malaysia's overall energy generation. Thus, the nation's ecological footprint from energy generation has gradually increased in recent years, deteriorating Malaysia's environmental quality. Malaysia's growing trends in energy production-related emissions throw doubt on the country's possibility of meeting the Paris Climate Change Agreement and SDG obligations. Taking into account Malaysia's current growth pattern and climatic circumstances, this study evaluated the association between ecological footprint and their potential determinants: economic growth, oil consumption, renewable energy, and domestic capital investment for the period between 1965 and 2017. The stationary nature of the parameters was investigated using the conventional unit root approach (ADF and PP unit root). In addition, to solve the concern of series breaks, we incorporated a dummy parameter in the framework which was detected using the structural break unit root (ZA unit root). To establish the anticipated association between series, we employed the second-generational econometrics approach, which includes the ARDL bounds approach for cointegration in combination with the critical approximation p-values of Kripfganz and Schneider (2018); however, we adopted the following regression estimators: ARDL, FMOLS, and DOLS for regression; and the spectral BC causality approach for causality.

Economic growth boosts the ecological footprint in Malaysia, according to the empirical findings. Likewise, oil consumption based on fossil fuels undermines the ecosystem in Malaysia. These findings are very helpful and informative to policymakers. This indicates Malaysia's growth trajectory needs to be cautious, as well as the necessity to pursue alternative and cleaner energy sources. The current research supports this necessity by suggesting that renewable energy reduces ecological footprint; therefore, it enhances environmental quality. This shows that Malaysia is on track to reduce environmental degradation. However,

additional efforts must be made to incorporate other alternative and cleaner energy sources into her energy mix in order to achieve environmental sustainability. However, domestic capital investment reduces ecological footprint in Malaysia having incorporated the dummy parameter. This clearly indicates that the Malaysian government and its private sector have to broaden their investment base towards clean and sustainable energy utilization in order to promote clean energy (SDG-7) and the ecosystem (SDG-13).

In summary, it is apparent that there is a commitment to find a compromise between Malaysia's energy mix and its macroeconomic and environmental ambitions by adopting efficient energy conservation policies. This will promote long-term sustainable growth and not compromise energy efficiency; but instead, a massive transition to renewable sources like thermal, wind, hydro, and solar energy should be encouraged.

The main constraint encountered in performing this analysis was the scarcity of data on ecological footprint beyond 2017. Furthermore, the scarcity of data hampered our analysis' capacity to consider the control parameters. Hence, future studies can extend the data span for investigation. Another limitation of the study caused by the data scarcity is that sectorial specific investigation could not be undertaken. However, future research can examine the impact of oil consumption, renewable energy, domestic capital investment, and economic growth on the sector-specific ecological footprint in Malaysia or other emerging economies. The sectoral analysis would give better and new perspectives for policymakers to prioritize specific areas where the reliance on fossil fuels might be decreased, therefore reducing ecological footprint and improving the environmental quality as a result.

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