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A Cointegration Analysis of Economic Growth and CO_2 Emissions: A Case Study of Malaysia

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Abstract

The paper aims to establish a long-run and the Granger causal relationship between economic growth, CO_2 emissions, international trade, energy consumption, and population density in Malaysia. The study will use annual data from 1970 to 2014. A unique cointegrating relationship between our variables $(\forall \equiv lnE_t, lnY_t, lnY_t^2,\ lnZ_t\ \equiv lnE_t, lnY_t, lnY_t^2, lnIT_t, lnEC_t, lnP_{OP_t})$ was identified. The study employed the Auto-Regressive Distributed Lag $(ARDL)$ model to examine the Environmental Kuznets Curve (EKC). Our empirical results analysis showed a long-run relationship between per capita CO_2 emissions (lnE_t) and our explanatory variables $(lnY_t, lnY_t^2, lnZ_t\ \equiv lnY_t, lnY_t^2, lnIT_t, lnEC_t, lnP_{OP_t})$. To investigate the Granger causal relationship between $\forall$, the Vector Error Correction Model $(VECM)$ was employed and our results, associated the absence of Granger causality between CO_2 emissions and economic growth (lnY_t, lnY_t^2) in the short-run while revealing a uni-directional Granger causality movement $CO_2 \leftarrow GDP\ left - right\ meovement$ from economic growth to CO_2 emissions in the long-run. Hence, an increase in GDP will lead to a rise in CO_2 emissions in Malaysia.

Keywords: Economic growth, CO_2 emissions, Environmental Kuznets Curve (EKC) Auto-Regressive Distributed Lag $(ARDL)$, Malaysia, Granger Causal Relationship

1. Introduction

Since the early 1800s, scientists have been laboring to understand Earth's climate and how it changes over time through direct and indirect causes. With high investment in research and development, scientists have discovered that many factors influence and affect our climate, and global warming is one of the several factors. In 1824, Joseph Fourier a French scientist, examined the Earth's temperature and concluded that it would drop significantly, if adequate atmospheric tools were not incorporated into the environment system to mitigate, reduce, and measure the Earth’s climate conditions; in 1859, John Tyndall, an English scientist discovered that the primary gases that trapped heat was H_2O and CO_2 (Klein et al., 1999), and in early 1896, Svante Arrhenius a Swedish scientist argued that burning fossil fuels such as coal would lead to additional CO_2 emission into the atmosphere and will result in a total rise in Earth’s average temperature.

In recent years, the issues of emissions reduction policies have garnered profound attention from both policymakers and academic researchers, with the highest per capita greenhouse gas (GHG) emitter among the Annex I parties (The United Nations Climate Change, 2017). The United Nations (UN) Framework Convention on Climate Change (Ministry of Natural Resources and Environment Malaysia, 2015), has led to many countries pledging and aiming to reduce GHG emissions at a considerable rate. This greenhouse effect is one of many contributors to global warming. Since the late 2000s, climate change, alternative sources of energy, and green subsidies have been at the center of an intense world debate. The current foundation for affirmative action and policies rest on the Paris Agreement of 2016, which builds upon the framework convention on climate change.

Table 1. Per capita CO_2 emissions

Years	World	Malaysia
1970 - 1979	42.30	16.64
1980 - 1989	41.32	23.80
1990 - 1999	40.65	47.80
2000 - 2009	48.09	69.24
2010 - 2014	24.76	38.96

The table shows Malaysia’s CO_2 emissions measured in metric tons as it compares with the rest of the world (World Development Indicator, 2017).

Recently, the effectiveness of environmental regulations in emerging markets has become more of a critical issue when it comes to climate change, both on a national and global level. As their production and economic activities increase, it eventually leads to pollution. Malaysia is an excellent example of an emerging market with local air and water pollution that has shown substantial health costs and issues to its locals. With a population size of 31.62 million people as of 2017, Malaysia CO_2 emissions per capita have increased from 4.63 metric tons in 1996 to 8.09 metric tons in 2015, which is a 74.73% increase in CO_2 emissions into the environment. In 2009, the National Green Technology Policy (NGTP) was introduced by the Malaysian government, which is responsible for many policies and programs (MNREM, 2015), and the Malaysian government has engaged with several international accords. Our study investigated the long-run and Granger causal relationship between economic growth and CO_2 emissions in Malaysia, using the EKC methodology

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from 1970 – 2014. The paper also explored the cointegration analysis approach by using the $ARDL$ model, and the Granger causality analysis was used to test the stability of $\forall$. The study contributes to the literature on CO_2 emissions and economic growth; by expanding on the work of (Saboori, Sulaiman, & Mohd, 2012) by adding more explanatory variables $Z_{i,t}$ where $Z_{i,t}$ is $lnIT_{i,t}, lnEC_{i,t}, and\ lnP_{OP_{i,t}}$. Although the research concentrates on the Malaysian economy, the model application can be applied to other related topics, queries', and research questions on $SO_2, CO_2, and\ GHG$ emissions and its effects on the environment, economic growth, development, and stability.

2. Literature Review

Saboori and Sulaiman (2013) used the EKC analysis to test the short and long-run Granger causal relationship between economic growth, CO_2 emissions and energy consumption in Malaysia. The authors analyzed the Malaysian economy energy consumption from 1980 – 2009 using the aggregated and disaggregated energy consumption datasets, as their variables of interest. The $ARDL$ model and the Johansen–Juselius maximum likelihood methodology was incorporated to analyze the cointegration and the Granger causality relationship using the $VECM$, for the final causality testing.

The results found no evidence of an inverted U-shaped relationship (EKC) when the aggregated energy consumption data set was used. But when the disaggregated based set was used (different energy sources: not limited to oil, coal, gas, and electricity) an inverted U-shaped EKC relationship was found. The authors' found evidence of the $EKC\ H_0$. The results from the long-run Granger causality test exhibited a bi-directional causality between economic growth and CO_2 emissions from (coal, gas, electricity, and oil consumption). This implies that decreasing the energy consumption from (coal, gas, electricity, and oil) appears to be associated with an effective way to control CO_2 emissions, but will also simultaneously reduce economic growth and development (Saboori, Sulaiman, & Mohd, 2012). The authors conclude that suitable policies are required when it comes to ensuring an effective and efficient path to (non)-renewable energy resources, and the use of renewable sources is necessary for a sustainable economic growth and development path. The EKC hypothesis was tested using the Ordinary Least Square (OLS) time-series methodology for studying individual countries. Other studies that estimated this method for different nations include:

Table 2. Related Literature

Authors	Area of Study
(Dijkgraaf & Vollebergh, 1998)	Individual OECD countries
(Bruyn, Bergh, & Opschoor, 1998)	Netherlands, UK, USA, and West Germany
(Dijkgraaf & Vollebergh, 2001)	OECD countries
(Stern & Common, 2001)	Ranging from some developed and developing countries
(Roca, Padilla, Farre, & Galletto, 2001)	Spain
(Day & Grafton, 2003)	Canada
(Friedl & Getzner, 2003)	Austria
(Perman & Stern, 2003)	74 countries
(Fredriksson, Vollebergh, & Dijkgraaf, 2004)	OECD countries
(Zarzoso & Morancho, 2004)	OECD countries
(Dijkgraaf & Vollebergh, 2005)	OECD countries
(Vollebergh, Dijkgraaf, & Melenberg, 2005)	OECD countries
(Galeotti & Lanza, 2005)	OECD countries (except the Czech Republic, Hungary, Poland, the Republic of Korea)
(Galeotti, Lanza, & Pauli, 2006)	OECD countries
(Vollebergh, Melenberg, & Dijkgraaf, 2009)	OECD countries
(AkbostancI, Turut-Aslk, & Tunc, 2009)	Turkey
(Fodha & Zaghdoud, 2010)	Greece, Malta, Oman, Portugal, and the UK
(Nasir & Rehman, 2011)	Pakistan
(Fosten, Morley, & Talylor, 2012)	United Kingdom
(Saboori & Sulaiman, 2013)	Malaysia
(Hervieux & Darne, 2013)	Argentina, Brazil, Canada, Chile, China, Colombia, France, India, Norway, Paraguay, Peru, Portugal, Spain, Sweden, and Uruguay
(Onafowora & Owoye, 2014)	Brazil, China, Egypt, Japan, Mexico, Nigeria, South Korea, and South Africa
(Cole & Lucchesi, 2014)	Holistic study
(Zhang & Zhao, 2014)	China
(Bento & Paulo, 2014)	Italy
(Liddle & Messinis, 2015)	OECD countries
(Shahbaz, Solarin, Sbia, & Bibi, 2015)	African countries
(Al-Mulali, Saboori, & Ozturk, 2015)	Vietnam
(Sinha & Bhattacharya, 2016)	Case of Indian cities
(Jebli, Youssef, & Ozturk, 2016)	OECD countries
(Mulali, Ozturk, & Solarin, 2016)	Central, Western, and Eastern Europe, East Asia, the Pacific, South Asia, and America
(Ab-Rahim & Xin-Di, 2016)	ASEAN+3 countries
(Liddle & Messinis, 2018)	OECD countries
(El-Aasar & Hanafy, 2018)	Egypt

Table 2 shows previous authors' works that have tested the EKC using the OLS model and more recent studies using alternative methodology.

There isn't implicit evidence in support of the declining CO_2 emissions and economic growth compared to air and water pollutants. Saboori, Sulaiman, and Mohd (2012) found a linear relationship between CO_2 emissions and per capita income which was supported by Shafik and Bandyopadhyay (1992), Shafik (1994), Azomahou et al. (2006), and Van and Azomahou (2007). Others' findings showed the inverted U-shaped or the N-shaped relationship (Roberts & Grimes, 1997; Cole et al., 1997; Schmalensee et al., 1998; Galeotti & Lanza, 1999; Apergis & Payne, 2009; Lean & Smyth, 2010; Shafik, 1994;Grossman & Krueger, 1995).

Fodha and Zaghdoud (2010) work on economic growth and pollutant emissions in Tunisia, investigated the Granger Causal relationship between the CO_2, SO_2, and GDP growth from 1961 – 2004. The EKC hypothesis and the cointegration analysis were tested. Their results show that there is a long-run cointegrating relationship between the per capita emissions of CO_2 & SO_2 and per capita GDP. An inverted U-shaped curve between SO_2 emissions and GDP were found, with the income turning point at approximately equal to (($1200 (constant 2000 USD pricing)) or ($3700 (in PPP, constant 2000 USD pricing)) (Fodha & Zaghdoud, 2010). The results exhibited a relationship between income and pollution in Tunisia is a uni-directional causality with income and environmental changes and not vice-versa, both in the short and long-run. The findings imply that emission reduction policies and more investment in pollution abatement expenses will not hurt economic growth in Tunisia (Fodha & Zaghdoud, 2010).

The purpose of Arouri et al. (2012) was to expand on the works of Liu and Muse (2005), Ang (2007), and Apergis and Payne (2009, 2010) by implementing recent bootstrap panel unit-root tests and cointegration techniques to investigate the relationship between CO_2 emissions, energy consumption, and $real\, GDP$ for 12 Middle Eastern and North African Countries (MENA) over the period 1981 – 2005. The authors' findings suggest that in the long-run, energy consumption has a significant positive impact on CO_2 emissions. Although the estimated long-run coefficients of income (Y_t) and it's square (Y_t^2) satisfy the EKC hypothesis in most studied countries, the turning points are meager in some cases and very high in a case by case situation, hence providing poor evidence in support of the EKC hypothesis. Today, CO_2 emission per capita has decreased in the MENA region, while the region exhibited economic growth over the period 1981 – 2005 (Arouri et al.; 2012).

Razzaq et al. (2013) examines the relationship between economic growth, energy consumption, financial development, trade openness, and CO_2 emissions over the period of 1975(Q1) – 2011(Q4) in Indonesia. The authors' used the Zivot-Andrews structural break unit-root test to test the stasis of the dataset; the $ARDL$ bounds test was used to test the long-run relationship between their variables; the $VECM$ was used to test the Granger causality between the explained and explanatory variable; and the robustness of causal analysis was tested using the Innovative Accounting Approach (IAA). The study found both the defined and the defining variables are cointegrated, which implies that there is a long-run relationship in the presence of a structural break. The findings suggest that economic growth and energy consumption increases CO_2 emissions, while financial development and trade openness decreases CO_2 emissions. Other studies on the EKC use panel or cross-sectional data. For groups such as developed or emerging market countries, these methods are appropriate in establishing a link between economic growth and environmental degradation (Saboori, Sulaiman, & Mohd, 2012). Some studies (Ang, 2008; Stern, Common, & Barbier, 1996; Carson, Jeon, & McCubbin, 1997; Lindmark, 2002; Friedl & Getzner, 2003) provide a general understanding of various variables and how they relate with CO_2 and SO_2

emissions in the environment.

These studies were selected because individual countries don't possess the same pollution path as assumed in the panel, cross-sectional, and multiple countries analysis. The primary advantage of a single country analysis is that it brings the report closer to home; that is, the researcher can spot the exogenous and endogenous variables and the dynamics in the area of study (Lindmark, 2002). Previous empirical literature tested the Granger causality along with testing cointegration of the explained and explanatory variables to see if the long-run relationship between environmental degradation and economic growth; and identified the direction of this relationship if it is a uni-directional (left-right movement (→)or right-left movement (←) or a bilateral movement (↔)), as the EKC model assumes, or if a reverse causal relationship exists.

Table 3. The Granger causality Results on CO_2 emissions as it relates to GDP

Authors	**Nations**	**Methodology**	**Granger causality results**
(Friedl & Getzner, 2003)	Austria	$CO_2 - EKC$	$CO_2 \leftrightarrow GDP$
(Aug, 2008)	Malaysia	$Granger\ causality\ based\ on\ VECM$	$CO_2 \rightarrow GDP$
(Halicioglu, 2009)	Turkey	$Granger\ causality\ based\ on\ VECM$	$CO_2 \leftrightarrow GDP$
(Jalil & Mahmud, 2009)	China	$Pairwise\ Granger\ causality$	$CO_2 \leftarrow GDP$
(Soytas, Sari, Hammoudeh, & Hacihasanoglu, 2009)	Turkey	(Toda & Yamamota, 1995)	$CO_2 \leftrightarrow$ GDP
(Fodha & Zaghdoud, 2010)	Tunisia	$Granger\ causality\ based\ on\ ECM$	$CO_2 \leftarrow GDP$
(Ghosh, 2010)	India	$Granger\ causality\ based\ on\ VECM$	$CO_2 \leftrightarrow GDP$
(Iwata, Okada, & Samreth, 2010)	France	$Pairwise\ Granger\ causality$	$CO_2 \leftarrow GDP$
(Lotfalipour, Falahi, & Ashena, 2010)	Iran	(Toda & Yamamota, 1995)	$CO_2 \leftarrow GDP$
(Menyah & Wolde-Rufael, 2010)	S. Africa	(Toda & Yamamota, 1995)	$CO_2 \rightarrow GDP$
(Choi, Heshmati, & Cho, 2010)	China, Korea, and Japan,	$OLS, Granger\ causality, \&\ VECM$	$CO_2 \leftrightarrow GDP$
(Nasir & Rehman, 2011)	Pakistan	$Granger\ causality\ based\ on\ VECM$	$CO_2 \leftarrow GDP$
(Pao & Tsai, 2011)	Brazil	$Granger\ causality\ based\ on\ ECM$	$CO_2 \leftarrow GDP$
(Saboori, Sulaiman, & Mohd, 2012)	Malaysia	$ARDL\ \&\ Granger\ causality\ VECM$	$CO_2 \rightarrow GDP$
(Bento & Paulo, 2014)	Italy	$Granger\ causality\ based\ on\ VECM$	$CO_2 \rightarrow GDP$
(Ab-Rahim & Xin-Di, 2016)	ASEAN+3	$Granger\ causality\ based\ on\ VECM$	$CO_2 \leftarrow GDP$
(El-Aasar & Hanafy, 2018)	Egypt	$ARDL\ \&\ EKC$	$GHG \leftarrow GDP$

Table 3 shows the summaries of previous literature on emissions and economic growth.

where $\rightarrow and \leftarrow$ is Uni-directional Granger causality relationship moving from left-right or right-left; $\leftrightarrow$ is a Bilateral Granger causality relationship; $VECM$ is the Vector Error Correction Model; ECM is the Error Correction Model. From Table 3, one can infer that eight out of the 17 studies had a uni-directional relationship where GDP Granger Caused an increase in CO_2 emissions $(CO_2 \leftarrow GDP)$, four out of the 17 studies had emissions Granger Causing an increase in GDP was the relationship showed a $(CO_2 \rightarrow GDP)$, and five out of the 17 studies had a bilateral causal relationship $(CO_2 \leftrightarrow GDP)$.

3. Data

This study uses annual data from 1970 – 2014. The per capita carbon dioxide (CO_2) emissions was our dependent variable (E_t), measured in metric tons. Our independent variables are: real per capita $real\ GDP_{per\ capita}$, measured in constant 2010 USD $(Y_t\ \&\ Y_t^2)$; international trade, measured by the sum of imported and exported goods and services, then divided by $real\ GDP$ in constant 2010 USD (IT_t); energy consumption, measured by the quantity of fossil fuel energy consumption and alternative and nuclear energy (EC_t); and demography, measured in total population (P_{OP_t}). The time-series data were collected from (World Development Indicator, 2017) and (Energy Information Administration (EIA), 2017).

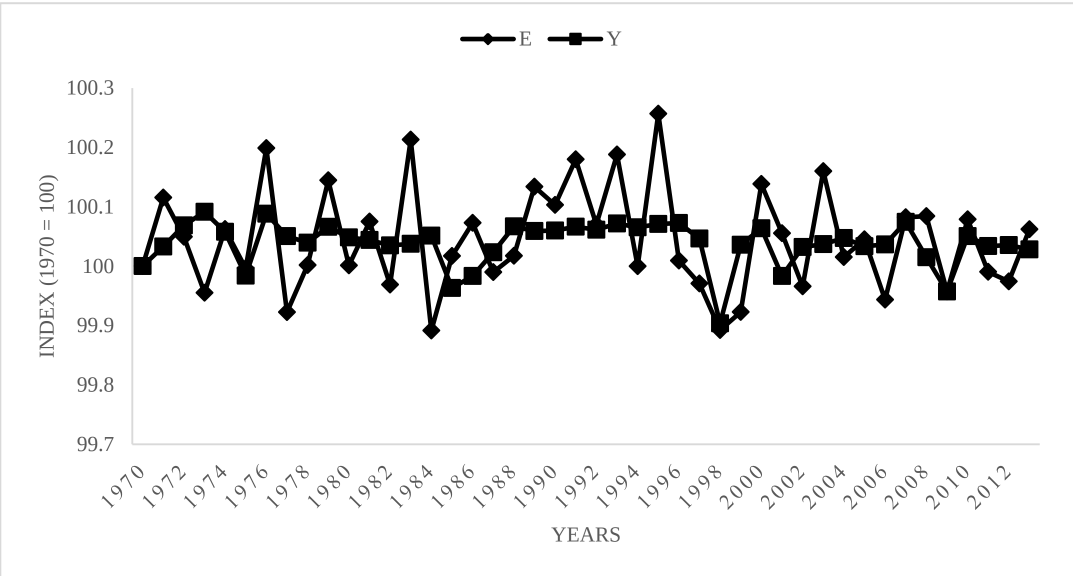

Figure 1. Shows the trend of $Real\ GDP_{per\ capita}\ (Y_t)$ and $CO_{2\ per\ capita}\ emissions\ (E_t)$ (1970 = 100) (World Development Indicator, 2017)

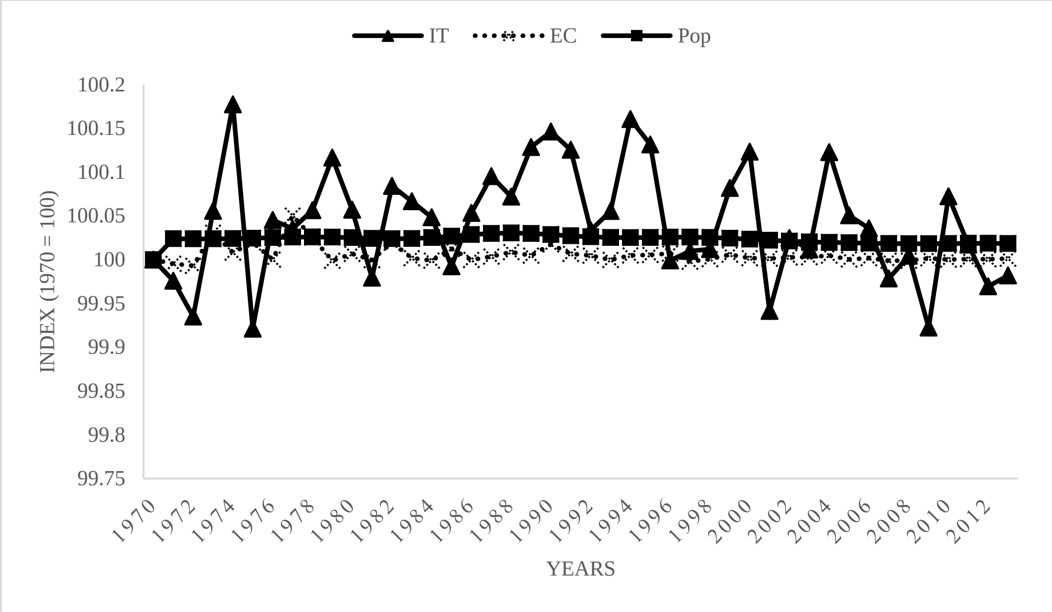

Figure 2. Shows the trend of international trade (IT_t), energy consumption (EC_t), and population (P_{OP_t}) (1970 = 100) (Energy Information Administration (EIA), 2017) and (World Development Indicator, 2017)

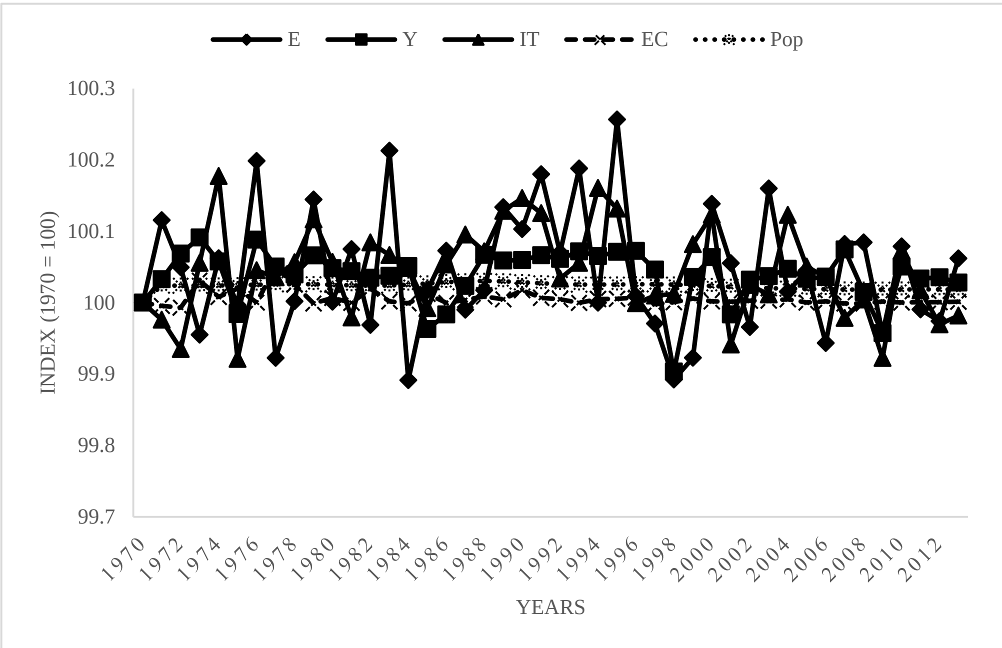

Figure 3. Shows the trends of variables $E_t, Y_t, IT_t, EC_t, and\ P_{OP_t}$ (1970 = 100). (Energy Information Administration (EIA), 2017) and (World Development Indicator, 2017)

The long-run and causal relationship between CO_2 emissions, $real\ GDP_{per\ capita}$, international trade, energy consumption, and population were calculated in two steps; first, testing the long-run relationship among the variables using the $ARDL$ bounds test of cointegration, and second testing the causal relationship between variables using the Granger causality test.

4. Methodology

4.1 Model Specification

Building on the work of Saboori et al. (2012), the economic model for the EKC hypothesis and the $ARDL$ is specified as

$$E_t = f\ (Y_t, Y_t^2, Z_t) \tag{1}$$

$$E_t = f\ (Y_t, Y_t^2, IT_t, EC_t, P_{OP_t}) \tag{2}$$

where E_t is an environmental indicator it is measured in CO_2 emissions in metric tons per capita. In Malaysia, the average value of CO_2 emissions between 1970 and 2014 was 4.173 metric tons per capita, with a minimum of 1.351 metric tons per capita and a maximum of 7.961 metric tons per capita. According to the World Development Indicator (2017), CO_2 emissions are a consequence of of fossil fuels and the manufacturing of cement. Examples are CO_2 produced during the consumption of solid, liquid, and gas fuels and gas flaring (Energy Information Administration (EIA), 2017); Y_t is income the $GDP_{per\ capita}$ in Malaysia, $GDP_{per\ capita}$ is about 144% that of the world's average when adjusted to Purchasing Power Parity (PPP) (Trading economics, 2017). The $GDP_{per\ capita}$ is calculated by dividing Malaysia's gross domestic product, adjusted by PPP by the midyear population. According to the World Development Indicator (2017), GDP is the sum of gross value added of final products in the economy and Z_t; where Z_t includes the following explanatory variables that may influence environmental degradation. For this study, we used international trade (IT_t) which is the exchange of capital, goods, and services across territories or international borders. For the last three decades, Malaysia's international trade has exceeded the world's expectations. After the Malaysian government expanded on its primary industries, it created a very productive environment for businesses in the country. As a result, it fostered close relationships between the Malaysian government, private businesses, and promoted international relations with enterprises and governments worldwide (World Development Indicator, 2017). Energy consumption (EC_t) is the amount of energy or power used. Malaysia is an independent country that can produce more than enough energy to supply its citizens. EC_t is a combination of fossil fuel energy sources and alternatives. Fossil fuel comprises of but not limited to coal, oil, petroleum, and natural gas products (Energy Information Administration (EIA), 2017). Alternative Clean energy consists of non-carbon energy that does not produce carbon dioxide when generated. It includes hydropower and nuclear, geothermal, and solar power, among others (World Development Indicator, 2017).

Our last explanatory variable under Z_t is total population (P_{OP_t}) it is the total population of a country consisting of all persons falling within the scope of the nation's census count. The entire population is all the inhabitants of a town, area, or country. For this study, it is based on all residents regardless of legal status or citizenship working in Malaysia within the working-age bracket (15 to 64), that is, the proportion of the working-age population who are employed (World Development Indicator, 2017). The main objective of this study is to test the cointegration and Granger causal relationship between income $(Y_t \,\&\, Y_t^2)$, international trade (IT_t), energy consumption (EC_t), total population (P_{OP_t}), and CO_2 emissions. The estimation model in logarithm form is as follows:

$$lnE_t = a_0 + a_1 lnY_t + a_2 lnY_t^2 + a_3 lnZ_t + \varepsilon_t \tag{3}$$

$$lnE_t = a_0 + a_1 lnY_t + a_2 lnY_t^2 + a_3 lnIT_t + a_4 lnEC_t + a_5 lnP_{OP_t} + \varepsilon_t \tag{4}$$

where the coefficients $\alpha_1, a_2, a_3, a_4, and\ a_5$, are the coefficients of our variables, α_0 is the constant term (drift), t denotes time, and ε_t is the error term. The following will be expected: α_1>0, α_2 < 0, α_3 > 0, α_4 >0, α_5 > 0.

Table 4. Descriptive Statistic Table: (1970 – 2014)

Variable	**Observation**	**Mean**	**Std. Dev**	**Median**	**Min (Max)**	**Total**
E_t	44	4.173	2.236	3.831	1.351 (7.961)	183.64
Y_t	44	5429.15	2441.81	4983.91	1993.45 (9981.15)	238882.6
Y_t^2	44	35302602	28640259	24861255	3973841 (99623447)	1.55E+09
IT_t	44	24145389	14503478	21922091	6578800 (45679054)	1.06E+09
EC_t	44	91.114	6.891	93.92531	75.841 (97.933)	40009.04
P_{OP_t}	44	19282669	5872532	18771089	10803978 (29706724)	8.48E+08

Table 4 shows the descriptive statistic of our explained and explanatory variables (Energy Information Administration (EIA), 2017) and (World Development Indicator, 2017).

The study employs the $ARDL$ bounds testing approach as an estimation technique. The reason for selecting this methodology is it has many attractive features over alternatives. The primary advantage of the $ARDL$ approach is that it doesn't require establishing the order of integration of the unit-root test. The method is applicable regardless of whether the underlying regressor is $I(0) or\ I(1)$.

Table 5. The critical values

	$l(0)$ Lower bounds (LCB)	**$l(1)$ Upper bounds (UCB)**	**Cointegration**	**Inconclusive**
10%	2.08	3	”	’
5%	2.39	3.38	‘‘	‘
2.5%	2.7	3.73	ª ª	ª
1%	3.06	4.15	**	*

Table 5 shows the critical values of our variables

A fractional integration can also be applied, while the other standard cointegration approaches, such as those taken by Engle and Granger (1987) and Johansen and Juselius (1990), can also be used. The $ARDL$ approach is free of pretesting problems associated with the order of integration of variables. The short-run and the long-run effects of the independent variables on the dependent variable are assessed at the same time, so it allows the researcher to distinguish between the variables which are essential in economic analysis. Finally, the $ARDL$ approach has better properties for small samples as well as large. Pesaran, Shin, and Smith (1999) showed that with the $ARDL$ framework, the estimators of the short-run parameters are consistent and the $ARDL$ based estimators of the long-run coefficients are consistent in small and large sample sizes.

4.2 Estimation Procedure

4.2.1 Cointegration Test

For this study, the $ARDL$ approach to the cointegration relationship between CO_2 emissions and economic growth are estimated using the following unrestricted error-correction regression. For the bounds test to be implemented in the cointegration model, the following restricted conditional version of the $ARDL$ model is estimated to test the long-run relationship between CO_2 emissions and its explanatory variables. The conditional $ARDL$ model is

$$\begin{aligned} lnE_t = a_0 &+ \sum_{k=1}^{n} a_1 k\Delta lnE_{t-k} + \sum_{k=0}^{n} a_2 k\Delta lnY_{t-k} + \sum_{k=0}^{n} a_3 k\Delta lnY_{t-k}^2 + \sum_{k=0}^{n} a_4 k\Delta lnIT_t \\ &+ \sum_{k=0}^{n} a_5 k\Delta lnEC_t + \sum_{k=0}^{n} a_6 k\Delta lnP_{OP_t} + \Delta_{1E} lnE_{t-1} + \Delta_{2E} lnY_{t-1} \\ &+ \Delta_{3E} lnY_{t-1}^2 + \Delta_{4E} lnIT_{t-1} + \Delta_{5E} lnEC_{t-1} + \Delta_{6E} lnP_{OP_{t-1}} \\ &+ \varepsilon_{1t} \end{aligned} \quad (5)$$

$$\begin{aligned} \Delta lnY_t = \beta_0 &+ \sum_{k=1}^{n} \beta_1 k\Delta lnY_{t-k} + \sum_{k=0}^{n} \beta_2 k\Delta lnE_{t-k} + \sum_{k=0}^{n} \beta_3 k\Delta lnY_{t-k}^2 + \sum_{k=0}^{n} \beta_4 k\Delta lnIT_t \\ &+ \sum_{k=0}^{n} \beta_5 k\Delta lnEC_t + \sum_{k=0}^{n} \beta_6 k\Delta lnP_{OP_t} + \Delta_{1E} lnE_{t-1} + \Delta_{2E} lnY_{t-1} \\ &+ \Delta_{3E} lnY_{t-1}^2 + \Delta_{4E} lnIT_{t-1} + \Delta_{5E} lnEC_{t-1} + \Delta_{6E} lnP_{OPP_{t-1}} \\ &+ \varepsilon_{2t} \end{aligned} \quad (6)$$

$$\Delta lnY_t^2 = \delta_0 + \sum_{k=1}^{n} \delta_1 k \Delta lnY_{t-k}^2 + \sum_{k=0}^{n} \delta_2 k \Delta lnY_{t-k} + \sum_{k=0}^{n} \delta_3 k \Delta lnE_{t-k} + \sum_{k=0}^{n} \delta_4 k \Delta lnIT_t + \sum_{k=0}^{n} \delta_5 \Delta lnEC_t + \sum_{k=0}^{n} \delta_6 \Delta lnP_{OP_t} + \Delta_{1E} lnE_{t-1} + \Delta_{2E} lnY_{t-1} + \Delta_{3E} lnY_{t-1}^2 + \Delta_{4E} lnIT_{t-1} + \Delta_{5E} lnEC_{t-1} + \Delta_{6E} lnP_{OP_{t-1}} + \varepsilon_{3t} \quad (7)$$

$$\Delta lnIT_t = \phi_0 + \sum_{k=1}^{n} \phi_1 k \Delta lnIT_{t-k} + \sum_{k=0}^{n} \phi_2 k \Delta lnY_{t-k} + \sum_{k=0}^{n} \phi_3 k \Delta lnY_{t-k}^2 + \sum_{k=0}^{n} \phi_4 k \Delta lnE_t + \sum_{k=0}^{n} \phi_5 k \Delta lnEC_t + \sum_{k=0}^{n} \phi_6 k \Delta lnP_{OP_t} + \Delta_{1E} lnE_{t-1} + \Delta_{2E} lnY_{t-1} + \Delta_{3E} lnY_{t-1}^2 + \Delta_{4E} lnIT_{t-1} + \Delta_{5E} lnEC_{t-1} + \Delta_{6E} lnP_{OP_{t-1}} + \varepsilon_{4t} \quad (8)$$

$$\Delta lnEC_t = \gamma_0 + \sum_{k=1}^{n} \gamma_1 k \Delta lnEC_{t-k} + \sum_{k=0}^{n} \gamma_2 k \Delta lnY_{t-k} + \sum_{k=0}^{n} \gamma_3 k \Delta lnY_{t-k}^2 + \sum_{k=0}^{n} \gamma_4 k \Delta lnIT_t + \sum_{k=0}^{n} \gamma_5 k \Delta lnE_t + \sum_{k=0}^{n} \gamma_6 k \Delta lnP_{OP_t} + \Delta_{1E} lnE_{t-1} + \Delta_{2E} lnY_{t-1} + \Delta_{3E} lnY_{t-1}^2 + \Delta_{4E} lnIT_{t-1} + \Delta_{5E} lnEC_{t-1} + \Delta_{6E} lnP_{OP_{t-1}} + \varepsilon_{5t} \quad (9)$$

$$\Delta lnP_{OP_t} = \theta_0 + \sum_{k=1}^{n} \theta_1 k \Delta lnP_{OP_{t-k}} + \sum_{k=0}^{n} \theta_2 k \Delta lnY_{t-k} + \sum_{k=0}^{n} \theta_3 k \Delta lnY_{t-k}^2 + \sum_{k=0}^{n} \theta_4 k \Delta lnIT_t + \sum_{k=0}^{n} \theta_5 k \Delta lnEC_t + \sum_{k=0}^{n} \theta_6 k \Delta lnE_t + \Delta_{1E} lnE_{t-1} + \Delta_{2E} lnY_{t-1} + \Delta_{3E} lnY_{t-1}^2 + \Delta_{4E} lnIT_{t-1} + \Delta_{5E} lnEC_{t-1} + \Delta_{6E} lnP_{OP_{t-1}} + \varepsilon_t \quad (10)$$

The null hypothesis, testing no long-run relationship among the variables in $equation\ 4$ is tested against the alternative hypothesis of the presence of long-run relationships among the variables denoted by $CO_2\ (E_t, Y_t, Y_t^2, EC_t, P_{OP_t})$. This is specified as:

$H_o: a_1 = a_2 = a_3 = a_4 = a_5 = 0$

$H_1: a_1 \neq a_2 \neq a_3 \neq a_4 \neq a_5 \neq 0$

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4.2.2 Long-run and Short-run Dynamics

Once the cointegration is established, the next step is to estimate the extended *ARDL* model of Saboori, Sulaiman, and Mohd (2012) $(equation\ 5, 6, 7, 8, 9,\ \&\ 10)$ to obtain the long-run coefficients. Next, the estimation of the short-run parameters of the variables with the error-correction representation of the $ARDL$ model is analyzed. Two different set(s) of critical values are given, with or without a time trend, for $I(0)$ lower bounders (LCB) and $I(1)$ upper bounders (UCB) critical values, respectively. If the computed F-stat is higher than the UCB, the null hypothesis of no cointegration is rejected, and if it is below the LCB we fail to reject the null hypothesis of no cointegration, and if it lies between the LCB and the UCB, the result will be inconclusive.

At this stage, the long-run relationship among our variables is estimated after the selection of the $ARDL$ model by using the $AIC\ \&\ SBC$ criterion. The next step is to apply the error-correction version of $ARDL$. The velocity of the equilibrium is determined if there is a long-run relationship between the variables. Once a long-run relationship has been established, the ECM is estimated; that is, a general ECM model of $(equation\ 5-10)$ is operationalized to $(equation\ 11-16)$, which is the unrestricted $ARDL$ error-correction model.

$$\Delta lnE_t = a_0 + \sum_{k=1}^{n} a_1 k\Delta lnE_{t-k} + \sum_{k=0}^{n} a_2 k\Delta lnY_{t-k} + \sum_{k=0}^{n} a_3 k\Delta lnY_{t-k}^2 + \sum_{k=0}^{n} a_4 k\Delta lnIT_t + \sum_{k=0}^{n} a_5 k\Delta lnEC_t + \sum_{k=0}^{n} a_6 k\Delta lnP_{OP_t} + \theta ECT_{t-1} + \varepsilon_{1t} \tag{11}$$

$$\Delta lnY_t = \beta_0 + \sum_{k=1}^{n} \beta_1 k\Delta lnY_{t-k} + \sum_{k=0}^{n} \beta_2 k\Delta lnE_{t-k} + \sum_{k=0}^{n} \beta_3 k\Delta lnY_{t-k}^2 + \sum_{k=0}^{n} \beta_4 k\Delta lnIT_t + \sum_{k=0}^{n} \beta_5 k\Delta lnEC_t + \sum_{k=0}^{n} \beta_6 k\Delta lnP_{OP_t} + \theta ECT_{t-1} + \varepsilon_{2t} \tag{12}$$

$$\Delta lnY_t^2 = \delta_0 + \sum_{k=1}^{n} \delta_1 k\Delta lnY_{t-k}^2 + \sum_{k=0}^{n} \delta_2 k\Delta lnY_{t-k} + \sum_{k=0}^{n} \delta_3 k\Delta lnE_{t-k} + \sum_{k=0}^{n} \delta_4 k\Delta lnIT_t + \sum_{k=0}^{n} \delta_5 k\Delta lnEC_t + \sum_{k=0}^{n} \delta_6 k\Delta lnP_{OP_t} + \theta ECT_{t-1} + \varepsilon_{3t} \tag{13}$$

$$\Delta lnIT_t = \phi_0 + \sum_{k=1}^{n} \phi_1 k\Delta lnIT_{t-k} + \sum_{k=0}^{n} \phi_2 k\Delta lnY_{t-k} + \sum_{k=0}^{n} \phi_3 k\Delta lnY_{t-k}^2 + \sum_{k=0}^{n} \phi_4 k\Delta lnE_t + \sum_{k=0}^{n} \phi_5 k\Delta lnEC_t + \sum_{k=0}^{n} \phi_6 k\Delta lnP_{OP_t} + \theta ECT_{t-1} + \varepsilon_{4t} \quad (14)$$

$$\Delta lnEC_t = \gamma_0 + \sum_{k=1}^{n} \gamma_1 k\Delta lnEC_{t-k} + \sum_{k=0}^{n} \gamma_2 k\Delta lnY_{t-k} + \sum_{k=0}^{n} \gamma_3 k\Delta lnY_{t-k}^2 + \sum_{k=0}^{n} \gamma_4 k\Delta lnIT_t + \sum_{k=0}^{n} \gamma_5 k\Delta lnE_t + \sum_{k=0}^{n} \gamma_6 k\Delta lnP_{OPt} + \theta ECT_{t-1} + \varepsilon_{5t} \quad (15)$$

$$\Delta lnP_{OP_t} = \theta_0 + \sum_{k=1}^{n} \theta_1 k\Delta lnP_{OP_{t-k}} + \sum_{k=0}^{n} \theta_2 k\Delta lnY_{t-k} + \sum_{k=0}^{n} \theta_3 k\Delta lnY_{t-k}^2 + \sum_{k=0}^{n} \theta_4 k\Delta lnIT_t + \sum_{k=0}^{n} \theta_5 k\Delta lnEC_t + \sum_{k=0}^{n} \theta_6 k\Delta lnE_t + \theta ECT_{t-1} + \varepsilon_{6t} \quad (16)$$

The $ARDL$ method tests the existence or absence of cointegration relationships between our variables, but not the direction of causality. If there is no cointegration between the variable in the model, the Vector Auto-Regressive (VAR) model will be employed to examine the causality between the variables. Thus, in the presence of cointegration between our variables, we obtain the lagged error-correction term (ECT_{t-1}) from the long-run cointegration relationship and include it in the equation as an additional independent variable. The enhanced form of the Granger causality test with ECM is formulated in a multivariate pth order of $VECM$ model as follows:

$$(1-B)\begin{bmatrix} lnE_t \\ lnY_t \\ lnY_t^2 \\ lnIT_t \\ lnEC_t \\ lnP_{OP_t} \end{bmatrix} = \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \end{bmatrix} + \sum_{i=1}^{p}(1-B)\begin{bmatrix} d_{11,i}d_{12,i}d_{13,i}d_{14,i}d_{15,i}d_{16,i} \\ d_{21,i}d_{22,i}d_{23,i}d_{24,i}d_{25,i}d_{26,i} \\ d_{31,i}d_{32,i}d_{33,i}d_{34,i}d_{35,i}d_{36,i} \\ d_{41,i}d_{42,i}d_{43,i}d_{44,i}d_{45,i}d_{46,i} \\ d_{51,i}d_{52,i}d_{53,i}d_{54,i}d_{55,i}d_{56,i} \\ d_{61,i}d_{62,i}d_{63,i}d_{64,i}d_{65,i}d_{66,i} \end{bmatrix}\begin{bmatrix} lnE_{t-i} \\ lnY_{t-i} \\ lnY_{t-i}^2 \\ lnIT_{t-i} \\ lnEC_{t-i} \\ lnP_{OP_{t-i}} \end{bmatrix} + \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \\ \lambda_5 \\ \lambda_6 \end{bmatrix}\{ECT_t - 1\} + \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \\ \gamma_4 \\ \gamma_5 \\ \gamma_6 \end{bmatrix} \quad (17)$$

where $(1-B)$ is the lag operator, and ECT_{t-1} is the lagged error-correction term. The residual terms $\gamma_t's$ are uncorrected random disturbance terms with zero mean, and the $d's$ are parameters to be estimated. The direction of causality can be detected through the $VECM$

of long-run cointegration. The $VECM$ allows us to capture both the short-run and long-run relationships. The long-run causal correlation can be established through the significance of the lagged ECT_s in the $VECM$, based on the t-test. The short-run Granger causality is detected using the significance of F-stat of the Wald test for the lagged independent variables. The model employs criteria such as AIC & SBC to choose the appropriate lag length.

5. Empirical Results

5.1.1 Unit-Root Test

The unit-root test, including the trend and intercept, was done to check the stasis of our variables, though it's not needed when using the $ARDL$ approach. The $ARDL$ approach is free of pretesting problems associated with the order integration of variables. The short-run and long-run effects of the independent variables on the explanatory variables are assessed at the same time, so it allows for distinguishing between the two, which are essential in economic analysis.

Table 6. Unit-Root test results

Variable	Level (P-Val)	1st Diff. (P-Val)
E_t	0.2983	0.00*
Y_t	0.600	0.00*
Y_t^2	0.9603	0.00*
IT_t	0.6180	0.0002*
EC_t	0.9439	0.0019*
P_{OP_t}	0.0019*	N/A

Table 6 shows the unit-root results of our variables.

where * means we reject the null hypothesis

To determine the integration order of the variables, the F-test was carried out to identify any long-run or cointegration relationships between the variables. If the F-test is sensitive to the lag imposed on each of the first-differenced variables, it is, therefore, vital to set a different order of lags for the variables of ($equation\ 5-10$). Lag 1 was first set for all first-differenced variables before the order of the lags was changed to 2, 3, 4, and 5.

Bahmani-Oskooee & Kantipong (2001) argued that there might be evidence of cointegration when variables in the model are replaced by the other independent variables in the model, so the F-statistics for the joint significance of lagged levels of variables were calculated when the dependent variables are $lnE_t, lnY_t, lnY_t^2, lnIT_t, lnEC_t, and\ lnP_{OP_t}$. The results are reported in Table 7. The results confirmed that the F-test is indeed sensitive to the Lag lengths. The bounds test indicates that in all chosen lag lengths, the calculated F-statistic is less than the upper bound critical value, supporting the null hypothesis of no cointegration or, in some cases, were inconclusive; see Table 5 for the key(s). The evidence of no cointegration in this stage was attributed to the fact that the same number of lags was imposed on each of the first-differenced variables.

At this stage, the optimum number of lags on the first-differenced variables is usually obtained from the unrestricted VAR using AIC & SBC. Given the number of variables and sample size in our study, we conducted optimal lag selection by setting the maximum lag lengths up to 5. SBC is preferred to other criteria because it tends to define more parsimonious specifications as it selects the smallest possible lag length and minimizes the loss of the degree(s) of freedom as well (Pesaran, Shin, & Smith, 1999). SBC criteria implied that the order is 2 for all models; given this, $SBC-based$ $ARDL$ suggest $ARDL$ (1,0,0,0,0,0) model, in which lnE_t is the dependent variable, and $ARDL$ (1,0,0,0,0,0) model, in which $lnY_t, lnY_t^2, lnIT_t, lnEC_t, lnP_{OP_t}$ are the dependent variables.

Table 7. F-test for cointegration

Equation	**Lag 1**	**Lag 2**	**Lag 3**	**Lag 4**	**Lag 5**
$Fln_E[lnE\|lnY, lnY^2, lnIT, lnEC, lnP_{OP}]$	8.557**	7.808**	4.083**	5.235**	2.998”
$Fln_Y[lnY\|lnE, lnY^2, ln\ IT, lnEC, lnP_{OP}]$	10.509**	11.080**	13.592**	8.418**	6.385**
$Fln_{Y^2}[lnY^2\|lnE, lnY, lnIT, lnEC, lnP_{OP}]$	6.845**	9.184**	9.915**	6.732**	11.749**
$Fln_{IT}[lnIT\|lnE, lnY, lnY^2, lnEC, lnP_{OP}]$	4.150**	6.849**	6.698**	8.064**	9.142**
$Fln_{EC}[lnEC\|lnE, lnY, lnY^2, lnIT, lnP_{OP}]$	8.482**	7.690**	4.285**	3.533‘‘	8.011**
$FlnP_{OP}[lnP_{OP}\|lnE, lnY, lnY^2, lnIT, lnEC]$	1182.1**	6.712**	12.466**	5.305**	11.805**

Table 7 shows the F-test cointegration result of our variables

After finding the integrating order of our variables and determining the optimal order of lag, the next stage is to carry out the bound test by imposing the optimum Lags on each of the first-differenced variables.

Table 8. Long-run estimation result; $ARDL$ (1,0,0,0,0,0) selected based on Schwarz Bayesian Criterion

Regressors	**Coefficient**	**T- values/Ratio [P-Value]**	**Standard Error**
lnY_t	0.001146	2.9483 [0.006] **	0.3889E-3
lnY_t^2	-0.1046E-7	-0.51749 [0.608]	0.2021E-7
$lnIT_t$	0.4991E-7	1.6670 [0.104]	0.2994E-7
$lnEC_t$	0.0054286	0.35152 [0.727]	0.015443
lnP_{OP_t}	-0.1725E-6	-1.4851 [0.146]	0.1162E-6
C	0.0809	2.7084 [0.144]	0.679E-8
Diagnostic test statistic			
Serial correlation	1.0925 [0.296]		
Functional Form	1.7014 [0.192]		
Normality	2.3193 [0.314]		
Heteroskedasticity	1.3090 [0.253]		
F(1,41)	1.2873 [0.263]		
F(1,36)	0.93850 [0.339]		

where ** is significant at the 1% level. Only lnY_t was significant at the 1% level. So, if GDP increases by 1% CO_2 also, increase by 2.9%-point

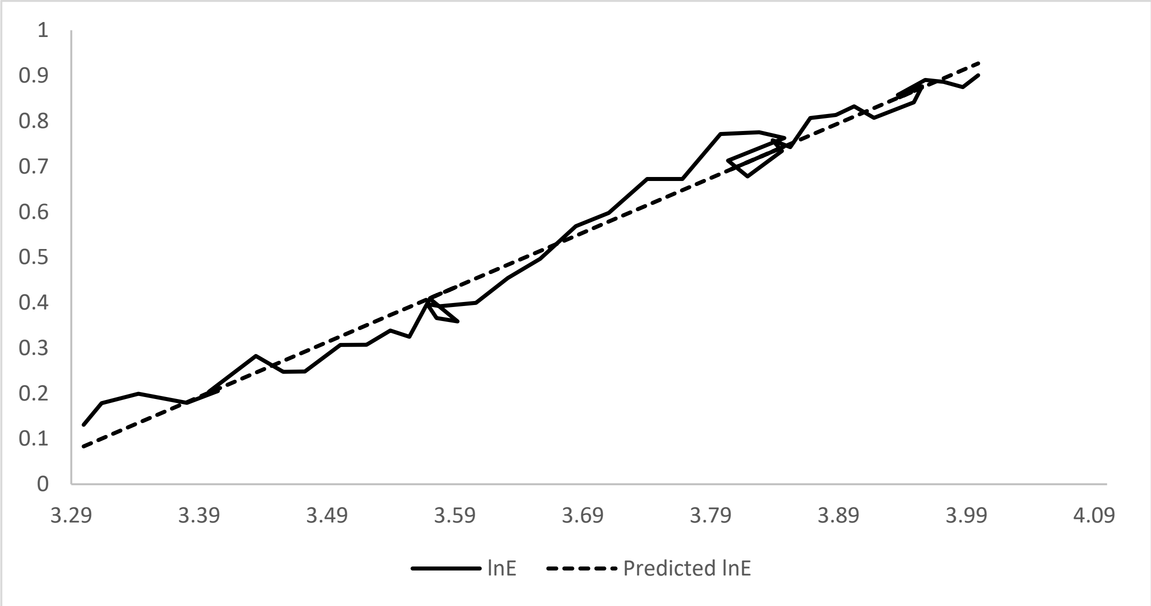

Figure 4. Long-run EKC relationship

According to (Saboori, Sulaiman, & Mohd, 2012), following the findings of (Kremers, Ericsson, & Dolado, 1992) that the significant lagged error-correction term (ECT_{t-1}) is a more efficient way of establishing cointegration; it can be concluded that there exists a strong cointegration relationship among variables in the model because of the coefficient of ECT_{t-1} is statistically significant at 1% significance level and has the correct sign. The ECT_{t-1} indicates any deviation from the long-run equilibrium between variables is corrected about 70% for each period and that it takes about 2.7 periods to return to the long-run equilibrium level.

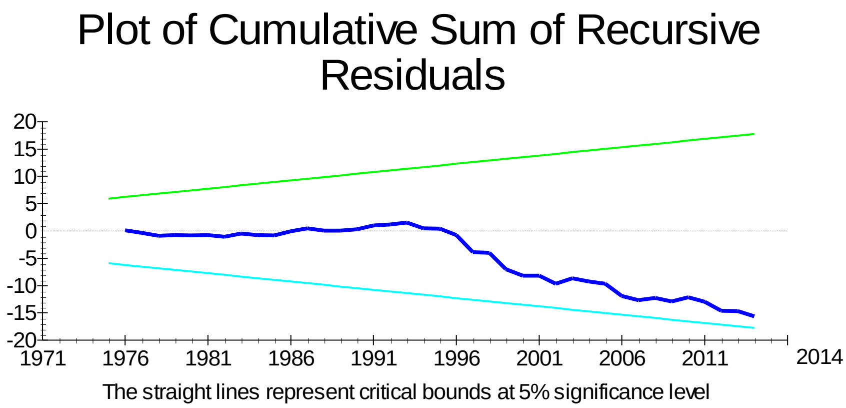

Figure 5. To check the stability of the coefficients, $CUSUM$ & $CUSUMSQ$ were employed

The statistics are plotted within two straight lines bounded by the 5% significance level. If any point lies beyond the 5% level, the null hypothesis of stable parameters is rejected. The plots of both statistics are well within the critical bounds, implying that our coefficients in the error-correction model are stable.

Table 9. The results of error-correction/ short-run for the selected $ARDL$ model is $ARDL$ (1,0,0,0,0,0) selected based on SBC

Regressors	**Coefficient**	**T- Ratio [p-value]**	**Standard Error**
ΔlnY_t	0.8091E-3	2.7199 [0.010] **	0.2975E-3
ΔlnY_t^2	-0.7380E-8	-0.51754 [0.608]	0.1426E-7
$\Delta lnIT_t$	0.3522E-7	1.6351 [0.111]	0.2154E-7
$\Delta lnEC_t$	0.0038305	0.35352 [0.726]	0.010835
ΔlnP_{OP_t}	-0.1217E-6	-1.5026 [0.141]	0.8101E-7
C	0.26288	2.9457 [0.005]	0.12492
ECT_{t-1}	-0.70562	-5.3543 [0.000] **	0.13179
Diagnostic test statistic			
R-squared	.4561		
F (5,37)	6.2060 [0.000]		
DW- statistic	1.7467		

$\mathrm{ECT}_{t-1} = 2.6288lnE_t - 0.8091E - 3 * lnY_t - 0.7380E - 8lnY_t^2 + 0.3522E - 7 * lnIT_t + 0.0038305 * lnEC_t - 0.1217E - 6 * lnP_{OP_t}$ where ** is significant at the 1% level

A 1% increase in Y_t will lead to a 2.7%-point increase in CO_2 emissions.

Table 10. Granger causality Result

Short-run Granger causality F-statistics [Prob]							Long-run Granger causality
	ΔlnE_t	ΔlnY_t	ΔlnY_t^2	$\Delta lnIT_t$	$\Delta lnEC_t$	ΔlnP_{OP_t}	ECT_{t-1} (t-stats)
ΔlnE_t	-	2.71481 [0.1073]	1.05322 [0.3109]	0.00738 [0.9320]	0.03586 [0.8508]	0.50186 [0.4828]	-0.00345 [-0.03293]
ΔlnY_t	3.77214 [0.0592]	-	0.57055 [0.4545]	0.32209 [0.5735]	0.06708 [0.7970]	0.11481 [0.7365]	-0.0971 [-2.4485]
ΔlnY_t^2	0.00253 [0.9602]	0.14075 [0.7095]	-	8.00532 [0.0073]	0.22240 [0.6398]	57.9871 [3.E-09]	-1111443. [-0.11770]
$\Delta lnIT_t$	16.3899 [0.0002]	2.69432 [0.1085]	1.50612 [0.2269]	-	0.18368 [0.6705]	0.01069 [0.9182]	-0.0517 [-0.75081]
$\Delta lnEC_t$	4.42078 [0.0418]	0.48047 [0.4922]	0.76822 [0.3860]	9.96240 [0.0030]	-	38.5969 [2.E-07]	-0.0064 [-0.6061]
ΔlnP_{OP_t}	6.68091 [0.0135]	6.07860 [0.0181]	2.04379 [0.1606]	1.46590 [0.2331]	0.00036 [0.9850]	-	-0.00078 [-1.9199]

The table shows the Granger causality relationship from $equation$ 4

The long-run cointegrating relationship between CO_2 emissions per capita and real $GDP_{per\ capita}$ implies the existence of a causal relationship between the variables. To identify whether the relationship appears to be either uni, bi, or no-directional. More testing was carried out, using the $VECM$ Granger causality test. The t-statistics of $ECTs$ in Table 10 provide the existence of a uni-directional long-run Granger causality from economic growth to CO_2 emissions $(CO_2 \leftarrow GDP)$, but there is no short-run causal relationship between CO_2 emissions E_t & $lnY_t, lnY_t^2, lnIT_t, lnEC_t, and\ lnP_{OP_t}$.

Further Study:

More studies should be conducted on how increasing or decreasing CO_2 emissions affect the lives of people living in emerging markets, how to efficiently allocate available resource, and if reducing CO_2 emissions is a priority to people in those regions. According to MY World, who aim to capture people's voices, priorities and views on the world and their economies, so world leaders and policymakers can be better informed (United Nations; Overseas Development Institute; Ipsos Mori, 2019); these show a different perspectives based on their survey on people's priorities and needs when it comes to CO_2 emissions and other basic human needs.

Limitations on the Aggregate Literature on CO_2 Emissions:

Most research analysis on CO_2 emissions and economic growth are from OECD countries (see Table 2), with little or no highlights on the roles that renewable energy sources play in the growth, development, and sustainability of nations'. It is recommended that future researchers test this phenomenon in other countries from Asia, Africa, and Latin America.

6. Conclusion

In line with the empirical literature, our research and results have shown similar outcomes to those of Saboori et al. (2012). An inverted-U shape relationship between CO_2 emissions and income were expected based on the EKC hypothesis, although we failed to find an association between the short and long-run per our time-series analysis. Therefore, our results fail to support the EKC hypothesis for Malaysia. Regardless of our findings, it is important to note this result doesn't provide enough information about the reasons behind the observed inverted-U relationship between environmental degradation (CO_2 emissions) and income. Several factors, such as changes in energy composition, level of international trade, and population density affects the environment, output, introduction of cleaner production technology, environmental policies and environmental awareness, play a significant role in making the decoupling between economic growth and environmental degradation (Panayotou, 1997).

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Appendix

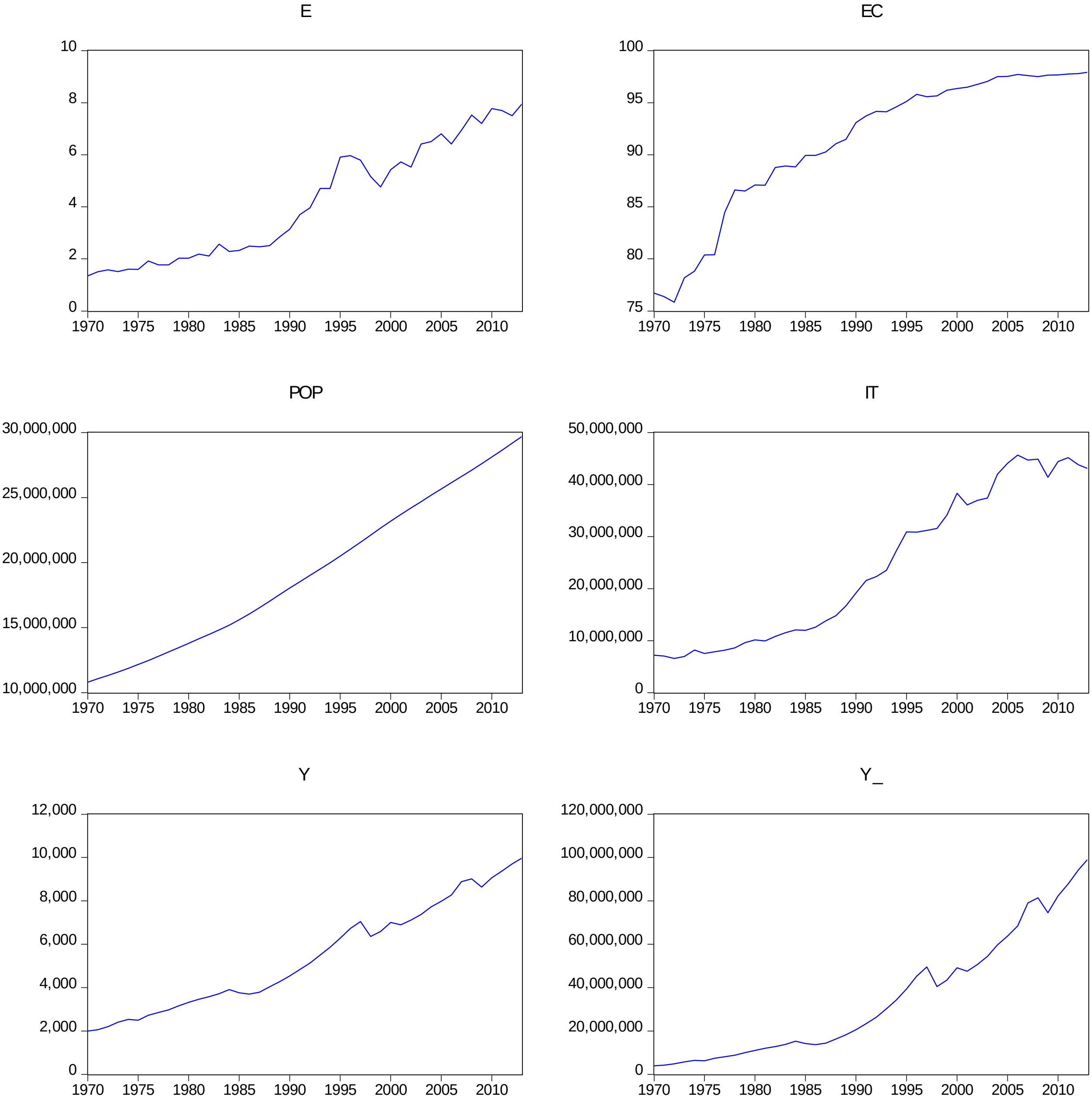

Figure 6. Shows the graphical representation of our variables; where E is E_t; EC is EC_t; POP is P_{OP_t}; IT is IT_t; Y is Y_t; and Y_ is Y_t^2 in the study