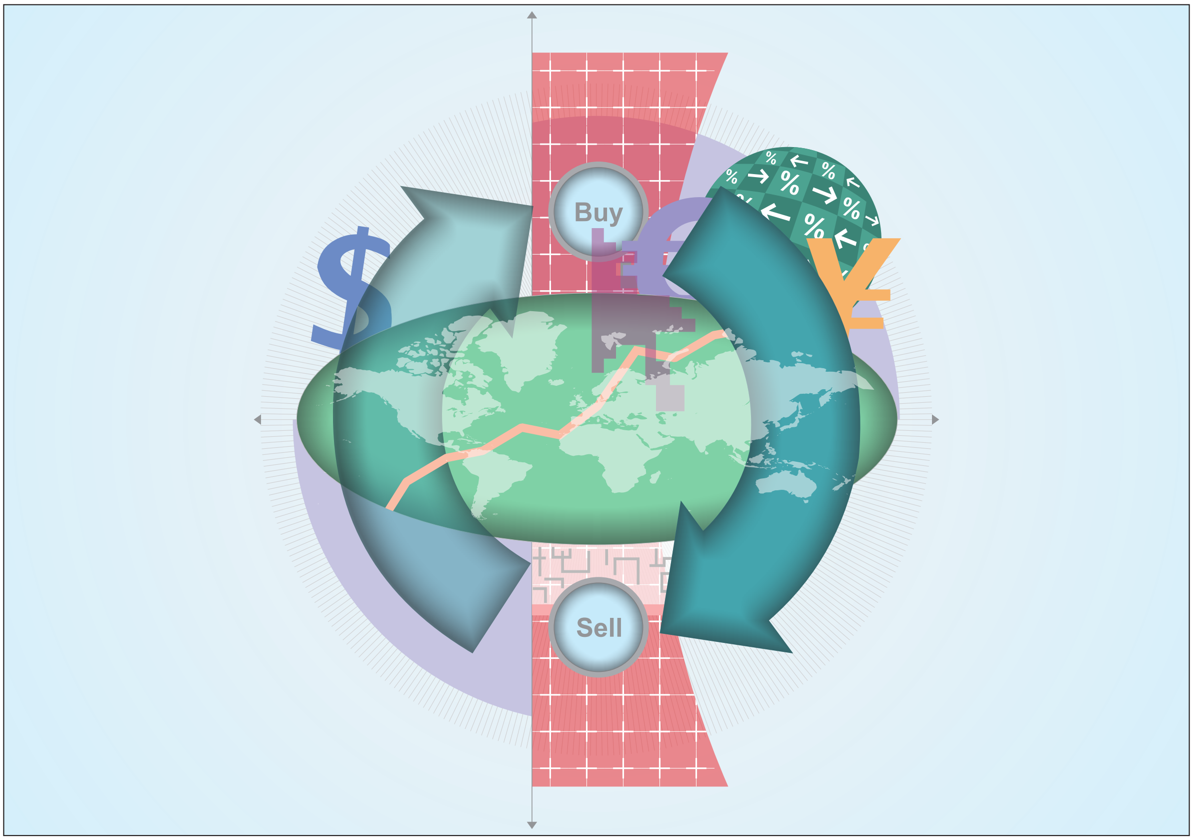

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Energy Consumption, Pollutant Emissions and Economic Growth: China Experience

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ABSTRACT

This study examined the relationship between carbon dioxide emission, energy consumption and economic growth in China. The period in view is 1971 to 2008 and the study introduced industrialization and capital as additional variables. Based on a VECM, we tested Granger causality after finding the cointegration among the variables. The result of the VECM shows a causal relationship between CO_2 emission and economic growth with causality running from CO_2 emission to economic growth. We also found a causal relationship between industrialization and economic growth with causality running from industrialization to economic growth. The important policy implication resulting from this analysis is that government can pursue the preservation and careful management of the environment by curtailing energy use for development purposes without creating harsh effects on economic growth. There is need for mitigation of emission by developing of carbon markets, taxes on carbon and subsidies to encourage faster technological progress. The study suggests that energy and environmental policies should recognize the differences in the energy consumption-growth nexus in order to maintain sustainable economic growth in China.

Key words: Energy consumption, pollutant emissions, industrialization, economic growth, cointegration

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) reported that the most important environmental problem of our ages is global warming, which is caused by greenhouse gas emissions, especially carbon dioxide (CO_2) emissions produced mainly from the consumption of fossil fuels (Mehrara, 2007).

Apergis and Payne (2010) noted that the worldwide concern about the threat of global warming and climate change was increasing during the last three decades. It has become a dominating question both politically and economically. One of the most questions worried out the researchers is: how can we assuage adverse effects of climate change? The 1997 Kyoto protocol had the objective of reducing greenhouse gases (GHG) that cause climate change by fixing the reduction of GHG emissions to 5.2% lower than the 1990 level during the period 2008 to 2012 and this came into force since 2005. There are several environmental pollutants which cause climate change, but Carbone dioxide (CO_2) still the dominant gas of total GHG in the world and (IEA, 2011).

Chien and Hu (2007) emphasized that the use of energy from exhaustible resources can create energy shortage in the future Of China's industrial development. The solutions to this problems of energy and environmental degradation will includes increasing in the use of energy-saving and environmentally friendly methods in production and consumption and promoting technological innovations that will reduce the use of energy per unit of output (reduce energy intensity or increase energy efficiency). We can regulate the use of energy by law or by economic incentives to limit the emission of pollutants (Kareem *et al*., 2012; Salami *et al*., 2012).

Moreover, there are that four aspects of the energy-environment problem, explicitly (1) air pollution, (2) water pollution, (3) the emission of CO_2 in the atmosphere that causes global warming, mainly from the burning of coal and (4) shortage of future energy supply that relies on exhaustible resources. Industrial boilers and furnaces consume almost half of China's coal and are the largest sources of urban air pollution. As the country becomes industrialized, pollution from both industrial and consumer sources have increased because of higher levels of output and consumption (Xu *et al*., 2002).

In 2004, China accounted for one-third of global demand in oil, turning the country into the world's second-largest oil importer (Zweig and Jianhai, 2005). Given current expansion in energy demand, China is expected to overtake the United States as the world's largest emitter of carbon dioxide by 2020 (Xu *et al*., 2002). Because most of China's energy facilities are located near major urban centers, energy consumption's negative effect is demonstrated visibly through poor air quality that is well above World Health Organization guidelines (Chien and Hu, 2007).

China's cumulative emissions of carbon dioxide from fossil fuel combustion accounted for only 9.33% of the world total during the period of 1959-2002 and the cumulative carbon dioxide emissions per capita are 61.7 tons over the same period, ranking the 92nd in the world (IEA, 2011). This indicate that per capita carbon dioxide emissions from fossil fuel combustion were 3.65 tons in 2004 in China, equivalent to only 87% of the world average and 33% of the level of the Organization for Economic Co-operation and development (OECD) countries. Along with steady social and economic development, the emission intensity defined as the carbon dioxide emission per unit of GDP declined generally.

The aim of this study was to fill this gap by investigating the relationship between economic growth, energy consumption and carbon-dioxide emissions in a multivariate framework by including government expenditure on science and technology and gross fixed capital formation as additional variables. The purpose is to show how environmental degradation and other crucial variables such as energy combine with capital to affect the growth process. The paper also examines the causality among the variables.

LITERATURE OVERVIEW

Future energy consumption in China as in World Energy Outlook (IEA, 2011), identified the different developing scenarios. Under the baseline scenario, considering the improvement of energy efficiency, the growing rate of energy demand is obviously lower than that of GDP. Even so, the total energy demand in 2030 will be over 5.1 billion tce. Under the policy scenario, considering further improvement of energy efficiency and the shift of energy structure to clean energy, the total energy demand in 2030 will reach 4.3 billion tce from the analysis of EIA (2006). Under policy scenarios, coal is still the dominator of energy use. Therefore, China will face the control of air pollution due to consumption of fossil fuel in a long period.

The first focuses on the relationship between economic growth and energy consumption dating back to the pioneering work by Kraft and Kraft (1978) and leading to the use of Granger causality test approach as a tool for studying the relationship between energy consumption and economic growth in different countries, that has been noted in the work of some researchers example of Stern (1993), Aqeel and Butt (2001), Yuan *et al.* (2008), Ghosh (2010), Lau *et al.* (2011), Binh (2011) and Kaplan *et al.* (2011).

Ozturk (2010) focuses on the relationship between economic growth and environment, discussing the inverted U-shaped relationship between environmental pollutants and economic growth by testing the validity of environmental Kuznets curve (EKC) hypothesis. The empirical studies carried out by several authors drew different conclusions. Tunc *et al.* (2009) provided empirical evidences on the validity of EKC hypothesis. However, Holtz-Eakin and Selden (1995) found a monotonic rising curve and Friedl and Getzner (2003) found an N-shaped curve. On the other hand, Agras and Chapman (1999) and Richmond and Kaufman (2006) concluded that there is no significant relationship between economic growth and environmental pollutants.

The investigation on the relationships between pollutant emissions, energy-consumption and economic growth in consider simultaneously in a modeling framework. These studies have attempted to analyze the causal relationships between these three variables by combining the literature on EKC with the energy consumption-growth literature as noted in following researchers like (Richmond and Kaufman, 2006; Soytas *et al.*, 2007; Ang, 2007; Soytas and Sari, 2009; Tunc *et al.*, 2009; Acaravci and Ozturk, 2010; Apergis and Payne, 2010; Ozturk and Acaravci, 2010; Wang *et al.*, 2011).

Apergis and Payne (2010) explored the relationship between carbon dioxide emissions, energy consumption and real output for 11 countries of the Commonwealth of independent states over the period 1992-2004. They found that in the long-run, energy consumption has a positive and statistically significant impact on carbon dioxide emissions while real output follows an inverted U- shape pattern associated with the Environmental Kuznets Curve (EKC) hypothesis. They found bidirectional causality between energy consumption and CO_2 emissions in the long run. But the short run dynamics reveal a unidirectional direction from energy consumption and real output, respectively, to carbon dioxide emissions and bidirectional causality between energy consumption and real output.

Wang *et al.* (2011) confirmed the existence of a relationship between the three variables using panel cointegration and panel vector error correction modeling techniques based on the panel data for 28 provinces in China during 1995-2007. They found bidirectional causality between CO_2 emissions and energy consumption as well as between energy consumption and economic growth. The authors also found that energy consumption and economic growth are the long-run causes for CO_2 emissions and CO_2 emissions and economic growth are the long-run causes for energy consumption.

Kraft and Kraft (1978) found a unidirectional Granger Causality running from output to energy consumption for the United States using monthly data during the period 1947-1974, to examine the causality relationships between economic development and energy consumption. Yu and Choi (1985) and Bentzen and Engsted (1993) confirmed or contradicted the results of Kraft and Kraft (1978), which differ in terms of time period covered, countries chosen, econometric techniques employed and the proxy variables or control variables used in the estimation. Acaravci and Ozturk (2010) investigated the dynamic relationship between these variables for 19 European countries by using autoregressive distributed lag (ARDL) bounds cointegration analysis developed by Pesaran and Shin (1999) and Pesaran *et al.* (2001) and error correction based Granger causality models. The bounds F-test for cointegration test yields evidence of a long-run relationship between carbon emissions per capita, energy consumption per capita, real gross domestic product (GDP) per capita and the square of per capita real GDP only for Denmark, Germany, Greece, Iceland, Italy, Portugal and Switzerland. Also, the cumulative sum and cumulative sum of squares tests reveal that the estimated parameters are stable for the sample period.

Also, China in 2004 accounted for one-third of global demand in oil, turning the country into the world's second-largest oil importer (Zweig and Jianhai, 2005). Given current expansion in energy demand, China is expected to overtake the United States as the world's largest emitter of carbon dioxide by 2020 (Xu *et al.*, 2002). Because most of China's energy facilities are located near major urban centers, energy consumption's negative effect is demonstrated visibly through poor air quality that is well above World Health Organization guidelines (Zweig and Jianhai, 2005). Increased energy use is fueled largely by industrial and trade expansion. With respect to the natural gas, China can basically maintain a balance between demand and supply. In 2007, the production of natural gas is 69,200 million cubic meter (cu.m), while the consumption of the corresponding time period is 69,500 million cu.m. As for the crude oil, China has become a net importer of crude oil since 1993 and in 2003 it surpassed Japan as the world's second-largest oil importer (Zhao and Wu, 2007).

Furthermore, the variation in production and consumption within provinces, there is a great deal of variation in the energy intensity as measured by 10 000 Yuan GDP per unit of ton of energy use, ranging from 0.71 in Beijing to 3.95 in Ningxia. China's current task is to solve the contradiction between rapid growth maintaining and greenhouse gas emissions reduction. The choice is also motivated by the fact that China's energy industries and policy makers face great pressure to change the energy structure and restore with the growing environmental concern among the Chinese people.

Ghali and El-Sakka (2004) analyzed the causal relationship between energy use and output growth in Canada. They found that energy enters significantly into the cointegration space by testing for multivariate cointegration between output, capital, labor and energy use. Moreover, the short-run dynamics of the variables showed that the flow of causality ran in both directions between output growth and energy use.

Lee (2005) applied panel estimation techniques to 18 developing countries, including sub-Saharan African, Kenya and Ghana and finds evidence of causality running from energy consumption to GDP. Lee and Chang (2008a) use a panel error correction model to examine the shor-trun and long-run causality between energy consumption and economic growth for a panel of 22 OECD countries. Their results show a bidirectional relationship between energy consumption, capital stock and GDP.

Mozumder and Marathe (2007) examined the causal relationship between the per capita electricity consumption and the per capita GDP for Bangladesh using a cointegration and vector error-correction model. Their results showed that there was unidirectional causality running from per capita GDP to per capita electricity consumption. Energy consumption is a prerequisite for economic growth given that energy is a direct input in the production process and an indirect input that complements labor and capital inputs (Masih and Masih, 1996; Soytas and Sari, 2003).

In this case a unidirectional Granger causality running from energy consumption to GDP means that the country's economy is energy dependent and that policies promoting energy consumption should be adopted in to stimulate economic growth because inadequate provision of energy may limit economic growth. The implication is that energy consumption and economic growth are complementary and that an increase in energy consumption stimulates economic growth and vice-versa.

Yuan *et al.* (2007) applied the cointegration theory to examine the causal relationship between electricity consumption and real GDP for China during the 1978 to 2004 period. Their estimates indicated that real GDP and electricity consumption for China were cointegrated and that there was only unidirectional Granger causality running from electricity consumption to real GDP, but not vice versa. There positive and significant relationships between energy consumption and economic growth are found by Lee and Chang (2008b) by including capital stock in the model for some Asian countries. Belloumi (2009) studied the casual relationship between energy consumption and economic growth using both bivariate and multivariate models. They found that economic growth, employment and energy consumption have cointegration relationship. The causality results show that economic growth causes energy consumption and economic activity.

In consideration of the high economy and energy consumption growth rate, as well as high industrial waste gas emission growth rate, the environment-energy- development nexus poses tremendous challenges to Chinese policy makers. Economic growth rate is expected to keep as high as 7%-8% in the next two decades (Zhao and Yuan, 2008). There is a simple cost-benefit relationship generalized from the Granger causal relationships between pollutant emission, energy consumption and economic development. Along with economic development, energy consumption will bring about the externality of environmental pollution. The question is whether energy consumption can result in greater benefits in economic development relative to the cost of environmental pollution (Huang *et al.*, 2008).

The aim of this study is to examine the effect of CO_2 emission and energy consumption on economic growth, to do this; we assume that economic agents in a country consist of households, firms and the rest of the world. We therefore represent the production function of the economic agents as:

$$Y_t = A_t K_t^{ai} E_t^{ki} C_t^{li} \tag{1}$$

where, Y_t represents the output, K_t represents capital, E_t represents energy consumption, C_t represents CO_2 emission and A_t represents industrialization (proxied by the government expenditure on science and technology). We later transform the production function into a regression equation of the form:

$$GDP = \alpha_0 + \alpha_1 T + \beta_2 CO_2 + \beta_3 EN + \beta_4 CAP + \varepsilon_t \tag{2}$$

where, GDP is the gross domestic product (in US$) as measure of economic growth, T represents the government expenditure on science and technology, CO_2 represents carbon dioxide emission (kt), EN represents energy consumption (kt of oil equivalent) and CAP represents the gross fixed capital formation(US$).

MATERIALS AND METHODS

Data: Our Analysis is confined to the period 1971-2008 due to data availability. During this period, the Chinese economy witnessed an annual growth rate of about 8-10% due to various reform programmes put in place by the Chinese government. We sourced the data on energy consumption (E), carbon dioxide emission(c), gross capital formation, real GDP (C) and government expenditure on science and technology from Data Stream.

Methodology

Vector error correction model: The Vector error correction (VEC) model is a restricted VAR that is usually used for estimating non stationary series that are cointegrated. The VEC has cointegration term known as the error correction term built into the specification so that it restricts the long run behavior of the endogenous variables to converge to their cointegrating relationships while at the same allowing short-run adjustment dynamics. The VEC model is based on the appropriate lag test with the equation;

$$\Gamma'_{0\Delta}z_t = \alpha\beta' Z_{t-1} + \Gamma'_{1\Delta}z_{t-1} + ...+ \Gamma'_{n\Delta}z_{t-n} + \Phi x_t + \Xi D_t + \mu_t \quad (3)$$

where, D_t represents the deterministic terms, x_t is a vector of exogenous or unmodeled variables, the vector z_t contains the endogenous variables, Δ is the differencing operator so that $_\Delta z_t = z_t - z_{t-1}$ and μ_t is the error vector which is assumed to be white noise and is serially uncorrelated with zero mean and constant nonsingular covariance matrix Σ_{μ}. Γ'_0 is not assumed to be an identity matrix, therefore, the Γ'_I matrices are structural co-efficient matrices. The error correction term $\beta' Z_{t-1}$, represents the response of the dependent variable in each period to departure from equilibrium. The weights of the cointegration relations in the equations of the system are in the loading matrix α which contains the weights of the cointegration relations in the equations of the system.

RESULTS AND DISCUSSION

Statistics: The descriptive statistics of the variables in the Table 1 shows that the mean of real GDP is the highest among the variable while the variation in GDP is also the highest as shown by the standard deviation.

In the descriptive statistic analysis show that all the variables used in this study shows considerable increase for the period. The trend is represented in the Fig. 1.

Also Fig. 1 shows the trend of the variables, from the figure, it can be observed that the GDP of China increased significantly during the period under study. Also, the expenditure on science and technology increases considerably, this is as a result of the recognition of science and technology as the key driver of economic growth by the Chinese government who have been investing heavily on science and technology.

Table 1: Descriptive statistics analysis

	GDP	CO_2	EN	EXPTECH	CAP
Mean	8.22E+11	2799476	923711.4	480.7934	3.01E+11
Std. Dev.	1.01E+12	1666063	440763	580.0725	4.11E+11
Skewness	2.071544	1.087559	1.121067	1.372459	2.175263
Kurtosis	7.082227	3.457423	3.638543	3.862387	7.479727
Jarque-Bera	53.56376	7.822262	8.60526	13.10729	61.74214

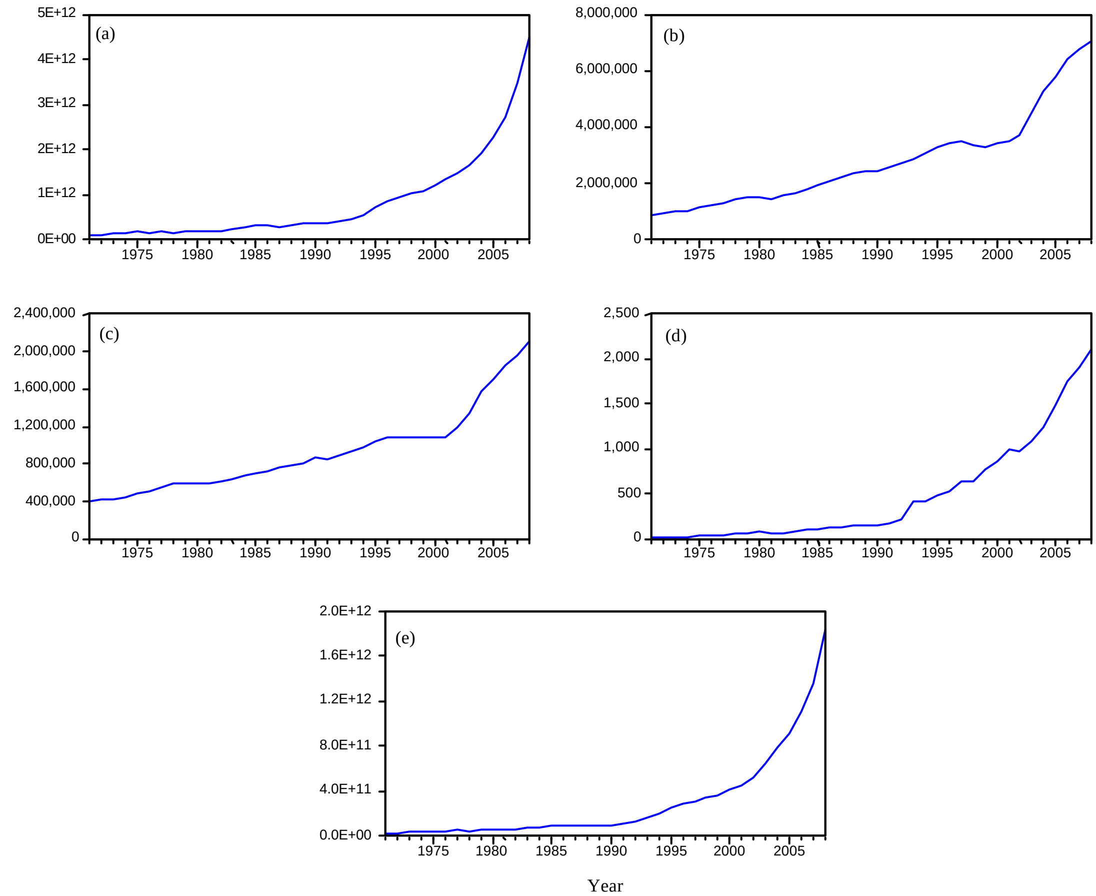

Fig. 1(a-e): Trend of the research variables, (a) GDP (current US\$), (b) CO_2 emissions (kt), (c) Energy use (kt of oil equivalent), (d) Expenditure on Technology(T) US\$ and (e) Gross fixed capital formation (current US\$)

Unit root: Before estimating the relationship amongst the variables, there is a need to test the order of integration of the each of the variables. Using a non-stationary variable in regression estimation has a number of consequences which are the inefficiency of the regression coefficient, non-optimality of the forecast based on the estimates and non-validity of the significant test on the coefficient (Granger, 1969). Therefore, to avoid the problems posed by using a non-stationary variable, we tested whether CO_2 emission, energy consumption, real GDP, expenditure on technology and capital stock are integrated of order zero, I(1) by performing both the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) test at levels and first difference. We present the result of the unit root in Table 2.

The result of the Unit root shows that the variables are not stationary at level; we therefore tested the stationarity at first difference. The result therefore shows that all the variables are stationary at first difference as shown in Table 2.

Cointegration test and error correction model: After establishing the level of integration of the series, we use tested whether there is long run relationship among the variables using the

Table 2: Unit root test

	Augmented dickey fuller (ADF)		Phillips perron (PP)	
	First difference			
Variables	Constant without trend	Constant with trend	Constant without trend	Constant with trend
LGDP	-4.6688**	-5.5539**	-4.9962***	-5.1505***
	(1)	(5)	[2]	[1]
LCAP	-7.8866***	-7.8202***	-7.8917***	-7.8424***
	(0)	(0)	[2]	[2]
LEN	-4.2243***	-4.2494***	-4.1600***	-4.1756**
	(0)	(0)	[3]	[3]
LT	-5.8985***	-6.5437***	-5.8984***	-6.6950***
	(0)	(0)	[1]	[5]
LCO_2	-7.3009***	-7.2580***	-7.2206***	-7.2291***
	(0)	(0)	[2]	[2]

*** and ** denotes significant at 1% and 5% significance level respectively. The value in parenthesis (...) represents optimum lag length selected based on Akaike Info Criterion. The value in bracket [...] represents the band width used in the KISS test selected based on Newey-West Bandwidth Criterion

Table 3: VAR lag order selection criteria

Endogenous variables: GDP EN CO2 CAP T

Exogenous variables: C

Included observations: 34

Lag	LR	FPE	AIC	SC	HQ
0	NA	2.93E+68	171.8392	172.0637	171.9158
1	342.8347	6.25E+63	161.0657	162.4125*	161.525
2	50.64525	3.33E+63	160.3344	162.8035	161.1764
3	30.55553	3.52E+63	160.1074	163.6988	161.3322
4	44.79095*	9.19e+62*	158.1325*	162.8463	159.7401*

*Indicates lag order selected by the criterion, LR: sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

Johansen multivariate cointegration tests. This test involves testing the number of cointegrating vectors. Before estimating cointegration test, the optimal lag order for estimating the Vector autoregression model (VAR) must be selected. To do that, we used several information criteria as shown in Table 3. The result shows that all criteria except Schwarz information (SC) indicate four lags. We therefore used an optimal lag length of four.

Having selected the lag length, we use Johansen cointegration test to examine whether there is long run relationship among this test involves testing the number of cointegrating vectors. The result of the Johansen cointegration test as presented in Table 4 shows that the null hypothesis of no cointegration is rejected for the trace statistics and the maximum eigenvalue since they are both greater than their critical value. The result also indicates that there are four cointegrating vectors in the model.

Vector error correction model: Having tested the presence of cointegration amongst the variables, we investigate the short run and long-run causality as well as joint causality of both long-run and short-run causality using VECM. The result of the causality test based on VECM is presented in Table 5 and 6.

Table 4: JOHANSEN-JUSELIUS cointegration test

Hypothesized no of Ces	Trace statistic	Max-eigen statistic	Critical values (5%) Trace	Max-Eigen
r = 0	217.122**	122.9848**	69.8189	33.8769
r = 1	94.1375**	39.4285**	47.8561	27.5843
r = 2	54.7090**	33.5591**	29.7971	21.1316
r = 3	21.1499**	20.9578**	15.4947	14.2646
r = 4	0.1921	0.19212	3.8415	3.8415

**Denotes significant at 5% significance level

Table 5: Results of long-run multivariate causality tests based on the error correction model

Error correction	D(GDP)	D(CO_2)	D(EN)	D(T)	D(CAP)
CointEq1	-4.169996**	1.04E-07	-1.07E-06	6.81E-10	-1.495406**
CointEq2	347096.6	0.186906	0.388074	-3.47E-05	117138.1
CointEq3	-777588.9	-0.313692	-1.346206	0.000554	-241554.6
CointEq4	-6.95E+08**	-2174.254	-88.51829	-0.813594	-4.38E+08**

**Denotes the rejection of the null hypothesis at 5%

Table 6: Summary the multivariate short run causality tests based on the error correction model

Y	X: GDP	CO_2	EN	T	CAP
GDP	-	0.0005**	0.5555	0.0027**	0.7269
CO_2	0.0921	-	0.6532	0.0481**	0.0181**
EN	0.0335**	0.0887	-	0.4984	0.018**
T	0.5825	0.8812	0.8338	-	0.0796
CAP	0.3997	0.0951	0.6178	0.5094	-

**Denotes rejection of the hypothesis (X does not Granger cause Y) at the 0.05 level

Table 5 shows the result the result of the long run causality; our result indicates a long run relationship between the dependent variables and the independent variables.

Table 6 shows the multivariate short run causality tests based on the error correction model. In the case of the short run causality result, as shown in Table 6, we found a causal relationship between CO_2 emission and economic growth with causality running from CO_2 emission to economic growth.

We also found a causal relationship between industrialization and economic growth with causality running from industrialization to economic growth. Our result shows a unidirectional causal relationship between economic growth and energy consumption with causality running from economic growth to energy consumption. Furthermore, the result also indicates a causal relationship between industrialization and carbon dioxide emission with causality running from industrialization to carbon dioxide emission.

CONCLUSION

Understanding the relationship between energy consumption, carbon dioxide emission and economic growth is important for policy makers if they are to develop policies that will safeguard the environment against degradation. In view of this, we examine the relationship between carbon dioxide emission, energy consumption and economic growth in China over the period 1971 to 2008 by introducing industrialization and capital as additional variables. Based on a VECM, we tested Granger causality after finding the cointegration among the variables.

Our result indicates that carbon dioxide emission-energy consumption -economic growth nexus is a serious challenge for China considering the growth rate of the Chinese economy. China is the highest emitter of greenhouse gases after the United States and the growth rate of the Chinese economy means the demand for energy will be high. Therefore, there is need for the authorities in the Chinese government to cut down CO_2 emission and at the same time shift to the development of alternative source of energy. Our result has also indicated the importance of government expenditure and energy to the economic growth of China; therefore, there is a need for the Chinese government to continue its policy on funding research in science and technology in order to provide a source of energy that will be environmentally friendly without abating the economic growth of the country. There is need for mitigation of emission by developing of carbon markets, taxes on carbon and subsidies to encourage faster technological progress. The study suggests that energy and environmental policies should recognize the differences in the energy consumption-growth nexus in order to maintain sustainable economic growth in China.

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