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Green technology, exports, and CO_2 emissions in Malaysia

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A R T I C L E I N F O

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A B S T R A C T

The pressing global effort to tackle CO_2 emissions has brought about a strong emphasis on adopting green technology by economies striving for low-carbon development. Within this context, this research investigates the environmental significance of green technology and exports in Malaysia. By examining 30-year data from 1989 to 2019 and utilising the autoregressive distributed lag model (ARDL), this study explores these variables' long-run and short-run effects on Malaysia's environment. The outcomes reveal noteworthy insights: population growth and green technology negatively impact environmental degradation, whereas exports and economic expansion contribute to environmental depletion over the long term. However, the influences of a higher population and exports are inconsequential in the short term. Additionally, the study captures the influences of transient economic challenges, such as the COVID-19 outbreak. Consequently, the study emphasises crucial policy implications for the Malaysian government. Firstly, it strongly recommends increasing investment in sustainable technology, especially within the manufacturing sector, to mitigate the adverse environmental impact of exports. Furthermore, it suggests incentivizing companies to embrace green technology through subsidies for acquiring renewable energy and imposing higher taxes on non-renewable energy sources. Additionally, policymakers are urged to prioritise human capital development by raising public awareness about the dangers of heightened CO_2 emissions. Malaysia can leverage its expertise to foster economic expansion without compromising the environment by engaging the working population in environmentally sustainable economic activities. These policy recommendations aim to expedite the shift towards a decarbonised economy, promote sustainable development, and safeguard Malaysia's natural resources.

1. Introduction

The intensifying menace of climate change has garnered international attention due to its profound effects on food production, respiratory health, and the well-being of ecosystems [1,2]. This concern holds particular significance for economies heavily dependent

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on fossil fuels for their economic prosperity, such as Malaysia [2,3]. Historically, Malaysia has predominantly relied on non-renewable energy sources, with hydropower being the sole renewable energy source until 2011 [4]. As a result, the country has experienced a steady increase in CO_2 emissions.

According to Countryeconomy.com [5] data, Malaysia witnessed a 1.02% decline in total CO_2 emissions in 1998, followed by a 9.5% increase the following year. In 2009, there was a significant drop of 9.91% in CO_2 emissions, likely due to the global economic downturn. However, the country experienced an 8.83% increase in CO_2 emissions the subsequent year and waited another seven years before observing another decline. In 2016 and 2017, Malaysia recorded decreases of 1.91% and 2.92% in CO_2 emissions, respectively. Nonetheless, there was an increase of 6.94% and 2.73% in 2018 and 2019, respectively. Over the last decade (2010–2019), Malaysia observed a 10.74% rise in CO_2 emissions per capita [6]. These statistics underscore the urgent need for intensified efforts to address current and future environmental threats [7].

A growing number of countries worldwide significantly emphasise adopting environmentally friendly (green) technology to drive economic activities while mitigating CO_2 emissions [7,8]. Green technology involves using techniques and materials that prioritise environmental sustainability while still meeting the needs and desires of society. The transition to a green economy involves replacing environmentally harmful industrial technology with green technology, promoting economic development while minimising environmental impact. This transition necessitates a shift from conventional energy sources towards sustainable and ecologically conscious alternatives and implementing sustainable production methods for exported goods.

In response to escalating environmental concerns, Malaysia has explored viable strategies for transitioning from environmentally depleting energy sources to eco-friendly alternatives [9]. It is important to make this shift due to the energy sector's ongoing status as the dominant contributor to greenhouse gas emissions. This sector alone was responsible for over 70.5% of total emissions in 2016 [10]. In 2009, Malaysia took a significant step towards encouraging the widespread use of renewable energy by introducing the National Green Technology Policy. The primary objective of this policy was to harness domestically produced renewable energy sources, ensuring a dependable electricity supply and fostering sustainable socio-economic advancement [11]. In 2010, the National Renewable Energy Policy was introduced and reduced 7262.59 Gg CO2eq in CO_2 emissions in 2016 [10]. Significantly, greenhouse gas emissions have experienced a decline since 2008, primarily attributed to a deliberate transition in the construction and manufacturing industries from coal fuel consumption to electricity consumption. However, despite these efforts, Malaysia still heavily depends on conventional energy sources, with only 3.9% of its energy consumption sourced from renewable energy as of 2020 [4] (see Fig. 1).

Malaysia's limited share of renewable energy consumption underscores the pressing need for further progress in embracing and promoting green technology. The country must expedite its shift towards green and sustainable energy integration to tackle the pressing environmental challenges effectively. By diversifying its energy sources and boosting the amount of renewable energy, Malaysia has the potential to considerably decrease greenhouse gas emissions and alleviate the detrimental consequences of global warming. This transition necessitates a holistic approach that includes policy reforms, allocating resources towards research and development, and implementing facilitative measures to promote the widespread integration of green technology across various sectors of the economy. The effective adoption of green technology in Malaysia promises to mitigate the negative environmental consequences resulting from economic activities and other contributing factors. This, in turn, paves the way for sustainable economic development [12,13]. Therefore, greater attention and emphasis should be given to adopting green technology in the Malaysian economy.

The significance of acknowledging the impact of trade on CO_2 emissions cannot be overstated. While trade is an important determinant of economic expansion, it also has consequences in terms of environmental degradation. The environmental issues associated with trade have far-reaching implications for production costs, trade patterns, industry location, gains from trade, and international relations. Around 27.2% of global CO_2 emissions from fuel combustion can be attributed to external trade in the year 2020. In 2015, the OECD reported that seven industrial sectors accounted for about 66.7% of CO_2 emissions embedded in exports. However, it is important to note that the World Bank [14] emphasises the potential of trade in addressing climate change. Trade can give consumers access to lower-emission goods and services while promoting adopting climate-friendly technologies. Although exports are often associated with CO_2 emissions, they can also serve as a means to prevent further environmental degradation, as highlighted

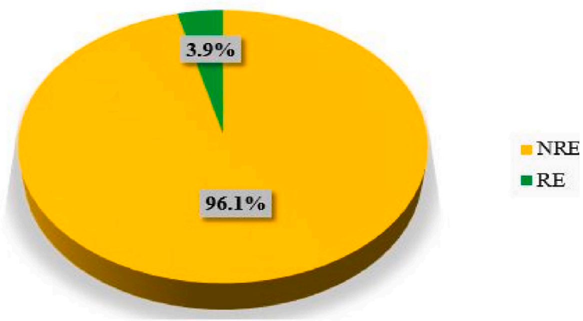


Fig. 1. Renewable energy (RE) and non-renewable energy (NRE) used in Malaysia in 2020
Source: Authors' compilation based on data from *Malaysia Energy Information Hub* [4].

by Pata [15].

The environmental implications of trade can be understood through three primary channels: the impact of scale, the impact of composition, and the impact of techniques [15,16]. The scale effect suggests that expanding economic activities increases environmental pollution due to higher energy consumption. The composition effect relates to structural changes in the economy, wherein a shift from industrialisation to services can enhance environmental quality. Lastly, the technique involves investing in research and development (R&D) and adopting modern technology to replace outdated ones, thereby reducing environmental pollution. In summary, while trade can contribute to environmental depletion through the scale effect, it can also assist in mitigating environmental damage through the composition and technique effects.

The depicted trends of exports and CO_2 emissions in Fig. 2 shed light on the scale effect of trade in Malaysia, where a rise in CO_2 emissions accompanies increased exports. However, the figure also reveals three notable declines in CO_2 emissions over the past three decades. The first decline occurred in 2009, coinciding with the global financial crisis, which decreased export demand and foreign direct investment. Consequently, there was a contraction in CO_2 emissions [17,18]. Although exports rebounded in 2017, CO_2 emissions decreased due to a decline in GDP growth in the same year [19]. More recently, the COVID-19 pandemic and subsequent nationwide lockdown in 2020 led to another decline in CO_2 emissions and exports. This reduction in CO_2 emissions can be attributed to the restrictive measures implemented to contain the spread of the virus [20,21]. These findings demonstrate the interdependence of trade, economic factors, and CO_2 emissions, underscoring how external events like global crises and pandemics can significantly impact environmental outcomes. The interconnected nature of these factors highlights the imperative for a thorough and all-encompassing understanding and approach to address the environmental challenges associated with trade and economic activities. By recognising and responding to the influence of external events, policymakers and stakeholders can develop more effective strategies to alleviate CO_2 emissions and foster sustainable practices in times of global crises.

The consistent economic expansion in Malaysia over the past three decades [16], accompanied by the simultaneous increase in exports and CO_2 emissions (as depicted in Fig. 2), has been a strong motivation for conducting this research. Malaysia needs to expedite its transition to green technology to address the environmental challenges associated with its economic development. Thus, by exploring the relationships between green technology, exports, and CO_2 emissions, this study endeavours to uncover the potential of green technology adoption in mitigating environmental damage while fostering sustainable economic expansion. By shedding light on these interconnections, policymakers and stakeholders can gain valuable insights into effective strategies for promoting green technology and achieving environmental sustainability in Malaysia.

The contribution of this study rests in its focus on Malaysia and its specific context, filling the research gap in understanding the environmental implications of green technology and exports. By considering multiple variables such as green technology, exports, population growth, GDP, and CO_2 emissions, this research aims to provide a holistic analysis of the relationships and their implications for sustainable development. Furthermore, using time series data allows for a comprehensive analysis of the long-term trends and dynamics, providing a more robust understanding of the relationships under investigation. This study holds significant importance for Malaysia as it addresses a research gap by examining the environmental implications of green technology and exports concerning CO_2 emissions. Existing research has predominantly concentrated on developed countries when exploring the relationship between green technology and environmental factors [23,24], leaving limited attention to other regions, leaving a dearth of research specific to Malaysia. Furthermore, studies highlighting the impacts of exports and energy use on CO_2 emissions have mainly employed panel data analysis [25–27]. By utilising time series data and drawing insights from existing literature, this study strives to provide meaningful comprehension into the relationships between green technology, exports, population growth, GDP, and deterioration of the environment in Malaysia. The outcomes of this research will enhance the current understanding and body of knowledge on sustainable development and low-carbon growth and assist in formulating effective policies to mitigate CO_2 emissions and preserve natural resources in Malaysia. The following sections of this study comprise a comprehensive review of the existing literature, methodology, research findings, and interpretation, and finally, a conclusion summarising the research work.

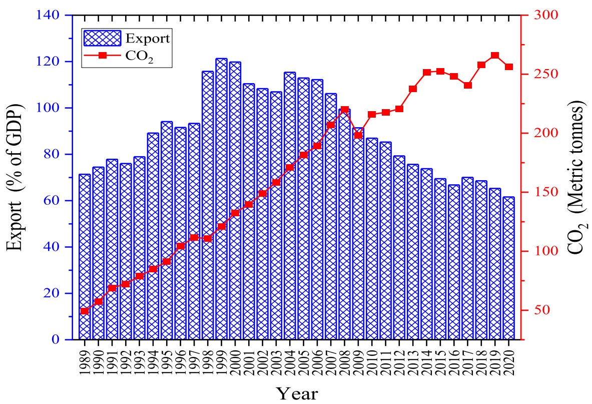


Fig. 2. Exports and CO_2 emissions in Malaysia (1989–2020)
Sources: Authors' compilation based on data from World Bank [22]; Countryeconomy.com [5].

2. Literature review

Many studies have explored the energy-carbon nexus, providing valuable insights. A comprehensive review of this literature is essential to grasp previous findings and identify existing research gaps. Many of these studies have demonstrated that finite energy sources and economic prosperity worsen environmental degradation, while renewable energy helps to mitigate it [9,28–32].

In the past few years, there has been a notable shift in research to delving into the consequences of renewable energy and green technology on the environment. For instance, Asif et al. [33] investigated BRICS countries, employing quantile-on-quantile regression to investigate the correlation between green technology advancements and environmental quality. Their findings indicated that green tech advancements conserve the environment, while higher emissions levels stimulate the development of green technology. Similarly, Ahmed et al. [7] and Saidi and Omri [34] found that renewable energy can effectively alleviate environmental damage in BICS and OECD nations. Additionally, Hussain et al. [24] utilised Autoregressive Distributed Lag (ARDL) analysis and demonstrated that adopting environmentally friendly technologies and using environmentally friendly energy results in a lower release of hazardous gases. In contrast, economic expansion is associated with environmental damage in emerging-7 countries. Conversely, Radmehr et al. [35] explored the connection between environmental quality, economic expansion, and environmentally friendly energy in the European region. Their study revealed a two-way directional association between national output and renewable energy consumption and between national output and environmental deterioration.

It is important to highlight that emphasising green technology can mitigate environmental depletion [7,36]. However, it should be noted that developing green technologies may lead to increased CO_2 emissions [37]. Nonetheless, numerous cross-sectional studies have consistently affirmed the favourable implications of green technology and renewable energy on reducing environmental deterioration, reinforcing these findings.

However, the findings from time series research on the association between energy and carbon have produced conflicting findings. For example, Ahmed et al. [7] applied the Grey system theory to assess the correlation between environmental technology, national output, and energy consumption. Their study revealed that China had the highest increase in CO_2 emissions among the BICS countries, followed by South Africa and India, while Brazil had the lowest emissions. In contrast, Mahmood [38] utilised an ARDL approach to assess the connection between biomass energy, a green energy source, and environmental quality in Pakistan. The study found that biomass energy could increase CO_2 emissions, supporting the feedback hypothesis in the country. On the other hand, Saidi and Omri [34] concluded that a combination of nuclear and renewable energy would be most effective in addressing environmental pollution. These discrepancies in findings can be attributed to the unique economic characteristics of different economies, underscoring the need for further investigation within the specific context of Malaysia.

In the meantime, research conducted by Ridzuan et al. [39] ascertained the correlation between environmental deterioration, national output, and renewable energy in Malaysia. Their study, which spanned from 1978 to 2016, employed the ARDL model and indicated that renewable energy significantly mitigates environmental pollution, aligning with Malaysia's Environmental Kuznets Curve (EKC) hypothesis. According to these results, environmental degradation slows down, and economic growth continues after a specific development threshold is reached. These conclusions are in line with the outcomes of similar investigations by Raihan et al. [40], Leitao and Lorente [41], and Saudi [42]. These studies also employed different econometric models, such as the bootstrapped ARDL, generalised moments system, and ARDL model, respectively, to analyse the Malaysian context.

In contrast, Raihan and Tuspekova [43] used the difference-of-means (DOLS) method to look into the connection between renewable energy and carbon emissions in Malaysia. They did this by analysing time series data from 1990 to 2019. According to their findings, renewable energy sources were found to have a small, detrimental impact on environmental degradation in Malaysia. Additionally, they suggested that economic growth can result in increased carbon emissions in the country. Similarly, Saudi [42] found that non-renewable energy sources and other non-economic variables sources can positively influence environmental damage in Malaysia while still supporting the applicability of the EKC hypothesis within the country.

Bekhet and Othman [44] researched the association between national output, environmental quality, and renewable energy in Malaysia and found that green energy can reduce environmental deterioration. Additionally, a unidirectional causal association was observed, indicating that environmental deterioration impacts the adoption of green energy. Considering Malaysia relies heavily on non-renewable energy for electricity generation, it is not surprising that Sharif et al. [45], who analyzed data from 1970 to 2014, identified electricity generation, increased consumption, and rising population are all factors that contribute to the deterioration of the country's natural resources. However, to mitigate the increase in environmental pollution, countries, including Malaysia, can adopt renewable energy sources and promote green tourism, as highlighted by Ben et al. [46].

In summary, previous time series literature focusing on the energy-carbon nexus in Malaysia has presented inconsistent findings. The discrepancies in their findings may be attributed to variations in the period of the studies. Studies have shown that renewable energy sources can improve environmental quality in a number of different ways. While many earlier studies focused on the impact of non-renewable energy sources, more recent ones have centred on the relationship between renewable energy and the natural world. It is crucial to revise and update the investigations on the determinants of environmental quality, as this information is essential for policymakers in Malaysia. Therefore, a recent study considering the most recent data is necessary to ascertain the current association between green technology and Malaysia's environmental quality.

The link between exports, energy use, and environmental degradation has been the subject of substantial study. In the context of oil-exporting developing countries, Hasanov et al. [47] made a noteworthy discovery, revealing that trade-adjusted carbon emissions exceed production-based carbon emissions. Examining the implication of trade openness on carbon productivity, Dou et al. [48] uncovered an intriguing U-shaped pattern, indicating that the connection between international trade liberalisation and carbon output initially plunges and subsequently hikes after reaching a particular point. Dou et al. [49], Ahmed [7], and Shahbaz et al. [2] further contributed to the field by addressing the favourable influence of trade openness on the greenhouse effect while emphasising the role of agreements in mitigating this impact on carbon emissions. Aldakhi et al. [8] also suggested that foreign direct investment (FDI) and trade stimulate environmental damage in South Asia. In contrast, Paramati et al. [36] found that trade openness and FDI inflows reduce environmental pollution in OECD countries. Furthermore, Leitao and Lorente [41] employed FMOLS, DOLS, and GMM systems and discovered that trade openness reduces environmental deterioration in the European Union.

When examining the disaggregated impact of trade, Dou et al. [49], Khan et al. [50], and Aldakhi et al. [8] discovered that imports contribute to increased carbon emissions while exports play a significant role in reducing them. Similarly, Khan et al. [51] observed that exports and renewable energy consumption are associated with decreased carbon energy, while imports and GDP show an increasing trend. Focusing on the D8 countries, Majekodunmi et al. [9] shed light on the negative association between exports, population growth, and environmental deterioration in the D8 countries. While exports and population growth generally increased environmental deterioration, the authors identified a mitigating effect of exports on emissions in Malaysia, Pakistan, and Turkey, particularly in the short run. Similarly, Haug and Ucal [52], using non-linear-ARDL, investigated the trade-emissions nexus in Turkey and found that environmental deterioration is not affected by increases in exports. However, they reported that environmental deterioration decreases when exports decrease. Additionally, their study found that GDP negatively influences environmental deterioration in Turkey.

These previous studies provide valuable insights into the intricate dynamics between exports, energy consumption, and their influence on environmental deterioration. Addressing these gaps in the literature can contribute to a more comprehensive understanding of the role of exports and energy consumption in environmental deterioration, thereby facilitating the development of effective strategies for sustainable economic and environmental policies.

3. Data sources and research methodology

3.1. Model specification and data sources

This investigation seeks to delve into the effects of green technology and exports on environmental damage using annual data from 1989 to 2019. The choice of the data period in this study was primarily influenced by the provision of reliable and comprehensive data for the investigated variables at the time of this research. In this context, we applied the longest time series data accessible for the variables of interest. While a more recent dataset would have been desirable to capture the most up-to-date trends and developments, data availability beyond 2020 is limited. Therefore, the chosen data period represents the most extensive and reliable dataset available for analysis. Additionally, the decision to use the Autoregressive Distributed Lag (ARDL) method supports the suitability of the selected data period. The ARDL model is particularly useful when dealing with small sample sizes, as it can handle mixed orders of integration and provides reliable parameter estimates even with limited data. It is important to acknowledge that the chosen data period does have limitations, and future studies should aim to incorporate more recent data as it becomes available. However, within the context of data availability and the application of the ARDL method, the selected data period is justified and provides meaningful insights into the research questions at hand.

This study incorporates population growth and Gross Domestic Product (GDP) into the analysis to avoid biased outcomes resulting from omitted variables. The utilisation of the ratio of renewable energy consumption to non-renewable energy consumption serves as a proxy for green technology, as it offers a straightforward and quantifiable indicator of a country's progress in adopting a more sustainable energy mix. Renewable energy sources are known to have lower greenhouse gas emissions and environmental impacts compared to non-renewable sources. By monitoring the ratio of renewable energy consumption in the energy mix, valuable knowledge is acquired regarding a nation's endeavours to decrease reliance on fossil fuels and encourage the uptake of sustainable energy sources. Moreover, the Paris Agreement aims to keep the global average temperature rise below 2° Celsius, aiming to keep the increase below 1.5° Celsius. This ratio represents progress towards these global climate change mitigation goals. To achieve these goals, a shift towards renewable energy is essential. The share of renewables in total energy consumption can also provide light on the growth and investment in environmentally friendly technologies and the effectiveness of regulatory frameworks.

The analysis utilises a model incorporating relevant macroeconomic variables, aligning with the IPAT model as shown in equation (1). The IPAT model was first presented by Ehrlich and Holdren in 1971, and it underlines the connection between population (P), affluence (A), technology (T), and environmental impact (I). Considering these variables, the study seeks to provide insights into the association between green technology, exports, and environmental damage over the specified time frame.

The IPAT framework is presented as follows:

$$I = P \times A \times T \tag{1}$$

where:

- I represents environmental impact, which is measured by carbon dioxide emissions.
- P represents population size, reflecting the demographic factor and measured by population growth.
- A stands for affluence, which is conventionally gauged by GDP per capita.
- T represents technology, encompassing the level of technological development, methods, and processes used in production, consumption, and waste generation. It is quantified by comparing the share of renewable energy to that of conventional energy sources.

Thus, the equation can be expressed as:

$$CO_{2t} = f(GDP_t, POP_t, RENR_t) \quad (2)$$

This study, however, extends the IPAT model with the inclusion of Exports.
Hence, equation (2) is given as:

$$CO_{2t} = f(GDP_t, POP_t, RENR_t, EXP_t) \quad (3)$$

The following econometric model in equation (4) is obtained by taking the natural logarithm of equation (3).

$$ln\ CO_{2t} = \beta_o + \beta_1\ ln\ GDP_t + \beta_2\ ln\ POP_t + \beta_3\ ln\ RENR_t + \beta_4\ ln\ EXP_t + \mu_t \quad (4)$$

Where:

- CO_2 emissions per capita (CO_2) are used as a proxy for environmental impact.
- Gross Domestic Product (GDP) per capita represents economic expansion.
- Population annual % growth (POP) is used as a proxy for population growth.
- The level of green technology is represented by the proportion of renewable to non-renewable power (RENR).
- Export is measured as the export % of GDP (EXP).
- 't' indicates the time, while 'μ' represents the error term.
- β_0 represents the intercept, while β_1-β_4 are the coefficients.

Data on GDP per capita, exports as a percentage of GDP, and population growth are all compiled by the World Bank [6]. Information on a country's total CO_2 emissions in megatons (Mt) is retrieved from countryeconomy.com. The Malaysia Energy Information Hub (MEIH) is where one may find information about both renewable and non-renewable energy (Ktoe) sources in the country. The proportion of renewable to non-renewable sources of energy is estimated manually.

4. Methodology

In this study, the econometric methodology employed is the Autoregressive Distributed Lags (ARDL) model, originally proposed by Pesaran and Pesaran [53]. This model is ideal for our study since it may be used to estimate both long- and short-term parameters. By incorporating the error correction term (ECT), we are able to investigate short-term dynamics while preserving the long-term coefficients. The ARDL model offers several advantages, such as addressing endogeneity concerns, accommodating varying lag lengths, and effectively resolving collinearity issues among variables [54,55].

This model presents several notable advantages compared to alternative time series models, including the Ordinary Least Squares (OLS) regression, the Engle and Granger co-integration method of 1987, and Johansen's approach of 1988 [55]. ARDL enables the simultaneous estimation of long- and short-term effects, offering a comprehensive understanding of the association between variables. It addresses endogeneity and collinearity issues by incorporating lagged and control variables, enhancing the robustness of the estimation. Additionally, ARDL allows for flexibility in selecting the appropriate lag length based on the dataset and economic theory. These advantages make ARDL a valuable tool for capturing both short-term dynamics and long-term equilibrium relationships while overcoming limitations such as identifiability issues in small sample sizes encountered by the Johansen Co-integration method. In contrast, the Johansen Co-integration method primarily focuses on long-run equilibrium relationships and assumes that variables are integrated in the same order. Moreover, OLS lacks the ability to capture long-run dynamics and may be more susceptible to endogeneity and omitted variable bias.

While the ARDL model offers several advantages, it also has limitations compared to the Johansen Co-integration method and Ordinary Least Squares (OLS) regression. One major disadvantage of ARDL is the potential for identifiability issues, particularly in small sample sizes, which can result in unreliable parameter estimation. Additionally, the complexity of ARDL models, including considerations of lag lengths, order of integration, and other model selection criteria, may make them more challenging to implement and interpret compared to OLS. Hence, selecting the ARDL method employed in this study has been done meticulously, considering the underlying assumptions. This selection ensures that the most suitable approach is chosen, aligning with the research objectives and characteristics of the data.

In order to utilise the ARDL method, the initial stage necessitates conducting tests for stationarity to ascertain the integration order of the variables. This step assumes paramount importance as it ensures that each variable is stationary at either the level or first difference, thereby mitigating the risk of obtaining spurious outcomes. Significantly, the ARDL model cannot be applied when a variable exhibits stationarity at the second difference. In this study, commonly used unit root tests, such as the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test, are employed to assess the stationarity of the variables.

Moreover, it is crucial to examine whether the variables in the ARDL analysis exhibit a long-term relationship. The strength of this relationship is assessed using various metrics, including the F-test and the Akaike Information Criterion (AIC). Calculating the upper and lower bounds of the critical values for a given significance level is essential. If the estimated F-statistic exceeds the upper bound, it indicates a long-term correlation between the variables, irrespective of the order of integration. Conversely, if the F-statistic falls below the lower bound, it indicates co-integration is absent. This can be expressed as the following co-integration equation for the bound test:

$$\Delta CO2_t = \theta + \sum_{i=1}^{P} \theta 1i \Delta CO2_{t-1} + \sum_{i=1}^{q} \theta 2i \Delta GDP_{t-1} + \sum_{i=1}^{q} \theta 3i \Delta POP_{t-1} + \sum_{i=1}^{q} \theta 4i \Delta RENR_{t-1} + \sum_{i=1}^{q} \theta 5i \Delta EXP_{t-1} + \theta 6CO2_{t-1} + \theta 7GDP_{t-1} + \theta 8POP_{t-1} + \theta 9RENR_{t-1} + \theta 10EXP_{t-1} + \mu_t$$

The equation above represents the dynamics in the error correction (coefficients θ1 to θ5) and the relationship between dependent and independent variables throughout time (coefficients θ6 to θ10). If the F-statistic is within the acceptable range, it becomes difficult to draw definitive conclusions. Therefore, it is crucial to determine the order of integration of the underlying regressors first. Serial correlation and functional form diagnostics (Ramsey set) and normality (Jarque-Bera) should also be conducted, ensuring that all statistics (p-values) are above the specified significance levels. Once the variables in the study satisfy the conditions of the previous tests, both the short-run and long-run bound tests are performed. The ARDL equations for the short run and long run are expressed as:

$$\Delta CO2_t = \theta + \sum_{i=1}^{P} \theta 1i \Delta CO2_{t-1} + \sum_{i=1}^{q} \theta 2i \Delta GDP_{t-1} + \sum_{i=1}^{q} \theta 3i \Delta POP_{t-1} + \sum_{i=1}^{q} \theta 4i \Delta RENR_{t-1} + \sum_{i=1}^{q} \theta 5i \Delta EXP_{t-1} + \eta 1ECT_{t-1} + \mu_t$$

The rate at which short-term deviations from the long-term equilibrium are corrected is influenced by the Error Correction Term (ECT), represented as η1 in equation [55]. Further tests, such as the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUMQ), are performed to examine the long-term and short-term stability of coefficients. These tests offer valuable insights into the consistency and reliability of the estimated coefficients over time, helping to assess the robustness of the findings.

5. Results interpretation

The results derived from the descriptive statistics presented in Table 1 provide pivotal data concerning the distribution and characteristics of the variables, thereby making a significant contribution to the analysis by offering valuable insights. The mean values for $LNCO_2$, LNEXP, LNGDP, LNPOP, and LNRENR are 5.016067, 4.475634, 8.871011, 0.742239, and −4.273108, respectively. These mean values provide an estimate of the central tendency of the data. The median values, representing the central tendency, are similar to the means, indicating a relatively symmetrical distribution. The maximum and minimum values reflect the range within which the variables vary.

The standard deviation measures the dispersion of the data around the mean, with higher values indicating greater variability. In this case, the variables have relatively low standard deviations, suggesting that the data points are relatively close to the mean and exhibit less variability. Distribution symmetry can be inferred from the skewness values, with negative values indicating left-skewed distributions. $LNCO_2$ and LNPOP exhibit negative skewness, suggesting a tendency towards lower values in these variables.

The kurtosis values indicate the degree of peakedness of the distributions. All variables have positive kurtosis, indicating that they have heavier tails and exhibit more extreme values than a normal distribution. This result suggests that the data may have more extreme values or outliers.

The ADF and PP unit root tests are employed at the level to examine the stationarity of the variables, which indicates a stable mean over time. The results of the tests reported in Table 2 show that $LNCO_2$ has highly significant negative values in both tests, indicating that it is stationary and has a stable mean. However, for variables such as LNGDP, LNPOP, LNRENR, and LNEXP, the ADF and PP tests do not yield significant results, suggesting that these variables may not be stationary.

The stationarity of the variables can be further examined using the ADF and PP tests conducted on the first difference form, which assesses whether the variables become stationary after differencing, indicating a stable trend or relationship. The tests reveal highly significant negative values for $LNCO_2$, LNGDP, LNRENR, and LNEXP, indicating that these variables become stationary in their first difference form and exhibit a stable trend or relationship. On the other hand, LNPOP in the first difference form exhibits strong significant coefficients in the ADF tests, providing strong evidence of stationarity.

In summary, the results indicate that CO_2 emissions per capita ($LNCO_2$), GDP per capita (LNGDP), green technology (LNRENR), population growth (LNPOP), and exports as a percentage of GDP (LNEXP) exhibit stationarity and stability in their first difference forms.

The results of the co-integration analysis of the model presented in Table 3 reveal that the selected lag order (1, 1, 1, 3, 2) yields an AIC value of 8.092574, indicating a relatively good fit for the model. The F-statistic for the co-integration test is highly significant, surpassing both the upper bounds for the 1% (5.06) and 5% (4.01) significance levels. This result indicates co-integration among the variables in the model, suggesting a long-term association among them. The significant co-integration results imply that the variables

Table 1
Descriptive statistics for the model.

	$LNCO_2$	LNEXP	LNGDP	LNPOP	LNRENR
Mean	5.016067	4.475634	8.871011	0.742239	−4.273108
Median	5.171930	4.477718	8.876047	0.849054	−4.333333
Maximum	5.584304	4.798361	9.342647	1.083376	−3.199463
Minimum	3.893533	4.120649	8.270153	0.182205	−4.980253
Std. Dev.	0.497163	0.205654	0.297238	0.285854	0.525036
Skewness	−0.677719	0.046768	−0.227918	−0.567839	0.474221
Kurtosis	2.267440	1.682897	2.199535	1.862826	2.140210

Table 2
Unit Root tests.

Variables	ADF		PP	
	Intercept	Trend and intercept	Intercept	Trend and intercept
Level				
$LNCO_2$	−4.1718***	−0.5759	7.2625***	1.7915
LNGDP	−2.1464	−2.6672	−2.1464	−2.6025
LNPOP	1.6958	−1.4921	1.9387	−1.0716
LNRENR	−1.8299	−1.2828	−0.5386	−1.1870
LNEXP	−0.6710	−1.5422	−0.6209	−1.3836
First Difference				
$LNCO_2$	−4.4153***	−6.6894***	−4.3678***	−12.0235***
LNGDP	−5.0101***	−4.5672***	−4.2085***	−4.5672***
LNPOP	−3.3551**	−4.3243***	−2.8094*	−3.1082
LNRENR	−4.3044***	−4.6988***	−4.2822***	−7.3370***
LNEXP	−3.4847**	−4.2722**	−3.5314**	−5.1852***

*** and ** represent significance at the 1% and 5% levels.

jointly influence the equilibrium relationship, and changes in one variable are expected to have a lasting impact on the others. These findings support a stable and meaningful association among the variables considered in the analysis. As a result, it becomes possible to investigate the long-run dynamics and causal effects among the variables in subsequent analyses.

Table 4 displays the results of the diagnostic tests performed on the model, and the conclusions can be summarised as follows:

- The test for serial correlation indicates a value of 1.158993, suggesting that no significant serial correlation is present in the model's residuals.
- The test for functional form produces a value of 1.755798, indicating that the model's functional form is appropriate and does not exhibit significant misspecification.
- The test for normality yields a value of 0.062638, suggesting that the model's residuals follow a normal distribution.
- The test for heteroscedasticity provides a value of 1.268376, indicating no significant violation of the assumption of constant variance in the model's residuals.

These results support the validity and reliability of the model, indicating that it provides a good representation of the underlying data.

Fig. 3(a) and (b) depict the results of the CUSUM and CUSUMQ tests, which show that the models are structurally stable and resilient. The blue lines always fall inside the acceptable range when the significance threshold is set at 5%, as seen in both figures. These findings provide no support for the existence of structural instability within the models. Consistent coefficients throughout time lend further credence to the accuracy of the model estimates and the veracity of the results.

The coefficients estimated for the long-run model, as shown in Table 5, reveal important relationships between the variables. The coefficient for LNGDP indicates a positive effect on CO_2 emissions, implying that economic expansion exacerbates environmental damage in the long run. However, the coefficient for LNPOP indicates a negative repercussion for CO_2 emissions, implying that higher population growth is associated with lower levels of environmental degradation. The coefficient for LNRENR reflects an adverse outcome on CO_2 emissions, indicating that promoting green technology can help reduce environmental degradation. Additionally, the coefficient for LNEXP suggests a positive effect on CO_2 emissions, indicating that export activity contributes to environmental degradation. The constant term represents other factors not included in the model that lead to decreased CO_2 emissions. These findings provide insights into the long-term dynamics and relationships between the variables, highlighting the importance of considering economic, demographic, and environmental factors in addressing environmental degradation.

The coefficients estimated for the short-run model, as shown in Table 6, provide valuable insights into the immediate factors influencing CO_2 emissions. The coefficient for LNGDP demonstrates a noteworthy positive correlation with CO_2 emissions, suggesting that economic expansion contributes to short-term environmental degradation. Conversely, the coefficient for LNRENR demonstrates an adverse effect on CO_2 emissions, indicating that promoting green technology can help mitigate short-term environmental

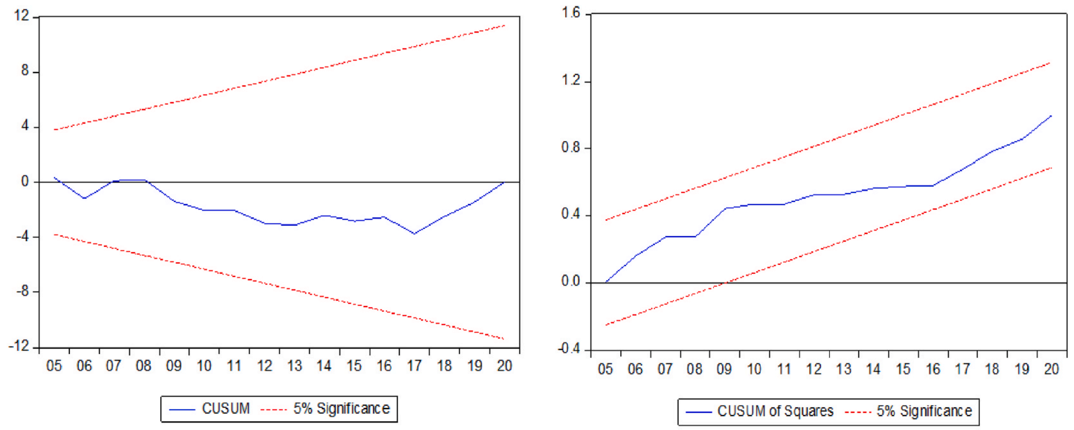
Table 3
ARDL test for Co-integration.

Model	AIC(Lag order)	F Statistic
K = 4	(1, 1, 1, 3, 2)	8.092574***
Critical values for F- Statistic #	Lower Bound I(0)	Upper Bound I(1)
1%	3.74	5.06
5%	2.86	4.01
10%	2.45	3.52

*** represents significance at the 1% level.

Table 4
Diagnostic test.

Model	Serial Correlation	Functional Form	Normality	Heteroscedasticity
	1.158993	1.755798	0.062638	1.268376



(a) (b)

Fig. 3. (a) Cummulative Sum (CUSUM) chart Fig. 3(b) Cummulative Sum of Squares (CUSUMQ) chart.

Table 5
Long run elasticities.

DV	CO_2		
Lag order	(1, 1, 1, 3, 2)		
IV	Coefficient	t-Statistic	Prob
LNGDP	0.7081***	3.0843	0.0071
LNPOP	−1.3961***	−4.3914	0.0005
LNRENR	−0.2187***	−5.4143	0.0001
LNEXP	0.7009***	4.8687	0.0002
C	−2.4888***	−7.0348	0.0000

*** and ** represent significance at the 1% and 5% levels.

degradation. However, the coefficients for LNPOP and LNEXP are insignificant, suggesting that population growth and export activity do not significantly impact CO_2 emissions in the short run. The importance of the Error Correction Term (ECT) demonstrates the existence of a long-lasting and consistent connection between the variables. This implies that any deviations from the long-run equilibrium will be gradually rectified in the short run as the system adjusts to restore the equilibrium state. The presence of a significant ECT highlights the dynamics of the relationship and underscores the importance of considering both short-term fluctuations and long-term equilibrium in analysing the interplay between the variables. It further emphasises the responsiveness and self-correcting nature of the system as it strives to maintain a balanced state over time. Due to its high R-squared and adjusted R-squared values, the model adequately a substantial portion of the variation in CO_2 emissions and is well-fitted to the data, enhancing its reliability in capturing the dynamics between the variables.

Table 6
Short-run elasticities.

Variables	Coefficient	t-Statistic	Prob
LNGDP	0. 0.9582***	8.1128	0.0000
LNPOP	−0.3067	−1.7008	0.1083
LNRENR	−0.0470**	−1.7582	0.0978
LNEXP	0.0140	0.1713	0.8661
ECT		−7.1119	0.0000
R Squared	0.99		
Adjusted R Squared	0.99		

*** and ** represent significance at the 1% and 5% levels.

6. Discussion of results and policy recommendation

This research adds significantly to the existing academic literature by exploring the environmental effects of factors including green technology adoption, exports, population growth, and economic income on CO_2 emissions in Malaysia. The findings reveal a strong inverse relationship between the uptake of environmentally friendly technology and carbon dioxide output, both in the short and long term, aligning with prior investigations conducted by Meirun et al. [56] and Obobisa et al. [57]. Bekhet and Othman [44], Khan et al. [50] and Leitao and Lorente [41]. These studies underscore the vital significance of green technology in alleviating environmental pollution and attaining a sustainable equilibrium between economic progress and environmental conservation. The findings of this study align with and contribute to the expanding wealth of information that bolsters the significance of integrating green technology approaches to foster environmental sustainability within the context of Malaysia.

Malaysia has taken significant steps towards reducing CO_2 emissions by adopting green technology. The Green Technology Financing Scheme (GTFS) is a noteworthy programme that has been running since 2010 to encourage businesses to adopt greener practices. The GTFS provides financing options with an allocation of RM1.5 billion and offers a 2% interest subsidy to companies obtaining loans from participating banks [58]. Furthermore, the Malaysian government established the Malaysian Green Tech Corporation (MGTC) as a dedicated organisation to promote green technology as a national agenda [59]. These initiatives demonstrate Malaysia's commitment to fostering the development and adoption of green technology to address environmental challenges and promote sustainable practices.

In addition, the study found that increased exports harm Malaysia's environment since they lead to higher production and energy consumption. However, it is determined that exports have a negligible impact on CO_2 emissions in the short term. Aldakhil et al. [8] research in South Asia and Acheampong et al. [60] research in Sub-Saharan Africa are consistent with these results. This is in contrast to the research conducted by Hasanov et al. [47] and Khan et al. [50], both of which found that exports can reduce consumption-based CO_2 emissions in some oil-exporting and G7 countries. The disparities in the environmental impacts of exports across different countries may be attributed to technological capabilities and environmental policy variations.

To address CO_2 emissions associated with exports, Malaysia can implement measures such as promoting green export practices, encouraging energy-efficient manufacturing, adopting sustainable packaging, and utilising environmentally friendly transportation methods. Additionally, implementing carbon pricing mechanisms and enhancing energy efficiency in export-oriented industries can reduce the carbon footprint and mitigate the environmental impact of exports. These strategies can support Malaysia's ongoing efforts to promote sustainable development and achieve its environmental targets.

Moreover, both short-term and long-term environmental harm in Malaysia is found to be positively correlated with economic growth. Shahbaz et al. [2], Hasanov et al. [47], Khan et al. [50], and Leitao and Lorente [41] all found similar things in their investigations and panel analyses of the Chinese market. However, Bekhet and Othman's [44] findings for Malaysia, in which they uncover an inverted N-shaped curve in the growth-carbon nexus, are at odds with these findings. To mitigate the negative impact of economic expansion on the environment, Malaysia has implemented environmental regulations, promoted the adoption of green technology, and actively participated in international agreements focused on sustainability.

Lastly, the study uncovers an inverse association between population growth and CO_2 emissions in Malaysia in the long run, although its effect on CO_2 emissions in the short run is insignificant. These findings are similar to those observed in studies conducted in Brazil by Alam et al. [61]. However, contradictory findings have been presented in studies conducted in other contexts [60,62,63]. To effectively leverage population growth in reducing CO_2 emissions, Malaysia can prioritise sustainable urban development, implement robust environmental education programs, and provide incentives for adopting renewable energy sources. By doing so, Malaysia can strive towards achieving a sustainable balance between population growth and environmental preservation.

Regarding practical implications, the study suggests several policy measures for the Malaysian government. Prioritising the adoption of green technology, providing incentives for renewable energy sources, encouraging sustainable export practices, and raising awareness among the population about the dangers of increasing CO_2 emissions are recommended. These policy actions can contribute to sustainable development, low-carbon growth, and the reduction of CO_2 emissions in Malaysia while supporting economic expansion and environmental preservation [7,64–67]. By implementing these measures, Malaysia can contribute to global climate change mitigation efforts while fostering its sustainable development.

7. Conclusion and recommendation for further studies

This research utilised the Autoregressive Distributed Lag (ARDL) model to analyse annual time series data spanning from 1989 to 2019, focusing on macroeconomic variables relevant to understanding environmental damage in Malaysia. The primary objective of this study was to examine the influence of green technology, exports, population growth, and GDP on CO_2 emissions. A unique measurement was introduced by considering the ratio of renewable energy use to non-renewable energy use to evaluate the impact of green technology. This measurement provides insights into the relative dependency or incorporation of these resources within the economy. This approach differs from previous studies that commonly relied on proxies such as renewable energy and overall innovation.

Based on this study's findings, Malaysia has several important policy implications for addressing environmental damage and promoting sustainable development. Policymakers in Malaysia should prioritise investment in adopting green technology across various economic sectors. One practical approach is encouraging businesses, especially those in industries with significant environmental impact, to incorporate green technology into their production processes. This can involve promoting renewable energy sources, encouraging the adoption of energy-efficient technologies, and advocating for sustainable practices. By embracing green technology, Malaysia can reduce CO_2 emissions and minimise environmental damage caused by economic activities.

Incentivizing Green Practices: To further encourage the adoption of green technology, the government can implement various incentives for businesses. For instance, they can consider increasing taxes on non-renewable energy sources to discourage their use and promote cleaner alternatives. Additionally, offering subsidies or tax benefits for companies that actively adopt renewable energy sources can incentivise businesses to invest in environmentally friendly practices. These measures can help drive the transition towards greener practices, substantially reducing CO_2 emissions and improving environmental performance. Besides, given the significant impact of exports on CO_2 emissions in the long run, Malaysia must develop sustainable export strategies. It can be achieved by actively promoting green export practices throughout the country. Encouraging energy-efficient manufacturing processes, such as using advanced technologies and optimising production systems, can significantly reduce the environmental footprint associated with exports. Also, Malaysia can implement sustainable packaging and transportation methods to minimise export activities' environmental impact. By integrating environmental considerations into export-oriented industries, Malaysia can effectively mitigate the adverse environmental consequences of increased production and energy consumption. By implementing these policies to promote green technology adoption, incentivise sustainable practices, and develop sustainable export strategies, Malaysia can make significant progress in reducing CO_2 emissions and achieving a more sustainable economy. These measures will contribute to environmental preservation and position Malaysia as a leader in sustainable development. By demonstrating a commitment to green practices, Malaysia can attract environmentally conscious businesses, investors, and consumers, creating new opportunities for economic expansion and ensuring a cleaner and healthier future for its citizens.

While this study successfully achieved its objective, it is important to acknowledge several limitations that should be considered in future research. These include exploring additional dimensions of green technology, such as energy efficiency, carbon pricing, and green infrastructure. Such investigations will aid in determining the most effective strategies for achieving Malaysia's objective of low-carbon growth. Furthermore, studies can investigate the effects of different types of exported goods and services to identify the major contributors to CO_2 emissions in Malaysia. It is also recommended to extend the data period to include the latest years, such as 2021 and 2022. By incorporating recent data, researchers can capture the most up-to-date trends and developments in Malaysia's environmental and economic landscape. It will provide a more accurate and comprehensive understanding of the country's association between green technology, CO_2 emissions, and environmental degradation.

Author contribution statement

Temitayo B. Majekodunmi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mohd Shahidan Shaari: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Noorazeela Zainol Abidin: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Abdul Rahim Ridzuan: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] World Health Organization, Wildfires (2023). https://www.who.int/healthtopics/wildfires?gclid=Cj0KCQjw4NujBhC5ARIsAF4Iv6cxe8YwfMR4U35kiIwuRbQ80o4ZhFua3jsfdAYduvtokD1k3xMNaZYaAudbEALw_wcB#tab=tab_1. (Accessed 1 June 2023).
[2] M. Shahbaz, C. Raghutla, M. Song, H. Zameer, Z. Jiao, Public-private partnerships investment in energy as new determinant of CO_2 emissions: the role of technological innovations in China, Energy Econ. 86 (2020), 104664, https://doi.org/10.1016/j.eneco.2020.104664.
[3] L.C. Voumik, M.A. Islam, S. Ray, N.Y. Mohamed Yusoff, A.R. Ridzuan, CO_2 emissions from renewable and non-renewable electricity generation sources in the G7 countries: static and dynamic panel assessment, Energies 16 (2023) 1044, https://doi.org/10.3390/en16031044.
[4] Malaysia Energy Information Hub, Statistics – Primary Energy Supply (2023). https://meih.st.gov.my/statistics. (Accessed 2 February 2023).
[5] Countryeconomy.com, Malaysia - CO2 emission (2022). https://countryeconomy.com/energy-and-environment/co2-emissions/malaysia. (Accessed 3 January 2023).
[6] World Bank Data (2023a). CO2 emissions (metric tons per capita) | Data. Available at: https://data.worldbank.org/indicator/EN.ATM.CO2E.PC (Accessed: 2 June 2023).

[7] S. Ahmed, K. Ahmed, M. Ismail, Predictive analysis of CO2 emissions and the role of environmental technology, energy use and economic output: evidence from emerging economies, Air Quality, Atmosphere Health 13 (2020) 1035–1044, https://doi.org/10.1007/s11869-020-00855-1.

[8] A.M. Aldakhil, A. Zaheer, S. Younas, A.A. Nassani, M.M.Q. Abro, K. Zaman, Efficiently managing green information and communication technologies, high-technology exports, and research and development expenditures: a case study, J. Clean. Prod. 240 (2019), 118164, https://doi.org/10.1016/j.jclepro.2019.118164.

[9] T.B. Majekodunmi, M.S. Shaari, N.F. Zainal, N. H Harun, A.R. Ridzuan, N.Z. Abidin, N.H. Abd Rahman, Gas consumption as a key for low carbon state and its impact on economic expansion in Malaysia: ARDL approach, Int. J. Energy Econ. Pol. 13 (3) (2023) 469, https://doi.org/10.32479/ijeep.14134.

[10] United Nations Framework Convention on Climate Change, Malaysia third biennial update report to the UNFCCC, Retrieved at, https://unfccc.int/sites/default/files/resource/MALAYSIA_BUR3-UNFCCC_Submission.pdf, 2020. on the 8th October, 2022.

[11] United Nations Framework Convention on Climate, Malaysia Biennial Update Report to the UNFCCC, 2016. Retrieved at, https://unfccc.int/documents/180659. on the 8th October, 2022.

[12] T. Meirun, L.W. Mihardjo, M. Haseeb, S.A.R. Khan, K. Jermsittiparsert, The dynamics effect of green technology innovation on economic growth and CO 2 emission in Singapore: new evidence from bootstrap ARDL approach, Environ. Sci. Pollut. Control Ser. 28 (2021) 4184–4194, https://doi.org/10.1007/s11356-020-10760-w.

[13] C. Mui-Yin, P. Chin-Hong, C.L. Teo, J. Joseph, The determinants of CO2 emissions in Malaysia: a new aspect, Int. J. Energy Econ. Pol. 8 (1) (2018) 190–194.

[14] World Bank Group, World Development Report 2020, World Bank Publications, 2021.

[15] U.K. Pata, The influence of coal and noncarbohydrate energy consumption on CO2 emissions: revisiting the environmental Kuznets curve hypothesis for Turkey, Energy 160 (2018) 1115–1123, https://doi.org/10.1016/j.energy.2018.07.095.

[16] A.R. Ridzuan, V.V. Kumaran, B.A. Fianto, M.S. Shaari, M.A. Esquivias, A. Albani, Reinvestigating the presence of environmental kuznets curve in Malaysia: the role of foreign direct investment, Int. J. Energy Econ. Pol. 12 (5) (2022) 217–225, https://doi.org/10.32479/ijeep.13461.

[17] G.S. Khoon, L.M. Hui, T.Y. Sua, The policy responses and implications of the global financial crisis on Asia: a case study for Malaysia, Eur. Res. Stud. 15 (1) (2012) 56–69. https://www.um.edu.mt/library/oar/handle/123456789/31000.

[18] S. Nambiar, Malaysia and the global crisis: impact, response, and rebalancing strategies, The Global Financial Crisis and Asia: Implications and Challenges (2009) 218, https://doi.org/10.1093/acprof:oso/9780199660957.003.0011.

[19] N.S.M. Safaai, Z.Z. Noor, H. Hashim, Z. Ujang, J Talib. Projection of CO2 emissions in Malaysia, Environ. Prog. Sustain. Energy 30 (4) (2011) 658–665, https://doi.org/10.1002/ep.10512.

[20] OECD, International trade during the COVID-19 pandemic, Big shifts and uncertainty (2022). https://www.oecd.org/coronavirus/policy-responses/international-trade-during-the-covid-19-pandemic-big-shifts-and-uncertainty-d1131663/. (Accessed 5 June 2023).

[21] M. Menhat, I.M.M. Zaideen, Y. Yusuf, N.H.M. Salleh, M.A. Zamri, J. Jeevan, The impact of Covid-19 pandemic: a review on maritime sectors in Malaysia, Ocean Coast Manag. 209 (2021), 105638, https://doi.org/10.1016/j.ocecoaman.2021.105638.

[22] World Bank Open Data, Exports of goods and services (% of GDP) (2023). https://data.worldbank.org/indicator/NE.EXP.GNFS.ZS. (Accessed 3 June 2023).

[23] Z. Yikun, L. Woon Leong, P.T. Cong, A. Abu-Rumman, A. Al Shraah, S.S. Hishan, Green growth, governance, and green technology innovation. How effective towards SDGs in G7 countries? Economic Research-Ekonomska Istraživanja. 36 (2) (2023), 2145984 https://doi.org/10.1080/1331677x.2022.2145984.

[24] M. Hussain, G.M. Mir, M. Usman, C. Ye, S. Mansoor, Analysing the role of environment-related technologies and carbon emissions in emerging economies: a step towards sustainable development, Environ. Technol. 43 (2022) 367–375, https://doi.org/10.1080/09593330.2020.1788171.

[25] T.B. Majekodunmi, M.S. Shaari, N.Z. Abidin, N.H. Harun, S.N.F. Muhsain, Remittance inflows, economic output, electricity use and CO_2 emissions in the D-8 countries: a panel ARDL analysis, Int. Energy J. 23 (1) (2023) 1–12.

[26] M.M. Rahman, K. Alam, E. Velayutham, E, Reduction of CO_2 emissions: the role of renewable energy, technological innovation and export quality, Energy Rep. 8 (2022) 2793–2805, https://doi.org/10.1016/j.egyr.2022.01.200.

[27] U. Shahzad, D. Ferraz, B. Doğan, B, D.A. do Nascimento Rebelatto, Export product diversification and CO_2 emissions: contextual evidences from developing and developed economies, J. Clean. Prod. 276 (2020), 124146, https://doi.org/10.1016/j.jclepro.2020.124146.

[28] N. Amin, H. Song, The role of renewable, non-renewable energy consumption, trade, economic expansion, and urbanisation in achieving carbon neutrality: a comparative study for South and East Asian countries, Environ. Sci. Pollut. Control Ser. 30 (2023) 12798–12812, https://doi.org/10.1007/s11356-022-229732.

[29] A. Mujtaba, P.K. Jena, F.V. Bekun, P.K. Sahu, Symmetric and asymmetric impact of economic growth, capital formation, renewable and non-renewable energy consumption on environment in OECD countries, Renew. Sustain. Energy Rev. 160 (2022), 112300, https://doi.org/10.1016/j.rser.2022.112300.

[30] H. Saleem, M.B. Khan, M.S. Shabbir, G.Y. Khan, M. Usman, M, Nexus between non-renewable energy production, CO_2 emissions, and healthcare spending in OECD economies, Environ. Sci. Pollut. Control Ser. 29 (31) (2022) 47286–47297, https://doi.org/10.1007/s11356-021-18131-9.

[31] N. Djellouli, L. Abdelli, M. Elheddad, R. Ahmed, H. Mahmood, The effects of non-renewable energy, renewable energy, economic expansion, and foreign direct investment on the sustainability of African countries, Renew. Energy 183 (2022) 676–686, https://doi.org/10.1016/j.renene.2021.10.066.

[32] F. Chien, How renewable energy and non-renewable energy affect environmental excellence in N-11 economies? Renew. Energy 196 (2022) 526–534, https://doi.org/10.1016/j.renene.2022.07.013.

[33] A. Razzaq, Y. Wang, S. Chupradit, W. Suksatan, F. Shahzad, Asymmetric inter-linkages between green technology innovation and consumption-based carbon emissions in BRICS countries using quantile-on-quantile framework, Technol. Soc. 66 (2021), 101656, https://doi.org/10.1016/j.techsoc.2021.101656.

[34] K. Saidi, A. Omri, Reducing CO_2 emissions in OECD countries: do renewable and nuclear energy matter? Prog. Nucl. Energy 126 (2020), 103425 https://doi.org/10.1016/j.pnucene.2020.103425.

[35] R. Radmehr, S.R. Henneberry, S. Shayanmehr, Renewable energy consumption, CO_2 emissions, and economic expansion nexus: a simultaneity spatial modeling analysis of EU countries, Struct. Change Econ. Dynam. 57 (2021) 13–27, https://doi.org/10.1016/j.strueco.2021.01.006.

[36] S.R. Paramati, D. Mo, R. Huang, The role of financial deepening and green technology on carbon emissions: evidence from major OECD economies, Finance Res. Lett. 41 (2021), 101794, https://doi.org/10.1016/j.frl.2020.101794.

[37] N. Ahmed, F. O Areche, D.D.C. Nieto, R.F.C. Borda, B.C. Gonzales, P. Senkus, A. Skrzypek, Nexus, between cyclical innovation in green technologies and CO2 emissions in nordic countries: consent toward environmental sustainability, Sustainability 14 (2022), 11768, https://doi.org/10.3390/su141811768.

[38] N. Mahmood, Z. Wang, N. Yasmin, N.W. Manzoor, How to bend down the environmental Kuznets curve: the significance of biomass energy, Environ. Sci. Pollut. Control Ser. 26 (21) (2019) 21598–21608, https://doi.org/10.1007/s11356-019-05442-1.

[39] N.H.A.M. Ridzuan, N.F. Marwan, N. Khalid, M.H. Ali, M.L. Tseng, L. M, Effects of agriculture, renewable energy, and economic expansion on carbon dioxide emissions: evidence of the environmental Kuznets curve, Resour. Conserv. Recycl. 160 (2020), 104879, https://doi.org/10.1016/j.resconrec.2020.104879.

[40] A. Raihan, D.A. Muhtasim, S. Farhana, M.A.U. Hasan, M.I. Pavel, O. Faruk, A. Mahmood, Nexus between economic growth, energy use, urbanisation, agricultural productivity, and carbon dioxide emissions: new insights from Bangladesh, Energy Nexus 8 (2022), 100144, https://doi.org/10.1016/j.nexus.2022.100144.

[41] N.C. Leitao, D.B. Lorente, The linkage between economic expansion, renewable energy, tourism, CO_2 emissions, and international trade: the evidence for the European Union, Energies 13 (2020) 4838, https://doi.org/10.3390/en13184838.

[42] M.H.M. Saudi, O. Sinaga, N.H. Jabarullah, The role of renewable, non-renewable energy consumption and technology innovation in testing environmental Kuznets curve in Malaysia, Int. J. Energy Econ. Pol. 9 (1) (2019) 299–307, https://doi.org/10.32479/ijeep.7295.

[43] A. Raihan, A. Tuspekova, A, Toward a sustainable environment: nexus between economic expansion, renewable energy use, forested area, and carbon emissions in Malaysia, Resources, Conservation Recycling Advances 15 (2022), 200096, https://doi.org/10.1016/j.rcradv.2022.200096.

[44] H.A. Bekhet, N.S. Othman, The role of renewable energy to validate dynamic interaction between CO2 emissions and GDP toward sustainable development in Malaysia, Energy Econ. 72 (2018) 47–61, https://doi.org/10.1016/j.eneco.2018.03.028.

[45] S.S. Sharif Ali, M.R. Razman, A. Awang, A, The nexus of population, growth domestic product growth, electricity generation, electricity consumption and carbon emissions output in Malaysia, Int. J. Energy Econ. Pol. 10 (3) (2020) 84–89, https://doi.org/10.32479/ijeep.8987.

[46] M. Ben Jebli, S. Ben Youssef, N. Apergis, The dynamic linkage between renewable energy, tourism, CO2 emissions, economic expansion, foreign direct investment, and trade, Latin American Economic Review 28 (2019) 1–19, https://doi.org/10.1186/s40503-019-0063-7.

[47] F.J. Hasanov, B. Liddle, J.I. Mikayilov, The impact of international trade on CO2 emissions in oil exporting countries: territory vs consumption emissions accounting, Energy Econ. 74 (2018) 343–350, https://doi.org/10.1016/j.eneco.2018.06.004.

[48] Y. Dou, F. Chen, Z. Kong, K. Dong, Re-estimating the trade openness–carbon emissions nexus: a global analysis considering nonlinear, mediation, and heterogeneous effects, Appl. Econ. (2023) 1–16, https://doi.org/10.1080/00036846.2023.2166659.

[49] Y. Dou, J. Zhao, M.N. Malik, K. Dong, Assessing the impact of trade openness on CO2 emissions: evidence from China-Japan-ROK FTA countries, J. Environ. Manag. 296 (2021), 113241, https://doi.org/10.1016/j.jenvman.2021.113241.

[50] Z. Khan, S. Ali, M. Umar, D. Kirikkaleli, Z. Jiao, Consumption-based carbon emissions and international trade in G7 countries: the role of environmental innovation and renewable energy, Sci. Total Environ. 730 (2020), 138945, https://doi.org/10.1016/j.scitotenv.2020.138945.

[51] A.A. Khan, S.U. Khan, M.A.S. Ali, A. Safi, Y. Gao, J. Luo, Identifying impact of international trade and renewable energy consumption on environmental quality improvement and their role in global warming, Environ. Sci. Pollut. Control Ser. 29 (2022) 33935–33944, https://doi.org/10.1007/s11356-022-18574-8.

[52] A.A. Haug, M. Ucal, The role of trade and FDI for CO_2 emissions in Turkey: nonlinear relationships, Energy Econ. 81 (2019) 297–307, https://doi.org/10.1016/j.eneco.2019.04.006.

[53] M.H. Pesaran, B. Pesaran, Working with microfit 4.0, in: Camfit Data Ltd, Oxford University Press, Cambridge, 1997.

[54] M.A.H. Norehan, A.R. Ridzuan, S. Ismail, M.I.M. Razak, S. M, Shaari dynamic linkages between foreign direct investment inflows, economic growth and information and communication technology: evidence from China and Malaysia, Int. J. Acad. Res. Bus. Soc. Sci. 12 (9) (2022) 419–433, https://doi.org/10.6007/IJARBSS/v12-i9/14850.

[55] M.K. Khan, J.Z. Teng, M.I. Khan, The effect of migrant remittances on economic expansion: an ARDL approach, Eng. Econ. 30 (2019) 434–441, https://doi.org/10.5755/j01.ee.30.4.21830.

[56] T. Meirun, L.W. Mihardjo, M. Haseeb, S.A.R. Khan, K. Jermsittiparsert, The dynamics effect of green technology innovation on economic expansion and CO_2 emission in Singapore: new evidence from bootstrap ARDL approach, Environ. Sci. Pollut. Control Ser. 28 (4) (2021) 4184–4194, https://doi.org/10.1007/s11356-020-10760-w.

[57] E.S. Obobisa, H. Chen, I.A. Mensah, The impact of green technological innovation and institutional quality on CO2 emissions in African countries, Technol. Forecast. Soc. Change 180 (2022), 121670, https://doi.org/10.1016/j.techfore.2022.121670.

[58] L.S. Lau, Y.O. Choong, S.L. Ching, C.Y. Wei, A. Senadjki, C.K. Choong, A.N. Seow, Expert insights on Malaysia's residential solar-energy policies: shortcomings and recommendations, Clean Energy 6 (2022) 619–631, https://doi.org/10.1093/ce/zkac043.

[59] Colombo Plan Staff College Government of Malaysia's Initiative for Green Economy and the TVET Response, 2020. Available at: https://www.cpsctech.org/2014/07/government-of- malaysias-initiativefor.html?m=1. (Accessed 1 June 2023).

[60] A.O. Acheampong, S. Adams, E. Boateng, Do globalisation and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa? Sci. Total Environ. 677 (2019) 436–446, https://doi.org/10.1016/j.scitotenv.2019.04.353.

[61] M. M Alam, M.W. Murad, A.H.M. Noman, I. Ozturk, Relationships among carbon emissions, economic expansion, energy consumption and population growth: testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia, Ecol. Indicat. 70 (2016) 466–479, https://doi.org/10.1016/j.ecolind.2016.06.043.

[62] K.I. Okere, F.C. Onuoha, O.B. Muoneke, A.M. Oyeyemi, Towards sustainability path in Argentina: the role of finance, energy mix, and industrial value-added in low or high carbon emission—application of DARDL simulation, Environ. Sci. Pollut. Control Ser. 28 (39) (2021) 55053–55071, https://doi.org/10.1007/s11356-021-14756-y.

[63] S. Muhammad, X. Long, M. Salman, L. Dauda, Effect of urbanisation and international trade on CO2 emissions across 65 belt and road initiative countries, energy 196 (2020), 117102, https://doi.org/10.1016/j.energy.2020.117102.

[64] Q. Yin, Y. Wang, Z. Xu, K. Wan, D. Wang, Factors influencing green transformation efficiency in China's mineral resource-based cities: method analysis based on IPAT-E and PLS-SEM, J. Clean. Prod. 330 (2022), 129783, https://doi.org/10.1016/j.jclepro.2021.129783.

[65] R.A. Begum, K. Sohag, S.M. S Abdullah, M. Jaafar, CO2 emissions, energy consumption, economic and population growth in Malaysia, Renew. Sustain. Energy Rev. 41 (2015) 594–601, https://doi.org/10.1016/j.rser.2014.07.205.

[66] M. Musah, Y. Kong, X.V. Vo, Predictors of carbon emissions: an empirical evidence from NAFTA countries, Environ. Sci. Pollut. Control Ser. 28 (9) (2021) 11205–11223, https://doi.org/10.1007/s11356-020-11197-x.

[67] V. Vija Kumaran, A.R. Ridzuan, F.U. Khan, H. Abdullah, Z.Z. Mohamad, An empirical analysis of factors affecting on renewable energy consumption in selected ASEAN countries: does quality of governance matters? Int. J. Energy Econ. Pol. 10 (2) (2020) 1–9, https://doi.org/10.32479/ijeep.8142.