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Moderating effect of institutional policies on energy and technology towards a better environment quality: A two dimensional approach to China's sustainable development

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ABSTRACT

Our study contributes towards identifying the world best practises and possible ways of attaining China's climate and sustainable goals. China is among the fastest growing emerging economies in the world, and its growth cannot be separated from utilization of energy sources which are capable of jeopardizing its climate and sustainable goals. China is ranked 1st in the global carbon emission which has great implications in both its domestic environment sustainable development and global climate change. Considering the position of China in the global economic and environmental performance, it is essential to investigate the possible global best practices to achieve its sustainable development. We utilized China's data of 1996Q1-2018Q4 for this study. Relevant instruments (renewable energy, technology innovation and institution) and methodology (Autoregressive Distributed Lag-ARDL bound and dynamics with granger causality) are adopted to scientifically test both the economic and environment performance of China. Findings from ARDL test established non validity of inverted U-shaped theory of Environmental Kuznets Curve (EKC) for the case of China. Also, inverse relationship is established between all the selected variables (*renewable energy, technological innovation and institution*) and the CO_2. Interestingly, the output from granger causality is in synergy with the output from ARDL short and long run outputs. Feedback transmission was found between the variables (*renewable energy, technological innovation and institution*) of our choice with both environment (carbon dioxide emissions-CO_2) and economic growth (Gross Domestic Product-GDP). The trend of relationship established between the selected variables (*renewable energy, technology innovation and institution*) points towards China's ability to achieve its climate and sustainable goal by framing its policy around energy sector and enhancement of technology with strong institutions.

1. Introduction

Sustainable development is a development strategy that manages natural resources and economic welfare in such a way that it can be passed on to future generations (Repetto et al., 1992). In recent years, the high rate of industrialization and rapid economic growth of countries have brought about many environmental problems. For this reason, the concept of sustainable development remains the agenda of developed and developing countries and has become a universal goal (Dong et al., 2021). Economists take renewable energy, the level of technological innovation, FDI, and economic growth as the indicators that will ensure sustainable development in a country or region. Additionally, to these criteria, as evident in some studies, institutional quality can also be an important criterion for sustainable development (Udemba, 2021).

Upon opening-up its economy and going through series of economic reforms, China has achieved fastest sustained economic growth. China's average annual GDP growth between 1980 and 2010 was markedly 10 % (World Bank, 2021). This rapid economic expansion has exposed the country to explosive urbanization and excessive utilization and dependence on carbon-based energy sources which come with some socio-economic challenges such as environmental impact, aging population due to health related problems. Amidst China's fast and robust growth with significant contribution to the world economy, it has also ranked 1st in global carbon emission rate. Achieving sustainable development goals is a global agenda that cut across countries of the world. The effects of environmental pollution are now known to transcend borders, and the environmental performance of the most important World Trade supplier, such as China, is important for both climate crises and

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international trade (Gürlük, 2010). Consequently, many researchers (e.g., Boateng, 2020; Majeed and Tauqir, 2020; Wang et al., 2020; Cancino et al., 2018; Adebayo et al., 2021; Khan et al., 2020a) have studied the determinants of China's economic growth and its environmental repercussions. The common conclusion is that fossil fuels are effective in China's growing industry and the best way to reduce carbon emissions is by means of renewable energy utilization and technology. Researchers (e.g. Dong et al., 2020; Akram et al., 2020; Anser et al., 2020a; A. Azam et al., 2021; M. Azam et al., 2021; Haldar and Sethi, 2021; Altinoz and Dogan, 2021; Hasanov et al., 2021; and Radmehr et al., 2021; Saidi and Omri, 2020) have studied the mitigating power of renewable energy consumption on carbon emissions, while others (i.e., Alam et al., 2021; Petrović and Lobanov, 2020; Paramati et al., 2020; Mo, 2021; Kihombo et al., 2021; Huang et al., 2021a; Lin and Zhu, 2019; Yu and Du, 2019; Bai et al., 2020; Khan et al., 2020b, and Liu et al., 2021) have considered technology in fostering good environmental prospects.

In all these aforesaid, besides the renewable energy use and technological innovation solutions examined, this study aims to find and add to the appropriate way to improve China's carbon emissions amidst its economic growth, and set the world best practises to achieve its sustainable development goals (SDGs). Many alternatives ways have been presented for the achievement of China's sustainable development goals, but in our study, institutional quality has been added as among the policies to foster SDGs for China. China has an economy that is governed by the state rather than the private sector. Therefore, the effects of State Institutions on the path to sustainability are included in the study. We explore this by adopting growth-energy- tech-institution nexus in our model and scientific analysis. As mentioned, studies have adopted renewable energy and technology policies in researching the best ways to decarbonize China, but not all studies have considered the role of institution in coordinating the other policies in moderating China's carbon emissions. The uniqueness of our study is the ability to quantify institution by adding the six (6) indexes that make up the institutional quality and juxtapose the combine effect of the institution with renewable and technology policies towards achieving China's climate and sustainable development goals. Different studies have adopted either renewable energy policy or technology with other trade related variables, or the two policies together and end up with different results. This permits and encourages subsequent and extended research into the subject matter but in addition with policy related variables such as institution.

The objective of our study is divided with questions as follows: a. what is growth-environment pattern of China? b. Are energy and technology policies inducing China's economic growth? c. Is energy policies through renewable energy capable of mitigating China carbon emissions? d. Is technological innovation sufficient in achieving China's climate and sustainable goals? e. Is China's institutional quality capable of moderating its carbon base economic activities to achieve its sustainable development target? Achieving the objective of our study is based on the answers to the above highlighted questions. We utilized approaches (such as Bound and short and long run dynamics of ARDL with granger causality) to reveal both the environmental and economic implication of the selected policy based instruments. Our study is a two-dimensional sustainability study that exposes both the China's economic and environmental development towards attaining its climate and sustainable goals. The application of granger causality analysis creates avenue for double analysis of environment cum economic performance of China. Our study contributes to the existing literature by incorporating policy related variable, institution in exposing the world best practise to achieve sustainable development. Also, a double analysis of both the economic and environmental development in ascertainment of the sustainable development for the case of China is not common in most of the sustainable studies, hence, our study add to the existing literature via double analysis of economic and environmental development. Environmental Kuznets Curve (EKC) is applied to this study to examine the current economic growth and environmental impacts in China. The EKC theory, which is derived from Kuznets Curve Theory (1995) suggests the existence of an inverted U-shaped nexus between income inequality and economic growth. The theory was later adopted by the environmental economists (Grossman and Ve Krueger, 1991; Panayotou, 1993; Shafik, 1994) to test the connection between economic growth and environmental quality.

The remaining parts of this study are; Section 2 for literature review, Section 3 for data, methodology and modeling, Section 4 for empirical analysis and discussion of the results, and Section 5 for conclusion and policy recommendation.

2. Literature review

Past literature examining sustainability goals has generally focused on the effects of renewable energy, technology innovation, and economic growth. On the other hand, in recent years, studies have begun to be added to the existing literature that examine whether institutional quality is an effective way to achieve sustainability goals in addition to these factors. Energy is known as the most basic factor that provides economic growth. Countries with growing economies have started to see renewable energy as an alternative to ensure sustainable growth. Looking at the literature examining the relationship between renewable energy consumption and carbon emissions, the common finding of the studies of such as Akram et al. (2020) study covering 66 developing countries between 1990 and 2014 and Anser et al.'s (2020b) study covering developing economies of Latin America and the Caribbean and Dong et al. (2020) study covering 120 countries from 1995 to 2015, it is observed that CO_2 emissions decrease as renewable energy consumption increases. In addition, looking at the most recent studies, Hasanov et al. (2021), A. Azam et al. (2021), M. Azam et al. (2021), Altinoz and Dogan (2021), Haldar and Sethi (2021), and Radmehr et al. (2021) also found a negative relationship between renewable energy consumption and carbon emissions. When we look at studies dealing with China, Chen et al. (2019a, 2019b), Yu et al. (2020), Zhang et al. (2021), Wang et al. (2018), Huang et al. (2021b), and Zhang and Zhang (2021) used China as a sample in their studies. These studies found a negative relationship between renewable energy consumption and CO_2 emissions in China in 1980–2014, 1995–2012, 2005–2016, 2004–2019, 1993–2011, 1995–2019 and 1960–2019, respectively. However, Saidi and Omri (2020) did not find a long-term relationship between renewable energy consumption and CO_2 emissions, unlike previous studies on 15 major renewable energy-consuming countries over the 1990–2014 periods and previous studies. However, according to this study, there is bidirectional causality between the two variables in the short run. In summary, it can be said that although there is no consensus, with some exceptions, the hypothesis that there is a negative relationship between renewable energy consumption and CO_2 emissions can be accepted.

There are many studies that conclude that there is a negative relationship between R&D expenditures and CO_2 emissions, which are an indicator of technological innovation, as in the use of renewable energy. Erdoğan et al. (2020) G20 countries for the period 1991–2017, Paramati et al. (2020) 25 European Union (EU) member countries for 1998–2014, Alam et al. (2021) for the period 1996–2013, Petrović and Lobanov (2020) for the period 1981–2014 examined OECD countries and found an inverse relationship between technological innovation and carbon emissions. This result was recently reported by Huang et al. (2021a), Mo (2021), and Kihombo et al. (2021) for different countries and country groups. Analyzing China, where technological innovation will lead to a reduction in CO_2 emissions, although the country and research method may change, Lin and Zhu (2019), Yu and Du (2019), Zhang et al. (2020), Bai et al. (2020), Khan et al. (2020b) and Liu et al. (2021) as well.

Institutions in a country can play an active role in ensuring economic development and sustainability. As strong and transparent institutions will prevent corruption in countries, it will benefit both the environment and society. Ulucak (2020), in his study that selected 18 Asia-Pacific Economic Cooperation (APEC) countries as a sample, investigated the relationship between institutional quality, economic performance and carbon emissions and concluded that institutional quality has beneficial effects on the environmental performance of countries. According to Shan et al. (2021), in their study of seven OECD countries (Spain, Belgium, Austria, Switzerland, Germany, Australia and Canada), and Haldar and Sethi (2021), in their study of 39 developing countries, observed that the improvement in the quality of institutions increases economic growth and reduces carbon emissions. On the other hand, M. Azam et al. (2021) determined that institutional quality had a positive and significant impact on CO_2 emissions, in their studies using the institutional quality index (political stability, administrative capacity, and democratic accountability) they created.

In summary, our study is a two-dimensional sustainability study that exposes both the China's economic and environmental development towards attaining its climate and sustainable goals. The application of granger causality analysis creates avenue for double analysis of environment cum economic performance of China. Our study contributes to the existing literature by incorporating policy related variable, institution in exposing the world best practise to achieve sustainable development. Also, a double analysis of both the economic and environmental development in ascertainment of the sustainable development for the case of China is not common in most of the sustainable studies, hence, our study add to the existing literature via double analysis of economic and environmental development.

3. Data and methodology

Following the objective of our study (*that is testing the possibility of China to attain its climate goal through the control and moderation of its carbon emissions*), we adopt symmetric long run analysis to expose the relevance of the selected series (*energy polices-renewable and non-renewable energy use, technological innovation and institutional quality*) in achieving this purpose, i.e. climate goal. We researched China's climate goal by examining the relationship between environmental performance indicator (CO_2) which is the dependent variable and the explanatory variables (*economic performance -economic growth and development of China, renewable energy source, technological innovation through research and development (R&D) and institutional quality*) for the period of 1996Q1- 2018Q4 due to the availability of data. The details of the data with regards to variables name, measurements and sources are given in Table 1 as following:

Model specification that contain all the selected variables was established to express the long run and symmetric relationship among

Table 1
Summary of data and variables.

Variables	Short form	measurements	Sources
Environmental performance	(CO_2)	Million tonnes of (CO_2)	British Petroleum (BP) statistics
Economic performance	GDP	Income per capita (Constant, 2010 US$)	World Bank Data
Squared economic performance	GDP^2	Income per capita (Constant, 2010 US$)	World Bank Data
Renewable energy use	REN	Million tonnes Oil equivalent	British Petroleum (BP) statistics
Technological innovation (R&D)	TECH	Research and Development expenditure	World Bank Data
Institutions quality	Inst.	Summation of six (6) series: voice and accountability, political stability, government effectiveness, regulatory quality, rule of law and control of corruption.	World Governance Indicator

Source: Authors compilation.

the selected variables. The variables adopted in our study are expressed in logarithmic form to ascertain a robust scientific estimation via reduction of the heterogeneity among the variables and stable distribution of the data. Hence, the model is specified as follow:

$$lnCO_2 = \alpha_0 + \beta_1 lnGDP_t + \beta_2 lnGDP_t^{\ 2} + \beta_3 lnRen_t + \beta_4 lnTech_t + \beta_5 lnInst_t + \varepsilon_t \quad (1)$$

where CO_2 is the carbon emissions which is the indicator representing the environment performance, where GDP, Ren, Tech and Inst. represent economic performance, renewable energy, technological innovation and institutions respectively. Also, α_0 and B_s represent the intercept and the coefficients of the explanatory variables. Moreover, t and ε represent the period and the error term for the empirical estimation.

Applicability of the models was tested with different methods including Augmented Dickey Fuller-ADF (1979), Philip Perron-PP (1990) and Kwiatkowski-Philips-Schmidt-Shin-KPSS (1992) for the test of unit root, Zivot and Andrew test for structural break test. Autoregressive Distributed Lag (ARDL) and bound tests are adopted for Cointegration and dynamic estimation of both short run and long run linear interactions among the selected variables. Granger causality test was equally applied for a direct inference from the linear relationship among the variables, and also as a robust check to the outcome of the ARDL estimation. The model expression is chiefly anchored on ARDL because of its advantage over other methods, especially as regards to cointegration and long run relationship test among the selected variables. The method (ARDL) is compactible for series with small sample size, and equally suitable for series with different order of integration. This study adopt both short and long run model expressions of ARDL according Pesaran et al. (2001), and they are specified with error correction model (ECM) is as follows:

$$\begin{aligned} \Delta lnCO_{2t} &= \alpha_0 + \delta_1 lnCO_{2t-1} + \delta_2 lnGDP_{t-1} + \delta_3 lnGDP_{t-1}^{\ 2} + \delta_4 lnRen_{t-1} \\ &+ \delta_5 lnTech_{t-1} + \delta_6 lnInst_{t-1} + \sum_{i=0}^{\rho-1} \partial_1 \Delta lnCO_{2t-i} + \sum_{i=0}^{\rho-1} \partial_2 \Delta lnGDP_{t-i} \\ &+ \sum_{i=0}^{\rho-1} \partial_3 \Delta lnGDP_{t-i}^{\ 2} + \sum_{i=0}^{\rho-1} \partial_4 \Delta lnRen_{t-i} + \sum_{i=0}^{\rho-1} \partial_5 \Delta lnTech_{t-i} \\ &+ \sum_{i=0}^{\rho-1} \partial_6 \Delta lnInst_{t-i} + ECM_{t-i} + \varepsilon_t \end{aligned} \quad (2)$$

Part of the properties of Eq. (2) are the variables (dependent and independent) which have been explained in Eq. (1). Other properties of the Eq. (2) are the coefficients of long run (δ_i) and short run (∂_i) of variables, differenced (Δ) form of short run series and the error correction model (ECM) for determination of the speed of adjustment in the long run after the short run disequilibrium. Expressing the short run and long run relationship between the variables (dependent-CO_2 and explanatory variables) entails accounting for cointegration to expose the long run relationship. For this purpose, bound approach testing is adopted in our study. This is done through specifying a hypothetical statement of no cointegration with null (H_0: $\delta_i = 0$) and alternative (H_1: $\delta_i \neq 0$) hypotheses. Cointegration is identified by comparing F-stats with critical values of upper bound. If F-stats $\geq$ critical values of upper bound, then cointegration is established (i.e. null hypothesis is rejected) and vice versa.

4. Empirical results and discussions

The outputs of the empirical estimations and discussion based on the interpretation of the outputs are presented in this section as they are shown in different tables.

4.1. Descriptive statistics

Outputs from the descriptive statistics are shown in Table 2 below

Table 2
Descriptive statistics.

	$LNCO_2$	LNGDP	$LNGDP^2$	LNREN	LNINST	LNTECH
Mean	6522	3837	1872	133.4	219.2	1.434
Median	7240	3480.	1211	109.8	215.9	1.374
Maximum	9428	7806	6095	272.08	255.6	2.186
Minimum	3163	1332	1775	42.53	200.5	0.563
Std. dev.	2418	2003	1741	78.78	12.65	0.518
Skewness	−0.241	0.430	0.890	0.461	1.450	−0.105
Kurtosis	1.418	1.839	2.540	1.775	4.720	1.695
Jarque-Bera	10.14	7.738	12.52	8.715	42.15	6.482
Probability	0.006	0.021	0.002	0.013	0.000	0.039
Sum	580,526.5	341,581.8	1.67E+09	11,867.	19,504.	127.6
Sum sq. dev.	5.15E+08	3.53E+08	2.67E+16	546,189.	14,071.	23.58
Observations	89	89	89	89	89	89

Source: Authors' computation with Eviews.

with skewness and kurtosis confirming the normal distribution of our data. The majority of variables display output within the acceptable range of ascertaining normal distribution with numbers under 2 and 0.5 or −0.5 for kurtosiss and skewness respectively. The volatility of the variables are equally confirmed, with CO_2 emissions and economic development (GDP) displaying the most volatile variables while renewable, institution and technology are moderately stable.

4.2. Stationarity test

The result displayed in Table 3 is the output of unit root estimation which exposes the stationarity of the variables and order of integration. Stationarity test is advised in any time series to avoid error in interpreting the result which is capable of misleading the policy framing from the erroneous output. Also, estimation of the unit root gives insight on the order of integration which helps in determining the appropriate methods to estimate the cointegration. According to the result, stationarity is achieved at first difference which established order of integration at l (1). The same result is found with structural break test. Structural break serves as a robust check to the findings from the conventional unit root test, and it account for any structural break that is capable of distorting the stability of the variables and its impact on the analysis is always misleading results. According to our findings, there are breaks in the prevailing years of this analysis which are mostly 2009, 2010 to 2013, and these break are mostly connected to 2008/9 economic meltdown that affected global economy. This is capable of causing instability in the working of any economic indicator used in any

Table 3
Stationarity test (ADF. PP and KPSS).

Variables	@level		@ 1st diff		
	Intercept	Intercept and trend	Intercept	Intercept and trend	Order
LCO_2	−0.6901	−0.9701	−1.9164	−1.9938*	I(1)
LGDP	6.7744	- 2.8531	−0.8926	−2.0688*	I(1)
LINST	0.3758	−0.7726	−3.8238***	−4.1233***	I(1)
LTECH	1.4718	−2.3088	−4.2795*	−4.4824*	I(1)
LREN	−1.1777	−1.0952	−3.8243***	−3.9165**	I(1)
			ADF		
LCO_2	−1.4663	−2.2778	−1.8739**	−1.9778	I(1)
LGDP	0.9558	−2.5987	−0.9236	−2.1464	I(1)
LINST	-0.0252	−0.3152	−1.6445	−2.6849**	I(1)
LTECH	−1.7205	−1.3913	−1.8616*	−2.3878*	I(1)
LREN	−0.1585	−2.4967	−2.1350**	−1.9913	I(1)
			KPSS		
LCO_2	1.1697***	0.1878**	0.2445	0.2154	I(1)
LGDP	1.1938***	0.3028***	1.1052	0.2260	I(1)
LINST	0.5308**	0.2525***	0.5311	0.0445	I(1)
LTECH	1.2094***	0.1430*	0.1913	0.00914	I(1)
LREN	1.1714***	0.2777***	0.5005	0.1157	I(1)

Attn: Significant levels are represented with *, ** and *** at 10 %, 5 % and 1 %.
Source: Authors' computation with Eviews.

Table 4
Structural break test (Zivot-Andrew).

Variables	ZA	P-value	Lag	Break period	CV@ 1 %	CV@5 %
LCO_2	−3.922***	0.000	4	2010Q3	−4.80	−4.42
LGDP	−3.191	0.313	4	2001Q1	−4.80	−4.42
LINST	−3.101***	0.006	4	2011Q2	−5.57	−5.08
LTECH	−4.801***	0.000	4	2013Q4	−4.80	−4.42
LREN	−2.561	0.102	4	2002Q3	−4.80	−4.42
$DLCO_2$	−3.298**	0.000	4	2002Q3	−4.80	−4.42
DLGDP	−3.653***	0.004	4	2006Q3	−4.80	−4.42
DLINST	−4.534***	0.004	4	2009Q2	−5.57	−5.08
DLTECH	3.938**	0.054	4	2011Q3	−4.80	−4.42
DLREN	−3.501**	0.015	4	2013Q4	−4.80	−4.42

Attn: Significant levels are represented with *, ** and *** at 10 %, 5 % and 1 %. ZA = Zivot Andrew, LG = lag, Prob. = Probability value, CV = critical values.
Source: Authors' computation with Eviews.

study. Even the 2011 attack on trade center brought about structural break to the world economy. These periods are covered in our structural break tests and the results are shown in Table 4.

4.3. Cointegration cum short and long run analysis with diagnostic estimates

The cointegration analysis with periodic (long run and short run) investigation part of our study is estimated and presented in Table 5. From the output, the values of R^2 and adjusted R^2 confirmed the model's goodness of fit at 0.980 and 0.973. This suggests that about 97 % of the variation or changes in the dependent variable (*LCO_2*) is explained by the explanatory variables (*LGDP, LINST, LTECH, and LREN*), while the remaining of the dependent variable is explained by the residual (error term). The ability of the model to adjust and retain equilibrium in the long run is also confirmed with negative output (−0.045) of error correction model (ECM) at 1 % significant level. This means that the model is able to restore the short run disequilibrium in the long run of about 22. 2 years (i.e. 1/0.045) at 4.5 %. Diagnostic tests such as Breusch-Godfrey LM and Breusch-Pagan-Godfrey tests are applied to verify if econometric problems such as serial and auto correlation, and heteroscedasticity exist in our estimations. The outputs from tests as shown in Table 5 confirmed the absence of the mentioned econometric issues and stability of the model. The extended version of diagnostic test is applied with recursive tests of cumulative sum (CUSUM) and cumulative sum squared ($CUSUM^2$) tests to ascertain the stability of the data and model. The output from the test as shown in Figs. 1 and 2 with the blue lines fitted inside the red lines in both CUSUM and $CUSUM^2$ debunks the argument of inconsistency in the model. The lag selection is performed with Akaike Information Criteria (AIC) and the lag chosen is 2. This will be available on request. Cointegration analysis is equally estimated with ARDL bound tests, the output rejects the null hypothesis

Table 5
Cointegration (ARDL-bound test), short run and long run linear relationships.

Variables	Coef	SE	T-stats	Variables	Coef	SE	T-stats
	Short-run				Long-run		
DLY	−1.656	0.642	−2.579**	*LY*	−1.656		
0.0003	0.929	−1.782*					
DLY^2	0.0003	6.59E-05	3.831***	*LY*^{2}		0.0001	2.510**
DLINST	−0.155	1.070	−0.145	*LINST*	−0.155	0.01317	−11.8***
DLTECH	−14.93	2.361	−6.322***	*LTECH*	−14.93	2.884	−5.175***
DLR.EN	−14.15	1.026	−13.79***	*LR.EN*	−14.15	1.266	−11.17***
CointEq(−1)	−0.045	0.007	−6.667***	*C*	14.36	18.26	0.786
R^2	0.980						
Adj R^2	0.973						
D.Watson	2.04						
Wald test	F-stats = 132.9	P-v = 0.000					
Bound-Coint. test	F-stats = 5.71	K = 5,@1 %	I(0) = 3.5	I(1) = 4.63			
LM Serial test	F-stats = 0.208	$R^2 = 0.324$	[0.65][0.57]				
Heteros.test	F-stats = 1.808	$R^2 = 40.15$	[0.03][0.06]				

Attn: *, ** and *** represent significant at 10 %, 5 % and 1 % respectively. Numbers inside brackets are the prob. Values of F-stats and Chi-square for serial correlation and heteroscedasticity.
Source: Authors' computation with Eviews.

with the values of F-stats (5.71) in both short and long run tests greater than the upper bounds (3.5; 4.63) at 1 % significant level. The output of the ARDL bound test is shown in Table 5. The analysis continues with the display, interpretation and discussion of both the short run and long run outputs.

The outputs from the short run and long run estimations are as follows: a significant negative and positive connections are established between carbon emissions and economic growth at 1 % and 5 % levels respectively in both periods (i.e. short run and long). This suggests the U-shape of Kuznets curve instead of the popular inverted U-shape. This finding aligns with the finding by Etokakpan et al. (2021). This simply means that carbon emissions were decreasing at the initial stage of China's economic development, but this trend was upturned at a certain point where the negative connection changed to positive connection between carbon emissions and economic growth. China is among the emerging markets that have shown the contrary pattern of Kuznets curve. This may likely portray the stage of China's development that involved excessive utilization of fossil fuels commenced. This means that in the long run, China's economic development will amount to increase in carbon emissions which will eventually affect the environmental development of the country. Statistically, a percentage increase in China's economic growth will lead to about 1.656 decrease of carbon emissions at the initial stage of growth in both periods (short run and long run) respectively. This points to a better environmental development during this period. However, this situation was upturned with 0.0003 increase in carbon emissions at the new phase of China's economic growth which means poor performance of environment due to the increase emissions via economic growth. Our finding supports the findings from Adedoyin et al. (2021), Bekun et al. (2020), Yilanci and Pata (2020) for China; Pata and Caglar (2021) for China.

A negative but not significant connection is found between carbon emissions and institution in the short run. However, the same connection is established in the long run but significant at 1 %. This points towards the ability of government through policies and institutions to mitigate carbon emissions. The insignificant nature of the connection shows laxity of environmental laws that still exist in the emerging countries like China. Though, the significant negative connection found in the long run estimates shows the likelihood of China mitigating carbon emissions through its institutions and policies, the controlling measures meted out for pollutants are still under-utilized and are likely to permit environmental degradation at minimal level, hence, the need to increase the efficiency of institution towards maintaining clean environment. Statistically, a percent increase in institutional quality will lead to 16 (−0.155) and 11.8 % decrease in carbon emissions in short run and long run periods respectively. This finding aligns with the findings from Bekun et al. (2022), Caglar et al. (2022), Ulucak (2020) for 18 Asia-Pacific Economic Cooperation (APEC) countries; Shan et al. (2021) for seven OECD countries (Spain, Belgium, Austria, Switzerland, Germany, Australia and Canada), and Haldar and Sethi (2021) for 39 developing countries and M. Azam et al. (2021).

A significant and negative connection is found between carbon emissions and technology. This finding reveals the technological implication in environmental development. The technology via innovation has a curtailing power towards carbon emissions. This involves research and development that sees to the evolvement of new and clean technologies that are structured to utilize sustainable energy sources. This trend will mitigate carbon emissions and enhance environmental quality. Statistically, a percent increase in technological innovation will significantly decrease carbon emissions at 15 (−14.93) percent in both periods. The trajectory continues even in the long run which points to the ability of policy inference anchored on innovation to mitigate environmental damage. Our finding supports the findings from Paramati et al. (2020) for 25 European Union (EU) member countries, Alam et al. (2021), Petrović and Lobanov (2020) for OECD countries who found inverse relationship between technological innovation and carbon emissions. This result was recently reported by Huang et al. (2021a), Mo (2021), and Kihombo et al. (2021) for different countries and country groups. Also for China, Lin and Zhu (2019), Yu and Du (2019), Zhang et al. (2020), Bai et al. (2020), Khan et al. (2020b) and Liu et al. (2021) found technological innovation reducing CO_2 emissions.

Moreover, it is observed that CO_2 emissions decrease as renewable energy consumption increases. The finding suggests a significant negative connection is confirmed between carbon emissions and renewable energy in both periods at 1 % level. This is a success trend for the case of China, which means that energy policy is effective in mitigating the negative impact of carbon emissions in its environmental development. Energy policy is identified as among the world best practises in controlling the climate change through its abating power towards carbon emissions. Statistically, a percent increase in renewable energy will significantly decrease carbon emissions at 14 (−14.15) percent in both periods. This finding supports the findings from the previous and current studies such as Bekun (2022), Bekun et al. (2021), Akram et al.'s (2020) for 66 developing countries, Anser et al.'s (2020b) for developing economies of Latin America and the Caribbean, Dong et al.'s (2020) for 120 countries. Also recent studies like Hasanov et al. (2021), A. Azam et al. (2021), M. Azam et al. (2021), Altinoz and Dogan (2021), Haldar and Sethi (2021), and Radmehr et al. (2021) also found a negative relationship between renewable energy consumption and carbon emissions. For the case of China, Chen et al. (2019a, 2019b), Yu et al. (2020), Zhang et al. (2021), Wang et al. (2018), Huang et al. (2021b), and Zhang and Zhang (2021) found similar output in their studies. However, a contrary finding was recorded by Alola et al. (2022), where renewable energy source is degrading the environment.

Summarily, from our findings, inverted U-shaped theory of EKC is not validated for China which has implication towards the sustenance of its environment amidst fast economic development. However, the trend of relationship established between the selected variables (*renewable energy, technology innovation and institution*) points towards China's ability to achieve its climate and sustainable goal by framing its policy around energy sector and enhancement of technology with strong institutions.

4.4. Diagnostic tests

4.5. Granger causality

Causality analysis is among the methods applied in our study to buttress the best practises that guarantee the achievement of climate and sustainable goals. The granger causality analysis is a robust check to the already established findings form other approaches. It goes beyond revealing the kind (positive and negative) of relationship that exist among the variables and exposes the origin and direction of the connection that exist among the selected variables. The granger causality analysis displays the origin and direction of relationship between the selected variables in either uni-directional (one-way) and bi-directional (two-way) direction. Following the order of integration −I (1) established from the stationarity test we applied pairwise granger causality test in our analysis. The output of the granger causality as displayed in Table 6 shows a bi-directional transmission between the variables. Specifically, two-way transmission is confirmed between economic growth and CO_2, between renewable energy and CO_2, between institution and CO_2, between renewable energy and economic growth, between technology and economic growth, between institution and economic growth, between technology and renewable energy, between institution and renewable energy and between renewable energy and institutions. It is evident from the output that the selected instruments are interacting with both environment (CO_2) and economic growth (GDP) in two way dimensions which shows the ability of China to achieve its climate and sustainable goal if policy is built on those instruments. Interestingly, the output from granger causality is synergy with the output from ARDL short and long run outputs. The selected variables show the sign and capacity to achieve China's sustainable development in both estimations.

5. Conclusion and policy suggestions

Our study is based on identifying the possible global best practices to achieve climate and sustainable goals for the case of China. China is among the fastest growing emerging economies in the world. The China's growth is cut across its economic cum social developments, and cannot be separated from engaging in some unfriendly environment practices and utilization of energy sources which are capable of jeopardizing its climate and sustainable goals. As remarked, China is ranked 1st in the global carbon emission which has great implications in both its domestic sustainable development and global climate change. Considering the position of China in the global economic and environmental performance, it is essential to investigate the possible global practices to achieve its sustainable development. The objectives of our study are identified and mentioned in the introductory section with questions as follows: a. what is growth-environment pattern of China? b. Are energy and technology policies inducing China's economic growth? c. Is energy policies through renewable energy capable of mitigating China carbon emissions? d. Is technological innovation sufficient in achieving China's climate and sustainable goals? e. Is China's institutional quality capable of moderating its carbon base economic activities to achieve its sustainable development target? Hence, we adopt different policies (*energy policy through renewable energy, technological innovation and institutions*) and approaches (ARDL bound with short and long run estimations and granger causality) to study this very research question.

Findings from ARDL test established non validity of inverted U-shaped theory of EKC for the case of China. Also, inverse relationship is established between all the selected variables (*renewable energy, technological innovation and institution*) and the CO_2. Interestingly, the output from granger causality is in synergy with the output from ARDL short and long run outputs. Feedback transmission was found between the variables (*renewable energy, technological innovation and institution*) of our choice with both environment (CO_2) and economic growth (GDP). The findings here attend to the highlighted questions that buttress the objective of our study, hence, the selected variables show the sign and capacity to achieve China's sustainable development in both estimations. The U-shape Kuznets theory found from the ARDL test has a significant implication towards the sustenance of China's environment amidst fast economic development. However, the trend of relationship established between the selected variables (*renewable energy, technology innovation and institution*) points towards China's ability to achieve its climate and sustainable goal by framing its policy around energy sector and enhancement of technology with strong institutions.

The findings from both ARDL and granger causality have given direction on the policy framing with a target of improving and sustaining both the China's economic and environmental development. The policy recommendation is anchored on energy policy, technological innovation and improving the institutional quality. The negative connection that exist between renewable energy technological innovation and carbon

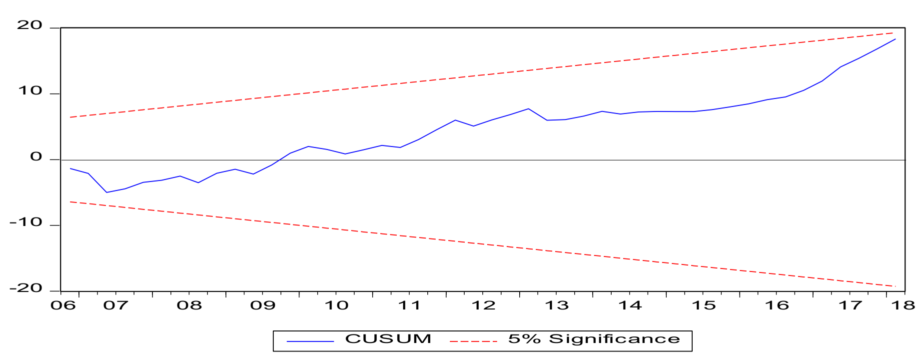

Fig. 1. Residual of cumulative sum.
Source: Authors' Computation.

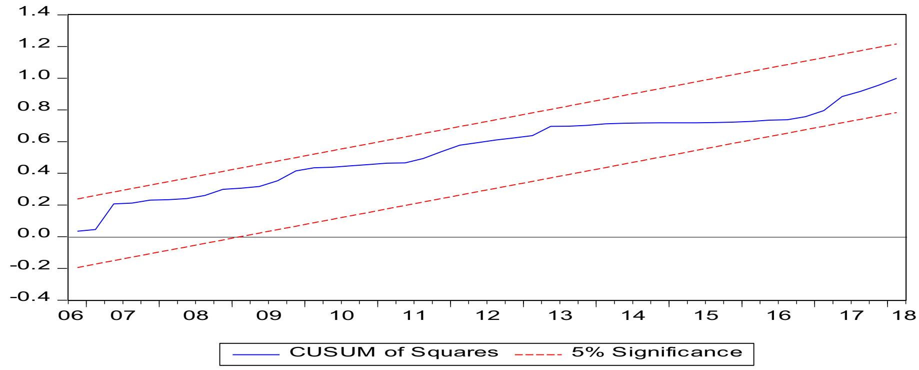

Fig. 2. Residual of cumulative sum square.
Source: Authors' Computation.

Table 6
Pairwise Granger causality tests.

Null Hypothesis (H_0):	F-Statistic	Prob.	Decision	Causality
LGDP ↔ LCO_2	27.06	1.E-06	*Reject H_0*	***YES** [Bi-Directional]*
LCO_2 ↔LGDP	155.3	7.E-21		**LGDP↔LCO_2**
LHYDRO ↔ LCO_2	40.81	9.E-09	*Reject H_0*	***YES** [Bi-Directional]*
LCO_2 ↔ LHYDRO	20.56	2.E-05		**LREN↔LCO_2**
LR_D ≠ LCO_2	0.017	0.896	*Accept*H_0	***NO** [Neutral]*
LCO2 ≠ LR_D	0.941	0.335		**LTECH≠LCO_2**
LINST ↔ LCO_2	35.54	6.E-08	*Reject H_0*	***YES** [Bi-Directional]*
LCO2 ↔LINST	12.22	0.001		**LINST↔LCO_2**
LHYDRO ↔LGDP	11.37	0.001	*Reject H_0*	***YES** [Bi-Directional]*
LGDP↔ LHYDRO	4.346	0.040		**LREN↔LGDP**
LR_D ↔ LGDP	91.76	4.E-15	*Reject H_0*	***YES** [Bi-Directional]*
LGDP ↔ LR_D	4.843	0.030		**LTECH↔LGDP**
LINST ↔ LGDP	50.88	3.E-10	*Reject H_0*	***YES** [Bi-Directional]*
LGDP ↔ LINST	15.54	0.000		**LINST↔LGDP**
LR_D ↔ LHYDRO	13.79	0.000	*Reject H_0*	***YES** [Bi-Directional]*
LHYDRO ↔LR_D	4.333	0.040		**LTECH↔LREN**
LINST ↔LHYDRO	8.639	0.004	*Reject H_0*	***YES** [Bi-Directional]*
LHYDRO ↔LINST	15.59	0.000		**LINST↔LREN**
LINST ↔ LR_D	2.067	0.154	*Reject H_0*	***YES** [Bi-Directional]*
LR_D ↔LINST	12.64	0.000		**LTECH↔LINST**

Note: The sign ≠ represents null hypothesis which reads as **"does not Granger Cause"** and the sign ↔ represents two-way direction of the granger causality (Bi-Directional).
Source: Authors' computation.

emission suggests the ability of mitigating carbon emission with the two policies (energy policy and technology policy). Hence, energy policy such as deregulation and subsidising and financing of investment into energy sector. This will improve the energy sector through diversification and transition into a more sustainable energy source, and this will drastically reduce the carbon emission from fossil fuels and eventually improve and sustain the economic and environment development of China. Policies towards development of new technologies and improving the existing technology to suit and function in line with the alternative and clean energy sources is very important for the achievement of the country's climate goal. Improving and maintaining a strong institution will help to facilitate the energy and technology policies already mentioned. Hence, from the findings and the suggested policies of this study, the world best practise that can assure and secure the China's climate and sustainable development are anchored on effective utilization of energy and technology policies through a strong institution.

Conclusively, the current study has implication for the countries that poses similar features as China. The policy inference in this study could be adopted by such countries. Also, our study has some limitations such as omission of some important variables such as trade, energy efficiency and other indicators that are likely to impact the sustainability study of China. This topic is still open for investigation.

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Declaration of competing interest

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Data availability

Data will be made available on request.

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