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The Dynamic Linkage between Technological Innovation and carbon dioxide emissions in Malaysia: An Autoregressive Distributed Lagged Bound Approach

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ABSTRACT

Environmental degradation and climate change are the main challenges encountered to achieve the predominant objective of sustainable development. There has been voluminous work done in this area, but the policies adopted and the empirical relationship between the determinants of carbon dioxide (CO_2) emissions are not clear to handle the problem. There exists a theoretical and empirical contradiction in the literature on the relationship between the variables under the study. Thus, the current study investigates the relationship between CO_2 emissions and its determinants namely economic growth, energy consumption, financial development, and technological innovations (TIs) for Malaysia between 1985 and 2012. To achieve the objective of long-run relationship the autoregressive distributed lagged model is used for parameter estimation. The empirical results reveal that TI is having a negative but insignificant relationship with environmental pollution in Malaysia during the period under study. The study also indicates that higher economic growth improves the environmental quality in the long-run and is in line with the environmental Kuznets curve (EKC) hypothesis. In a similar vein, the results indicate that financial sector development will lessen the CO_2 emissions, thus, improving the quality of the environment in Malaysia. The short-run results reveal no evidence of the validation EKC hypothesis. Furthermore, the study applied Granger causality approach for causal relationship and found bidirectional causality running between economic growth and CO_2 emissions and between TI and CO_2 emissions in the long-run. The study also found that the impact of energy consumption in the short-run is environmentally friendly. Moreover, the results indicate a short-run bidirectional causality running between energy consumption and economic growth and also between economic growth and TI.

Keywords: Carbon Dioxide Emissions, Environmental Kuznets Curve, Technological Innovation, Autoregressive Distributed Lagged, Malaysia
JEL Classifications: C32, O52, Q43, Q50

1. INTRODUCTION

The achievement of higher and sustainable economic growth is the foremost objective of the worldwide government strategies. However, larger material and energy inputs are required for the greater economic activities which pollute the environment and have deleterious consequences on the human health and productivity as they produce a lot of waste byproducts in the process. Accordingly, these activities add to the concentration of greenhouse gasses (GHG) and lead to global warming and climate change. The increase in the average global ocean and air temperature, rising of the sea level, melting of snow and ice sheets and exhaustion of the different species throughout the world are evidence of the global warming and climate change due to increasing concentration of GHG in the atmosphere. It is argued that there would be a rise in the sea level of about 16.5-53.8 cm and global average temperature by 1.1-6.4°C by 2100 (Bernstein et al., 2007) and it would endanger the lives half of the world's population living in the coastal areas (Lau et al., 2010).

Climate change is considered as one of the greatest threats encountered in attaining sustainable development (de Jesus, 2013). The subject of climate change and global warming took the center stage as a result of the environmental quality deterioration due to the economic and other activities, and it has become the major ongoing concern for the human beings to control this

environmental pollution and global warming, thus, climate change. There have been attempts made via intergovernmental agreements and bindings to reduce the devastating effects of global warming. One of the major agreements is the Kyoto protocol, signed in 1997 under the United Nations Framework on Climate Change, having the objective to reduce GHG emissions, causing climate change.

The vision to become a high-income developed country is the predominant objective of Malaysia, and the country practices an export-oriented system of open economy. One of the key determinants and performance measures of the national growth and development of an economy is the economic growth of that country. The development of the economy, the growth of infrastructure and additional infrastructure are determined by the economic growth of the country. Malaysia, one of the fast-growing economies in South Asia is dependent upon the fossil fuels like oil, gas and coal to continue its economic growth with the rapid pace. The swift development of the country is causing a large amount of GHG emissions in the atmosphere as a result of production activities and burning fossil fuels and even making it more severe with the increasing deforestation in order to build more buildings and agricultural land for development. The country ratified the Kyoto protocol in September 2004 and there has been a total of 35 sets of orders and regulations introduced and enforced by the Malaysian Environmental Authorities since 1974 (Ministry of Natural Resources and Environment Malaysia, 2010). Regardless of the efforts made by the government, since the 1970s, the air quality has deteriorated, and per-capita carbon dioxide (CO_2) emissions have increased from 1.584 metric tons in 1974 to 7.7 metric tons in 2010. The country has shown remarkable accomplishments in the field of economic growth as the rise in the per capita income is noted to have raised from US$200 in 1957 to US$10,687 in 2013. Similarly, the energy consumption has increased from 6965.682 kilo-tons of oil equivalent in 1974 to 72645.419 kilo-tons of oil equivalent in 2010 reported by world development indicators 2014. Furthermore, the trend of technological innovation (TI) and CO_2 emissions can be shown in Figures 1 and 2.

The trend of CO_2 emissions is clearly increasing with the passage of time and only in a period from 1996 to 2000 there occur a slight decrease in the CO_2 emissions. The X-axis of Figure 1 shows the years of the study period and the Y-axis shows the amount of CO_2 emissions in the logarithmic form. On the other hand, Figure 2 shows ups and downs in the TI in the country. The TIs show an abrupt decrease from a logarithmic value of 7.2 in 1985 to almost 5.6 in 1986 while there occur an increase from 5.6 to 8.2 in 1987, and a slight decrease is noted in 2007 and 2008.

Looking into the significance of financial development, it is said that if a country has a capable and enduring financial sector, it can ensure, the enhancement of the investment process, financial risk mitigation and also capital accumulation etc., which in turn, can attract more foreign direct investments (FDI) and, thus, enhance the TI and keep the environmental quality improved. It is argued that financial development is crucial in allocating funds to productive endeavors and mobilizing saving, which enhances production on the domestic level and adds to the economic growth. It is argued that the development of the financial sector will attract FDI and modern environmental friendly technology (Birdsall and Wheeler, 1993; Frankel and Rose, 2002). Furthermore, it is concluded that energy consumption can be influenced by the development of the financial sector (Islam et al., 2013; Sadorsky, 2010), and also it can affect the CO_2 emissions (Alam et al., 2015; Tamazian et al.,2009).

Environmental degradation is one of the hottest issues under discussion in the present-day world. Many researchers have discussed the problem, but the results of their work are contradictory and the problem still persists. In the light of the aforementioned literature and different empirical studies, the primary objective of the current study is to empirically investigate the impact of TI on the environmental quality in Malaysia. The investigation of the relationship between TI and CO_2 emissions is taken into consideration as the IPPC Fourth Assessment Report (IPCC, 2007) declared that rise in the mean global temperature should not exceed the 2°C and this change in the mean global temperature can be kept under 2°C only if there are alternative energy technologies available at reasonable prices (Tol, 2007). The study focused Malaysia because the country is very prone to the climate change as if there occurs an increase in the world

Figure 1: The trend of CO_2 emissions in Malaysia

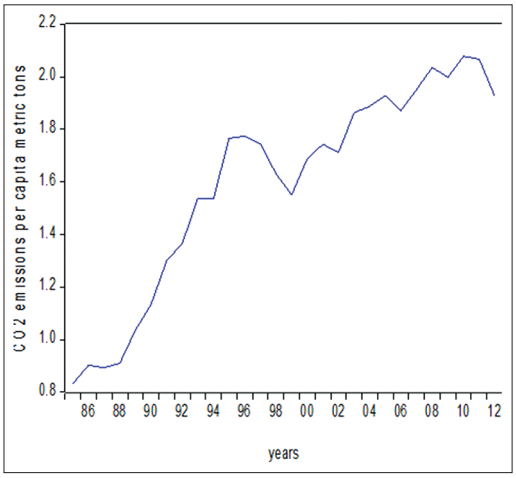
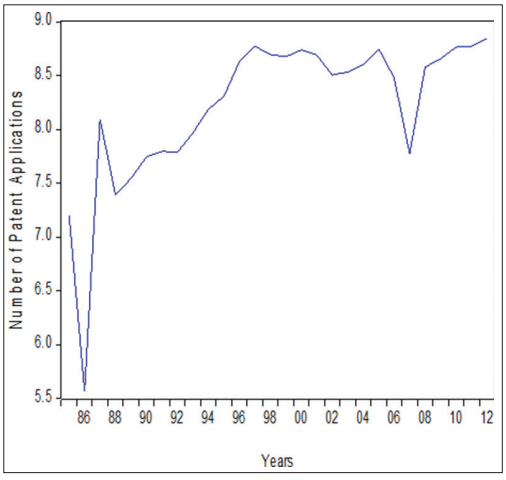


Figure 2: The trend of technological innovation in Malaysia



temperature the coastal areas in Malaysia will be under severe floods while some other regions in the country will face droughts and shortage of clean drinking water. The study used annual time series data for Malaysia from 1985 to 2012. This empirical study is different from the previous studies not only in the time range but is also different in terms of methodology and the explanatory variables included in the study. Based on the researcher's knowledge of the earlier studies this study is the first of its kind covering the relationship between TI and the environment. This study is even different from the most recent study of (Sohag et al., 2015) for Malaysia, where they focused on the relationship between TI and energy consumption. This study contributes to the knowledge and literature related to the TI and its impact on the environmental degradation in the case of Malaysia and this relation can be tested to other countries as well. The study also focused on the validity of environmental Kuznets curve (EKC) between economic growth and environmental pollution. Furthermore, the impact of the financial development of the CO_2 emissions is also the focal point of the study.

This study is organized as follows: Section 2 is related to the literature review. Section 3 covers the data, methodology and estimation procedure of the study. The empirical results are covered in Section 4. Finally, the conclusions and recommendations are given in Section 5.

2. REVIEW OF LITERATURE

The relationship between economic growth, financial development, trade openness and CO_2 emissions has intrigued both the policymakers and academicians. Some of the researchers provide with the positive relation between these variables, and others have advocated the negative or neutral relationship. This study will look into some of the past studies to take the discussion forward.

2.1. Economic Growth and CO_2 Emissions

The prime objective of any economy is to maximize the economic growth in order to get its place in the developed economies of the world, and this makes the response of the environment to economic growth very special and crucial because economic growth affects the natural environment. It is known that economic growth takes place at the expense of environmental quality; however, it is also evidenced that developed economies can introduce environmental friendly technology which in turn will make the environment better to live. After the prediction of (Kuznets, 1955) that the changing relationship between environmental quality and per capita income and income inequalities takes the inverted U-shape According to EKC hypothesis, environmental quality is first worsened by economic growth of the country but after gaining enough growth up to a threshold, level economic growth can improve environmental quality and there occur an inverted U-shaped curve between them. The study of (Grossman et al., 1991) was the first attempt to propose and approve this hypothesis but until now, the literature on the relationship is contradictory and no clear conclusion can be drawn. In a recent study (Farhani et al., 2014) use two different specifications of EKC to investigate the presence of EKC in a panel of 10 MENA countries for a period 1990-2010. The study concluded an inverted U-shape relationship between income and environmental deterioration in the first case, while for the second specification of EKC, the study found an inverted U-shaped relationship between human development and sustainability, called the modified EKC. Similarly, a group of most recent studies, including (Al-Mulali et al., 2015; Apergis and Ozturk, 2015; Jebli et al., 2016; Onafowora and Owoye, 2014; Shahbaz et al., 2014) among others, confirmed the existence of the EKC hypothesis relationship between economic growth and environmental pollution.

Conversely, it is argued that there exists a monotonic rising curve between economic growth and CO_2 emissions (Holtz-Eakin and Selden, 1995). Another most recent study of Begum et al. (2015) analyzed the Malaysian data on economic growth, energy consumption, population growth and CO_2 emissions for a period 1980-2009 and concluded that there is no inverted U-shape relationship between CO_2 emissions and economic growth in Malaysia. Similarly, a strand of studies, including (Al-Mulali et al., 2014; Caviglia-Harris et al., 2009; Halkos and Tzeremes, 2009; Mills and Waite, 2009) among others concluded that there is no inverted U-shape relationship found between economic growth and environmental pollution. Furthermore, some previous studies including (Friedl and Getzner, 2003; Martinez-Zarzoso and Bengochea-Morancho, 2004) among others, concluded that the relationship curve between economic growth and CO_2 emissions is N-shaped and rejects the EKC hypothesis. More differently, a study of Richmond and Kaufmann (2006) concludes that economic growth and CO_2 emissions are not related. Summarizing the above inconclusive and controversial literature a need for further research is felt, therefore, the study hypothesized that the existence of EKC will be validated.

2.2. Financial Development and CO_2 Emissions

The relationship between financial development and environmental conditions is one of the rising concerns in the recent field of research. The role of the developed financial sectors in an economy is a key factor in achieving the economic growth. It is maintained that stride of the economic growth can be motivated by the developed financial markets if they are able to attract FDI and also by achieving higher investments in research and development (R&D) (Frankel and Romer, 1999) and hence the dynamics of environment can be affected. Similarly, it is claimed that the use of new environment friendly technology can be made possible due to financial development, which can keep the environment clean, help in cleaner production, thus, can cause an increase in the developmental sustainability on the regional level (Birdsall and Wheeler, 1993; Frankel and Rose, 2002). In a similar vein, it is perceived that energy consumption in an economy can be affected directly by the financial sector development (Islam et al., 2013; Sadorsky, 2010) and, thus, affect the pattern of CO_2 emissions (Tamazian et al., 2009). Furthermore, a same strand of studies claimed that the cost of borrowing can be decreased and the investment activities can be motivated by the developed financial sector (Shahbaz, 2009). Nonetheless, it is stated that the financial development can enhance the efficiency of the energy sector which can reduce the energy emissions (Tamazian and Bhaskara Rao, 2010; Tamazian et al., 2009). Again, it is stated that all tires (levels) of government will be benefited from the financial

development in terms of financing the development projects and it may also lead to innovations in the field of technology (King and Levine, 1993), and these advances in technology can lead to the reduce the emissions significantly by efficient use of energy (Kumbaroğlu et al., 2008).

Contrariwise, it is said that apart from the constructing role of the financial development by inducing the consumption of energy and emissions reduction activities a developed financial sector also increase the CO_2 emissions by encouraging the manufacturing activities in an economy (Jensen, 1996). Likewise, it is argued that financial development attract FDI, increase energy consumption by investing in new projects, develop the stock markets, provide loans to residents, and buy new installations which in turn boost the consumers' ability to buy automobiles thus adds to the CO_2 emissions (Sadorsky, 2010; Zhang, 2011). Similarly, (Tamazian and Bhaskara Rao, 2010) argued that in transition carbon emissions are evidently influenced by financial development. Furthermore, a study of Ozturk and Acaravci (2013) in Turkey recently concluded that financial development does not significantly affect CO_2 emissions. Looking into the above discussion, it can be drawn that environmental performance may be deeply influenced by the role of financial development (Ziaei, 2015; Omri et al., 2015).

2.3. TI and CO_2 Emissions

The theoretical background of the technological change can be traced back to the philosophies of Joseph Schumpeter (1942), as cited by Fields (2004), who described that a new and superior technology enters the market in three stages namely invention, innovation, and diffusion. He argued that the process of R&D is used to carry out the invention and innovation process of technology. Finally, the process of diffusion is carried out when a successful innovation is adopted by individuals and firms for its relevant use and is widely available for the use in relevant applications. The collective impact of all the three, either economic or environmental is known as the process of technological change. The new growth theory is often known as "endogenous" growth theory due to the internalization of technology as a variable into a model of how market function. It is stated that technical change has a critical importance in describing the key environmental issues, mainly the long-term and large-scale environmental problems, including climate change (IPCC, 1995; Weitzman, 1997). It is argued that there may be a variety of reasons due to which we can understand the importance of technological changes in the reduction of environmental pollution, including changes in the fuel mix; utilization of production technologies that are more energy efficient; and the installation of end-of-pipe technology which is considered as the most important of all the three (Bruyn and Sander, 1997). It is claimed that looking into the assessment of climate change, which is the issue of energy and environment in the long-run, the most critical assumptions are concerning the nature and rates of change in technology (Yeh et al., 2011). Similarly, it is argued that investments in R&D and change in technology are among other sources that can lead to reductions in the CO_2 emissions (Jones, 2002). It is argued that if the costs are acceptable to society, in the long-run, he future development of the technology is considered to decrease the intensity of the emissions from economic activities and is the main solution to meet the challenge of climate change (Newell and Pizer, 2008). More recently, the study of (Sohag et al., 2015) concluded that economic growth and openness of trade increase the intensity of energy consumption while TI is said to increase the energy efficiency and reduce the energy consumption, thus, ultimately reducing CO_2 emissions.

On the other hand, there are some studies having the contradictory results regarding the role of technological change in environmental scenario. In a study to compare the welfare gains from TI, and optimal pollution control (Parry, 2003) assessed to measure whether it is TI or the optimal pollution control (Pigouvian) welfare, which adds more to the reduction in CO_2 emissions. The empirical results found that the welfare gains from optimal pollution control are greater than the welfare gains from the TIs. The study of Smulders and Nooij (2003) claimed that induced innovation was only able to mitigate the per capita income reduction but cannot fully offset its effect due to the energy conservation policies.

The above analysis indicates that there are no such prior studies covering the set of variables use by the present study in the context of Malaysia. Therefore, the outcomes of this study will largely contribute to the literature on the linkages analysis between TI and CO_2 emissions for Malaysia and can be extended to the other countries in the region also. This study will also add to the literature regarding the environment-friendly role of financial development and the importance of economic growth can also be understood. This study can also be helpful in understanding the role of the efficient use of energy consumption to prevent emissions.

3. DATA, METHODOLOGY AND MODEL SPECIFICATION

3.1. Data Sources

This study is related to the sustainable development and analyzing the determinants of environmental degradation due to CO_2 emissions. The study will find out the role of economic growth, financial development, and trade openness in the environmental scenario. The study collected the data on the variables like CO_2 emissions (metric tons), economic growth (real gross domestic product [GDP] per capita) financial development (broad money), TI (patents applications) from World Development Indicators, 2016 which is an international source published by the World Bank. The study also collected data from International Monetary Fund library and Index Mundi Malaysia. The study used energy consumption as a control variable. The study analyzed annual data over a period 1985-2012 because the data on patent applications (proxy for TI) in Malaysia are available only 1985 onwards. The time period is also in line with the work of (Sohag et al., 2015) over a period 1985-2012 (Mustapa and Bekhet, 2015) over a period 1990-2013 among others.

3.2. Model Specification

The introduction of technology as an endogenous factor open the ways for better economic growth and efficient energy consumption. The literature on the environment shows that TI can be applied to

determine its impact on different dependent variables including energy consumption, CO_2 emissions, and economic growth (Chèze et al., 2013; Greaker and Pade, 2009; Sohag et al., 2015) among others. The study derived the CO_2 emissions function from the endogenous growth model presented by Romer and the production function can be written as:

$$Y=f(A, K, L) \quad (1)$$

Where y is the income earned, A is the research technology (technological advancement) as considered endogenous by Romer, K is the capital stock of a firm, and L represents the available labor to carry out the production activities. This study replaced the research technology (A) with TI. Since it is obvious that environmental quality is affected by economic growth which is the aggregate real output of the economy, thus, we can write the CO_2 emissions function as:

$$CO_2=f(Y) \quad (2)$$

Thus, we can say that:

$$CO_2=f(K, L, TI) \quad (3)$$

Furthermore, as we know that there two types of capital, one is the polluting capital and other is non-polluting capital. The polluting capital is known as the emitting capital which is non-renewable energy resources and the other one is the renewable and non-emitting energy resources as shown:

$$K=K_e+K_{ne} \quad (4)$$

So the part of capital responsible for environmental pollution is the non-renewable energy use, thus, we can rewrite the CO_2 emissions function as:

$$CO_2=f(TI, EC, L) \quad (5)$$

Where EC is the energy consumption measured in kilotons of oil equivalent and is in line with the former studies including (Azam et al., 2015; Saboori and Sulaiman, 2013a; Sohag et al., 2015) among others, TI is the TI and is measure in the form of patent application following the work of Ang (2010a, 2010b); Bonilla et al. (2014); Madsen and Andersen (2010); Madsen et al. (2010) and L can be replaced by GDP as labor activities can be considered as economic activities and can be replaced with GDP. The GDP is measured in constant $US 2005 similar to the work of Azam et al. (2015); Azlina et al. (2014); Begum et al. (2015); Saboori and Sulaiman (2013a) among others. Similarly, from the literature, it can be concluded that TI can be boosted with the help of a developed financial sector by investing in the research activities. Thus, the study also included the financial development in the CO_2 emissions function. The study measured the financial development using the proxy of broad money (M2) following the work of Ahmad et al. (2015); Akinlo and Egbetunde (2010); Al-naif (2012); Bekhet and Al-Smadi (2015); Jenkıns and Katırcıoglu (2010); Li et al. (2015) among others. The CO_2 emissions function thus can be written as:

$$CO_2=f(EC, GDP, TI, M2) \quad (6)$$

This regression model can be converted into an econometric model by applying the log on both sides as follows:

$$\ln CO_2=\beta 0+\beta 1\ \ln EC+\beta 2\ \ln GDP+\beta 3\ \ln GDP^2+\beta 4\ \ln TI+\beta 6\ \ln M2+\mu \quad (7)$$

Where GDP is the per capita income of the country, GDP^2 is the squared term of per capita income used for the validation of EKC. TI represent the advancement in technology (TI) and M2 represent the broad money which is a proxy for financial development. Energy consumption is shown by EC and μ represents the error term in the model.

3.3. Estimation Procedure

The data was first checked for the stationarity properties and was found to be non-stationary at levels. Most of the variables of the study were found stationary at first differences, i.e., Integrated of order, I(1), and TI was noted stationary at the level form, I(0). Based on the integration of the variables, the study decided the method to find out the long-run relationship between the variables of the study. The study adopted autoregressive distributed lagged (ARDL) model for the long-run relationship between the variables. The study applied to error correction mechanism (ECM) within ARDL to find out the short-run relationship between the variables. This ARDL technique is preferred over other estimation techniques because there is no restriction on the order on variable to enter the equation (i.e., either I(0), I(1) or a mixture of both) (Pesaran and Pesaran, 1997). Secondly, a sufficient number of lags are captured by the data generating process by ARDL test while shifting from general to a specific framework. Thirdly, simple linear transformations can be used to derive the ECM from the ARDL to integrate the short-run adjustments without disturbing the equilibrium in the long-run. The error correction term (ECT) is used to show the speed of adjustment towards the long-run if there is any short-run disequilibrium. Fourth, this approach surpasses the Johansen, and Juselius approach due to its unique properties regarding small sample (Pesaran et al., 1999). Fifth, due to its proper lag selection this technique is free from residual correlation and thus endogeneity (Pesaran et al., 1999). Sixth, the ARDL technique has the ability to distinguish the dependent and independent variables. The study adopted the Ramsey's RESET test to check the overall stability of the model. The study converted the variables into log form to avoid the problems of multicollinearity and autocorrelation and used a double-log model which is in line with the work of Ang (2009), Muhammad Shahbaz (2012) for Portugal and (Shahbaz et al., 2013) for Malaysia among others.

4. EMPIRICAL RESULTS

The graphs of the data show that most of the variables are non-stationary in the levels as they have an increasing trend in the series while two variables do not have clear increasing or decreasing trend in the data, thus, they are stationary in levels as depicted in Figure 3a-f.

4.1. Unit Root Results

The time series data was checked for the stationarity properties applying Ducky Fuller-generalized least squares (DF-GLS), augmented DF (ADF) (1979) and Phillips-Perron (PP) (1988) unit root test. The test indicated that dependent variable CO_2 emissions have unit root in the level form. The unit root tests also revealed that economic growth, its squared term, and energy consumption all have unit roots in the level form as their ADF, PP and DF-GLS tests statistics values are less than those of the critical values of the tests at all significance levels and all the probability values cannot reject the null hypothesis of unit root, they are non-stationary in the level form.

The study also discovered that TI does not have unit root in the level form and is stationary at levels as all the ADF, PP, and DF-GLS test statistics values are greater than those of the critical values at all levels of significance and the probability value of the tests also reject the null hypothesis of the presence of unit root. Furthermore, it is observed that in the case of financial development the ADF and PP tests indicate the presence of unit root in the series while the DF-GLS test rejects the null hypothesis and claimed that the series is stationary at levels on the 10% level of significance. The results are depicted in Table 1.

4.2. ARDL Results

Looking into the unit root results, the study applied ARDL bounds test to explore the long-run relationship between the variables. The Johanson co-integration test cannot be applied because all the variables are not stationary at first difference. The study adopted the bound test or joint F significance test of the lagged values to find out the presence of a long-run relationship between the variables within ARDL approach. The calculated F values were compared to the already given Pesaran et al., in 2001 critical values (Pesaran et al., 2001). The number of lags of the first differenced variables is considered very important for the results of the F-test

Figure 3: (a-f) Time series plots of the study variables in level form

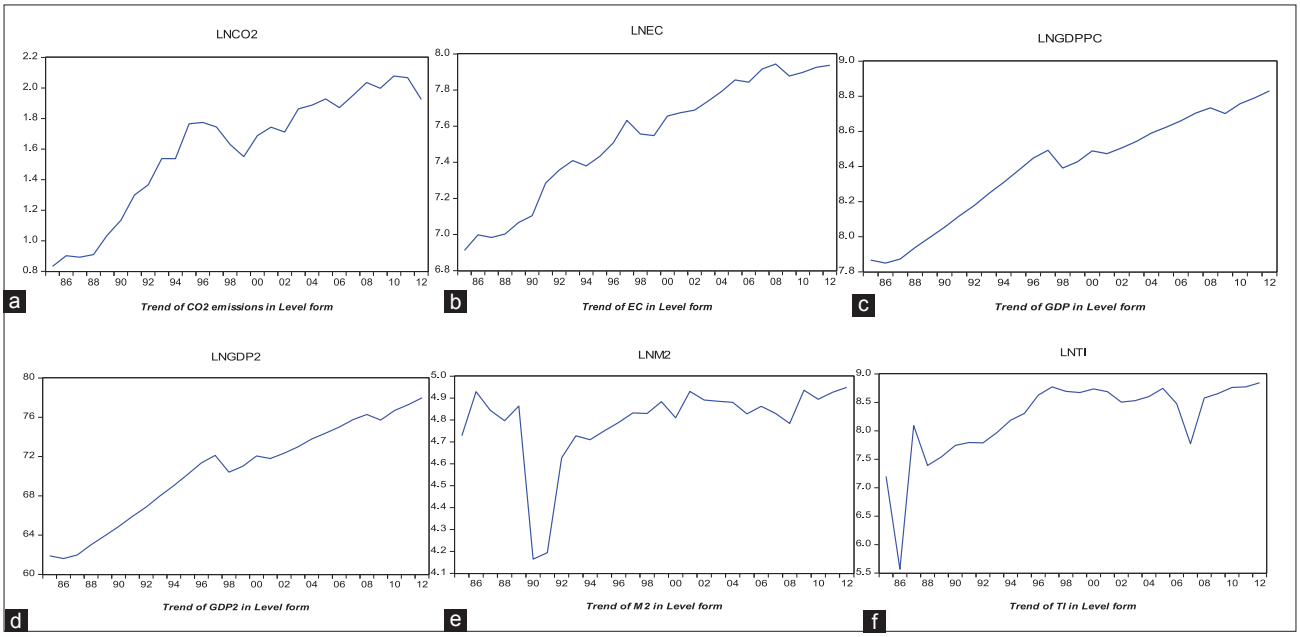


Table 1: Unit root tests results

Level form	ADF test		PP test		DF-GLS test	
Variables	Intercept	Trend and intercept	Intercept	Trend and intercept	Intercept	Trend and intercept
$lnCO_2$	−2.027	−1.108	−2.027	−1.108	−0.717	−1.338
lnEC	−1.709	−1.554	−3.231	−1.257	−0.175	−1.725
lnGDP	−1.074	−1.438	−1.094	−1.513	0.407	−1.507
$lnGDP^2$	−0.926	−1.624	−0.943	−1.547	0.473	−1.619
LnTI	−2.785*	−4.068**	−2.785*	−4.066**	−2.459**	−4.221**
lnM2	−1.775	−2.940	−2.544	−2.866	−2.569*	−3.040*
First difference	**ADF test intercept**	**Trend and intercept**	**PP test intercept**	**Trend and intercept**	**DF-GLS test intercept**	**Trend and intercept**
$lnCO_2$	−4.315***	−4.710***	−4.317***	−4.710***	−4.420***	−4.903***
lnEC	−5.164***	−5.013***	−5.228***	−7.224***	−4.990***	−5.275***
lnGDP	−4.680***	−4.891***	−4.676***	−4.979***	−4.098***	−4.629***
$lnGDP^2$	−4.781***	−5.009***	−4.780***	−4.914***	−4.212***	−4.693***
lnM2	−5.408***	−5.352***	−6.366***	−6.657***	−4.912***	−5.333***

***.**.*Are 1%, 5% and 10% of significant levels, respectively. GLS: Generalized least squares, ADF: Augmented Ducky Fuller, PP: Phillips-Perron, DF-GLS: Ducky Fuller-generalized least squares, GDP: Gross domestic product

for cointegration. The number of lags is selected on the basis of a different test that does not violate the assumptions of classical linear regression. The SIC indicates that there should be one lag taken of each variable in the study. The results of the bound test F-statistics value indicated the presence of a long-run relationship between the variables as the calculated F-value is greater than the tabulated values of the upper bound of the Pesaran et al. (2001). The ARDL results of cointegration via bound test are shown in Table 2.

The alternate way to check the presence of a long-term relation between the study variables is the value of cointegrating equation ECT_{t-1}. The negative and statistically significant value of the ECT_{t-1} is the evidence of the long-run relationship. In the current study, the results of the error correction test (ECT) also demonstrated the presence of long-run relationship as the value of ECT_{t-1} is negative and significance. This value of the ECT is considered as the speed with which the short-run disequilibrium moves towards equilibrium in the long-run and as known as the speed of adjustment. The ARDL long-run results along with the diagnostics test statistics are given in Table 3 of the study.

The long-run estimates of ARDL approach indicate that economic growth has a positive and significant impact on the CO_2 emissions in Malaysia and if the economic growth of the country will increase by 1%, it will give rise to an increase of 22.62% in the CO_2 emissions. Thus in case of Malaysia, the economic growth is at the cost of environmental pollution as there is a positive impact of the economic growth on the pollutant emissions, which is in line with the studies of Ang (2008); Azlina and Mustapha (2012); Saboori et al. (2012) for Malaysia among others. The statistics of Malaysia shows that per capita income growth is growing at an increasing trend from $US 1383.29 to $US 6841.44 so as the per capita CO_2 emissions which have raised from 1.34 metric tons per capita to 6.85 metric tons per capita. Thus, it can be concluded that economic growth of Malaysia is at the cost of environmental quality to a certain limit but according to the results of the EKC a higher income can reduce the environmental pollution, the country should focus more on the renewable and efficient use of energy to keep the economic growth increasing but not the emissions. The number of patent's applications both resident and non-resident have increased to a great extent during the study period as noted from 1377 in 1985 to 7205 in 2012. The long-run results revealed that the development in the field of technology is having negative relation with pollution, but the impact is very low at present as the innovation is at a point which cannot decrease the environmental pollution to a greater extent as there will be a decrease of 0.22% in the pollution due to advancements in the technology by 1%. The process of manufacturing and production, which is the sole ingredient of economic growth leads to more deterioration of the environment. The technological advancement is having an environmentally friendly impact regarding the pollution abatement, but it is still in its early stage and will take the time to show some greater results in this regard.

The impact of financial development in the long-run is environmentally friendly but insignificant as an increase in the broad money of the country as a percent of GDP will have no such impact regarding the environmental quality. This finding of the study is partially in line with the work of Shahbaz et al., (2013) for Malaysia. The results of the study are also similar to those of (Tamazian and Bhaskara Rao, 2010; Tamazian et al., 2009) who included the financial development in the model and claimed that financial development can reduce the environmental pollution. Furthermore, the EKC hypothesis is validated in the case of Malaysia during the study period as there is a negative relationship between high income (GDP square) and CO_2 emissions in the long-run. The relationship between higher economic growth and environmental pollution is inverted U-shape, as the pollution increases with an increase in the economic growth but reaching a peak point of income and pollution the relationship changes and a further increase in income lead to investments in environmental sustainability process, and the quality of environment get improved. These findings of the EKC results are in line with work of (Saboori et al., 2012) for Malaysia who stated that in the case of Malaysia the environmental quality is first deteriorated and then improved after the threshold level of income is reached, because the government and people become more cautious about the environment and spend more money for the betterment of environmental quality.

The energy consumption is affecting the environmental pollution positively and will lead to an increase in the pollution which is partially the same as other various studies including (Ang, 2008; Saboori and Sulaiman, 2013a) for Malaysia and also the work of (Sehrawat et al., 2015). The impact is insignificant, which means that the exploitations of energy resources in Malaysia are not the sole cause of polluting the environment. The diagnostic test

Table 2: The ARDL model of cointegration

Model	ARDL	F-statistics	ECT_{t-1} (t-statistics)	Results
$FlnCO_2$ ($lnCO_2$/lnEC lnGDP $lnGDp^2$ LnTI lnM2)	1	3.97*	−0.72891 (−3.00)***	Cointegration
FlnEC (lnEC/$lnCO_2$ lnGDP $LnGDp^2$ LnTI LnM2)	1	2.89	−0.53488 (−3.97)***	Cointegration
FlnGDP (lnGDP/$lnCO_2$ lnEC $lnGDp^2$ LnTI LnM2)	1	12.87***	−0.17169 (−2.35)**	Cointegration
$FlnGDP^2$ ($lnGDp^2$/$lnCO_2$ lnEC lnGDP LnTI LnM2)	1	12.83***	0.15128 (−2.17)**	Cointegration
FlnTI (LnTI/$lnCO_2$ lnEC lnGDP $lnGDP^2$ lnM2)	1	10.85***	−1.5369*** (−7.80)	Cointegration
FlnM2 (lnM2/f ($lnCO_2$ lnEC lnGDP $lnGDP^2$ LnTI)	1	1.60	−0.56791 (−2.54)**	No-cointegration
Critical bound values for F-statistics (%)		**Lower bound I(0)**	**Upper bound I(1)**	
1		3.41	4.78	
5		3.2304	4.6477	
10		2.6442	3.9078	

*.**.***Represent significance at 10%, 5% and 1% respectively. GDP: Gross domestic product, ARDL: Autoregressive distributed lagged, ECT: Error correction test

results show that the test for serial correlation detected no sign of serial correlation in the model as the F-statistics value and probability value are more and cannot reject the null hypothesis of no serial correlation in the model. The study also conducted the Jarque-Bera test of Normality and concluded that the model is normally distributed as the value of the Jarque-Bera test and P value are 0.049 and 0.976 respectively, so we cannot reject the null hypothesis of the normal distribution of residuals. Similarly, he study also detected no sign of heteroscedasticity as the F-statistics (2.399) and P value (0.121) cannot reject the null hypothesis of homoscedasticity. The functional form of the model is also tested for validation using the Ramsay's RESET test, and the test concluded that the squared terms and cubic terms of the fitted values should not be included in the model as they do not qualify the test of the omitted variables in the model. The values of the test are 0.104 and a P value of 0.746.

The short-run results of the study reveal that the lag value of the dependent variable cause an increase in the CO_2 emissions. The impact of energy consumption is positive and insignificant in the short run similar to the results of the long-run estimates. The short-run impact of economic growth is positive as economic activities will lead to more pollution when the income level is low. On the other hand, the impact of TI in the short run is also negative and significant, which states that the technological advancement is in its infant stages in Malaysia and is trying to improve the quality of the environment. Moreover, the impact of financial development is having an improving effect on the environmental quality and the loans and investments for the betterment of environmental quality seem to be effective. The EKC hypothesis does not hold in the short run as the higher economic growth will deteriorate the environment. This result can be justified as EKC is the long-run phenomenon not a short-run, so the EKC hypothesis did not hold in short-run. In the short-run, the impact of energy consumption polluting the environment is insignificant. The short-run results are given in Table 4.

4.3. Granger Causality

It is argued that when there is a long-run relationship between the variables, there must be some sort of causal relationship between them either unidirectional or bidirectional. To find out the direction of causality between the variable Granger causality tests is applied. The study captured the directions of causalities in the model by adopting the Granger causality within vector error correction model (VECM) because VECM covers the short and long-run relationship between the variables. The short-run causal relationship is detected by the Wald test and the significant significance F-statistics shows the presence of causal relationship in the short run. The long-run Granger causality is determined by the negative and significant coefficient values of the ECT lagged value and their t-statistics. The current study shows that there is a long-run bidirectional causality running between CO_2 emissions and economic growth, which is supporting the previous studies of Pao and Tsai (2011); Saboori and Sulaiman (2013b). The study also found a long-run bidirectional causality relationship between CO_2 emissions and TIs, which is according to the assumption that both TI and environmental pollution will affect each other. The results also revealed a long-run unidirectional causality running from energy consumption to CO_2 emissions similar to the work of Apergis and Payne (2009) for Central America and (Apergis and Payne, 2010) for the Commonwealth Independent States. The study also noted a unidirectional causal relationship running from financial development towards CO_2 emissions in Malaysia these results are in line with the work of (Muhammad Shahbaz Solarin, and Mahmood, 2012) for Malaysia. The results of long and short-run causality are given in Table 5.

The short-run results of Granger causality declared a bidirectional relationship between economic growth and energy consumption. Similarly, a bidirectional causality between TI and economic growth is also observed. In the short-run, there is a unidirectional causality running from economic growth and TI towards CO_2 emissions. The study also revealed a short-run unidirectional causality running from financial development towards energy consumption. Furthermore, energy consumption is also caused by CO_2 emissions in the short-run. Furthermore, a short-run causality also run from financial development towards economic growth, thus, it can be concluded that development of financial sector will improve the economic growth of the country.

Last but not the least, as the model has passed all the diagnostic tests including serial correlation, heteroscedasticity, the functional form test, and also the test of normality and the model is declared as alright. The study also emphasized on the short and long-run coefficients by applying the CUSUM and CUSUMSQ tests proposed by Brown et al. (1975) to find out the stability

Table 3: ARDL long-run results

Variable	Coefficient	SE	t-statistic	P
LnEC	0.00105	0.43387	0.0024	0.998
LnGDP	22.62	6.7297	3.3622	0.003***
$LnGDP^2$	−1.261	0.39257	−3.2132	0.005***
LnTI	−0.2020	0.09470	−2.1334	0.047**
LnM2	−0.0085	0.11022	−0.07758	0.939
C	−97.64	27.741	−3.5198	0.002
Diagnostic tests version	**LM version**			**F version**
Serial correlation	2.219 [0.136]			1.5223 [0.234]
Functional form	0.104 [0.746]			0.0661 [0.800]
Ramsey reset test				
Jarque-Bera (normality)	0.049 [0.976]			Not applicable
Heteroscedasticity	2.399 [0.121]			2.4385 [0.131]
P (F-statistics)	136.32 [0.000]			

.*Represent 5% and 1% significance respectively. ARDL: Autoregressive distributed lagged, SE: Standard error, GDP: Gross domestic product

Table 4: Short-run results

Variable	Coefficient	SE	t-statistics	P-value
D (LnEC)	0.7665E-3	0.31617	0.00242	0.998
D (LnGDPpc)	16.6237	4.8462	3.4302	0.003
$D (LnGDP)^2$	0.9194	0.27916	3.2937	0.004
D (LnTI)	−0.0693	0.034541	−2.0083	0.058
D (LnM2)	−0.00623	0.079864	−0.0780	0.939
ECM	−0.72891	0.23771	−3.0664	0.006
Diagnostic tests				
R^2	0.66982	D-W statistics		2.573877
Adjusted R^2	0.52303	SE of regression		0.062509
P (F-statistics)	0.001	RSS		0.070333

ECM: Error correction mechanism, GDP: Gross domestic product, SE: Standard error

of the coefficients. The results of the tests concluded that the model coefficients are stable as both the graphs of CUSUM and CUSUMSQ fall within the critical boundaries at 5% significance as shown in Figure 4a and b.

5. CONCLUSIONS AND RECOMMENDATIONS

Malaysia, one of the fast developing economy in South Asia, depends on upon the use of petroleum and other liquids (40%), gas (36%), coal (17%) to meet the energy requirements (U.S. EIA, 2014), thus, due to its high dependence on these resources of energy, the country is emitting a large amount of GHG in the atmosphere which is the source of the environmental pollution. This study investigated the relationship between environmental quality and TI and also included some other determinants of CO_2 emissions in the equation. The study concluded that in the short run economic growth of the country is at the cost of environmental quality, which is not the favorable and the study suggested that the government should focus more on the future precautions in terms of economic growth to be green and sustainable. The study also concluded that financial sector development can lead to improving the environmental quality by investing more in the advanced and environmentally friendly technology, thus, there should be more focus on the investments in the green and environmentally friendly technology in the long-run. The phase of TI is in the early stages in Malaysia, and the study concluded that it is negatively related to the CO_2 emissions, thus, can lead to a decrease in the pollution if handled properly. The study suggested that the country should invest more in the technological sector which may provide the opportunity to import new technology, the installation of which will help reduce more CO_2 emissions. Energy consumption is having no significant increasing impact on the CO_2 emissions which means that work on energy efficiency is improving to control its increasing impact on the environmental pollution.

The causality results of the study conclude that economic growth is the main cause of the CO_2 emissions. The causality results of the study also claimed that energy consumption is also a threat to the environment in the case of Malaysia in the long-run as the consumption of energy resources like oil, gas, coal etc. emit a large amount of GHG in the atmosphere, thus, causing pollution. On the other hand, the study reveals that TI and environmental quality cause changes in each other, so, TI is a good determinant of the CO_2 emissions and improvements in the technological development can lead Malaysia to accomplish the goals of reducing the CO_2 emissions. Furthermore, the study found that financial development can cause a decrease in the environmental pollution in the case of Malaysia in the long-run. The study discloses the fact that if a country is having high per capita income and developed financial sector, it can reduce the environmental pollution by investing more in the TI and R&D activities.

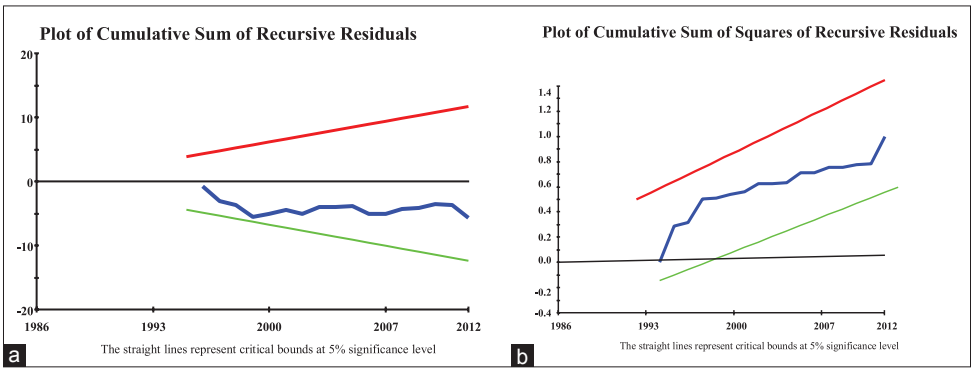
The results of the study may be of use to the policy makers and industrialists in order to utilize the existing energy resources and look towards the TI for the betterment of society and environment. The study is very important because the country is very prone to the changes in the climate due to its geographical position, the coastal areas are prone to floods and some other areas can be on the brink of facing severe droughts. The present study emphasized on the basic determinants of pollution emissions and tried to capture their impact in order to know the future damage they will cause and to formulate strategies to reduce the carbon emissions and protect the environment to help to reduce the danger of floods and more severe droughts. The contradictory arguments and results about the relationship between the study variables both on the

Table 5: Short and long-run granger causality results

Variables	Short-run causality results						Long-run causality
	$LnCO_2$	LnEC	LnGDPpc	$LnGDP^2$	LnTI	LnM2	ECT_{t-1} (t-statistics)
$LnCO_2$	-	0.860 (0.43)	12.88 (0.002)	12.43 (0.002)	3.64 (0.04)	0.049 (0.82)	−0.32 (−3.64)***
LnEC	3.07 (0.07)	-	2.97 (0.07)	2.72 (0.09)	0.06 (0.80)	3.38 (0.05)	−0.09 (−1.17)
LnGDPpc	1.67 (0.22)	3.56 (0.05)	-	15375 (0.000)	6.83 (0.007)	4.90 (0.02)	−0.14 (−2.49)**
$LnGDP^2$	1.63 (0.22)	3.69 (0.04)	15800 (.0000)	-	6.56 (.008)	4.96 (0.02)	−0.40** (−2.40)
LnTI	2.96 (0.10)	2.40 (0.13)	11.10 (.0007)	10.57 (0.000)	-	0.64 (0.43)	−0.73 (−1.99)*
LnM2	1.49 (0.24)	0.93 (0.34)	0.42 (0.52)	0.29 (0.59)	0.51 (0.47)	-	−0.21 (−0.84)

.*Represent 5% and 1% significance respectively, GDP: Gross domestic product, CO_2: Carbon dioxide, ECT: Error correction test

Figure 4: (a and b) The results of the stability test of CUSUM and CUSUMSQ



theoretical and empirical basis make this topic more important and are asking more research on the issue. Future researchers and students working in this area will be benefited from the results of the study because it provides them with a clear picture both on the theoretical and empirical basis of the role of the study variables. This study may be helpful to the society as it will create public awareness about the environmental degradation and its devastating impacts on the climate system.

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