Are population and international trade the main factors for environmental damage in China?

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Abstract

This paper investigates whether population and international trade, along with energy consumption, are the main factors for environmental damage in China during the period 1971-2011. The stationary analysis is examined by the Zivot–Andrews unit root test and the ARDL bounds testing approach is used for a long run relationship between the series in the presence of structural breaks. The causality between CO_2 emissions, energy consumption, economic growth, population and international trade is examined by the VECM Granger causality technique. Our results show that the selected variables are cointegrated; it means that the long run relationship exists in the presence of structural breaks. The empirical findings indicate that in long run, energy consumption and population increase CO_2 emissions, while in short run, energy consumption and international trade decrease CO_2 emissions. The VECM causality analysis shows that CO_2 emissions Granger cause energy consumption, while energy consumption and population Granger cause trade. The VECM analysis also indicates the feedback hypothesis between trade and CO_2 emissions. Policy recommendations are made following the obtained results.

Key Words: CO_2 emissions; population; international trade; energy consumption.
JEL Classification: Q43; Q53; Q56; C22; O44.

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1. Introduction

China has attained some remarkable achievements over the last several decades. For example, the GDP per capita of China (constant 2005 US$) increased dramatically from US$ 121.19 in 1960 to US$ 3,862.91 in 2014. The total trade (import and export) per capita (constant 2005 US$) increased from US$ 10.68 in 1960 to US$ 1,604.59 in 2014. The poverty headcount ratio at US$ 1.9 a day (2011 PPP, % of population) decreased rapidly from 88.32 % in 1981 to 1.85 % in 2013. However, the total population of China increased dramatically (more than double), from 0.667 billion in 1960 to 1.371 billion in 2015. The population density (people per square km of land area) increased from 70.33 in 1961 to 145.31 in 2013. The CO_2 emissions of China (metric tons per capita) increased significantly from 1.17 in 1960 to 7.55 in 2013 [1]. Now China is the biggest consumer of energy and largest contributor of CO2 emissions, with 20% of global energy consumption and 29% of total CO_2 emissions [2].

A number of studies examined main factors (including energy consumption, economic growth, financial development, foreign direct investment and trade openness) affecting the environmental damage across countries (for details, see literature review section); however, no previous studies, to the best of our knowledge, investigated whether population and international trade are the main reasons for environmental damage in China. Therefore, our study will fill up this gap in literature by exploring the answer to proposed question where the ARDL bounds testing approach and the VECM Granger causality technique are applied.

The main contributions of the paper are: (i) we provide the evidence of the linkage between population, international trade and carbon emissions in China both in the short and long runs, which is absent in literature to date; (ii) we verify the robustness of causality results among the variables examining the results of Impulse Response Functions (IRF) and Variable Decomposition (VD) approach; (iii) finally, we have initiated a discussion for China whether it should go for continuous increased production using non-renewable energy or it should limit its growth aspiration by achieving sustainable production using more renewable energy and energy efficient technologies.

This study is important for the policy makers of China and other countries to know the complex nexus between energy consumption, population, international trade, economic growth and environmental quality for formulating effective policies. For example, if population and trade do adversely affect CO_2 emissions, the government should re-design its trade policy in terms of exports and imports, and population policy to have optimum population by birth control and/or controlling migration. Similarly, if energy consumption increases CO_2 emissions, limiting growth target by optimum production and less use of non-renewable energy and energy-inefficient technologies will be the desired options.

The remaining paper is organized as follows. Section 2 presents a brief literature review on the key factors causing environmental damage across countries. Section 3 outlines the methodology, while Section 4 describes the data used in this study. Section 5 discusses the study's empirical results and Section 6 concludes.

2. Literature review

Extensive studies investigated the main factors causing environmental damages across countries. This current research only reviews the relevant studies.

Shahbaz et al. [3] examined the relationships between CO_2 emissions, economic growth, energy consumption, financial development and trade openness during the period 1975–2011 in Indonesia. The Zivot–Andrews unit root test was used to examine the selected variables' stationarity and the Autoregressive distributed lag (ARDL) bounds test was applied for testing a long run relationship between the series in the presence of structural breaks. The causality between the variables is explored by the VECM Granger causality technique and robustness of causal analysis is tested by innovative accounting approach (IAA). The results show that the variables are cointegrated indicating that the long run relationship exists in the presence of structural breaks. The findings show that economic growth and energy consumption increase CO_2 emissions, while financial development and trade openness decrease it. The VECM causality analysis shows the feedback hypothesis between energy consumption and CO_2 emissions. Economic growth and CO_2 emissions are also interrelated. Financial development Granger causes CO_2 emissions. The study suggests energy efficient technologies should be used to control the environment from degradation.

Islam et al. [4] applied the ARDL approach to cointegration for a long run relationship and the Granger causality within the vector error correction model for the short run dynamics to investigate the environmental Kuznets curve (EKC) hypothesis for Bangladesh using data from 1971 to 2010. The results show that energy consumption contributes the most significantly to CO_2 emissions; trade openness reduces CO_2 emissions, but urbanization increases it. Economic growth, energy consumption, trade, and urbanization Granger cause CO_2 emissions.

Linh and Lin [5] and Tang and Tan [6] examined the dynamic relationships between CO_2 emissions, energy consumption, foreign direct investment (FDI) and economic growth in Vietnam based on the cointegration and Granger causality approaches during the period 1980-2010 and 1976-2009, respectively. Linh and Lin [5] found that there is a dynamic relationship between CO_2 emissions, energy consumption, FDI and economic growth. Linh and Lin [5] suggested that a dual strategy of increasing investment in energy infrastructure and promulgating energy conservation policies should be implemented to increase energy efficiency and reduce wastage of energy. Tang and Tan [6] found the existence of long-run equilibrium among the variables. Meanwhile, energy consumption and income positively affect CO_2 emissions, but square of income has negative impact on CO_2 emissions. Tang and Tan [6] supported the EKC hypothesis assuming an inverted U-shaped relationship between CO_2 emissions and economic growth, while Linh and Lin [5] did not find evidence to support the EKC hypothesis. Tang and Tan [6] also found that energy consumption Granger-causes CO_2 emissions in the short-run and long-run.

Shahbaz et al. [7] investigated the relationship between CO_2 emissions, energy consumption, economic growth and trade openness in Pakistan over the period of 1971–2009. Bounds test for cointegration and Granger causality approach are employed for the empirical analysis. The result suggests that there exists a long-run relationship between the variables and the Environmental Kuznets Curve (EKC) hypothesis is supported. The significant existence of EKC shows the country's effort to reduce CO_2 emissions and indicates certain achievement of controlling environmental degradation in Pakistan. Furthermore, the authors found a one-way causal relationship running from economic growth to CO_2 emissions. Energy consumption increases CO_2 emissions both in the short and long runs. Trade openness reduces CO_2 emissions in the long run but it is not significant in the short run.

Nain et al. [8] investigated the long-run and short-run causal relationships among energy consumption, real gross domestic product (GDP) and CO_2 emissions using aggregate and disaggregate (sectoral) energy consumption measures in India from 1971 to 2011. The ARDL bounds test shows that there is a long-run relationship between the variables at both aggregate and disaggregate levels. However, the Toda–Yamamoto causality tests indicate that the long-run as well short-run causal relationship between the variables is not uniform across sectors. The weight of evidences of the study indicates that there is short-run causality from electricity consumption to economic growth, and to CO_2 emissions.. Mohapatra and Giri [9] examined the causal and co-integrating relationship between energy consumption, economic growth and CO_2 emissions, urbanization, trade openness and gross fixed capital formation in India from 1971 to 2012. The results of ARDL test indicate that energy consumption and urbanization have positive impact on CO_2 emissions while economic growth has positive impact on the energy consumption in the long run. The short run and long run causality results show the presence of unidirectional causality from energy consumption and urbanization to air pollution and short run causality from economic growth to energy consumption.

Uddin et al. [10] investigated the long-run Granger causality relationship between CO_2 emissions, energy consumption, economic growth and trade openness in Sri Lanka during the period of 1971–2006. The findings reveal that there exists long run causal relationship between CO_2 emissions and economic growth. In addition, there is unidirectional causality running from economic growth to CO_2 emission and energy consumption. The result infers that CO_2 emission reduction policies will negatively affect economic growth if no supplementary policies are taken to modify this causal relationship.

Similar studies were undertaken for developed countries. Hossain [11] examined the dynamic causal relationship between CO_2 emissions, energy consumption, economic growth, foreign trade and urbanization in Japan during the period of 1960-2009. Short-run unidirectional causalities are found from energy consumption and trade openness to CO_2 emissions, from trade openness to energy consumption, from CO_2 emissions to economic growth, and from economic growth to trade openness. The results also support the evidence of existence of long-run relationship between the variables. The findings indicate that higher energy consumption leads to more CO_2 emissions.

Dogan and Turkekul [12] investigated the relationship between CO_2 emissions, energy consumption, real GDP, trade openness, urbanization, and financial development in the USA for the period 1960–2010. The bounds testing for cointegration indicates that the analyzed variables are cointegrated. In the long run, energy consumption and urbanization increase environmental degradation while financial development has no effect on it, and trade leads to environmental improvements. In addition, the finding does not support the validity of the environmental Kuznets curve (EKC) hypothesis because GDP leads to environmental improvements while the square of GDP increases the levels of CO_2 emissions. The results from the Granger causality test show that there is bidirectional causality between CO_2 emissions and GDP, CO_2 emissions and energy consumption, CO_2 emission and urbanization, GDP and urbanization, and GDP and trade openness while no causality is determined between CO_2 emissions and trade openness, and CO_2 emissions and financial development. In addition, the results support one-way causality running from GDP to energy consumption, from financial development to output, and from urbanization to financial development.

Jalil and Feridun [13], Bloch et al. [14], Alper and Onur [15], Li and Yang [2] and Solarin and Lean [16] examined the main determinants causing CO_2 emissions in China. Jalil and Feridun [13] investigated the impact of financial development, economic growth and energy consumption on environmental pollution in China during the period 1953-2006 using the Autoregressive Distributed Lag (ARDL) bounds testing procedure. The results reveal a negative sign for the coefficient of financial development, suggesting that financial development in China has not taken place at the expense of environmental pollution. In contrast, the finding shows that financial development has led to a decrease in environmental pollution. Also, CO_2 emissions are mainly determined by income, energy consumption and trade openness in the long run. Moreover, the findings confirm the existence of an Environmental Kuznets Curve in China. Alper and Onur [15] investigated the validity of the environmental Kuznets curve (EKC) hypothesis for the period of 1977-2013 by using the sub-elements of pollution in China. Based on the fully modified ordinary least squares and pairwise Granger causality methodologies, the results show that financial development reduces the sub-elements of pollution but an increase in energy consumption per capita leads to an increase in the sub-elements of CO_2 emissions. The findings also show that the EKC hypothesis is valid for CO_2 emissions from gaseous fuel consumption, liquid fuel consumption, solid fuel consumption and transportation. However, the EKC hypothesis is not valid for aggregate CO_2 emissions, CO_2 emissions from residential buildings and commercial and public services, from electricity and heat production and from manufacturing industries and construction. Solarin and Lean [16] examined the impact of natural gas consumption, GDP and urbanization on CO_2 emission in China for the period, 1965–2013. The cointegration test providing for endogenously determined structural breaks was used to explore the long-run relationship and to investigate the presence of environmental Kuznets curve (EKC). The presence of causal relationship between the variables is also investigated. The findings show that there is a long-run relationship between the variables and natural gas, real GDP, and urbanization have long-run positive impact on CO_2 emissions. There is no evidence for the EKC in China. The findings further suggest that there is a long-run feedback relationship between the variables. Li and Yang [2] examined the dynamic impact of non-fossil energy consumption on CO_2 emissions in China for a given level of economic growth, trade openness, and energy usage between 1965 and 2014. The results show that the variables are in a long-run equilibrium. The ARDL approach indicates that consumption of non-fossil energy plays a key role in reducing CO_2 emissions in the long run but not in the short term. The results also suggest that, in both the long and short term, energy consumption and trade openness have a negative impact on the reduction of CO_2 emissions, while GDP per capita increases CO_2 emissions only in the short term. In addition, the Granger causality test indicates a bidirectional causality between CO_2 emissions and energy consumption.

The above survey indicates that empirical findings regarding the factors responsible for environmental degradation are inconclusive. Therefore, further specific studies will help mitigate the debate on the issue.

3. Methodology

3.1. Modelling framework

Following Shahbaz et al. [3], Uddin et al. [10] and Hossain [11], the general form of empirical equation is modeled as follows:

$$C_t = f(E_t, G_t, P_t, TR_t) \quad (1)$$

The series of equation 1 are transformed into logarithm to gain direct elasticities. The empirical equation is as follows:

$$\ln C_t = \alpha_0 + \alpha_E \ln E_t + \alpha_G \ln G_t + \alpha_P \ln P_t + \alpha_{TR} \ln TR_t + \mu_t \quad (2)$$

where Ct is CO_2 emissions per capita; Et is energy consumption per capita; Gt is real GDP per capita used as a proxy of economic growth; Pt is population density; TRt represents trade per capita; and μi is the error term assumed to be normally distributed with zero mean and constant variance.

We assume that an increase in energy consumption will increase CO_2 emissions and $\alpha_E > 0$. Rise in economic growth is associated with high CO_2 emissions and $\alpha_G > 0$. An increase in population density will lead to higher CO_2 emissions and $\alpha_P > 0$. The expected sign of trade is negative, $\alpha_{TR} < 0$ if production of pollutant intensive items is reduced due to the environmental protection laws.

3.2. Zivot–Andrews unit root test

A number of unit root tests (including ADF test developed by Dickey and Fuller [17] and KPSS test developed by Kwiatkowski et al. [18]) are available to test the stationarity properties of the variables. However, these tests provide biased and spurious results due to not having information about structural break points occurred in the series [3]. To overcome the biases, the Zivot–Andrews unit root test developed by Zivot and Andrews [19] is used to examine the stationarity properties of the variables in the presence of a structural break point in the series.

3.3. Cointegration analysis

After testing the stationarity properties of the series, we use the autoregressive distributive lag (ARDL) bounds tests developed by Pesaran et al. [20] to examine cointegration for a long-run relationship between CO_2 emissions, energy consumption, economic growth, population density and international trade in China. This test has the following advantages: (1) bounds tests can be conducted with a mixture of I(0) and I(1) processes; (2) the test comprises a single-equation setup; and (3) various lag lengths can be assigned [Narayan and Smyth [21] and Rahman and Mamun [22]]. We also apply the Johansen and Juselius's approach [Johansen [23] and Johansen [24]] to examine the robustness of ARDL bounds test approach for the long-run relationship.

The ARDL bounds testing procedures are as follows. The joint F-statistic is performed which tests the null hypothesis of no cointegration. Two sets of critical values are determined in the tests. If the calculated F-statistic is below the upper limit of the critical value, the null hypothesis of no cointegration is accepted. If the calculated F-statistic is above the upper limit of the critical value, the null hypothesis of no cointegration is rejected. If the calculated F-statistic lies between the upper limit and lower limit of the critical value, a conclusive inference cannot be made.

The ARDL approach includes two steps for estimating the long run relationship. The first step comprises investigating the existence of a long-run relationship between all variables in the equation under estimation. If a long-run relationship (cointegration) exists between the variables, the second step contains estimating separate short-run and long-run models. In the presence of cointegration, the vector error correction model (VECM) offers a strategy to separate a short-run effect from a long-run effect. Vector Auto Regressive (VAR) models are considered where cointegration is not present explicitly [25]. The VAR model is formed as follows:

$$\begin{bmatrix} \ln C_t \\ \ln E_t \\ \ln G_t \\ \ln P_t \\ \ln TR_t \end{bmatrix} = \begin{bmatrix} \beta_1 \\ . \\ . \\ . \\ \beta_5 \end{bmatrix} + \begin{bmatrix} a_1 \ldots a_n \\ . \\ . \\ . \\ a_5 \ldots a_n \end{bmatrix} + \begin{bmatrix} \ln C_{t-1} \\ \ln C_{t-2} \\ \ln C_{t-3} \\ \ln C_{t-4} \\ \ln C_{t-5} \end{bmatrix} + \ldots \begin{bmatrix} \delta_1 \ldots \delta_n \\ . \\ . \\ . \\ \delta_5 \ldots \delta_n \end{bmatrix} + \begin{bmatrix} \ln TR_{t-1} \\ \ln TR_{t-2} \\ \ln TR_{t-3} \\ \ln TR_{t-4} \\ \ln TR_{t-5} \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ . \\ . \\ . \\ \varepsilon_t \end{bmatrix} \quad (3)$$

where lnCt is the logarithm of CO_2 emissions per capita; lnEt is the logarithm of energy consumption per capita; lnGt is the logarithm of real GDP per capita; lnPt is the logarithm of population density; lnTRt represents the logarithm of trade per capita; *β*, *a* and *δ* are coefficients; and ε is white noise.

3.4. Granger causality analysis

As the ARDL cointegration approach does not suggest the direction of causality between the selected variables, we apply the Granger causality tests [26] to explore the direction of causality. A VAR model (Equation 3) is estimated to conduct Granger-causality test in the absence of the long-run causal relationship. Since Granger causality is based on the least square prediction of finite period of time ahead (for example, ahead of the first period), the Granger causality can be named as a "short-run (non)-causality".

3.5. Time paths of effects and robustness analysis

According to Rahman and Mamun [22], ARDL approach and Granger causality analysis explore the existence of a long-run relationship and the direction of causality; however, these tests cannot investigate the time path of effect and the corresponding sign of the effect (positive or negative). Therefore, we apply the generalized Impulse Response Function (IRF) and Variable Decomposition (VD) analysis to address the shortcomings. The IRF displays the response of each dependent variable to a one standard deviation shock on the current or future values of the endogenous variable, while the VD illustrates the percentage of the variance attributable to innovations to all variables in the system [27]. It is noted that the shocks in the model include structural shocks, policy shock, preference shock, productive shock, etc.

4. Data

4.1. Data sources

The data on CO_2 emissions (metric tons) per capita, energy consumption (kg of oil equivalent) per capita, population density (people per square km of land area), economic growth (GDP per capita at constant 2005 US$) and trade (trade per capita at constant 2005 US$) have been collected from the World Development Indicators (World Bank, 2017). The data sample of present study is 1971–2011 where annual observations are used. We have used Eviews 9 for the data analysis.

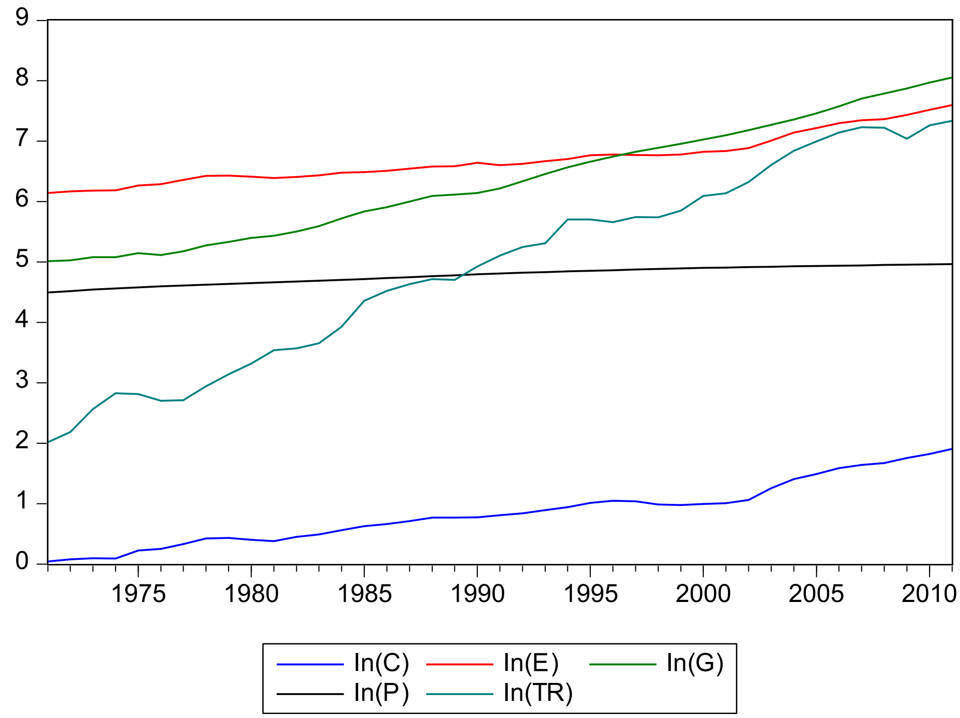
4.2. Preliminary examinations of data

All variables, except the time variable, have been transformed into natural logarithms. A summary statistics of the variables used in this study is presented in Table 1. As can be seen in Table 1, all the series have normal distribution as confirmed by Jarque-Bera test. A positive correlation between CO_2 emissions, energy consumption, economic growth, population density and trade is also observed. Figure 1 indicates the upward trends of CO_2 emissions, energy consumption, GDP per capita, population density and trade per capita in China from 1971 to 2011.

Table 1: Descriptive statistics and correlation matrix

	LN_C_	LN_E_	LN_G_	LN_P_	LN_TR_
Mean	0.845829	6.703796	6.341910	4.780310	4.929093
Median	0.809107	6.623572	6.216749	4.808736	5.108126
Maximum	1.903644	7.598098	8.055210	4.964047	7.338404
Minimum	0.041372	6.141894	5.013494	4.495258	2.014294
Std. Dev.	0.512934	0.392885	0.958620	0.142268	1.643620
Skewness	0.371192	0.701450	0.185502	-0.399440	-0.139314
Kurtosis	2.316084	2.610970	1.767356	1.870523	1.772404
Jarque-Bera	1.740577	3.620770	2.830804	3.269629	2.707066
Probability	0.418831	0.163591	0.242828	0.194989	0.258326
Sum	34.67898	274.8556	260.0183	195.9927	202.0928
Sum Sq. Dev.	10.52404	6.174336	36.75807	0.809605	108.0595
Observations	41	41	41	41	41
LN_C_	1.000000				
LN_E_	0.991976	1.000000			
LN_G_	0.981085	0.968886	1.000000		
LN_P_	0.944814	0.909538	0.970583	1.000000	
LN_TR_	0.969699	0.943555	0.987566	0.989112	1.000000

Figure 1: Trend lines of logarithm of CO_2 emissions, energy consumption, GDP per capita, population density, trade per capita in China from 1971 to 2011



5. Findings and analysis

5.1. The results of Zivot–Andrews unit root test

Although the ARDL method has many advantages, it can be only used if the variables are I(1) or I(0) [2]. Therefore, we undertake a unit root test before applying the ARDL method. Shahbaz [3] argued that numerous unit root tests such as ADF and KPSS are available to test the stationarity properties of the variables. However, these tests provide biased and spurious results because of not having information about structural break points occurred in the series. To overcome the biases, the Zivot–Andrews unit root test developed by Zivot and Andrews [19] is used to examine the stationarity properties of the variables in the presence of a structural break point in the series.

The results of Zivot–Andrews structural break trended unit root tests are presented in Table 2. Our results indicate that almost the series (except economic growth - ln(G)) show unit root problem at their level but found to be integrated at I(1). This means that the series are stationary in their first differenced form. Therefore, we apply the ARDL bounds testing approach to cointegration in the presence of structural break in the series over the period of 1971-2011 to examine the existence of a long run relationship between CO_2 emissions, energy consumption, population density, economic growth and trade.

Table 2: Zivot-Andrews Structural Break Trended Unit Root Test

Variables	At level		At 1^{st} difference	
	T-statistic	Time break	T-statistic	Time break
ln(C) CO_2	-4.3371 (3)	2008	-5.3928 (3) *	2001
ln(E) Energy consumption per capita	-1.9040 (0)	2001	-6.2228 (7) *	2003
ln(P) Population density	-3.2584 (9)	1985	-5.1221 (8) **	1984
ln(G) GDP per capita	-4.9584 (4) **	2006		
ln(TR) Trade per capita	-4.3597 (3)	1984	-5.3171 (0) **	1985

Notes: lag order is shown in parentheses

* and ** denote Significant at 1% and 5% level of significance.

5.2. The results of ARDL co-integration test and the Johansen's cointegration test

As the choice of lag length can affect the F-test, it is needed to choose the proper lag order of the variables before applying ARDL bounds testing. Application of the following system-wide methods determines the optimal lag order: Akaike information criterion (AIC), Final Prediction Error (FPE) criterion, Hannan-Quinn (HQ) criterion, Schwarz information criterion (SIC), and likelihood ratio (LR). The test results indicate that the optimal lag length is five (Table 3).

We apply the ARDL bound testing approach to examine the long run relationship between CO_2 emissions, energy consumption, population density, economic growth and trade in China. Table 4 shows that our calculated F-statistic is greater than upper critical bound at 10 per cent level, once CO_2 emission is treated as predicted variable. Also, the calculated F-statistics are greater than upper critical bound at one per cent level, once population density, economic growth and trade are treated as predicted variables. Therefore, we reject the null hypotheses of no cointegration. This means that there are four cointegrating vectors and the variables are cointegrated for a long run relationship between CO_2 emissions, energy consumption, population density, economic growth and trade in China. The structural break stems in the series of CO_2 emissions, population density, economic growth, energy consumption and trade in 2001, 1984, 2006, 2003 and 1985, respectively.

Table 3: Lag order selection criteria.

Lag	LogL	LR	FPE	AIC	SIC	HQ
0	187.5878	NA	2.71e-11	-10.14377	-9.923834	-10.06701
1	485.9535	497.2762	6.97e-18	-25.33075	-24.01115*	-24.87018
2	526.5402	56.37045*	3.19e-18	-26.19668	-23.77742	-25.35229
3	557.8441	34.78201	2.84e-18	-26.54689	-23.02796	-25.31869
4	587.7686	24.93712	3.59e-18	-26.82048	-22.20188	-25.20846
5	652.9168	36.19345	1.11e-18*	-29.05093*	-23.33267	-27.05511*

Note: * indicates the lag order selected by the criterion.

Table 4: The results of ARDL co-integration test.

Bounds testing to cointegration				Diagnostic tests (P-value)			
Estimated models	Optimal lag length	Structural break	F-statistics	Normality test	Heteroskedasticity Test: ARCH	Ramsey RESET	Serial Correlation LM Test
F_C (C/E, G, P, TR)	2, 0, 1, 3, 1	2001	3.2816***	0.0422	0.8415	0.2223	0.2536
F_E (E/C, G, P, TR)	1, 0, 5, 4, 0	2003	2.8071	0.8075	0.6369	0.7898	0.4291
F_P (P/C, E, G, TR)	5, 1, 2, 3, 0	1984	5.3897*	0.1845	0.3761	0.2043	0.0021
F_G (G/C, E, P, TR)	4, 4, 5, 4, 4	2006	7.2643*	0.3875	0.9319	0.1014	0.0160
F_{TR} (TR/C, E, G, P)	5, 4, 4, 4, 5	1985	17.1299*	0.1554	0.3219	0.9970	0.0457
Significance level	Critical values (T = 36)						
	Lower bounds I(0)	Upper bounds I(1)					
10%	2.2	3.09					
5%	2.56	3.49					
1%	3.29	4.37					

Note: * and *** represent significant at 1 per cent and 10 per cent levels, respectively.

To investigate the robustness of ARDL bounds test results for long-run relationship, we also apply the Johansen's test. The Trace test and the Maximum-Eigen value test results indicate that there exists four cointegration equations. The Johansen's test for cointegration confirms the ARDL test results (see Table 5).

Table 5. Results of the Johansen's cointegration test.

Hypothesized No. of Cointegrated Equation(s)	Trace Statistic	5% Critical Value	Max-Eigen Statistic	5% Critical Value
None *	191.4592*	69.81889	79.8379*	33.87687
At most 1	111.6213*	47.85613	49.1327*	27.58434
At most 2	62.48853*	29.79707	38.7772*	21.13162
At most 3	23.71131*	15.49471	23.1662*	14.26460
At most 4	0.545030	3.841466	0.54503	3.841466

Model: Intercept and no trend in cointegration equation and VAR.

5.3. The long-run and short run analyses

After examining the long run relationship between the variables, we investigate marginal impacts of energy consumption, population density, economic growth and trade on CO_2 emissions. The long run analysis (see Table 6) indicates that energy consumption has positive and statistically significant impact on CO_2 emissions. This indicates that an increase in energy consumption leads to energy pollutants significantly. The results infer that a one per cent increase in energy consumption is associated with a 1.1781 per cent rise in CO_2 emissions, all else the same. Also, the relationship between population density and CO_2 emissions is positive and significant at one per cent level. The finding shows that a one per cent rise in population density is connected with a 1.2802 per cent increase in CO_2 emissions. Our empirical exercise indicates that among the variables estimated, population is a key contributor to CO_2 emissions in China.

The short run results demonstrate that energy consumption and trade have negative impact on CO_2 emissions at 10 per cent levels of significance. The finding shows that a one per cent rise in the use of energy in China leads to a 1.9345 per cent decline in CO_2 emissions. The negative sign of energy consumption may be interpreted that China has used more renewable energy in recent years (short run) and our conclusion is relevant to the Li and Yang [2]'s finding. Li and Yang [2] indicated that to mitigate CO_2 emissions while sustaining economic and social development, China has developed renewable and nuclear energy resources to replace traditional fossil fuels as well as created energy policies to promote the use of clean energy. The non-fossil energy consumption in China increased from 3.8% in 1965 to 10.9% in 2014. In addition, China plans to raise the share of non-fossil energy in the energy mix to around 20 per cent by 2030. Also, the renewable energy will begin to mitigate CO_2 emissions when it represents at least 8.39 per cent of the total energy supply [28]. Therefore, the tendency for use more renewable energy in recent years in China is the most significant factor resulting in decline in CO_2 emissions.

Similarly, the negative sign for trade in short run may also be interpreted that China is importing more nowadays than exports. World Bank (2017) shows that the ratio of import to export in China increased from 0.74 in 2007 to 0.91 in 2011. It implies that in recent years in China, domestic production reduces which contributes to reduction in CO_2 emissions or China is importing more energy efficient technology now-a-days than before, that reduces CO_2 in recent years (short run). Table 6 shows that the lagged error term (ECMt-1) is -2.1732 and statistically significant at 5 per cent level. This confirms the long-run relationship between the selected variables.

The empirical evidence for diagnostic tests is detailed in Table 6. The results suggest that the short run model seems to pass all tests successfully such as Heteroskedasticity Test (ARCH) and Breusch-Godfrey Serial Correlation LM Test. This indicates that there is no problem of the heteroskedasticity and serial correlation. The variables are homoscedastic and functional form of short run model is well organized. The results show that short run empirical evidence is consistent and stable for policy purpose regarding carbon emissions in China.

Table 6: Long-and-short Runs Analysis.

Dependent variable = lnC_t		
Variables	Coefficients	T-statistics
Long run analysis		
Constant	-12.8623*	-6.9168
lnE_t	1.1781*	15.0278
lnG_t	-0.1005	-1.3748
lnP_t	1.2802*	3.5228
$lnTR_t$	0.0182	0.4587
Short run analysis		
Constant	-0.0407	-0.1619
lnE_t	-1.9435***	-2.1132
lnG_t	-0.1256	-0.3142
lnP_t	-3.0673	0.8376
$lnTR_t$	-0.2237***	-1.8429
ECM_{t-1}	-2.1732**	-2.4659
Short run diagnostic tests	F-statistic	P-value
Heteroskedasticity Test: ARCH	0.6643	0.4209
Breusch-Godfrey Serial Correlation LM Test	1.9201	0.2021

Note: *, ** and *** show significant at 1, 5 and 10 per cent level of significance, respectively.

5.4. The VECM Granger Causality analysis

The presence of cointegration for a long run relationship between CO_2 emissions, energy consumption, population density, economic growth and trade in China leads us to implement the VECM Granger causality approach to analyze the direction of causal relationship between these series. The appropriate knowledge about the direction of causality between the variables helps policy makers in articulating inclusive energy, population, economic, trade and environmental policies to sustain economic growth and improve the environmental quality over the long period of time. Granger [26] indicated that in the presence of cointegration, once variables are found to be stationary at unique order then the VECM Granger causality framework is an appropriate approach to detect the long-and-short runs causal relationship between CO_2 emissions, energy consumption, population, economic growth and trade.

Based on the VECM model, we examine Granger causality among CO_2 emissions, energy consumption, population density, economic growth and trade. The results (see Table 7) show that trade Granger causes CO_2 emissions; CO_2 emissions Granger causes energy consumption; CO_2 emissions, energy consumption and population Granger cause trade.

Table 7: VECM Granger Causality/Block Exogeneity Wald Tests

Dependent variable: D(LN_C_)

Excluded	Chi-sq	df	Prob.
D(LN_E_)	7.522415	4	0.1107
D(LN_G_)	6.975180	4	0.1372
D(LN_P_)	3.354929	4	0.5003
D(LN_TR_)	8.319988	4	0.0805
All	30.20010	16	0.0170

Dependent variable: D(LN_E_)

Excluded	Chi-sq	df	Prob.
D(LN_C_)	9.134937	4	0.0578
D(LN_G_)	5.772618	4	0.2168
D(LN_P_)	2.560587	4	0.6338
D(LN_TR_)	2.467301	4	0.6505
All	27.33915	16	0.0379

Dependent variable: D(LN_G_)

Excluded	Chi-sq	df	Prob.
D(LN_C_)	4.708557	4	0.3185
D(LN_E_)	4.102296	4	0.3923
D(LN_P_)	5.479408	4	0.2415
D(LN_TR_)	1.086379	4	0.8964
All	18.43983	16	0.2988

Dependent variable: D(LN_P_)

Excluded	Chi-sq	df	Prob.
D(LN_C_)	2.624682	4	0.6225
D(LN_E_)	3.214185	4	0.5226
D(LN_G_)	2.559029	4	0.6341
D(LN_TR_)	1.647967	4	0.8001

All	13.35270	16	0.6468

Dependent variable: D(LN_TR_)

Excluded	Chi-sq	df	Prob.
D(LN_C_)	20.11448	4	0.0005
D(LN_E_)	20.36951	4	0.0004
D(LN_G_)	5.355029	4	0.2528
D(LN_P_)	14.24698	4	0.0065
All	39.27370	16	0.0010

5.5. The results of variance decomposition approach and the impulse response function

The results of variance decomposition approach are described in Table 8. The empirical evidence indicates that a 31.03 per cent of CO_2 emissions is contributed by its own innovative shocks and one standard deviation shock in energy consumption explains energy pollutants by 48.80 per cent. Population density contributes to CO_2 emissions by 13.23 per cent due to one standard shock stemming in population. The share of economic growth and trade in CO_2 emissions are very minimal, for example 5.79 and 1.12 per cent, respectively.

The contribution of CO_2 emissions, economic growth, population density and trade to energy consumption are 30.10, 7.04, 5.81 and 0.91 per cent while rest is explained by innovative shocks of energy consumption itself. One standard shock in economic growth explains 29.25 per cent itself. CO_2 emissions contribute to economic growth by 17.38 per cent and share of energy consumption to economic growth is 41.56 per cent. Economic growth is explained by 11.51 per cent due to one standard shock stemming in population.

A 33.96 per cent of population is explained by one standard deviation shock in CO_2 emissions (energy consumption) and 55.49 per cent is contributed to population by its own innovative shocks. A standard deviation shock stemming in energy consumption, economic growth and trade attribute to population by 6.51, 3.77, and 0.25 per cent, respectively. One standard shock stemming in CO_2 emissions and energy consumption explain trade by 27.01 and 33.00 per cent, respectively. The share of economic growth and population to contribute in trade are 11.22 and 25.26 per cent, and a 3.49 per cent portion of trade is contributed by its own standard shocks.

Table 8: Variance decomposition approach.

Variance Decomposition of LN_C_:

Period	S.E.	LN_C_	LN_E_	LN_G_	LN_P_	LN_TR_
1	0.030767	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.049815	89.42132	7.965249	0.817620	0.246989	1.548823
3	0.056171	79.79749	15.06017	0.666604	3.184021	1.291713
4	0.066166	64.73115	27.26179	0.629168	5.825647	1.552242
5	0.077001	49.83522	40.26562	0.894569	7.512197	1.492397
6	0.093211	35.14753	52.46575	1.113438	10.25401	1.019269
7	0.104497	31.30060	51.90119	3.405199	12.54014	0.852879
8	0.108797	31.66965	49.23297	5.032749	13.26960	0.795035
9	0.109409	31.67009	48.68467	5.327134	13.34220	0.975901
10	0.110856	31.03866	48.80548	5.792282	13.23538	1.128199

Variance Decomposition of LN_E_:

Period	S.E.	LN_C_	LN_E_	LN_G_	LN_P_	LN_TR_
1	0.027859	57.17505	42.82495	0.000000	0.000000	0.000000
2	0.041191	57.11609	30.62538	11.35758	0.382439	0.518510
3	0.045860	56.76450	31.38232	9.255221	1.973891	0.624068
4	0.049138	53.22168	35.07002	8.244286	2.717375	0.746638
5	0.052843	46.17130	42.87152	7.294826	2.714181	0.948174
6	0.060908	34.95544	55.27098	5.563232	3.487810	0.722532
7	0.065977	31.26839	58.22800	5.756769	4.100749	0.646089
8	0.067253	31.22416	57.35758	6.507562	4.288725	0.621973
9	0.067655	30.98231	56.73521	7.124277	4.350159	0.808038
10	0.069117	30.10475	56.11876	7.048603	5.817290	0.910599

Variance Decomposition of LN_G_:						
Period	S.E.	LN_C_	LN_E_	LN_G_	LN_P_	LN_TR_
1	0.025250	6.818858	11.23366	81.94749	0.000000	0.000000
2	0.034315	4.220855	13.15189	81.80857	0.811115	0.007567
3	0.037359	3.780708	13.68517	81.63602	0.890769	0.007334
4	0.038172	5.443251	13.56182	79.29577	1.386821	0.312342
5	0.040911	5.533923	23.44229	69.27028	1.221015	0.532492
6	0.049092	5.727891	42.81622	48.15405	2.931968	0.369867
7	0.058317	10.74753	47.59473	35.12373	6.226619	0.307389
8	0.063751	14.84689	45.11935	30.95184	8.791506	0.290410
9	0.065960	16.70326	42.83995	29.42280	10.76047	0.273524
10	0.066977	17.38417	41.56283	29.25047	11.51923	0.283301
Variance Decomposition of LN_P_:						
Period	S.E.	LN_C_	LN_E_	LN_G_	LN_P_	LN_TR_
1	0.000528	27.60724	2.753532	0.631292	69.00793	0.000000
2	0.001357	30.20394	1.983326	2.223580	65.29378	0.295379
3	0.002110	30.32193	0.848274	3.508020	64.75997	0.561798
4	0.002882	30.99630	0.617783	5.204520	62.73697	0.444429
5	0.003803	32.55381	0.356776	7.446251	59.34331	0.299855
6	0.004719	33.53799	0.456854	8.222196	57.54393	0.239029
7	0.005539	34.15086	1.213893	7.282169	57.10718	0.245900
8	0.006315	34.45167	2.538121	5.915634	56.82029	0.274285
9	0.007117	34.25689	4.401544	4.732157	56.33167	0.277748
10	0.007971	33.96214	6.513556	3.774042	55.49235	0.257911

Variance Decomposition of LN_TR_:

Period	S.E.	LN_C_	LN_E_	LN_G_	LN_P_	LN_TR_
1	0.078625	23.94343	7.052752	36.77628	8.509481	23.71806
2	0.098182	30.87106	13.39671	26.35041	14.05344	15.32838
3	0.128521	38.23863	18.08099	15.44963	19.26278	8.967963
4	0.148690	40.64929	13.64170	11.99095	27.01756	6.700499
5	0.177785	34.10452	24.41078	8.988871	27.80899	4.686839
6	0.193936	28.82247	30.17481	10.79590	26.23032	3.976509
7	0.197498	27.89737	30.38761	10.57611	27.28737	3.851537
8	0.201683	27.84573	29.23551	12.11623	27.10134	3.701185
9	0.204486	27.49252	30.65610	11.78933	26.40580	3.656255
10	0.209810	27.01189	33.00736	11.22850	25.26223	3.490016

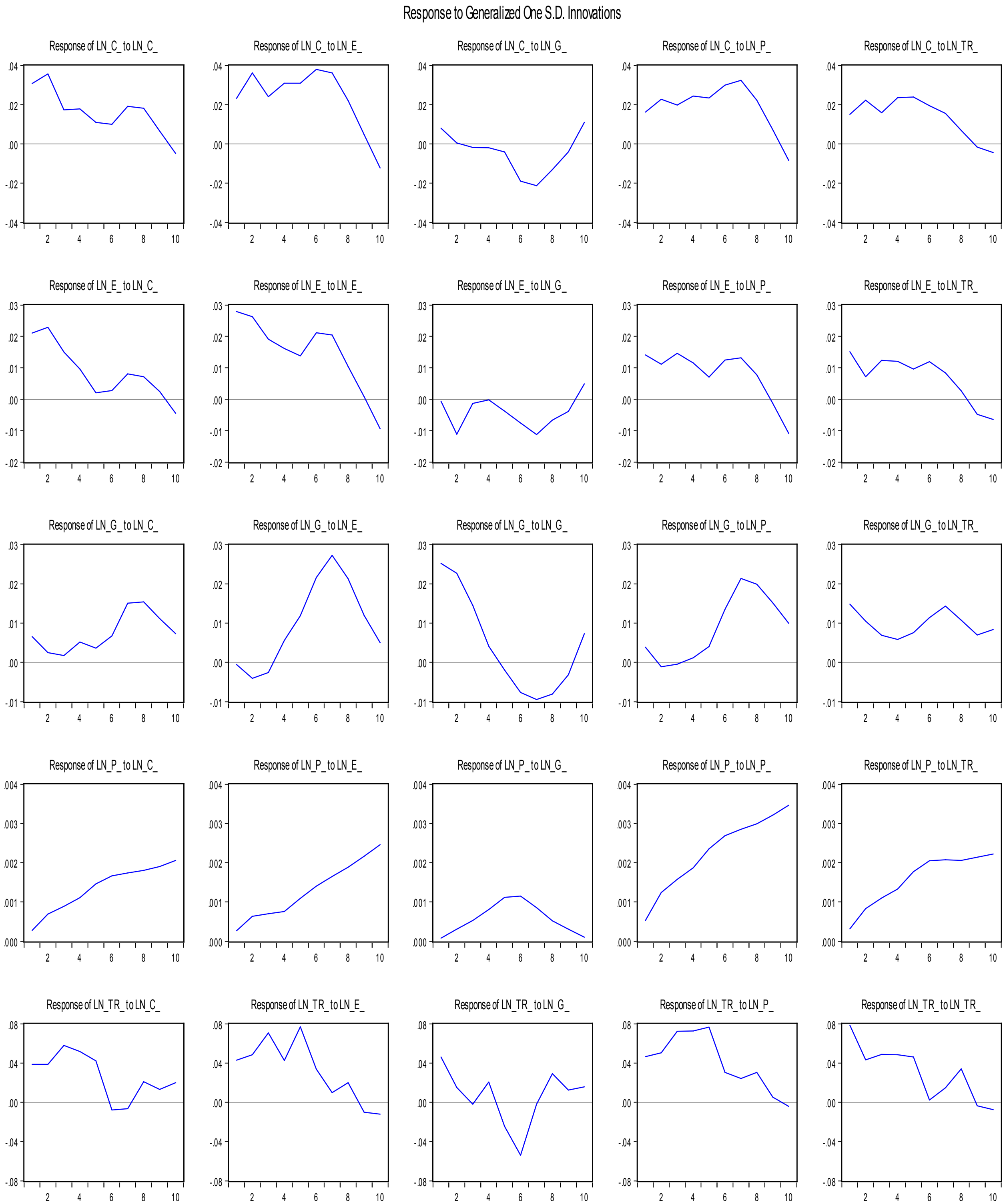
Cholesky Ordering: LN_C_ LN_E_ LN_G_ LN_P_ LN_TR_

The impulse response function is an alternate of variance decomposition approach and shows the reaction in one variable due to shocks stemming in other variables. Figure 2 indicates that the CO_2 emissions is approximately inverted U-shaped responded by energy consumption. This implies that CO_2 emissions rise, go to peak and then start to fall with continued energy consumption. The response of CO_2 emissions is negative and then positive by shocks stemming in economic growth. This means that economic growth contributes in condensing and then increasing carbon emissions. The contribution of population and trade to CO_2 emissions is from positive to negative.

The responses of energy consumption tend to decline due to shocks stemming in carbon emissions population and trade. The contribution of economic growth is negative to energy consumption. CO_2 emissions, energy consumption, population and trade contribute to economic growth positive. The impact of CO_2 emissions, energy consumption and trade on population is positive. The population is inverted U-shaped responded by economic growth.

The impact of energy consumption and population on trade tended to increase and then decrease. However, the impact of CO_2 emissions and economic growth on trade tended to decrease and then increase.

Figure 2


Response to Generalized One S.D. Innovations
Response of LN_C_ to LN_C_
Response of LN_C_ to LN_E_
Response of LN_C_ to LN_G_
Response of LN_C_ to LN_P_
Response of LN_C_ to LN_TR_
Response of LN_E_ to LN_C_
Response of LN_E_ to LN_E_
Response of LN_E_ to LN_G_
Response of LN_E_ to LN_P_
Response of LN_E_ to LN_TR_
Response of LN_G_ to LN_C_
Response of LN_G_ to LN_E_
Response of LN_G_ to LN_G_
Response of LN_G_ to LN_P_
Response of LN_G_ to LN_TR_
Response of LN_P_ to LN_C_
Response of LN_P_ to LN_E_
Response of LN_P_ to LN_G_
Response of LN_P_ to LN_P_
Response of LN_P_ to LN_TR_
Response of LN_TR_ to LN_C_
Response of LN_TR_ to LN_E_
Response of LN_TR_ to LN_G_
Response of LN_TR_ to LN_P_
Response of LN_TR_ to LN_TR_

6. Conclusion and policy implications

This study analyses the relationships between CO_2 emissions, energy consumption, economic growth, population density and international trade in China during the period of 1971-2011. The stationary analysis is explored by the Zivot–Andrews unit root test and a long run relationship between the series in the presence of structural breaks is explained by the ARDL bounds testing approach. The causality between CO_2 emissions, energy consumption, economic growth, population and international trade is investigated by the VECM Granger causality technique. Our findings show that the selected variables are cointegrated; it indicates that the long run relationship exists in the presence of structural breaks. The results show that in long run, energy consumption and population increase CO_2 emissions, while in short run, energy consumption and international trade decrease CO_2 emissions. The VECM causality analysis shows that CO_2 emissions Granger cause energy consumption, while energy consumption and population Granger cause trade. The VECM analysis also shows the feedback hypothesis between trade and CO_2 emissions. Based on the study results, the following four policy recommendations are made. Firstly, China should limit its high growth aspiration and should be careful for continued increase in production and exports that demand more energy consumption which ultimately increases CO_2 emissions; Secondly, more imports of energy efficient technologies for domestic production should be encouraged to reduce CO_2 emissions. Thirdly, the government should encourage and provide incentives for the use of renewable energy to mitigate CO_2 emissions as well as the environmental damage. Finally, people should be further educated through campaigns, advertisement and trainings to be more responsible for the environmental protection as the finding shows that the population is one of main factors causing the environmental damage in China.

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