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The Nexus Between Economic Growth, Foreign Direct Investment, Renewable Energy and Ecological Footprint in Malaysia

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Abstract: *The growing human demand for biologically productive land and ocean areas significantly affects nature's ability to restore its ecosystems. Therefore, this study aims to examine the impact of economic growth, foreign direct investment (FDI), and renewable energy usage on Malaysia's ecological footprint from 1970 to 2018 using the environmental Kuznets curve model. The data was analysed using unit root tests, autoregressive distributed lag (ARDL), and the Granger causality test. The results suggest that increased economic growth and FDI have a negative impact on environmental quality, both in the short term and the long term. Moreover, a rise in the utilisation of renewable energy enhances the extent of environmental deterioration. The analysis further confirms the validity of the environmental Kuznets curve hypothesis, which suggests that the relationship between economic growth and environmental quality in Malaysia follows an inverted U-shaped pattern. The results of the Ganger causality test indicate a unidirectional relationship between economic growth and ecological footprint, as well as a unidirectional association between ecological footprint and renewable energy. These findings offer valuable information to policymakers about the promotion of renewable energy consumption and the impact of foreign direct investment on the sustainable development of the host country.*

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1. Introduction

Economic activity and development initiatives are crucial for a country's progress and enhancement of its citizens' quality of life. However, the positive impacts of greater industrialisation and economic growth are accompanied by a stark increase in environmental degradation, presenting a significant challenge in the modern era. Rapid economic growth is intricately linked to a surge in greenhouse gas (GHG) emissions, particularly CO_2 (Zhang, 2011), which adversely affects environmental quality in developing countries (Kon et al., 2023). Fast industrialisation and globalisation processes fuel high energy demands, resulting in substantial carbon emissions and strained ecosystems. This environmental deterioration, representing the adverse consequences of heightened human economic activity amid a global economic upswing, contributes to global warming and climate change.

According to the Global Footprint Network, a staggering 86% of the world's population reside in countries experiencing ecological deficits, wherein human demand for natural resources surpasses the Earth's regenerative capacity. This ecological deficit, attributed to human activities, poses multi-dimensional challenges and is a matter of concern for both scholars and decision-makers (Jaz et al., 2023). The concept of ecological footprint (EF), introduced by Wackernagel and Rees in 1996, measures the magnitude of anthropogenic activities on nature. It signifies the biocapacity needed to generate a continuous supply of renewable resources for absorbing the waste generated by economic activity. Furthermore, the ecological footprint provides individuals and nations with a tool to assess the environmental impact of their lifestyles, enabling informed resource management and corrective actions to mitigate ecological deficits. Therefore, the term 'ecological footprint' denotes the potential of an ecosystem to continuously create renewable resources and absorb the trash generated by economic activities (Washington, 2018).

It is found that previous studies used CO_2 emissions as a measurement of environmental degradation levels. CO_2 emissions measure solely air pollution and do not account for all human activities on the environment, which is unable to adequately capture the entire nature of environmental degradation (Danish et al., 2019; Danish et al., 2020; Dogan et al., 2019; Destek & Sinha, 2020). Consequently, EF is a relatively new proxy for environmental indicators and has gained attention by researchers as a new indicator to measure environmental degradation (Danish et al., 2020; Destek & Sinha, 2020; Dogan et al., 2019; Dada et al., 2022).

In the Malaysian context, the government has implemented various environmentally sustainable initiatives, prominently featuring green energy generation programs such as the Large Scale Solar (LSS) project. These initiatives align with Malaysia's commitment to fostering a sustainable environment, evident in policies promoting green energy production, investment tax allowances for green initiatives, incentives offering income tax exemptions for environmentally friendly practices, and financial support for green technology (SEDA, 2021). The government's ambitious target is to boost renewable energy generation to 18,000 megawatts (MW) by 2035, a significant increase from the current 8,700 MW, with the aim of making renewable energy account for 40% of the country's energy supply by 2035 (SEDA, 2021). Despite these commendable efforts, the ecological footprint in Malaysia has surged by more than 182% from 1961 to 2016, accompanied by a reduction of over 60% in biocapacity resources, resulting in an ecological deficit of 120% (Suki et al., 2022). This escalating ecological deficit poses a considerable threat to the future economy, highlighting the challenge of balancing environmental sustainability with the expanding economic demand (Suki et al., 2022). Malaysia faces the intricate task of navigating the trade-off between environmental security and energy consumption in the pursuit of global competitiveness, necessitating the exploration of strategies to conduct operations with minimal environmental impact (Suki et al., 2022; Suki et al., 2020). Therefore, a comprehensive assessment of how Malaysia's ecological footprint is influenced by factors such as foreign direct investment, renewable energy and economic growth becomes crucial for devising effective and sustainable operational strategies.

The impact of FDI, economic growth and renewable energy consumption on the ecological footprint is complex. The global movement of FDI has triggered extensive discussions among researchers and policymakers regarding its economic consequences. FDI inflow can facilitate technology transfer, knowledge spillover, infrastructure development, market penetration and efficient management practices (Lee, 2009), potentially leading to reduced pollution as theorised by the pollution halo hypothesis. On the other hand, the pollution haven hypothesis suggests that FDI inflows might degrade the environment due to increased energy consumption (Zhou et al., 2018; Ahmad et al., 2019). The interplay between FDI and environmental quality is multifaceted, with mixed arguments on its effect, warranting further investigation. This is particularly crucial for the effective implementation of environmental control and economic policies in developing countries like Malaysia, which heavily depend on FDI to accelerate their economic development.

Energy plays a pivotal role in propelling a nation's economic development, serving as the cornerstone of modern economic activities that drive productivity and industrial growth (Zahid, 2008). However, about 60% of the carbon emissions generated were from the consumption of energy through burning fossil fuels, constituting a substantial portion of the global ecological footprint. The negative effects of fossil fuels on the environment, contributing to global warming, have spurred global attention toward developing a sustainable agenda that emphasides the use of green and renewable energy sources (Elum & Momodu, 2017). Renewable energy assumes a critical role in mitigating environmental and climate impacts by reducing GHG emissions. With cost-effective and technically viable strategies (Gyamfi et al., 2018), renewable energy offers a pathway to reduce dependence on fossil fuels and ensure energy security (Al-Mulali et al., 2016). FDI plays a facilitating role in the development of renewable energy by enabling technology and knowledge transfer, thereby mitigating the adverse spillover effects associated with substantial non-renewable energy consumption (Bekun et al., 2019). The International Renewable Energy Agency (IRENA) projects that renewable energy is poised to replace fossil fuel as the main source of electricity generation, accounting for 90% of global electricity production by 2050. Besides, countries worldwide are proactively addressing environmental challenges through various countermeasures, including the implementation of carbon taxes, innovation in renewable energy technologies, adoption of energy-saving technologies and the promotion of green technology (Usman et al., 2020). These concerted efforts reflect a global commitment to creating a sustainable and environmentally friendly energy landscape.

The environmental Kuznets curve (EKC) hypothesis, proposed by Grossman and Krueger (1991), has been extensively studied concerning the interplay between environmental pollution and GDP growth. According to the inverted U-shaped EKC theory, economic growth initially contributes to environmental degradation, but beyond a certain threshold, continued growth leads to a reduction in environmental degradation (Grossman & Krueger, 1991; Zilio & Recalde, 2011). Dealing with the escalating levels of environmental degradation and energy consumption whilst maintaining high rates of economic growth is one of the most formidable challenges of this century. Rapid growth and development have resulted in various adverse environmental effects, impacting the national economy, depleting natural resources and compromising human health. However, these negative consequences of economic and development initiatives are often overlooked. Consequently, researchers are now delving into the intricate relationship between economic growth and environmental quality, taking into account the associated costs of economic expansion and the transformative processes within economies.

This study empirically investigates the effect of economic growth, FDI and renewable energy on the EF in Malaysia from 1970 to 2018, utilising the EKC model with FDI pollution effects. The research contributes to existing literature in four different ways. First, Malaysia has had an ecological deficit over recent decades, indicating the country's EF surpasses its biocapacity. Achieving Malaysia's goal of sustainable development necessitates identifying the root causes of EF and implementing environmental measures to curtail its growth. Second, while previous studies on Malaysia's EKC primarily employed CO_2 emissions as a measure of environmental deterioration, this study adopts a more comprehensive proxy—ecological footprint. Unlike CO_2 emissions, which focus solely on one aspect, the ecological footprint considers various anthropogenic impacts, including bio productive land use types, such as grazing land, farmland, ocean, carbon footprint, and built-up land (Nathaniel & Khan, 2020; Rashid et al., 2018). This approach provides a distinctive assessment of environmental effects. Third, the study incorporates FDI and renewable energy consumption into the EKC hypothesis, exploring their applicability to Malaysia. Limited research has delved into these dimensions, and their inclusion enriches the understanding of the factors influencing environmental sustainability in the

Malaysian context. Finally, the findings contribute valuable insights for policymakers, offering guidance in developing policies related to FDI and energy efficiency to enhance environmental quality.

The rest of the study is outlined as follows: Section 2 presents the relevant literature on the topic of this study. Section 3 presents the methodology and description of the models. Section 4 presents empirical findings. Finally, Section 5 discusses the findings and Section 6 concludes the paper and provides implications for the study.

2. Literature Review

This section is dedicated to conducting a comprehensive examination of the theoretical and empirical literature on the determinants of ecological footprint.

2.1 Theoretical literature

As environmental concerns gained prominence, Grossman and Krueger (1991) pioneered the examination of the nexus between environmental quality and per capita income. Their seminal work revealed an initial increase in environmental pollution with rising per capita income. However, a critical turning point emerged, indicating that beyond a certain income level, the environment's quality demonstrated a consistent improvement. This trade-off between rapid economic growth and environmental quality is encapsulated by the EKC hypothesis, portraying a reverse U-shaped curve correlating GDP per capita with environmental quality.

According to Grossman and Krueger (1991), the relationship between environmental quality and per capita income is implied by the following model.

$$EE_t = \beta_0 + \beta_1 GDPC_i + \beta_2 GDPC^2{}_t + \varepsilon_t$$

where EE_t refers to per capita carbon emissions; *GDPC* is per capita GDP; ε_t denotes the error term; and t represents the time period. The inverted U shape of the EKC hypothesis is illustrated by the positive value for *GDPC* and the negative value for $GDPC^2$. Moreover, the theoretical framework considers the impact of FDI on the environment and economy, delineated by the pollution haven and pollution halo hypotheses. The pollution haven hypothesis suggests that FDI may contribute to environmental degradation in the host country by attracting polluting industries. In contrast, the pollution halo hypothesis postulates that FDI could lead to a decrease in pollution in the host country through the adoption of greener technologies by international corporations. These theoretical perspectives offer a lens through which the complex interplay between economic development, environmental quality, and FDI.

2.2 Empirical literature

The pervasive issue of environmental degradation has attracted the attention of global researchers, prompting investigations into its contributing factors. Accordingly, numerous studies (Bulut, 2020; Doğan, 2019; Doytch, 2020; Hassan et al., 2019; Pata & Caglar, 2021) have substantiated the existence of EKC in various contexts, including Malaysia (Chuah, et al., 2022; Mehraaein et al., 2021), China and Pakistan (Khan et al., 2021) and Belt and Road Initiative countries (Kon et al., 2023). However, it is worth noting that some investigations challenge the validity of the EKC theory (Ansari, et al., 2020; Mikayilo, et al., 2019), highlighting the ongoing debate and diverse perspectives within the scholarly community. A substantial body of research has been dedicated to exploring factors influencing environmental quality, often employing CO2 emissions as a proxy for environmental degradation. Frequently investigated explanatory variables include FDI, energy consumption and economic growth. While previous studies have concentrated on these factors individually, there is a scarcity of research comprehensively examining their impacts on the ecological footprint within the same analytical framework.

2.2.1 Foreign direct investment (FDI) and environmental degradation

Findings from previous studies on the relationship between FDI and the environment were controversial, particularly for developing nations. Existing literature revealed diverse findings, with both positive and negative consequences associated with FDI for the ecology and economy of the host countries (Yilanci et al., 2020). These contrasting perspectives on the effects of FDI are encapsulated in the FDI heaven and halo hypotheses. The FDI haven theory posits that FDI negatively influences environmental quality, particularly in developing countries (Doytch, 2020; Murshed et al., 2022; Sabir et al., 2020), while the FDI halo hypothesis suggests potential positive impacts.

The spatial heterogeneity impact of FDI on the environment is underscored by the previous studies. For instance, Doytch (2020), using a generalised method of moments (GMM) approach, investigates the impact of FDI on ecological footprints across a panel of 117 industrialised and developing nations from 1984 to 2011. Her findings supported the EKC model and revealed that the FDI ecological haven hypothesis applied to low- and middle-income nations, while the FDI ecological halo hypothesis applied to high-income countries. Similarly, Murshed et al. (2022) evaluated the effects of FDI and renewable electricity generation on the ecological footprint in Bangladesh from 1972 to 2015. Their findings align with the EKC hypothesis, indicating that FDI inflow heightened ecological footprints in Bangladesh, adversely impacting the ecosystem. Sabir et al. (2020) also identify a significant positive association between FDI and environmental degradation in South Asian countries, further validating EKC for developing countries. Contrasting findings have emerged in studies focusing on developed nations. For example, Zafar et al. (2019) find a negative and significant association between FDI and ecological footprint in the long run for the United States, by establishing bidirectional causality between the variables. This observation aligns with the conclusion of Solarin and Al-Mulali (2018) that FDI inflow does not harm the environment in developing nations but does so in developed economies.

Diverse perspectives on the relationship between FDI and ecological footprint have also been reported in studies conducted in Turkey (Bulut, 2020), India (Khan et al., 2021), Pakistan (Khan et al., 2021; Udemba, 2021), China (Destek & Okumus, 2019; Khan et al., 2021) and South Africa (Mahmood et al., 2020). Specifically, the study conducted by Bulut (2020) in Turkey from 1970 to 2016 based on the ARDL approach reveals that while the EKC model prevails in Turkey, the pollution haven hypothesis does not, evidencing a negative correlation between FDI and the ecological footprint over the long term. This unexpected outcome was attributed to a significant influx of FDI into the service sector, and multinational corporations refraining from relocating unethical and environmentally detrimental operations to Turkey.

Furthermore, Khan et al. (2021) find that FDI negatively impacts ecological footprints in India, Pakistan and China. However, the inverted U-shaped EKC theory was validated for Pakistan, as opposed to the U-shaped EKC hypothesis for China and India. Udemba (2021) echoes similar results for Pakistan, highlighting the detrimental impact of FDI on the ecological footprint. However, Xu et al. (2022) present contradictory findings for China, indicating that the relationship between FDI and ecological footprint is complex and context dependent. Destek and Okumus (2019) conducted a study across newly industrialised nations, including Brazil, China, Malaysia, Thailand and Turkey, between 1982 and 2013. Their findings do not conclusively support either the pollution haven or pollution halo hypothesis. Instead, they identify a U-shaped association between FDI and ecological footprint in these nations. Mahmood et al. (2020), on the other hand, unveil a statistically insignificant nexus between FDI and environmental quality in South Africa, further contributing to the inconclusive landscape surrounding the influence of FDI on environmental deterioration. These multifaceted findings underscore the intricate nature of the relationship and emphasise the need for nuanced analyses considering specific country conditions.

2.2.2 Renewable energy and environmental sustainability

The intersection of energy consumption and environmental deterioration is a critical concern in a nation's developmental trajectory. Policymakers globally are steering towards sustainable practices, emphasising the use of clean and renewable energy sources to achieve environmental sustainability aligned with the Sustainable Development Goals (SDGs). Several studies investigating the impact of renewable energy consumption on the ecological footprint reveal complex dynamics.

For example, Al-Mulali et al. (2016) investigate the relationship between ecological footprint and renewable energy for a panel of 58 developed and developing countries for the period of 1980–2009. Their findings established a positive association between the ecological footprint and renewable energy consumption, lending support to the EKC hypothesis. This observation is inconsistent with that of Destek and Sinha (2020) in 24 OECD nations, who find a beneficial impact of energy consumption on ecological footprints, thereby negating the EKC hypothesis. Sharma et al. (2021) explore the environmental dynamics in eight developing Asian nations, revealing an N-shaped association between GDP per capita and CO2 emission. Their findings emphasise that increasing the use of renewable energy could contribute to a reduction in ecological footprints, offering a potential pathway for sustainable development.

Using the method of moments quantile regression (MMQR) technique, Miao et al. (2022) validated the EKC hypothesis in 10 newly industrialised nations, highlighting the potential of renewable energy and financial globalisation to mitigate environmental damage. This is further corroborated by Murshed et al. (2022), who demonstrate the contribution of renewable energy to carbon and ecological footprint reduction in five South Asian nations from 1995 to 2015, supporting the EKC hypothesis for these countries except for Pakistan. Roy's (2023) findings for India reveal a negative impact of FDI, renewable energy and GDP on ecology footprint in the long run, aligning with the broader discourse on the potential of renewable energy in fostering environmental quality.

2.3 Determinant of ecological footprint in Malaysia

In the Malaysian context, recent studies have investigated factors that shape the country's ecological footprint, yet it is still limited. As an instance, Mehraaein et al. (2021) assessed the effects of economic growth, financial development, and FDI on the country's ecological footprint over the period 1971 to 2014 using the ARDL analysis approach. Their findings, rooted in the pollution haven hypothesis and the EKC hypothesis, revealed a positive and significant effect on the ecological footprint in the short and long terms. However, this study does not include renewable energy in the model and studies on the effects of renewable energy on ecological footprint in Malaysia context is yet limited. Suki et al. (2022) focus on the impact of innovation and the use of renewable energy on Malaysia's ecological footprint. Employing a bootstrapped autoregressive distributed lag (BARDL) model, their research contributes to the understanding of Malaysia's EKC model, showcasing an inverted U shape. Their findings underscored the pivotal role of incorporating renewable energy sources to effectively mitigate ecological footprint levels. Beton Kalmaz and Awosusi (2022) expand the exploration by examining a broad spectrum of determinants, including economic growth, oil consumption, renewable energy, and domestic capital investment in Malaysia from 1965 to 2017. Utilising the ARDL approach, their study unveiled substantial influences of economic growth and oil consumption on the ecological footprint. Furthermore, the strategic utilisation of renewable energy sources and capital investment demonstrated a potential avenue for reducing the ecological impact.

3. Methodology

3.1 Data

This study examines the impact of FDI and renewable energy consumption on ecological footprint using the EKC model for Malaysia. Following Usman et al. (2020), the empirical model specification is expressed as follows:

$$\log EF_t = \beta_0 + \beta_1 \log GDPC_t + \beta_2 \log GDPC^2{}_t + \beta_3 \log FDI_t + \beta_4 \log RENEWC_t + \varepsilon_t$$

where EF represents ecological footprint; GDPC denotes gross domestic product per capita; $GDPC^2$ is the square of GDP per capita; FDI signifies FDI (% of GDP); RENEWC is renewable energy per capita consumption; and ε indicates an error term. Descriptions and sources of the variables are presented in Table 1. All variables were transformed into logarithm form. EF data were obtained from the Global Footprint Network (2020), GDPC and FDI data were retrieved from the World Development Indicator (WDI) and World Bank Database, while RENEWC data was collected from the BP Statistical Review of World Energy. The study's annual time series spans from 1970 to 2018, reflecting the data availability. Table 2 presents the descriptive statistics of the variables and Table 3 presents the correlation matrix for the variables.

Table 1: Description and Sources of Variables

Variable	Description	Source
EF	Ecological footprint per capita	Global Footprint Network
GDPC	Gross domestic product (constant 2010 US$) per capita	World Bank
$GDPC^2$	Square of gross domestic product (constant 2010 US$) per capita	World Bank
FDI	Foreign direct investment, net inflow (% of GDP)	World Bank
RENEWC	Renewable energy per capita consumption	BP Statistical Review of World Energy

Table 2: Descriptive Statistics

Variable	Mean	Median	Maximum	Minimum	Standard deviation
log *EF*	1.065	1.201	1.490	0.536	0.309
log *GDPC*	8.575	8.676	9.404	7.558	0.525
log $GDPC^2$	73.807	75.276	88.427	57.122	8.955
log *FDI*	1.158	1.238	2.170	-2.870	0.751
log *RENEWC*	-0.523	-0.399	0.809	-1.789	0.627

Table 3: Correlation Matrix

	log EF	*log GDPC*	*log* $GDPC^2$	*log FDIIN*	*log RENEWC*
log *EF*	1.000	0.962	0.960	0.071	0.763
log *GDPC*		1.000	0.999	-0.027	0.845
log $GDPC^2$			1.000	-0.031	0.845
log *FDI*				1.000	-0.066
log *RENEWC*					1.000

3.2 Unit root tests

The present study investigates the stationary properties of time series data through unit root tests, which assess the null hypothesis of a unit root, indicating non-stationarity, against the alternative hypothesis of time series stationarity. The notation (0) or I(1) is used to denote whether a series is stationary at the level or first difference level, respectively. The augmented Dickey-Fuller (ADF) and Philips-Perron unit root tests were employed to assess the stationarity and the order of cointegration for all variables in the study.

3.3 Autoregressive distributed lag (ARDL)

In this study, the cointegration of variables was tested using an autoregressive distributed lag (ARDL) bound test, which helps identify both short-run and long-run relationships between variables. The ARDL framework is suitable for small sample sizes and accommodates variables with integration orders of I(0) or I(1). Analysing the long-run and short-run impacts of economic growth, FDI and renewable energy on environmental quality can provide valuable insights for policymakers formulating environmental policies. The unrestricted error correction model (UECM) estimation of the cointegration ARDL bound test equation in this study is as follows.

$$\Delta\, log\, EF_t = \alpha + \sum_{i=1}^{p} \beta_1 \Delta\, log\, EF_{t-1} + \sum_{i=0}^{q_1} \beta_2 \Delta\, log\, GDPC_{t-i} + \sum_{i=0}^{q_2} \beta_3 \Delta\, log\, GDPC^2{}_{t-i}$$
$$+ \sum_{i=0}^{q_3} \beta_4 \Delta\, log\, FDI_{t-i} + \sum_{i=0}^{q_4} \beta_5 \Delta\, log\, RENEWC_{t-i} + \alpha_1\, log\, EF_{t-1}$$
$$+ \alpha_2\, log\, GDPC_{t-1} + \alpha_3\, log\, GDPC^2{}_{t-1} + \alpha_4\, log\, FDI_{t-1}$$
$$+ \alpha_5\, log\, RENEWC_{t-1} + \varepsilon_t$$

where Δ indicates the first difference operator, $\beta_1 - \beta_5$ are short-run coefficients, $\alpha_1 - \alpha_4$ are long-run coefficients and ε_t is the residual term. The presence of cointegration was tested using the Wald or F-statistics for a joint significance test. The ARDL bound test null hypothesis of non-cointegration (H_o: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0$) was tested against the alternative hypothesis of cointegration (H_a: $\alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \neq 0$). The estimated F-statistics were compared with the critical F-statistic values developed by Narayan (2005), and if the estimated F-statistic value exceeds the upper critical value, the null hypothesis is rejected, indicating the presence of cointegration. Conversely, if the estimated F-statistic value falls below the critical value, the null hypothesis is not rejected. If the estimated F-statistic falls between the upper and lower critical F-values, the analysis is deemed inconclusive.

The long-run relationship of the cointegrated variables is estimated as follows:

$$log\, EF_t = \alpha + \sum_{i=1}^{p} \beta_1\, log\, EF_{t-1} + \sum_{i=0}^{q_1} \beta_2\, log\, GDPC_{t-i} + \sum_{i=0}^{q_2} \beta_3\, log\, GDPC^2{}_{t-i}$$
$$+ \sum_{i=0}^{q_3} \beta_4\, log\, FDI_{t-i} + \sum_{i=0}^{q_4} \beta_5\, log\, RENEWC_{t-i} + \varepsilon_t$$

Then, the short-run dynamic coefficients were assessed using an error correction model (ECM) with the following equation:

$$og\, EF_t = \alpha + \sum_{i=1}^{p} \beta_1 \Delta\, log\, EF_{t-1} + \sum_{i=0}^{q_1} \beta_2 \Delta\, log\, GDPC_{t-i} + \sum_{i=0}^{q_2} \beta_3 \Delta\, log\, GDPC^2{}_{i}$$
$$+ \sum_{i=0}^{q_3} \beta_4 \Delta\, log\, FDI_{t-i} + \sum_{i=0}^{q_4} \beta_5 \Delta\, log\, RENEW_{t-i} + \lambda ECT_{t-1} + \varepsilon_t$$

where ECT_{t-1} represents the coefficient error correction term, and λ serves as an indicator of the speed of adjustment to the long-run equilibrium after a short-run shock.

3.4 Granger causality test

The causal relationships between dependent and explanatory variables are estimated using Granger causality test based on VAR (Toda & Yamamoto, 1995). The Granger causality test determines whether there is uni, bi, or no causal relationship between the variables. The null hypothesis of Granger causality test is no presence Granger causality between two variables.

3.5 Diagnostic test

The diagnostic and stability tests were conducted to examine the functional form, serial correlation, normality, and heteroscedasticity of the model. The stability of the model was tested using the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residual (CUSUMSQ) tests. If the plots of CUSUM and CUSUMSQ fall within the critical bounds of 5% significance level, the model is considered stable.

4. Results

4.1 Unit root test

The integration order of the variables in the study was determined using ADF and PP tests for stationarity. The results, presented in Table 4, indicated that all variables exhibit stationarity at both the level and first difference, corresponding to integration orders of I(0) and I(1), respectively. None of the variables exhibited integration at the second level of difference, I(2).

Consequently, the ARDL is deemed suitable for estimating the cointegrated long-run relationship between variables in the model. The optimum lag length of two was selected for yearly data based on the Akaike Information Criteria (AIC). Consequently, the optimal ARDL specification (2,2,2,2,0) was determined for the analysis.

Table 4: ADF and PP Unit Root Test Estimates

Variables	Level		First difference	
	Intercept	**Trend and intercept**	**Intercept**	**Trend and intercept**
ADF test statistics				
EF	-0.943 (0.766)	-2.694 (0.244)	-9.722*** (0.000)	-9.623*** (0.000)
GDPC	-1.736 (0.407)	-2.566 (0.297)	-5.934*** (0.000)	-6.026*** (0.000)
$GDPC^2$	-1.180 (0.676)	-2.591 (0.286)	-6.087*** (0.000)	-6.079*** (0.000)
FDI	-5.893*** (0.000)	-5.873*** (0.000)	-6.072*** (0.000)	-6.010*** (0.000)
RENEWC	-0.274 (0.921)	-2.341 (0.405)	-5.417*** (0.000)	-5.440*** (0.000)
Phillips-Perron test statistics				
EF	-0.739 (0.827)	-3.212 (0.094)	-10.366*** (0.000)	-10.455*** (0.000)
GDPC	-0.702 (0.424)	-2.662 (0.256)	-5.933*** (0.000)	-6.028*** (0.000)
$GDPC^2$	-1.166 (0.681)	-2.750 (0.222)	-6.088*** (0.000)	-6.081*** (0.000)
FDI	-5.895*** (0.000)	-5.874*** (0.000)	-25.773*** (0.000)	-27.351*** (0.000)
RENEWC	-0.243 (0.925)	-2.062 (0.553)	-5.474*** (0.000)	-5.417*** (0.000)

Notes: *, **, and *** stand for significance at 1%, 5% and 10% levels, respectively. The p-values are shown in brackets ().

4.2 ARDL bounds cointegration test

The F-statistic results of the ARDL bound test are presented in Table 5. The calculated F-statistic (4.711) exceeded the critical F-value of Narayan (2005) at the 1% upper bound level, thus confirming the cointegration among the variables in the long run.

Table 5: Cointegration with Bound Test

F-bound test	Value	Narayan (2005) critical value		
		Significance	I(0)	I(1)
Value of F statistic	4.711	10%	2.20	3.09
k	4	5%	2.56	3.49
		1%	3.29	4.37

The estimated results of the long-run ARDL bound test in Table 6 indicate the presence of cointegration relationship among variables in the long-run. The results of the short-run ECM revealed that economic growth and FDI are significant positively influence on the ecological footprint. In contrast, renewable energy influence exerted a significant negative influence on the ecological footprint. The significant negative sign of the error correction term (ECT) coefficient further validates the cointegration relationship between variables in the model. Specifically, the ECT(-1) term indicates the speed of short-run disequilibrium adjusts toward the long-run equilibrium. The negative coefficient of ECT at -0.374 suggests that the adjustment speed toward the long-run equilibrium is 37.4%. This implies a reasonable convergence process in response to shock within the model.

Table 6: Estimated long-run and short-run coefficients of the ARDL bound test

F-bound test	Long-run results		Short-run results	
	Coefficient	t-statistic	Coefficient	t-statistic
C	-22.817***	-4.410	-0.010	-0.685
log *GDPC*	4.725***	3.984		
log *GDPC2*	-0.228***	-3.354		
log *FDI*	0.083***	2.737		
log *RENEWC*	-0.070*	-1.815		
Δ log *GDPC*			12.704***	2.947
Δ log $GDPC^2$			-0.653**	-2.559
Δ log *FDI*			0.022**	2.198
Δ log *RENEWC*			-0.015	-0.317
$ECT_{t\text{-}1}$			-0.374***	-3.424

$ECT = LEF – (4.723 \times LGDPC – 0.228 \times LGDPC^2 + 0.083 \times *LFDIIN – 0.070 \times LRENEWC – 22.817$

Notes: *, ** and *** stand for significance at 1%, 5% and 10% levels, respectively.

4.3 Granger causality test

Table 7 presents the Ganger causal relationship between dependent and explanatory variables. As shown in Table 7, there is unidirectional causality from log *GDPC* to log *EF* and log $GDPC^2$ to log *EF*. Additionally, a significant unidirectional relationship was found from log *EF* to log *RENEWC*, while no significant causality relationship was observed between log *FDIIN* and log *EF*.

Table 7: Granger Causality Test

Null hypothesis	Obs.	F-statistic	p-value
log *GDPC* does not Granger cause log *EF*	48	5.950**	0.019
log *EF* does not Granger cause log *GDPC*		0.107	0.745
log $GDPC^2$ does not Granger cause log *EF*	48	5.325**	0.026
log *EF* does not Granger cause log $GDPC^2$		0.195	0.661
log *FDI* does not Granger cause log *EF*	48	0.400	0.530
log *EF* does not Granger cause log *FDI*		0.136	0.714
log *RENEWC* does not Granger cause log *EF*	47	1.363	0.267
log *EF* does not Granger cause log *RENEWC*		3.666**	0.034

Notes: AIC and SIC choose the lag length. *, ** and *** stand for significance at 1%, 5% and 10% levels, respectively.

4.4 Diagnostic tests

According to Table 8, the lack of statistical significance in the BG-LM, Ramsey-RESET, Jarque-Bera, and ARCH tests indicates that the model is free from the concerns related to serial correlation, normality of residual term, model misspecification model, and heteroscedasticity.

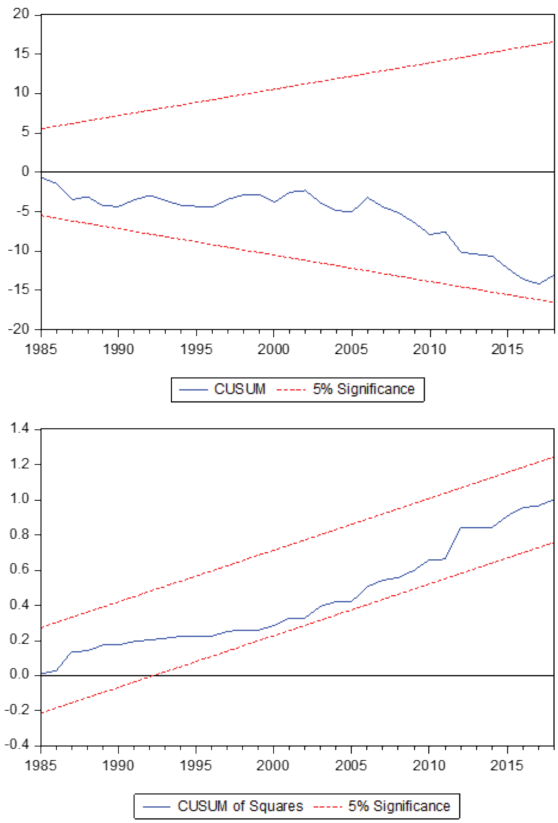
Table 8: Diagnostic Tests

Diagnostic test	F-statistic	p-value
Breusch-Godfrey serial correlation LM test^2	2.338	0.311
Breusch-Godfrey serial correlation LM test^4	3.380	0.496
$ARCH^2$	0.871	0.647
$ARCH^4$	2.127	0.713
Jarque-Bera	4.711	0.095
Ramsey-RESET	2.435	0.128

Note: 2,4 denote two and four lags included in the test model, respectively.

The stability of the model was evaluated through CUSUM and CUSUMSQ tests. As presented in Figure 1, the plots of CUSUM and CUSUMSQ statistics fall within the critical bounds of the 5% significance level, thus validating the stability of the model.

Figure 1: CUSUM and CUSUMSQ Plots



4.5 Robustness check

The FMOLS and DOLS were employed as robustness checks for the long-run results obtained from the ARDL estimator. The analysis results of FMOLS and DOLS are presented in Table 9.

Table 9: FMOLS and DOLS Results

Variable	FMOLS	DOLS
log *GDPC*	1.626*	4.508***
	(0.936)	(0.642)
log $GDPC^2$	-0.057	-0.210***
	(0.055)	(0.036)
log *FDI*	0.042**	0.079***
	(0.016)	(0.019)
log *RENEWC*	-0.092**	-0.098***
	(0.037)	(0.023)
C	-8.733**	-21.992***
	(4.009)	(2.837)
R^2	0.944	0.984
Adjusted R^2	0.939	0.976

Notes: Standard errors are given in the bracket. *, ** and *** stand for significance at 1%, 5% and 10% levels, respectively.

As shown in Table 9, the FMOLS model results showed that a 1% increase in GDP per capita significantly increases the ecological footprint by 1.626% at a 10% significance level. However, the coefficient of the square of GDP per capita was not significant. Furthermore, a 1% increase in FDI inflow significantly increases the ecological footprint by 0.042%, while a 1% increase in renewable energy consumption results in a 0.092% reduction in the ecological footprint in Malaysia. Notably, the significant coefficients of GDP per capita, FDI inflow and renewable energy consumption align with findings from the ARDL results.

According to the DOLS model results, a 1% increase in GDP per capita caused a 4.508% increase in the ecological footprint at the 1% significance level, and the square of GDP per capita was also found to be significant with a negative coefficient. Additionally, a 1% increase in FDI inflow significantly caused a 0.079% increase in the ecological footprint, while a 1% increase in renewable energy consumption resulted a 0.098% reduction in the ecological footprint in Malaysia. These results are consistent with the ARDL long-run estimation results.

5. Discussion

The long-run estimates highlight the statistical significance of the ecological footprint's elasticity in relation to economic growth. Specifically, a 1% increase in GDP per capita is associated with a substantial 4.72% increase in the ecological footprint. The quadratic equation derived from the EKC model revealed an inverted U-shaped relationship between economic growth and the ecological footprint. This is substantiated by the negative and significant coefficient of the square of GDP per capita. These findings provide empirical support for the validity of the EKC hypothesis in the context of Malaysia, aligning with similar conclusions reached by Mehraaein et al. (2021) and Abid et al. (2022) for Saudi Arabia as well as Khan et al. (2021) for Pakistan. The results suggest that as economic growth advances, the ecological footprint initially increases, reaching a threshold level where the environmental impact starts to improve due to the enhancement in environmental standards through the adoption of cleaner technology, investments in societal improvements and the implementation of government pollution control regulations.

The results further revealed a significant positive impact of FDI inflow on the ecological footprint in Malaysia over the long run. Specifically, the estimated coefficient of FDI showed that a 1% increase in FDI inflow results in a 0.08% increase in the ecological footprint. This finding supports the pollution haven hypothesis, as observed by Mehraaein et al. (2021) and Xu et al. (2022). The pollution haven hypothesis posits that multinational corporations (MNCs) may transfer their polluting industrial activities to developing countries with less stringent environmental policies. This strategic move allows MNCs to reduce the costs associated with complying with stricter environmental regulations in their home countries, contributing to a decline in environmental efficiency in the host countries (Mehraaein et al., 2021). Furthermore, the results showed a statistically significant negative effect of renewable energy consumption on the ecological footprint in the long run. This indicates higher renewable energy consumption improve the environment degradation level. Specifically, a 1% rise in renewable energy consumption reduces ecological footprint by 0.07% in Malaysia. This result is consistent with findings reported by Pata (2021) for Brazil and China, Roy (2023) for India and Abid et al. (2022) for Saudi Arabia.

The empirical results underscore the importance of transitioning to cleaner energy sources, in line with the objectives outlined in the Malaysia Renewable Energy Roadmap. By emphasising the usage of renewable energy, Malaysia can effectively reduce its ecological footprint and promote sustainable economic growth. This shift toward a low-carbon economy, facilitated by significant renewable energy consumption, reflects a critical aspect of climate change policy. The findings emphasise the need for prioritising renewable energy sources (RECs) over non-renewable energy sources (NERCs) in climate change policies. To encourage this transition, market mechanisms can be employed to promote the utilisation of renewable energy sources across various sectors while discouraging the widespread usage of fossil fuel-based energy sources. This approach supports the broader goal of achieving environmental sustainability and mitigating the impact of climate change.

6. Conclusion

Every country necessitates economic activity and development programmes to modernize and elevate its residents' standards of living. However, the accelerated environmental degradation resulting from increased industrialisation poses a significant challenge in the modern era, prompting concerns among researchers and policymakers about the rise in carbon and CO_2 emissions. Consequently, this study, employing the EKC model, aims to comprehend the impacts of FDI, economic growth and renewable energy on environmental degradation in Malaysia from 1970 to 2018. Unlike many previous studies that rely on CO_2 emissions, this investigation measured environmental quality using the ecological footprint.

The study's findings support the existence of cointegration relationship among the variables over the long term. The long run cointegration estimations indicate that an increase in GDP per capita impedes the ecological footprint. This relationship aligns with the inverted U-shaped pattern suggested by the EKC model, as indicated by the negative and significant coefficient associated with the square of GDP per capita. This suggests that during the initial phases of development, economic growth contributes to an increase in the ecological footprint, but this effect improves as economic growth reaches a specific threshold. The study also highlights that, in the long run, FDI influx significantly raises the country's ecological footprint, while increasing the use of renewable energy lessens Malaysia's ecological footprint.

The findings carry valuable policy implications for improving environmental quality. The identified inverted U-shaped link between environmental pollution and GDP suggests that the efforts targeted at fostering economic growth while prioritising environmental protection should continue. In addition to ongoing expansion, there is also a need to consider the implementation of more stringent environmental regulations.

To advance sustainability, i.e., to stimulate economic growth while mitigating environmental deterioration, a greater emphasis must be placed on incorporating alternative and cleaner energy sources. The Malaysian government has taken strides in this direction by promoting the adoption of alternative clean energy sources, envisioning a transition to a carbon-neutral country by 2050. This initiative is underpinned by various supportive policies and incentives, particularly focusing on renewable energy sources such as solar energy for residential, commercial, and industrial applications. While these initiatives are important to curtail environmental degradation, effective governance is essential to sustain them (Jaz et al., 2023). Given the significant long- and short-term effects of renewable energy consumption, it is recommended that the Malaysian government accentuate policies fostering increased awareness of environmentally friendly practices and incentivising the corporate sector and households to boost their usage of renewable energy. Implementing tax deduction policies could serve as a potent tool in encouraging and sustaining the usage of renewable energy sources across various sectors.

Given the support for the pollution haven hypothesis in this study, Malaysia should consider strengthening its policy framework for FDI inflows to mitigate negative environmental impacts. To achieve this, Malaysia can strategically encourage FDI in technology-intensive and environmentally friendly enterprises. Simultaneously, regulatory measures should be implemented to closely monitor potential environmental harm stemming from FDI inflows with a significant pollutant footprint. Moreover, the government should set clear requirements for industries with a high carbon footprint, prompting them to undergo reforms toward greater energy efficiency. This proactive approach aligns with the broader objective of transitioning industries to more sustainable practices. Additionally, FDI policies should be closely integrated with industrial policies, ensuring a harmonised and comprehensive approach to environmental stewardship and economic development.

Despite the valuable insights, the study acknowledges limitations related to the study period until 2018. Future studies could consider including additional variables and extending the data beyond 2018. Furthermore, employing more sophisticated econometric techniques, such as a threshold regression model, could enhance the analysis. Furthermore, focusing on the ecological footprint of specific industries in Malaysia or conducting comparative analyses with other Southeast Asian countries could provide deeper insights into the relationship between economic activities and environmental degradation.

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