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Relationship between Energy Consumption, Carbon Dioxide Emissions and Economic Growth: Evidence from Selected Top Oil Energy-Consuming Countries

Maryam Noorymotlagh [a*] and S. Çiftçioğlu [a]

[a] *Faculty of Business and Economics, Eastern Mediterranean University, Via Mersin 10, TRNC, Turkey.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

With rising climate change concerns and increasing energy demand, many of the developed countries are pursuing sustainable and low carbon economic development plans. The dramatic use of fossil-fuel energy in the economy increases the level of carbon dioxide emissions. Carbon dioxide (CO_2) is the dominant greenhouse gas that intensifies the global warming phenomena as a rising challenge over the last two decades. As developed nations around the world are taking immediate steps to address this issue, it is vital to use energy efficiently and minimize environmental pollution effects. Thus, this research examined the relationship between energy consumption, CO_2 emissions, and economic growth for the top oil energy-consuming countries, including the U.S., Japan, Canada, and Australia. It also estimated the impact of other

**Corresponding author: E-mail: Maryam_nm@hotmail.com;*

macroeconomic parameters comprising inflation rate, investment rate, and trade openness on economic growth. Multiple regression analysis was employed for the time series data covering the timespan from 1990-2018. The empirical findings indicated that energy consumption has a positive and significant impact on economic growth in the selected countries. Unsurprisingly, CO_2 emissions, a proxy for fuel-based energy use, had a destructive influence on the environment. Moreover, the results showed that a positive association existed between investment rate, trade openness, and economic growth. Conversely, the inflation rate in all of the selected countries had an insignificant impact on growth output. Policies such as efficient use of energy, increasing the rate of tax, replacing bio-diesel fuel, or implementing renewable energy instead of fossil-fuels were suggested to curb carbon emissions.

Keywords: Economic growth; energy consumption; CO_2 emissions; global warming; macroeconomic parameters.

ABBREVIATIONS

ADF : Augmented Dicky Fuller
IEA : International Energy Agency
ARDL : Autoregressive Distributed Lag
INF : Inflation Rate
BP : British Petrol
INV : Investment Rate
CO_2 : Carbon Dioxide Emissions
OLS : Ordinary Least Square
EC : Energy Consumption
TAR : Threshold Auto-Regression
EKC : Environmental Kuznets Curve
The U.S. : United States of America
G7 : Group of Seven
TO : Trade Openness
GDP : Gross Domestic Product
VAR : Vector Autoregressive
GNP : Gross National Product
VECM : Vector Error Correction Model.

1. INTRODUCTION

Energy is an integral part of every economy. The exploration of new sources of energy and the innovation of new energy reserves are indispensable aspects of economic growth. Currently, three main factors drive high rates of economic growth: industrialization, urbanization, and transport infrastructure. These factors highly depend on energy consumption, such as oil and other fossil fuels. Fossil fuels provide electricity for industrial, operations and means of transportation [1]. Studies have shown that industrialized countries are accountable for the intense discharge of greenhouse gas into the atmosphere. However, according to [2], it appears that the growth in greenhouse gas emissions has been higher in the emerging market economies in recent years and the threat of global warming related to climate change has increased. These issues have attracted the attention of experts and motivated them to investigate the relationship between economic growth, energy consumption, and environmental degradation.

Carbon dioxide (CO_2) is the most debatable greenhouse gas that causes environmental destruction through global warming and climate change phenomena. CO_2 emissions are released in different ways, such as through burning oil, gas, coal, hydrocarbon, products, and deforestation [3]. The increase in the CO_2 emissions and methane gas into the atmosphere has led to a rise in the temperature of the Earth's surface [4]. An international agreement called the Kyoto Protocol was signed in 1997. The agreement aimed to achieve various targets in industrial countries. The aims include sustainable development, environmental quality, and setting certain limitations on greenhouse gas emissions. Therefore, the protocol requires policymakers to implement policies targeted at reducing environmental inequality [5]. Based on the findings of different scientific studies, in terms of emissions, the top 25 countries account for approximately 80 percent of the world's carbon dioxide emissions. Thus, significant inequality exists across the globe due to the greenhouse gas emissions [6]. The list of high-ranked countries includes the U.S., Japan, Canada, and Australia.

This study aims to examine the long-term association between energy consumption and CO_2 emissions and economic growth (denoted by GDP growth) in the U.S., Japan, Canada, and Australia. Moreover, the effects of global warming and environmental degradation caused by CO_2 emissions are stated. Annual data for the relevant variables were obtained from the database of the World Bank for the period from 1990 to 2018. Besides, this study empirically examines the relationship between GDP growth and other macroeconomic parameters including the investment rate, inflation rate, and trade openness in the selected countries which has surprisingly remained scarce thus far. The main purpose of this paper is to understand the critical role and contribution of oil energy consumption and CO_2 emissions in the economic growth of the top oil energy-consuming economies. Furthermore, based on the results, this study offers some policies for the efficient use of energy to have sustainable economic growth in the selected developed countries.

The rest of this paper is structured as follows: Section two is devoted to the basic findings of the previous studies and the theoretical framework of the economic growth within the context of this research. In section three, the data and methodology based on multiple regression analysis and an alternative specification of the growth model used are described. The empirical results based on the estimation of the alternative growth equations for each country are presented and discussed in section four. Section five, provides conclusion and policy suggestions.

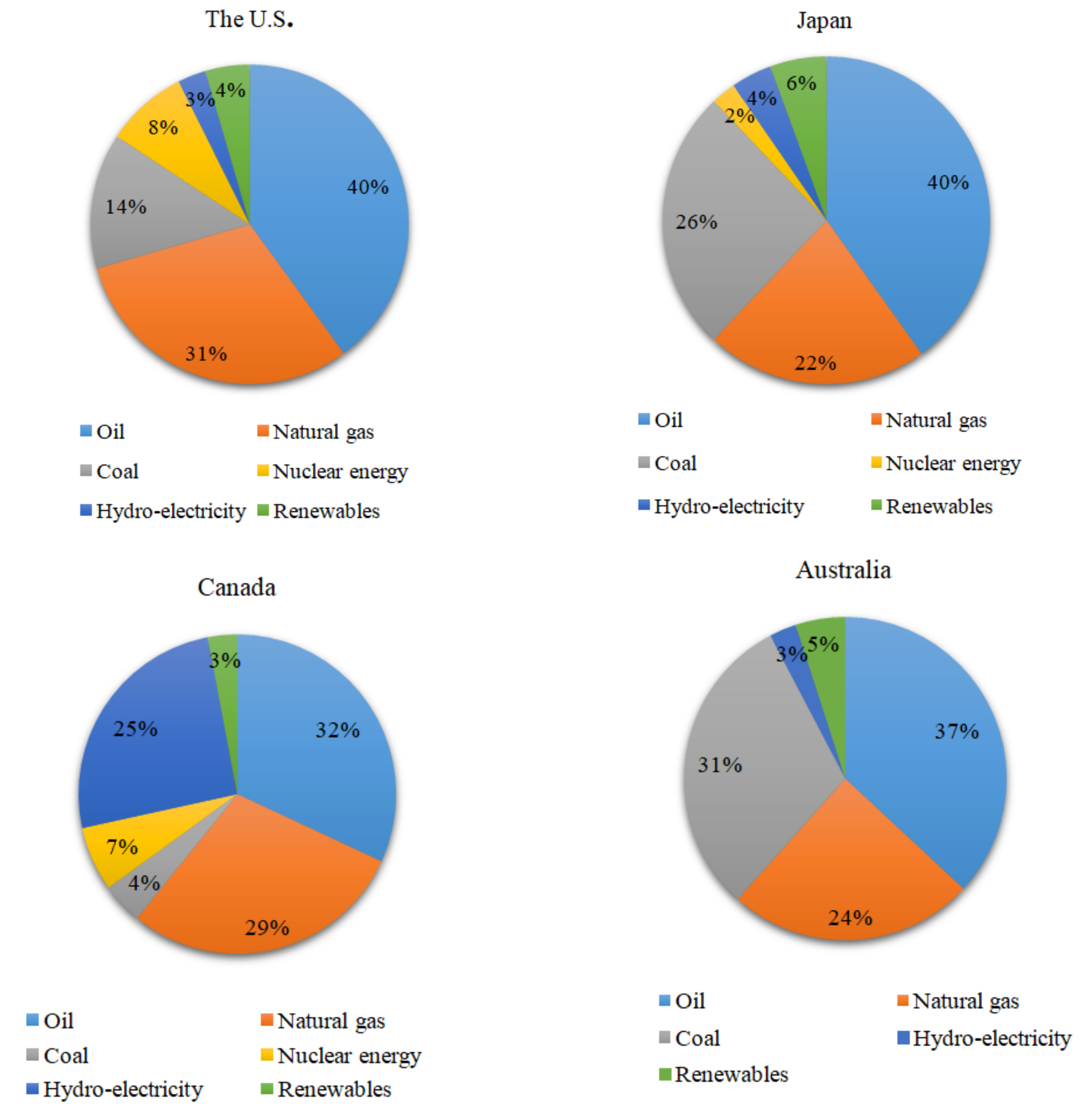

Fig. 1. Primary energy consumption in the U.S., Japan, Canada and Australia in 2018 (BRITISH PETROLEUM, 2019)

2. LITRATURE REVIEW AND THEORETICAL FRAMEWORK

2.1 Energy Consumption and CO_2 Emissions

Past literature has confirmed that energy plays a crucial role in the production. Undoubtedly, energy is a primary input for both production and transportation. According to [7] the classical macroeconomic theory mainly focuses on capital and labor and does not consider energy as a component of economic development. However, new growth theories pay more attention to energy and investigate the association between energy consumption and economic growth through the production function. As suggested by this theory, using energy through technological progress, capital, and labor transform materials to final goods and services [8,9].

A large number of studies have shown that natural resources are crucial sources of energy for economic growth. The excessive use of natural resources will increase the level of carbon dioxide emissions, which cause pollution in the environment. Economists emphasize the importance of reducing fossil fuel energy consumption to decrease the problems caused by climate change. On the other hand, sustainable economic development is now being encouraged globally. Hence, it is essential to focus on three areas: 1-improving the efficiency of useful work[1], which means that extra output will be generated with lower amounts of useful work. 2- Improving the efficiency of conversion. Therefore, more output will be produced with lower input and less carbon dioxide will be emitted. 3-Continue production at a lower cost [10].

[11] argued that a large proportion of theoretical and empirical works have been conducted on economic growth. Most of these studies have attempted to develop a model for the association between economic growth, energy consumption as well as economic growth and CO_2 emissions based on the Solow growth model. [12] mentioned that energy resources are among the significant determinants of economic growth. The study further reported that in the long run, the increased use of energy has a negative impact on the environment. [13] were among the initial authors to analyze the association between energy consumption and economic growth. The study found unidirectional causality running from economic growth to energy. Their study additionally revealed that energy exerts no causality effects on economic growth. In a different research, [14] used employment as a replacement for economic growth and reported that an increased level of energy consumption resulted in higher levels of employment. On the other hand, [15] applied different methodologies as well as a variety of annual datasets to examine how the gross national product (GNP) and energy consumption are related. They found no evidence of a causal relationship between energy and GNP.

Through the utilization of the method originally developed by [16], in early studies, researchers examined bivariate Vector Autoregressive (VAR) models to discern the Granger causality between energy and output. However, recent studies have used cointegration methods. Since the variables of interest are doubtlessly non-stationary and trending randomly, it is necessary to conduct a cointegration test to find worthwhile results. For example, [17] employed cointegration and error-free techniques to determine the nature of the association between energy use and income for India, the Philippines, Indonesia, and Thailand. His results suggested that in the short term, a single direction of causality runs from energy to GDP growth in Indonesia and India. In contrast, his analysis also showed a causal association running from energy consumption to income in the Philippines and Thailand.

Previous studies utilized different measurements and methods to discover the association between energy consumption and output growth. One such study conducted by [18] explored the association between energy consumption and economic growth in the group of seven (G7) countries by utilizing the Granger causality test. The outcome of their study revealed that causality does not exist between energy and economic development. [19] conducted another empirical research by applying the panel regression model. They indicated that a unidirectional causal relationship runs from energy consumption to economic productivity in the (G7) countries[20] performed a study by implementing the Auto Regressive Distributed Lag (ARDL) methodology to explore the association between energy consumption and economic growth in Saudi Arabia. He argued that

[1] In this study, useful work is defined in physics books as the amount of energy needed to lift an object against the force of gravity or the amount of energy applied to move an object over a distance. However, in Economics, useful work is what human capital or labor do for the purpose of production.

there is a one-way direction of the causal effect of GDP growth on energy consumption. On the contrary, [21] determined that a reciprocal causal relationship exists between energy and economic development in Pakistan. His empirical methodology was based on the Auto Regressive Distributed Lag (ARDL) model and the Johansen Julius test.

For the past two decades, a large number of studies have concentrated largely on the CO_2 emissions that result from energy consumption. The studies have concluded that energy consumption has a notable impact on carbon dioxide discharge. As an illustration, RITI, et al., (2017) applied the Environmental Kuznets Curve (EKC) hypothesis to investigate the nature of the relationship among economic growth and carbon dioxide emission and energy consumption over the sample period of 1970-2015 for China. In past studies, the relationship between economic growth and carbon dioxide emissions that leads to environmental degradation can be explained through the Environmental Kuznets Curve (EKC) theory. The Environmental Kuznets hypothesis explains the nexus between economic growth and carbon emissions in two phases. First, environmental degradation starts to increase as the economy develops. After reaching a peak, the second phase starts; environmental degradation begins to decrease although economic growth continues. An inverted u-shaped graph appeared from the theory (KUZNET, 1955).

[22] examined the nexus between economic growth and carbon dioxide emissions via the application of panel regression models over the period covering 1990-2011 for China. Their results showed that there is an inverted u-shaped relationship between GDP growth and CO_2 emissions. However, the study of [23] rejected the Environmental Kuznets hypothesis. He examined the nexus between GDP growth and CO_2 emission in Tunisia by implementing Granger causality and the Vector Error Correction Model (VECM) for the period of 1980 to 2009. His analysis indicated that there is a sustainable relationship between economic growth and carbon emissions. [24] found an inverted u-shaped relationship between economic growth and carbon emissions in their study of Latin American countries for the period of 1971-2011.

Recent studies have also tried to explore the nexus between income and pollution. [25] claimed that a long-run relationship exists between environmental inequality and energy consumption (per capita) as well as foreign trade in South Africa. [26] argued that energy consumption and carbon emissions have a causal and cointegrating association with economic activities in Bangladesh. He also investigated an inverted u-shaped relationship that existed between economic activities and CO_2 pollution.

Succinctly, all countries are highly reliant on energy consumption to develop their infrastructure and transportation, improve their social circumstances, increase their market size and grow investments in different sectors. However, inadequate fossil fuel energy restrains the speed of economic growth. The intensive increase in energy consumption and expansion of economic development are recognized as sources of carbon dioxide emission. Therefore, it is vital to implement appropriate policies for overcoming the problems [27]. Carbon emissions are considered to be one of the global warming gasses that have a significant negative effect on human health. Hence, it will be beneficial to implement various pollution control policies such as tax credits on renewable energy production and to invest in energy-efficient technology projects in all countries around the world [28].

2.2 Investment

Investment can be explained by the neoclassical Solow growth theory. According to [29], economic growth depends on a higher rate of savings or investment. [30] subsequently clarified that increasing savings (investment) permanently in countries will increase the rate of output, which will consequently lead to faster economic growth. Furthermore, the stimulating investment will foster medium-term growth via the effect of transferring technology to industries. Additionally, savings (investment) which represent the key component of economic growth provide resources that can be used to increase capital accumulation (machinery, building, etc.) and labor force, which enhances the productive capacity.

Most previous studies have emphasized the importance of investment in growing and developing the economy. Investors need to borrow high levels of capital to invest in production-related activities. Based on the production function, a higher rate of output depends on the higher rate of capital. There is a consensus among all economists that capital accumulation can be increased through the investment process. It cannot be underestimated that this process has a significant role in both growth and development. [31] found evidence that increasing capital accumulation is one of the most important factors impacting long-run growth across countries.

Routinely, borrowing from outside is not an appropriate way to increase economic activity. Not only does it have an unfavorable impact on the balance of payments, but it increases the exposure to foreign exchange risk. A decline in the currency is one of the circumstances associated with borrowing from the International Monetary Fund. Thus, instead of borrowing from other countries or organizations, it is better to save domestically to finance domestic capital formation, which speeds up the growth rate of the economy [32].

According to [33], the domestic investment that leads to capital formation, productive activity, and improvement of infrastructure, can lead to the rapid and sustainable growth of exports and economic development. Thus, investors endeavor to find appropriate investment options. [34] claimed that there is a positive relationship between productivity and investment. In another study, [35] argued that there is a favorable nexus among investment, economic growth, and financial improvement.

[36] mentioned that capital formation is one of the significant factors needed to maintain sustainable economic growth. Capital formation is also a determining variable for creating long-run economic growth. The reason for this is that a relatively higher rate of investment is associated with a higher rate of accumulation of capital stock, which causes the economy to grow faster. [37] used cross-country datasets and attempted to analyze the relationship between public investment and economic growth. Unfortunately, their results were not statistically robust.

Investments made in economic activity can be categorized into three parts. First is “business fixed investment”, such as investing in manufacturing systems, equipment, infrastructures in the plant. Second is “residential investment”, which includes significant investments in housing. Third is “inventory investment”, which consists of the accumulation of inventories [38].

The impact of investment on economic growth can be explained by aggregate demand. Aggregate demand is defined as the total demand for final goods and services at a given price and time in the economy. It is determined by the demand for investment goods. An increase in investment demand leads to an increase in capital stock. Therefore, increased capital stock accumulation leads to increased production capacity, which enables the economy to produce larger amounts of output. Thus, investing in different manufacturing sectors by utilizing new technology will increase productivity and affects the economic growth rate [39].

It can be concluded that to boost the economy, investment is necessary. [40] observed that physical capital accumulation is a significant element of the rise in economic growth. Consequently, to increase the nation’s physical capital, national and international policies are implemented to strengthen the economy. In terms of policy actions, the government should always monitor the economic situation of the country. In critical situations, it provides subsidies and funds for industries to improve their productivity. It also supports entrepreneurs who can develop innovative products, which leads to greater competition in the market and will also attract foreign direct investment [41].

2.3 Inflation

The primary objectives of every macroeconomic policy are to achieve a low and stable rate of inflation and also a high economic growth rate. The stability of prices is one of the prominent factors necessary for a high economic growth rate. Hence, in most countries, the central bank takes necessary actions such as monetary policy to maintain the inflation rate at an appropriate level. According to [42], high inflation usually has a dramatic effect on the economy. However, past researchers have revealed that in some cases, moderate inflation can also decrease the rate of growth. On the other hand, [43,44] claimed that it is not worthwhile to reduce the inflation rate to zero as the costs outweigh the benefits.

Based on the extant literature, the effects of the inflation rate on economic growth divided into four categories. First, a positive association between inflation and economic growth does not exist [45,46]. Second, [47] and also [48] posit a positive association between inflation and economic growth. Third, [49] claimed that inflation exerts a negative influence on economic growth. The last category suggests that inflation affects economic development through a specific threshold framework. In other words, inflation fosters economic growth when it is below a threshold level [50]. However, if the inflation rate is above the threshold level, it will have a negative influence.

A study conducted by [51] showed that the threshold is between 1–3% for industrialized countries and 11–12% for developing countries, and inflation prevents the economy from growing beyond these levels. However, it may not have a statistically significant effect below the threshold. A study by [52] examined the association between inflation and economic growth for Pakistan. The research was based on an annual dataset from 1973 to 2000 using threshold analysis. According to the results of the study, an inflation rate of over 9%, which was found to be the threshold, had a negative impact on economic growth. Research by [53] in Turkey showed a nonlinear relationship between inflation rate and economic growth via the two-regime Threshold Auto-Regression (TAR) model for the period 2003-2009. The results of the study revealed that an inflation threshold of 1.26% for the whole period of analysis exerted a negative effect on economic growth.

[54] investigated the influence of inflation threshold on long-term economic growth in 124 industrialized and non-industrialized countries based on data for the period between 1950 and 2004. They forecasted that the inflation threshold would be 2% for industrialized countries. The rate for non-industrialized countries was 17%. According to the results of the study, an inflation rate over the threshold had a negative effect on economic growth. Conversely, an inflation rate below the threshold had an insignificant influence on economic growth.

[55,56] argued that a large volume of studies has shown that a mild and stable inflation rate facilitates the decision-making processes of businesses. Researches have shown that high inflation crises lead to a significant decrease in growth rate. However, the growth rate will recover when inflation falls. The effect of inflation on economic growth was examined by [57]. Their study showed the effect of inflation on long-term economic growth based on data obtained for 170 countries covering from 1960 to 1992. The results suggested that inflation has a detrimental impact on growth rate by more than 10% to 20% annually.

The increase in domestic inflation caused by increasing production costs in different sectors can influence on their competitiveness and reduces productivity. Inflation also exclusively affects labor costs because wages are often considered as a cost of living index. In the study conducted by [58] the results indicated that domestic inflation affects the prices of energy and capital since most of these inputs are sourced domestically in the economy.

One of the greatest challenges of less-developed countries is macroeconomic instability. Therefore, the countries rely on international agencies for stabilizing their economies. The World Bank, International Monetary Fund, and Asian Development Bank are examples of such agencies. These agencies have different guidelines and suggestions in terms of reducing or increasing prices but suffer from a lack of effective coordination with each other in many cases. This situation can make it harder for policymakers to determine the levels of inflation required by Asian countries to stabilize their economies [59].

2.4 Trade Openness

The association between trade openness and economic growth has been one of the most important topics in recent decades. Neoclassical growth theories based on the Solow growth model state that there is no causal nexus between trade openness and economic development. The main reason for this argument is that the economic growth of a country is considered as an exogenous factor. This means that economic development can be designated by technological change or the population growth rate. Consequently, it is not affected by the country's openness to international trade. On the contrary, the new growth theory considers economic growth as an endogenous factor. Based on the new growth theory, capital accumulation also occurs through trade openness that facilitates the efficient use of resources and the transfer of technology between countries, which exert a positive effect on economic growth. Additionally, international commerce leads to the import of capital goods and other inputs that are costly to produce domestically. Hence, these goods are important for production because they provide the opportunity to export to less-developed countries [60,61,62]. Growth theories based on endogenous and exogenous theory are highly reliant on the rate of knowledge accumulation.

Knowledge accumulation can be improved by liberalizing the trade policy unilaterally and multilaterally and trade openness [63]

Studies from the past have indicated mixed and different results due to the selection of different countries and methodologies. Some researchers have found that trade and output growth are positively associated [63-69]. In contrast, [70] claimed that trade openness has a negative impact on economic growth.[71] argued that trade has a significant negative impact on income levels. In another study, [72] examined the unsatisfactory nexus between trade openness and economic growth rate. According to [73], countries with lower incomes benefit more from international trade compared to higher-income economies. He examined the trade-growth nexus for 150 countries.

[74] claimed that the effect of openness on low-growth rate countries is higher than for high-growth rate countries. The study used the Quantile-Regression technique to explore the association between trade and growth for 75 nations. In another study, [75] found that international trade is more beneficial in rich countries than in poor countries. The main reason for this is the inability of poor countries to exploit the accumulation of knowledge and technology for economic growth. Hence, it can be concluded that trade openness has different impacts on different countries.

2.5 Theoretical Framework

Following the theoretical background, this study used two models (i.e. equations 1 and 2) to investigate the association between energy consumption and CO_2 emissions and economic growth. Additionally, it investigates the relationship between other key macroeconomic parameters including inflation rate, investment rate, trade openness, and economic growth. The reason behind the selection of the two separate equations will be explained later. These equations are based on simple multivariate analysis and are formulated as follows:

$$GDP = \beta_0 + \beta_1 EC + \beta_2 INF + \beta_3 INV + \beta_4 TO \quad [1]$$

$$GDP = \alpha_0 + \alpha_1 CO_2 + \alpha_2 INF + \alpha_3 INV + \alpha_4 TO \quad [2]$$

Where GDP represents economic growth, EC is energy consumption and CO_2 stands for carbon dioxide emissions. INF is the inflation rate, while INV represents the investment rate and TO stands for trade openness.

The study hypotheses are as follows:

The null hypothesis based on the theories explained in this study suggests that energy consumption should increase the growth rate of the economy.

- - $\mathbf{H_1}$: There is a positive relationship between GDP growth and energy consumption.
- - $\mathbf{H_2}$: There is a positive relationship between GDP growth and CO_2 emissions.

The explanation for H_2 is that the amount of CO_2 emissions is intuitively expected to be positively correlated with the amount of fossil-based sources of energy such as oil and coal. This research subsequently estimates the equations above and investigates whether they reject the null hypothesis or not.

3. METHODOLOGY

Annual time series data were used from 1990 to 2018 for the selected countries, including the U.S., Japan, Canada, and Australia. These countries are highly dependent on oil energy consumption and their data are also available. All data have been collected from the electronic World Bank dataset. The dependent variable in the estimated models is the annual growth rate of Real GDP (annual growth rate of gross domestic product per capita at 2010 constant US dollars), which is the proxy for economic growth. The second variable is EC (energy consumption in kg of oil equivalent per capita). The third variable is CO_2 (carbon dioxide emissions in metric tons per capita). The fourth variable is INF (inflation rate which is considered as an annual consumer price as a percentage of GDP). The fifth variable is INV (investment rate that is considered as gross fixed capital formation as a percentage of GDP) and the last variable is TO (trade openness, which is the annual summation of the imports and exports of goods and services as a percentage of GDP).

3.1 Descriptive Analysis

Summary of descriptive statistics of variables from 1990 to 2018 are depicted in Tables 1-3.

Table 1. Descriptive statistics of variables

	Real GDP (2010 US dollars per capita)					**Energy Consumption (kg of oil equivalent per capita)**				
	Mean	**Median**	**Max**	**Min**	**SD**	**Mean**	**Median**	**Max**	**Min**	**SD**
The U.S.	2.46	2.68	4.75	-2.53	1.56	-0.61	1.01	3.54	-4.92	1.87
Japan	1.13	1.22	4.89	-5.41	1.91	-0.04	0.33	5.52	-7.49	2.78
Canada	2.51	2.79	6.86	-2.92	2.05	1.33	1.38	5.29	-4.25	1.93
Australia	3.07	3.20	5.07	-0.39	1.18	1.55	1.52	6.82	-2.30	2.02

Notes: Max, Min, and SD are maximum and minimum and standard deviation, respectivel

Table 2. Descriptive statistics of variables

	CO_2 emissions (Metric tons per capita)					**Investment (Gross fixed capital formation %GDP)**				
	Mean	**Median**	**Max**	**Min**	**SD**	**Mean**	**Median**	**Max**	**Min**	**SD**
The U.S.	0.18	0.95	4.65	-7.06	2.72	20.99	20.86	23.14	18.38	1.32
Japan	0.57	0.72	8.73	-6.38	3.28	26.24	24.60	34.12	21.32	3.62
Canada	1.06	1.38	6.14	-4.78	2.52	21.57	21.78	24.55	18.40	1.90
Australia	1.62	1.62	6.36	-2.44	2.07	25.75	25.99	28.26	22.88	1.59

Notes: Max, Min, and SD are maximum and minimum and standard deviation, respectively

Table 3. Descriptive statistics of variables

	Inflation (The annual consumer price %GDP)					**Trade Openness The annual sum of import and export of goods and services share of GDP (%GDP)**				
	Mean	**Median**	**Max**	**Min**	**SD**	**Mean**	**Median**	**Max**	**Min**	**SD**
The U.S.	2.47	2.60	5.39	-0.35	1.14	22.89	21.48	32.32	13.12	6.60
Japan	0.47	0.13	3.25	-1.35	1.16	21.74	20.64	32.88	13.09	6.52
Canada	2.02	1.86	5.62	0.16	1.10	51.31	51.35	67.57	31.92	10.91
Australia	2.62	2.44	7.33	0.22	1.42	29.99	23.56	54.74	16.33	12.52

Notes: Max, Min, and SD are maximum and minimum and standard deviation, respectively

3.2 Trend of Energy Consumption and GDP Growth

The graphical trend of energy consumption and GDP growth of each country is presented in Fig. 2 This figure shows that energy consumption moves in the same direction as the GDP growth in all the countries.

3.3 Correlation Matrix

Table 4 shows the correlation coefficient among the variables. The results show that for the U.S. and Australia strong correlations, (0.8758) and (0.7980), exist between energy consumption and CO_2 emissions. These results could cause a multicollinearity problem. Therefore, to avoid the multicollinearity problem, energy consumption and CO_2 emissions have been estimated in two separate regression equations. All other variables are weakly or moderately correlated with each other.

3.4 Unit Root Test

Unit root tests are used to determine whether time series data are stationary or non-stationary. A time series might be equal to its value plus an error terms. This means random walk phenomenon. Stationary series have constant means, constant auto covariance and constant variance for each lag [75]. Augmented Dicky-Fuller (ADF) test for unit root is used individually for each variable of each country. The null hypothesis is that the series has unit root in series. This means that the series is not stationary. The alternative hypothesis is that the series is stationary. The decision rule is to reject the null hypothesis when the t-statistics is more negative than the critical value at a chosen level of significance. Otherwise, do not reject the null hypothesis. Table 5 shows unit root results for each country, some of the variables are stationary at levels while others are stationary at first difference. Put differently, some variables are integrated of order zero, that is I(0), while others are integrated at order one, that is I(1). This means the former is stationary at levels but the latter only becomes stationary after taking the first difference.

3.5 Multiple Regression Analysis

Regression analysis is the most effective for econometric analysis. It is evaluating the effects of variables on other variables. In a simple way, regression analysis estimates the nature of relationship and impact of one or multiple independent variables on a dependent variable[76]. If the regression analysis examines the relationship between multiple independent variables and the dependent variable, it is identifying as a Multiple Regression method.

Multiple Regression equation is specified as follows;

$$Y_j = \beta_0 + \beta_1 + \beta_1 X_{1j} + \beta_2 X_{2j} + \cdots \beta_p X_{pj} + \varepsilon_j \quad [3]$$

In the above equation, X represents independent variables while Y is the dependent variable. In addition, j is denotes the cross-sections while the βs refers to the unknown regression coefficients and ε is stochastic error (residual) term which is used for testing the overall significance (F-test) of the equation and the significance of each regression coefficient (t-test). In order to obtain valid results from these tests the residual has to be normally and independently distributed, with a mean of zero and a constant variance of σ2 [77]. This is verified by what is called a residual analysis. This analysis may also lead to the elimination of data outliers. Another important indicator is the coefficient of determination, R-squared, which not only indicates the goodness of fit, but can also be interpreted as the amount of variation of the dependent variable explained by the regression equation [78].

3.6 Econometric Model

In this study, regression analysis has been conducted to estimate the relationship between selected explanatory variables and economic growth in each country. Therefore, multiple regression analysis has been conducted for each country to test the hypotheses. The main focus of the analysis in this research is to explore the impact of energy consumption and CO_2 emissions on economic growth.

Based on the production function, the empirical regression models are as follows:

$$GDP = f(EC.INF.INV.TO) \quad [4]$$

$$GDP = \beta_0 + \beta_1 EC + \beta_2 INF + \beta_3 INV + \beta_4 TO + u_t \quad [5]$$

Where variables are defined as follows:

GDP= GDP Growth Rate, EC= Energy Consumption, INF=Inflation Rate, INV=Investment Rate, TO= Trade Openness, u_t = Error Term, β_0 = Constant Term, $\beta_1 . \beta_2$, and β_4 are the slope coefficients of the variables respectively.

$$GDP = f(CO_2.INF.INV.TO) \quad [6]$$

$$GDP = \alpha_0 + \alpha_1 CO_2 + \alpha_2 INF + \alpha_3 INV + \alpha_4 TO + e_t \quad [7]$$

Variables are defined as follows:

GDP= GDP Growth Rate, CO_2= Carbon Dioxide Emissions, INF=Inflation Rate, INV=Investment Rate, TO= Trade Openness, e_t = Error Term, α_0 = Constant Term and $\alpha_1 \dots \alpha_4$ are the slope coefficients of the variables.

4. RESULTS AND DISCUSSION

In this section, two separate regression analyses have been conducted individually for the selected high oil energy-consuming countries (The U.S., Japan, Canada, and Australia). Annual time-series data obtained from the World Bank database covering the period from 1990 to 2018 for each country is used. The primary purpose of conducting regression analysis is to test the research hypotheses mentioned earlier.

4.1 Regression Results for the U.S.

Table 6 indicates that both energy consumption and investment rate have a positive impact on GDP. The coefficients of energy consumption and the investment rate are significant at 1%. Holding other variables constant, a 1% increase in energy consumption is associated with an increase of 0.56% increase in GDP growth. Similarly, a 1% increase in investment rate results in a 0.41% increase in GDP growth. Moreover, the R-squared showed the variation in explanatory variables explains 61% of the variation in GDP growth. This indicates that the regression is a good fit and the estimates are valid for policy inferences.

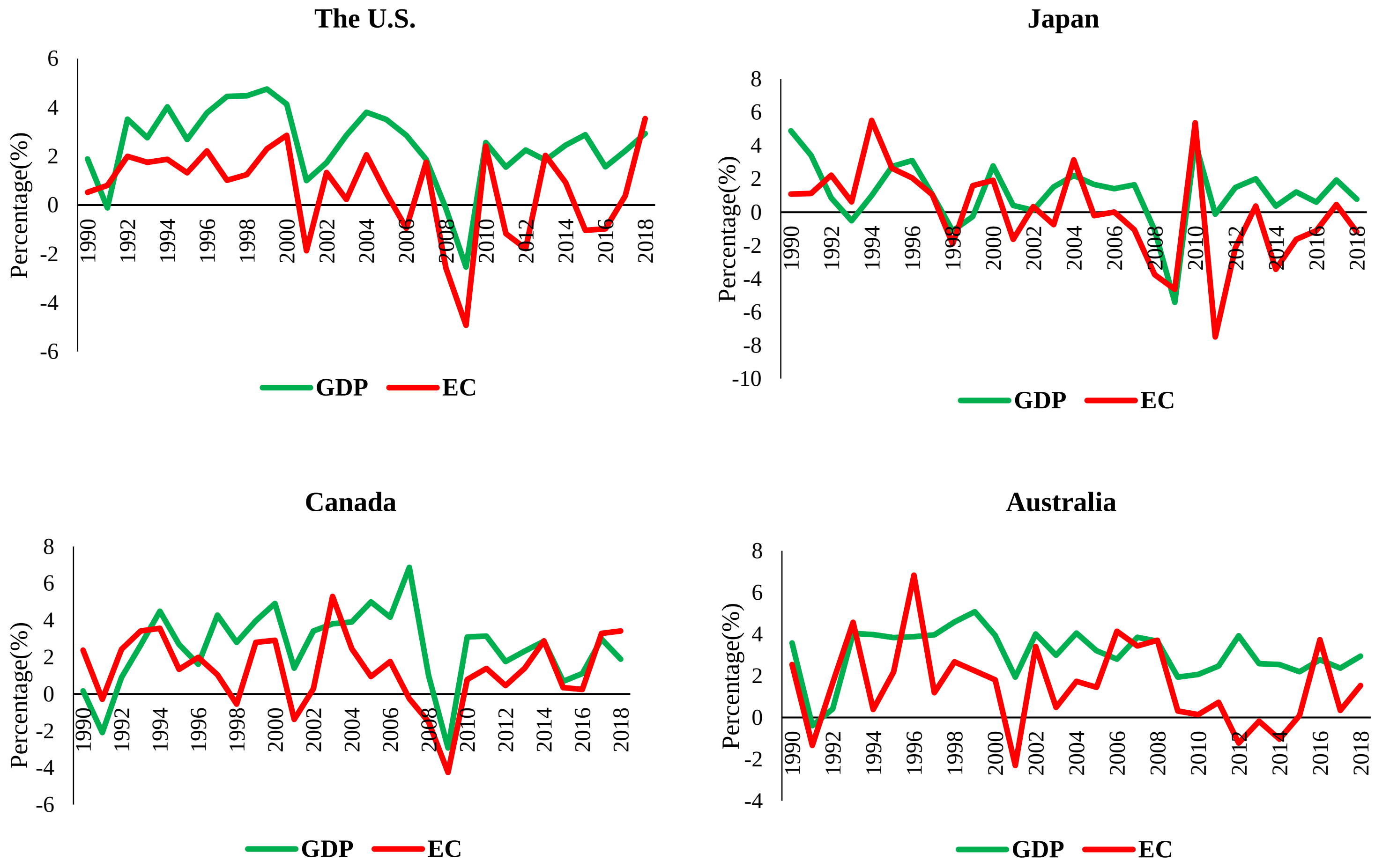

Fig. 2. Energy consumption and GDP growth in the U.S., Japan, Canada, and Australia (WORLD BANK, 2018)

Table 4. Correlation matrix

The U.S.	**EC**	**CO_2**	**INF**	**INV**	**TO**	**Japan**	**EC**	**CO_2**	**INF**	**INV**	**TO**
EC	1.0000					EC	1.0000				
CO_2	0.8758	1.0000				CO_2	0.3863	1.0000			
INF	0.2508	0.1872	1.0000			INF	0.0418	-0.0246	1.0000		
INV	0.2155	0.2136	0.3423	1.0000		INV	0.4437	0.2367	0.5834	1.0000	
TO	-0.276	-0.2637	-0.43	-0.3065	1.0000	TO	-0.4955	-0.1721	-0.1721	-0.5268	1.0000
Canada	**EC**	**CO_2**	**INF**	**INV**	**TO**	**Australia**	**EC**	**CO_2**	**INF**	**INV**	**TO**
EC	1.0000					EC	1.0000				
CO_2	0.5216	1.0000				CO_2	0.7980	1.0000			
INF	0.0917	-0.1848	1.0000			INF	0.0325	0.1527	1.0000		
INV	-0.2646	-0.242	-0.1024	1.0000		INV	-0.0321	-0.1156	0.3283	1.0000	
TO	-0.1605	-0.0083	-0.2729	0.5445	1.0000	TO	-0.3165	-0.5545	-0.1668	0.5061	1.0000

Table 5. Unit root test results

	Level t-stat	**First difference t-stat**	**Result**		**Level t-stat**	**First difference t-stat**	**Result**
The U.S.				**Canada**			
GDP	-3.35*		I(0)	GDP	-3.76**		I(0)
EC	-4.95***		I(0)	EC	-3.74**		I(0)
CO_2	-4.93***		I(0)	CO_2	-5.93***		I(0)
INF	-4.54***		I(0)	INF	-4.20**		I(0)
INV	-3.31*		I(0)	INV		-4.61***	I(1)
TO		-5.53***	I(1)	TO		-5.35***	I(1)
Japan				**Australia**			
GDP	-5.36***		I(0)	GDP	-5.25***		I(0)
EC	-6.87***		I(0)	EC	-5.15***		I(0)
CO_2	-5.21***		I(0)	CO_2	-5.12***		I(0)
INF		-5.57***	I(1)	INF	-5.21***		I(0)
INV		-3.77**	I(1)	INV		-5.13***	I(1)
TO		-5.77***	I(1)	TO		-3.28*	I(1)

*Note: I(0) denotes the variable is stationary at the level, while I(1) denotes the variable is stationary after the first difference. *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively*

On the other hand, the parameter estimates of the CO_2 emissions and investment rate are positive and statistically significant at 1% and 5% respectively. This indicates that CO_2 emissions and investment rate have a significant positive impact on the growth rate of GDP. By magnitude, holding other variables constant, a 1% increase in investment rate is associated with about 0.40% increase in GDP growth in the U.S. Furthermore, R-squared indicates that changes in the explanatory variables explain about 59% variation in GDP growth.

4.2 Regression Results for Japan

The regression result for the case of Japan in Table 7 shows that energy consumption and trade openness have positive nexus with a growth rate of GDP. Energy consumption is highly significant at 1% while trade openness is significant at 10%. The size of the coefficients indicates that, holding other variables constant, a 1% increase in energy consumption and trade openness bring about 0.47% and 0.18% increase in GDP growth respectively. R-squared indicated variation in independent variables explains 50% variation in GDP growth.

According to the regression result CO_2 emission has a positive association with GDP growth rate. This is shown by the positive value of the coefficients. CO_2 emission is statistically significant at 1%. The result is validated by the R-squared statistic which shows that variations in independent variables explain 42% variation in GDP growth.

4.3 Regression Results for Canada

Regression analysis in Table 8 showed that energy consumption, investment rate, and trade openness positively associated with GDP growth. The positive coefficients of variables indicate a positive nexus. Further, the result shows that energy consumption and trade openness are significant at 1% while the investment rate is significant at 5 %. By the magnitude of the coefficients, a 1% increase in energy consumption and investment rate results in 0.46% and 0.76% rise in GDP growth.

Table 6. The U.S. regression results

Variables	**C**	**EC**	**INF**	**INV**	**TO**
Coefficient	-5.84	0.56	-0.24	0.41	0.00
Std. Error	3.61	0.11	0.19	0.16	0.03
t-Statistics	-1.61	5.00	-1.21	2.54	-0.20
Probability	0.11	0.00***	0.23	0.01***	0.84
R-squared	0.61				
Variables	**C**	**CO_2**	**INF**	**INV**	**TO**
Coefficient	-5.52	0.37	-0.16	0.40	-0.00
Std. Error	3.70	0.07	0.20	0.16	0.03
t-Statistics	-1.48	4.76	-0.83	2.40	-0.16
Probability	0.14	0.00***	0.41	0.02**	0.87
R-squared	0.59				

*Note: *, **, *** denotes significance at 1%, 5% and 10%, respectively*

Table 7. Japan regression results

Variables	**C**	**EC**	**INF**	**INV**	**TO**
Coefficient	-9.38	0.47	0.14	0.24	0.18
Std. Error	7.84	0.11	0.40	0.22	0.10
t-Statistics	-1.19	4.11	0.36	1.08	1.78
Probability	0.24	0.00***	0.72	0.28	0.08*
R-squared	0.50				
Variables	**C**	**CO_2**	**INF**	**INV**	**TO**
Coefficient	-3.28	0.32	0.33	0.10	0.05
Std. Error	8.89	0.09	0.45	0.25	0.11
t-Statistics	-0.36	3.34	0.75	0.42	0.47
Probability	0.71	0.00***	0.45	0.67	0.63
R-squared	0.42				

*Note: *, **, *** denotes significance at 1%, 5% and 10%, respectively*

Table 8. Canada regression results

Variables	C	EC	INF	INV	TO
Coefficient	10.03	0.46	-0.10	0.76	0.16
Std. Error	4.66	0.16	0.29	0.31	0.05
t-Statistics	2.14	2.78	-0.36	-2.40	2.98
Probability	0.04	0.01***	0.72	0.02**	0.00***
R-squared	0.47				
Variables	**C**	**CO_2**	**INF**	**INV**	**TO**
Coefficient	6.33	0.48	0.09	0.50	0.12
Std. Error	4.34	0.11	0.26	0.29	0.05
t-Statistics	1.45	4.10	0.36	-1.68	2.35
Probability	0.15	0.00***	0.71	0.10*	0.02**
R-squared	0.59				

*Note: *, **, *** denotes significance at 1%, 5% and 10%, respectively*

Table 9. Australia regression results

Variables	C	EC	INF	INV	TO
Coefficient	-1.92	0.25	-0.12	0.21	-0.01
Std. Error	3.88	0.10	0.16	0.17	0.02
t-Statistics	-0.49	2.37	-0.74	1.22	-0.82
Probability	0.62	0.02**	0.46	0.23	0.41
R-squared	0.28				
Variables	**C**	**CO_2**	**INF**	**INV**	**TO**
Coefficient	-1.84	0.27	-0.14	0.19	0.00
Std. Error	3.98	0.12	0.17	0.18	0.02
t-Statistics	-0.46	2.09	-0.86	1.07	0.17
Probability	0.64	0.04**	0.39	0.29	0.85
R-squared	0.25				

*Note: *, **, *** denotes significance at 1%, 5% and 10%, respectively*

Likewise, a 1% increase in trade openness leads to about a 0.16% increase in GDP growth while holding other factors constant. R-squared value indicates that variation in predictor variables explains a 47% variation in GDP growth.

Result demonstrates that CO_2 emissions, investment rate, and trade openness have a positive relationship with GDP growth. The coefficients of variables are subsequently significant at 1%, 10% and 5%. According to the regression result, a 1% increase in investment rate and trade openness brings about a 0.50% and 0.12% increase in GDP growth. Besides, the R-squared illuminated variation in the predictor variable explains 59% variation in GDP growth.

4.4 Regression Results for Australia

It is obvious in Table 9; the fitted regression depicted that energy consumption positively associated with GDP growth. It is also significant at 5%. Ceteris paribus, a 1%increase in energy consumption is likely to be associated with a 0.25% increase in GDP growth. The R-squared showed variation in explanatory variables explains 28% variation in GDP growth. This indicates that the independent variables weakly explained the variation in economic growth.

In Table 9, the result demonstrates that CO_2 emission has a positive relationship with GDP growth and the parameter estimate of CO_2 emission is significant at 5%. The R-squared statistic indicated that variation in predictor variables explains a 25% variation in GDP growth.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

This research provided an empirical evaluation of the association between energy consumption, CO_2 emissions, and economic growth in the U.S., Japan, Canada, and Australia. Besides, the study analyzed the impact of some primary macroeconomic variables, including inflation rate, investment rate, and trade openness on the economic growth of the selected countries. Multiple regression analysis has been employed for the annual time series data from 1990 to 2018.

The findings showed that the inflation rate does not have a significant impact on economic growth in all of the countries. The plausible explanation is that the governments of the sampled countries maintain the rate of inflation as low and stable as possible to boost economic growth. Low inflation rate is also necessary to minimize uncertainty of financial market which in turn boost investment in country [79].

The investment rate had a positive and significant impact on economic growth in the U.S. and Canada. This suggested that in these countries, the accumulation of physical capital is essential for the process of economic growth. The low-interest rate and low unemployment, combined with a high rate of savings, have a positive influence on economic growth. Moreover, because of globalization, countries have significantly transformed their economies and provide investment opportunities over the years [80].

Furthermore, the findings of this study revealed that trade openness has a significant positive relationship with economic growth in Japan and Canada. This means that the relative GDP shares of exports and imports are likely to influence the rate of economic growth positively in these two countries through their positive effects on productivity growth. By increasing trades, technological advances and innovations will be improved which can be so helpful for countries to upgrade and modernize their industries.Therefore, policies in terms of trade liberalization and trade agreements that eliminate trade barriers for these countries would propel long-run economic growth.

The main conclusion of this study is that a significant positive association existed between economic growth and energy consumption and between economic growth and CO_2 emissions in the selected countries. Thus, hypotheses have been accepted based on the findings. Moreover, the results suggested that in the top oil-consuming countries, energy is indeed an indispensable part of economic development. This conforms to the submission of ANG (2008) that fossil fuel energy is vital for industrialization, agriculture, and transportation to enhance economic activity. Policy makers should adopt several actions to improve energy efficiency. In order to control the excessive usage of energy government regulators should also recognize those divisions which consumes less energy. Those sectors which consume higher energy are suggested to improve their technology which should be energy efficient. If policy makers will not apply rules according to these suggestions then this may adversely affect the GDP growth [81-84]. Moreover, Increasing the rate of tax or price of energy for industries that have high energy consumption will encourage them to use energy efficiently [85]. Therefore, implementing advanced technologies to augment the efficient use of energy in industries or plants is necessary.

Consequently, carbon dioxide gas emission results from the consumption of fossil fuel energy that has an unfavourable impact on the environment. In a nutshell, even though the level of GDP can increase as a result of using more fuel-based sources of energy, this may have an adverse effect on the environment and quality of life. Since carbon emissions are destructive for the environment, various policies should be implemented to reduce environmental inequality. For instance, by using bio-diesel fuel instead of fossil fuel energy, the industrial and transportation sectors can mitigate the effects of greenhouse gas problems [86]. Besides, based on the feasibility in the individual countries, governments can invest more in renewable sources of energy including solar energy, wind energy, hydro energy, nuclear energy to augment productivity [87-88]. It is highly recommended that special funds and support allocated to scientific research institutes in developed countries to find solutions for converting carbon emissions into green energy. This will be beneficial for the environment and the citizens of those countries. Furthermore, the standardization of manufacturing systems will lead to the efficient use of energy and promote sustainable and low carbon economies.

The method of this study can be used by energy consultant and managers to control and audit energy usage in different sectors. Likewise, Future studies can develop these models with other input variables and compare with non-linear models for better forecasting of energy consumption and economic growth.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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