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Does renewable energy ensure environmental quality in favour of economic growth? Empirical evidence from China's renewable development

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Abstract An economy in transition that is growing fast coupled with rising population requires more energy. Economic growth and greenhouse gas emissions in China have been increasing together over the past several years. Exploring the dynamic relationship among these variables has a lot of policy implications related to environment–growth–energy linkage. This paper explores the interrelationship among CO_2 emissions, economic growth, disaggregated energy (fossil fuel and renewable) consumption and population. The broad objective of the paper is to examine the potential role of renewable energy consumption to ensure environmental quality in favour of growth. Data spanned from 1971 to 2013 sourced from World Bank data base. The results from auto regression distributed lag suggests that fossil fuel energy consumption increases CO_2 emissions, both in the short and the long run, but renewable energy consumption reduces CO_2 emissions in the long run. Although economic growth and population increase CO_2 emissions in the short run, their impacts on CO_2 emissions in the long run diminish, validating the environmental carbon Kuznets curve hypothesis in China. Short run vector error correction mechanism Granger

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causality results reveal unidirectional causality from both fossil fuel and renewable energy consumption to CO_2 emissions revealing growth hypothesis. Bidirectional causality exists between both energies and economic growth confirming the role of energy on economic expansion vis-à-vis the role of income on energy consumption. The findings have important policy implications for harmonizing economic growth vis-à-vis environmental quality and thus climate change mitigation with a higher proportion of energy from renewables.

Keywords Renewable energy · Environmental quality · Economic growth · Green environment · China

JEL Classification Q27 · O44 · Q43 · Q54

1 Introduction

From the beginning of the twenty-first century (21st C), less developed economies and economies in transition have been confronted with the twin burden of attaining economic expansion and environmental quality. It is pertinent that continuous development and improved ecological environment should be the core mandate of energy exploitation and profiteering in economies in transition. Thus the objective of harmonizing the interconnections among society, economy and viable environment that meet the needs of the present generation without negotiating the ability of the future generation to meet their own needs can be attained (Demirbaş 2001; Milne and Gray 2013). One of the crucial approaches in many economies is examining the rising and increasing dependence on environmentally viable renewable energy. This is because the application of these renewable energy resources on an enormous scale is cost effective and reduction in the competition with the conventional non-renewable energy of fossil fuels (Panwar et al. 2011; Krewitt et al. 2012).

Economic revolution in China is matched with the country's fast growing energy sector. There is no doubt that at present China is attaining the position as the world leading country in the utilization of nearly all considerable kinds of commodities including energy. Consequently, the fast industrialization and urbanization of the country due to the 1980's economic reforms has occurred as a result of energy generation and consumption (Fischer-Kowalski and Hausknost 2014; Valli 2015). This development has sparked a huge need for energy both to provide for the expanding industry and business and to meet enlarging consumer demand. The energy demand has a significant weight for China, the whole of East Asian continent and worldwide energy merchandise. It is framing Chinese foreign policy as well as posts one and the other challenges and opportunities for governments and other energy professionals. To meet this great energy demand, the country is depending heavily on fossil fuels of coal and oil, however, the Chinese governments intends to shift attention to new sources of renewable energy in the next coming decades (Hong 2015; Morse and Jaffe 2011). China has continued to raise its ventures in order to exploit the renewable energy sources due to the needfulness to find a substitute to oil, to the bountiful but yet fixed resource of coal; the compelling pressure to combat pollution; to adhere to global urgency to reduce global warming connected with the zeal to keep with technological development of the advanced economies (Gunn 2015). Figure 1 displays the trend of China's energy consumption (renewable and fossil fuel) with other variables such as Gross domestic Product per capita, population and growth of carbon dioxide. The trends indicate that as population and the economy grow the demand for energy especially fossil

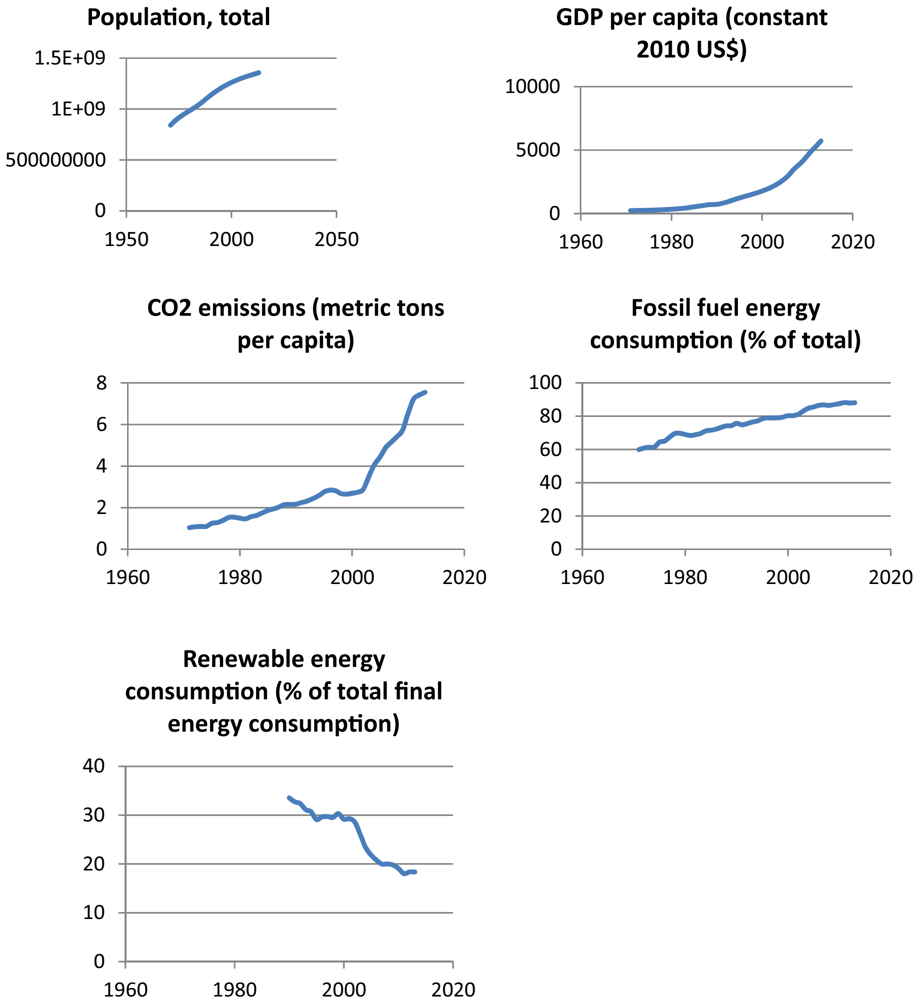

Fig. 1 Trend of variables

fuel increases giving rise to greenhouse gas emissions. Renewable energy as a percentage of total energy has not been increasing from 1990 to 2009. However, 2010 has seen an upsurge in the increase consumption of renewable energy due to the renewable roadmap to combat climate change.

Anthropogenic greenhouse gas emissions emanating from the provision of energy services have added greatly to the outstanding rise in climatic greenhouse gas clusters. According to the intergovernmental panel on climate change (IPCC) in its fourth assessment report (AR4), the perceived rise in anthropogenic greenhouse gas clustering is the major cause of most of the realized increase in the average temperature since the mid twentieth century. Recently, available data upholds that the consumption of non-renewable energy of fossil fuels accounts for the bulk of global greenhouse gas emissions. By the end of year 2010, greenhouse emissions continue to grow and carbon dioxide in particular has risen to over 390 pm (over 39%) above pre-industrial level (Liu et al. 2013a; Pachauri et al. 2014).

Numerous options are available to reduce greenhouse gas emissions from the energy schemes while still meeting the universal demand for energy services (Chen and Chen 2013; Karali et al. 2014; Menegaki 2013; Pirotta et al. 2013). Among the possible options available which were assessed in the international panel on climate change‘s fourth assessment report include: energy conservation and efficiency, switching from fossil fuel, application of new sources of renewable energy, nuclear and CCS (carbon capture and storage) (Change 2007; Metz et al. 2007). A thorough appraisal of any portfolio of mitigation options to reduce greenhouse gas emissions entails an evaluation of their various mitigation potential as well as their augmentation to sustainable development and all associated risks and costs.

This study emphasizes the role that the deployment of renewable energy technologies can play in such a portfolio of mitigation options. At the same time renewable energy source can provide wider benefits due to its large potentials and capacity to reduce climate change in favour of growth. If implemented, renewable energy technology has the capacity to contribute to socio-economic development, provide access to energy services as well as reducing adverse effects on the environment. Under the ‘business as usual’, adopting policies to encourage changes in the energy system would greatly increase the proportion of renewable energy source in the energy mix. To attract the needed increase in investment in technology and infrastructure, additional policies would be required Kang (2014; Kaygusuz 2012; Masini and Menichetti 2013; Wu et al. 2014).

Although a lot of research on the nexus of energy and environment have been carried out, such researches have not been able to empirically disaggregate energy consumption in order to disentangle the effect of energy by source on greenhouse gas emissions as well as to identify the best combination of energy (energy mix) needed to achieve growth related climate change mitigation for sustainable development in China. The available literatures, to the best of our knowledge, affirmed that very few studies are available on the issues of disaggregated energy (fossil fuel and renewable) consumption and its link to economic growth, CO_2 emissions and climate change. Previous studies on the relationship between energy consumption, economic growth and environmental degradation such as Kang (2014), Kaygusuz (2012), Masini and Menichetti (2013), Wu et al. (2014), Al-Mulali et al. (2015), Hamit-Haggar (2012), Jalil and Feridun (2011), Shahbaz et al. (2013), Yang et al. (2015), Zhang et al. (2016), Zhi et al. (2014), Zhou et al. 2013), Siali et al. (2016) and Riti et al. (2017b) used aggregated energy consumption. In addition, Murata et al. (2016) examined a new optimization method of the investment cost of a distribution grid supplied by photovoltaic (PV) sources. The obtained results show that: for a lowest global investment cost, the optimal GSP is referred to the minimum cost center (MCC), for the grid joule losses minimization, it can be in the minimum joule losses cost center (MJLCC). Rafindadi (2016) evaluated the effectiveness of the co-benefits of reducing air pollutant emissions for renewable power generation Clean Development Mechanisms (CDMs). Their results show that the co-benefits of reducing air pollutant emissions per avoided carbon dioxide (CO_2) emission is shown to be much lower than the values reported in previous studies, and the positive effect of the co-benefits of CDMs is rather limited. Tampakis et al. (2013) investigated the position of the Japanese environmental Kuznets curve in period of natural disaster and deteriorating income following the recent Fukushima energy crisis using the ARDL bounds test. The study further discovered energy consumption to be the major contributor of environmental degradation in Japan, while exports declines CO_2 emissions, but imports adds to environmental degradation. Hansen et al. (2016) examined a scenario on the island of Andros, where a wind park has been in operation since 1992, with a total annual capacity of 4740 MW using a structured questionnaire, and involved the citizens as electrical energy consumers. Their research results indicate that the citizens are positively disposed towards the installation of wind parks in their area, particularly in the northern part of the island, where a wind park is already installed. While Cai and Lu (2013) analyze and justify the challenges in the use of TFR and POD from wind power plants (WPPs). The study is conducted with an aggregated wind power plant model which is integrated into a generic power system model. The study shows that WPPs can provide additional control features such as TFR and POD to enhance the stability of power systems with large share of wind power. Against this backdrop, the present study intends to close this gap by identifying the energy mix consumption (disaggregated energy consumption of renewable and non-renewable) with the aim to decompose the effects of energy consumption that reduces the emission of greenhouse gases (GHGs) capable of ensuring a growth and sustainable green environment for China. The three questions underpinning this study are as follows:

1. Does renewable energy consumption ensure environmental quality in favour of economic growth in China?
2. Does fossil fuel consumption increases greenhouse gas emissions in China?
3. Does the environmental Kuznets curve exist in china?

The objectives of the study, therefore, revolve around the following:

1. to examine the possibility of renewable energy consumption to ensure environmental quality in favour of economic growth in China;
2. to examine whether fossil fuel and population add to greenhouse gases in china
3. to examine the existence of the environmental Kuznets curve in china.

To achieve these objectives, the study utilizes Auto Regression Distributed Lag (ARDL) model to estimate the coefficients for environment–growth–energy policies. This method has been commonly reported in the recent literature and is preferred over the Johansen method of co-integration because it has the flexibility to change lag-lengths, avoid endogeneity and authenticate even small sample sizes to achieve better results. ARDL can be applied irrespective of the order of integration, i.e., I(0), or I(1). A dynamic error correction model (ECM) can be derived from a simple linear transformation of a modified ARDL model which integrates the short-run dynamics with the long-run equilibrium without loss of any long-run information. The paper is divided into five sections. Following the introduction in Sect. 1 is the literature review which occupies Sect. 2. Section 3 examines the methodology while Sect. 4 presents the results with discussion of findings. Section 5 concludes the paper with policy recommendations and future directions.

2 Theoretical considerations

2.1 Current energy patterns in China

China has become the second largest energy consumer in 2006 after the United States, consuming 73.808 quadrillion Btu, two times its consumption level in 2000. The country has witnessed a yearly growth in energy consumption of approximately 8.9% from late 1950’s. Hence, China’s economic tool is doubling energy demand every 8 years. The overall producing quantity ranges from coal, petroleum, natural gas, nuclear, hydroelectric, and other renewable sources that are not hydroelectric. Although the total renewable energy source is rising gradually, the consumption of coal and oil as part of the production of electricity is regularly increasing and is forecasted to account for nearly 80% of energy production by year 2030. The level of carbon dioxide emissions within the country has also clearly risen within the past decade. In 2004, China was the second to the United States in terms of carbon dioxide production. However, China surpassed the United States and became the world's largest carbon dioxide emitter, producing about 6200 million tons, which is approximately 8% rise from its 2005 level (Dong et al. 2014; Meng et al. 2015). Based on the predictions made by the International Energy Agency (IEA), China will be responsible for 40% of global carbon dioxide emissions' growth between 2005 and 2030 if the current policy does not change. In the light of this, it is mandatory for the Chinese authority to start creating and implementing incentives and policies that can propel China towards clean, renewable energy sources and move away from non-renewable-fired generation. It is estimated that by 2007, China utilized 2.77 billion tons of coal, a 53% rise from the amount of 1.28 billion consumed in 2000. As it stands now, China's coal production and consumption account for 69% of the country's total energy utilization which makes it the largest producer and consumer of coal worldwide. The country is by far the largest coal supplier worldwide, generating about 46% of total global coal supply which is a significant increase compared to 1973 when it only generated 18% of global supply (Lindner et al. 2013; Tian et al. 2012).

While many of the other regions have maintained or reduced levels of coal generation, China has demonstrated significant growth in coal generation for the past 30 years. It was declared that China had 28,000 coal mines at the end of year 2005. The country is reported to have been adding new 500 megawatts coal-fired plant every four days, amounting to 91 new power plants yearly. It is estimated that four different industries make the core of China's coal consumption accounting for 50% generation and utilization. These four different sectors include: power generation, building material, metallurgy and chemical generation. Among these industries, power generation is the largest user of coal. Coal-fired power production was found to be the principal donor of coal consumption based on both internal and external experience (Sovacool and Brown 2010).

The Shenhua Group Corporation Limited declared an overall coal generation of 114.68 million tons in year 2006—an annual generation rise of 10 million which made it the seventh year in a row in 2006. If this trend of production rise continues, by 2020, China will be generating over 250 million tons of coal yearly. An average annual rise of 4.1% (60.6 quadrillion Btu's) is expected of China's coal consumption. Coal will remain the principal near-time source of power generation for both industrial and domestic consumers due to the finite reserves in oil and natural gas (Saidur et al. 2011).

In 2008, China's daily generation capacity of oil was around 3.9 million barrels while crude oil accounts for 97% of the total oil. In the same year, the volume of oil consumption was 7.9 million barrels per day with an increase of 389,000 barrel per day from 2007's volume. With this development, China was left with a proven reserve of 16 million barrels. In addition, it related petroleum-carbon emissions amounted to 9.6 billion metric tons from 2006 volume. Comparing the rise in the production of coal, China has stabilized its oil production over the past 30 years, rising with a small margin. Currently, less than 5% of overall global oil supply is from China's oil production, a figure that is expected to decline in the next decades (Outlook 2010). Furthermore, China's current natural gas is regarded as a minor fuel source in the energy generation sector, accounting for only 3% of the overall energy consumption in 2005 while gas consumption is expected to increase by 5.5% yearly. Compared to the world's overall natural gas production, China still remains one of the smaller producers of global natural gas accounting for 2.2% of the total natural gas production. However, due to its 11th year plan that called for an increase in the proportion of natural gas in the principal energy source to account for 5.3% by 2010, China's natural gas production and consumption rose to 1956 billion cubic feet in 2006, a 10 and 17% jump from the previous year respectively. Estimates have shown that China could trimmed down its yearly particulates, sulphur dioxide and carbon dioxide by 1, 3 and 70 million tons respectively provided it expands gas consumption to 10% of the overall energy demand by year 2020 (EIA 2013; Tan et al. 2013). According to (Cao and Bluth 2013) China's primary energy consumption mix comprised of the following:

Table 1 depicts China's primary energy consumption mix. Coal consumption takes about 69% of the total energy consumption, followed by oil with 6% while natural gas takes only 4%. This is an indication that among the fossil fuel energy consumption, coal maintains the lead. In the renewable category, hydroelectricity leads with only 4% while such as Geothermal, solar, wind considered as other renewable contribute marginally less than 1% to the primary energy consumption. Likewise the contribution of nuclear energy to the principal energy source is less than 1%.

2.2 China's climate and energy policy

As a fast developing economy, China occupies about 20% of global population. Having realized the economic and environmental unsustainability of its economy in terms of resource intensity, the Chinese government is rapidly encouraging growth driven by efficiency gains, industrial shift, and renewable energy (Feng et al. 2013; Bach 2016). As part of the zeal to become economically and environmentally sustainable, China submitted its climate action plan (CAP) better known as INDCs (intended nationally determined contributions) to the UNFCCC (United Nations Framework Convention on Climate Change in June, 2015 to be discussed during the conference of parties-21 (COP-21) in Paris, France (Hannam et al. 2015; Belis et al. 2015). In the INDCs document, China reaffirmed the conditions of a benchmark mutual climate agreement it made with the United States in 2014. China promised to peak its total emissions latest by the year 2030, however, with the best intentions to peak it much earlier, and to raise the proportion of its non-fossil fuels in its energy mixture to 20% by the year 2030 (Ciuriak and Ciuriak 2015; Li and Wang 2012). In addition, China declared two important extensions to the November accord: to meet the goal of reducing carbon concentration by 60–65% from the levels obtained in 2005 and the target to restore around 4.5 billion cubic meters of forested land beyond the 2005 levels. China's increasing decoupling of its economic growth from the growth of greenhouse emissions as its target of peaking emissions by 2030 has been termed by IEA (International Energy Agency) as "important change in the right and good direction" (Yuan et al. 2015).

Table 1 China's Primary energy consumption mix. *Source*: International Energy Statistics, January 2013

Sources of energy	Coal (%)	Oil (%)	Hydroelectricity (%)	Natural gas (%)	Nuclear power (%)	Other renewables (%)
Percent of consumption mix	69	18	6	4	Less than 1	Less than 1

Table 2 Statistical output for unit root test (Ng-Perron)

Variable	MZa	MZt	MSB	MPT
LEM	−6.0419	−1.3922	0.2304	5.0477
LFUE	−8.6941	−2.0016	0.2319	9.9792
LGDP	−1.3031	−0.4281	0.3285	29.8462
LPOP	−25.8569	−3.5950	0.1390	3.5277
LREN	−33.9311	−4.0881	0.1204	2.8561
ΔLEM	−29.5839*	−3.6273	0.1226	4.3029
$\Delta LFUE$	−10.4847**	−2.0164	0.1909	3.0772
$\Delta LGDP$	−5.3875**	−1.5946	0.2959	16.7589
ΔPOP	−42.1272*	−4.4575	0.1058	2.8426
$\Delta LREN$	−74.2928*	−6.0912	0.0819	1.2416

*, **, *** indicate significance of variables at 1, 5, 10% level respectively

Table 3 Statistical output for co-integration test (Bounds test)

Bounds testing to Co integration		Diagnostic tests				
	Optimal Lag	F-statistics	Chi-sq. Normal	Chi-sq. ARCH	Chi-sq. Reset	Chi-sq. Serial
$F_{EM}(EM/FUE,GDP,POP,REN)$	4, 2, 2, 0, 4	11.7546*	1.9187	[1]2.5650	[1]2.2690	[2]1.8323
$F_{FUE}(FUE/EM,GDP,POP,REN)$	4, 4, 0, 4, 3	6.7597**	1.4054	[1]2.4044	[1]2.4973	[2]3.9920
$F_{GDP}(GDP/EM,FUE,POP,REN)$	2, 2, 0, 1, 0	4.3182**	0.4610	[1]0.3918	[1]2.1202	[2]2.5904
$F_{POP}(POP/EM,FUE,GDP,REN)$	3, 0, 1, 1, 4	1.8560	0.0839	[1]0.0010	[1]2.3121	[2]2.7049
$F_{REN}(REN/EM,FUE,GDP,POP)$	4, 0, 1, 0, 1	6.0991**	1.5406	[1]2.7491	[1]2.3200	[2]1.8149

Significant level (%)	Critical values (T = 42)#	
	Lower limit	Upper limit
1	4.40	5.72
2.5	4.26	5.62
5	3.89	5.07
10	3.03	4.06

The optimal lag length is determined by SBC. [ ] is the order of diagnostic tests

*, ** and *** denote significance at 1, 5 and 10% levels, respectively

Critical values are collected from Pesaran et al. (2011), Table CIV

China has invested significant assets in clean energy and desire to reduce greenhouse gas emissions as part of its 12th 5 Year Plan for 2011–2015. Moreover, the country has been working assiduously to reduce air pollution at the same time scheming itself into the position of peaking and then cut emissions by the next decade. The designing of a solid mutual climate deal with the United States and aiding to factor the significant progress in the Durban round of the UNFCCC agreement has also raised China's profile on the global node as a giant on climate actions (Liu et al. 2013b; Ming et al. 2014).

China is taking the lead in clean energy ventures and renewable energy production. To meet its enormous energy demand at low economic and environmental cost, the Chinese government is making effort and working towards achieving the goal. It is evident that as a global giant in clean energy ventures, China's investment in renewable energy in 2014 recorded 89.5 billion US dollars, up by 32% from the previous year's investment of 60.8 billion US dollars. Investment in renewable electric generation on the other hand supersedes all total investment in both nuclear energy and non-renewable of fossil fuel (Zhang and Yang 2013; Wandesforde-Smith et al. 2014). From year 2007, the proportion of investment in renewable energy has rose steadily, from the tune of 32% of the overall in 2007 to nearly 59% in 2013. China established more new renewables intensity than non-renewable capacity in 2013 and replicated that landmark in 2014. At present, China has surpassed the US with a total of 378 GW of renewable energy intensity, more than double the entire present capacity obtained in the US. To meet the target of producing 20% of its energy from non-fossil fuel sources by 2030, China will need to install extra 800 to 1000 GW of zero-emission facilities, equal to the volume of the entire United States electricity network (Zhang et al. 2016; Huang 2013).

China is demonstrating notable official initiative on climate change. The country's leadership is incorporating further plans to reduce emissions in the 13th 5 Year Plan which is to be completed in 2016 having devoted considerable deliberations to energy-climate related issues in the 12th 5 Year Plan. The next 5 year plan of action of China is to develop the policy structure for scaling up non-fossil fuels to accounts for 20% of its energy mixture by 2030 and for massively reducing the carbon concentration of its energy by 60–65% from the top levels (den Elzen et al. 2016). Part of this leadership is made up of a set of sub-national actions presently in pilot program level, including carbon pricing, carbon-cap and trade programs and a low-carbon cities initiative concentrating on establishing renewable power and energy efficiency at city level. Indeed, about 11 principal cities in china, including Beijing which together account for an estimated 25% of China total urban emissions have pledged to peak their emissions by 2020 before the national target year of 2030. The sole aim of starting the programs at the urban level is to implement it on a national scale, if it is effective. To cap it all, the Chinese leadership maintained that a national cap-and-trade market is on the pipeline to be roll-out as early as 2016. In addition, China declared that it will cap greenhouse gas emissions from the steel and cement sectors in 2015 as part of its 2014–2020 national plans to cope with climate change. At present, one-fifth of China's overall carbon emissions come from the steel and cements industries (Grubb et al. 2015).

As part of its commitments, China has pledged to peak its overall greenhouse gas emissions by the year 2030 with best efforts to peak much earlier. Based on estimations by some analysts, both coal consumption and greenhouse emissions could peak between the periods of 10–15 years. Achieving this target would surely be welcome news to global players because a peak in Chinese emissions is crucial to keep warming below 2 °C. This pledge by China was initially announced at the United Nations climate conference in 2014, repeated in the historic climate deal sealed with the United States 2 months later, and certified in its official INDCs to the United nations in 2015 (Korsbakken et al. 2016; Sovacool et al. 2015). This century has witnessed first China's decline in coal consumption because coal generation and utilization both fell in 2014 by more than 2% from the value obtained in 2013. The country's major coal producer known as Shenhua Energy Company has declared that both its internal generation and sales have reduced by 10% in March 2015. This is an indication that the year 2015 has witnessed another great reduction in the country's coal consumption, as China continuously decoupling its economic growth from huge level of carbon pollution (Blazey and He 2015).

China is partnering with international actors, including the United States, on issues bordering climate. The groundbreaking November 2014 climate deal between the two highest emitters (United States and China) entrenched a synergetic structure for two global largest emitters to unite on tackling climate change. In 2013, China and the United States also concluded a joint mutual deal to work through the existing Montreal Protocol and UNFCCC tool to cut down the use of HFCs (hydro-fluorocarbons), established a collaborative framework for the world's two largest emitters to cooperate on tackling climate change. In 2013, the U.S. and China also arrived at a joint bilateral agreement to work through existing Montreal Protocol and UNFCCC mechanisms to reduce the use of hydrofluorocarbons (HFCs), potent greenhouse gases emitted through a variety of industrial processes. China's negotiating position is driven primarily by domestic considerations—energy demand, smog and economic restructuring—but international responsibility also plays a role. While China's past and current carbon pollution emissions are relatively modest for a country, its size, its future emissions would exhaust the remainder of the global carbon budget if the country does not transition to a higher percentage of clean energy. China's constructive engagement in a global climate agreement is an absolute prerequisite for success in addressing climate change (Zhi et al. 2014).

2.2.1 Renewable energy roadmap in China

To achieve its 10th 5 year plan, China profiled out goals to raise its renewable energy capacity in respective divergent sectors. As part of the plan, China intended to raise production capacity of solar cells to an aggregate level of 53 megawatts while raising solar hot water heating to 11 million square meters. It outlined to raise installed capacity of 1.2 gig watts in the wind sector while increase in bio-energy is to supply 2 billion square meters of fuel. Renewable energy promotion law was enacted by the Chinese authority in order to actualize some of these set targets in 2003. To also allow the government at the lower levels, corporations and individuals to mutually stimulate and use renewable, incentive policies in the law were planned to strengthen the development of renewable

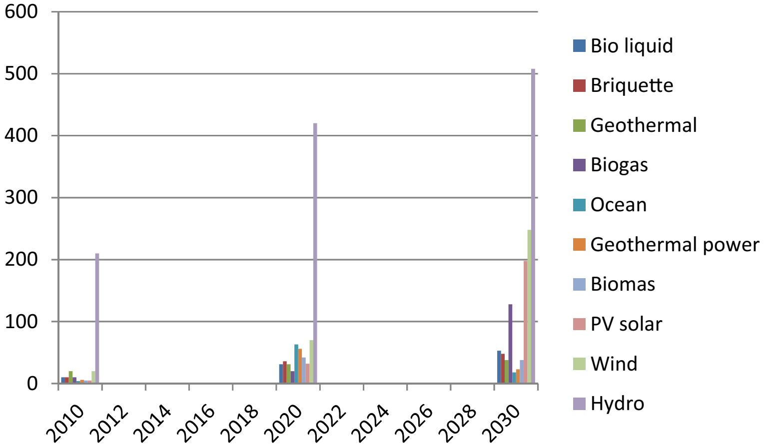

Fig. 2 China's renewable development plan (ERINDFRC 2011)

technologies while providing opportunities for renewable energy companies. In summary, the 10th 5 year scheme was successful in strengthening renewable energy with established capacity rising essentially 25% during the considered time period. By the year 2007, hydroelectric, nuclear and geothermal/solar/wind/biomass contributed 1.3, 20.7 and 0.5% of the overall renewable energy capacity respectively. Traditional thermal, principally coal maintained its lead as the largest source of energy in China accounting for 77.6% of the installed capacity. This shows that geothermal, solar, wind and biomass sector still have enormous potentials of unused renewable resources (He et al. 2013).

The three development schemes based on divergent attributes of renewable energy provided by China's renewable road map include: low middle and high scenarios. While the high scheme is prompted by the environmental and climate change reviews, the medium term scenario examines the different types of factors such as potential environmental restriction, social cost which commits scheming with equilibrium and cohesion. The low scenario focuses on energy efficiency development. As a result of the development of renewable energy technologies, China's level of competitiveness of renewable energy will be better. Specifically, renewable energy is improved to augment more significant performance in the energy network of China. Despite the fact that the proportion of renewable energy in China's overall energy consumption is minimal, the development of renewable energy mechanizations will supplementary make huge impact to the new energy demand. Although, renewable energy contributed about 9.7% of the overall energy before 2010, the country primarily depends on non-renewable. The medium (2020) renewable development is set to accord 550–820 MTce, about 13.8–20.6% of the overall energy demand. The long term scenario (2030) renewable development on the other hand is expected to accord 840–1330 MTce (16–26%) of the overall energy need. Added to this, it is expected to have a major high-tech in on-shore wind power in both the short and medium term schemes. Crystalline silicon cell is expected to provide the principal technology for high photovoltaic and thin film will get a huge development, high efficiency, and high stability at low cost. Solar road map by 2020 is based on research and development of middle and high temperature of solar thermal application technology. Biofuel development on the other hand is grouped into three phases: the pre-2015 (short term), 2015–2020 (medium term) and post 2030 regarded as the long term (Energy Research Institute National Development and Reform Commission 2011).

Hydroelectricity in China remains the largest provider of renewable in all the scenarios as depicted in Fig. 2. The sub-renewable energy had an installed capacity of 118 GW and produced 423 billion kW/h. The country has developed greatly in the volume of hydroelectricity it generates, accounting for 14% of the overall global hydro generation. In the world ranking, the three Gorges Dams is currently the largest hydro power house with an 18.2 gigawatts score. In 2010, China possessed almost 430 billion kW/h of hydro power production and utilized the same quantity with an installed capacity of 128.5 billion. Nuclear power is also increasing in China, just like other types of primary energy sources. The operational nuclear plants in mainland China are about eleven. While seven are under construction, ten more of the plants to begin development soon. Among the operational plants, two are sited in Daya Bay, near Hong Kong; five are located in Qishan, south of Shanghai, two in Lingao, and two in Tianwan. The conveniences of nuclear plants are that they can be sited close to populated areas, reducing the volume of transportation needed to get energy from where it is generated to where it is demanded. The volume of the installed producing strength of the geothermal, solar, wind, and biomass industries only amounts to 0.5% of overall generating capacity. Due to its low capacity in the renewable share, it is broadly classified into a single sector known as 'non-hydro renewable energies'. However, for the past couple of years, China's attention has shifted its attention to the enormous potential of these types of renewable energies particularly solar and wind. Currently, China is a global player in the production and consumption of solar, thermal accounting for 55% of global solar heating capacity (Zhou et al. 2013; Wang et al. 2014; Rockström et al. 2013).

3 Methodology

3.1 Sources of data

The source of data for this study is mainly from the World Bank data base (WDI 2015). The data include CO_2 emissions measured as metric tons per capita. Renewable energy consumption is measured as percentage of total final energy consumption and fossil fuel energy consumption is measured as percentage of total energy consumption. Economic growth is measured GDP per capita (2010 constant US dollars), and population refers to total population.

3.2 Model formulation

The theoretical underpinning regarding the relationship between the variables of interest has been practically demonstrated using energy consumption, economic growth and the environment. Emissions scenarios are assumed to be driven by some factors and which certain equations are formulated upon.

- The first is the rise in population. It is generally assumed that utilization of energy increases with rising population.
- Second, the type of energy an economy consumes determines the level of emissions (energy options).
- Third, anthropogenic activities that constitute economic growth. As an economy grows, the need to consume more energy especially non-renewable becomes eminent.
- Fourth, energy efficiency. The more efficient energy is used, the less emission it produces (Shaw 2013; Tuana and Cuomo 2014; Pesaran et al. 2011).

To achieve the goal of co-integration among the variables, the study utilizes ARDL (autoregressive distributed lag) model also known as the bounds test co-integration approach proposed by Pesaran et al. (2011) and Engle and Granger (1987). The reason for the application of this technique is not far-fetched: the ARDL has some properties that are advantageous over other econometrics techniques such as the Johansen co-integration test. The procedure has the advantage of desirable small sample properties. It can be implemented irrespective of the integration order of the series. In other words, it can be applied when variables are I(0) or I(1) but not I(2). A dynamic error correction model (ECM) can be obtained from a simple linear transformation of a modified ARDL model which integrates the short-run dynamics with the long-run equilibrium without loss of any long-run information (Burck et al. 2014; Lütkepohl 2011).

To estimate the coefficients of the variables, the following empirical model is formulated.

$$EM_t = f(FUE_t, REN_t, GDP_t, POP_t)\upsilon \tag{1}$$

The model is then converted to natural logarithm to bring the data to the same units, reduce the variances as well as to interprete the coefficients in terms of elasticities.

$$LEM_t = \varpi_0 + \varpi_1 FUE_t + \varpi_2 REN_t + \varpi_3 GDP_t + \varpi_4 POP_t + \upsilon \tag{2}$$

EM_t carbon dioxide emission at time t measured as metric tons per capita

RENt renewable energy consumption at time t measured as percentage of total energy consumption (kg of oil equivalent per capita)

FUEt fossil fuel consumption at time t measured as percentage of total energy consumption (kg of oil equivalent per capita)

GDPt gross domestic product at time t measured in 2010 constant US dollars

POPt population density at time t measured as number of people per square kilometer

ν is the error term of Eqs. (1) and (2).

On the theoretical justification regarding the signs of the variables, the following signs are expected on the coefficients of the variables: ϖ_1, ϖ_3 and $\varpi_4 > 0$, $\varpi_2 < 0$. In other words, an increase in fossil fuel consumption, economic growth or population would lead to an increase in greenhouse gas emissions, while an increase in renewable energy consumption is expected to decrease emissions of greenhouse gases.

The conditional error correction version of the ARDL model is specified thus:

$$\Delta y = \lambda_1 + \lambda_2 y_{t-1} + \lambda_3 Z_{t-1} + \lambda_4 x_{t-1} + \sum_{i=1}^{p} \gamma \Delta y_{t-1} + \sum_{j=0}^{p} \beta_i \Delta x_{t-j} + \sum_{s=0}^{p} \omega_s \Delta z_{t-s} + \mu_i \tag{3}$$

where λ_t is a drift component and μ_t represents a white noise error processes. The ARDL approach estimates $(p + 1)^k$ number of regressions in order to obtain optimal lag length for each variable, where p refers to the maximum number of lags used; and k to the number of variables in Eq. (3). The optimal lag structure for the regression is selected by the

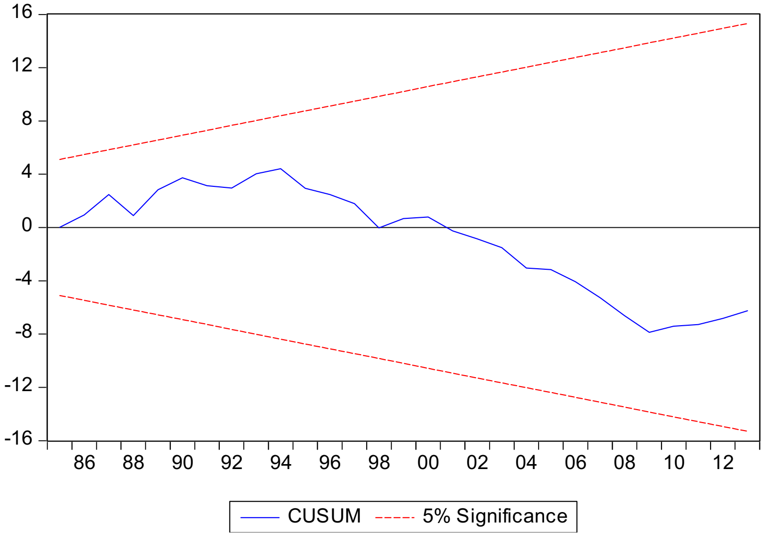

Fig. 3 Plot of cumulative sum of recursive residuals

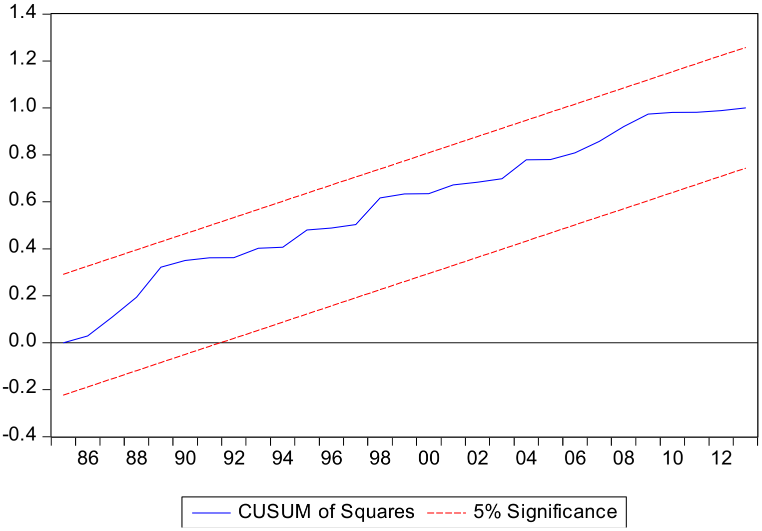

Fig. 4 Plot of cumulative sum of squares of recursive residuals

Schwarz-Bayesian criteria (SBC) to eliminate serial correlation (Engle and Granger 1987; Tiwari et al. 2013). Following Engle and Granger (1987), two separate statistics are employed to test for the existence of long-run relationship and *F-test* for the joint significance of the coefficients of lagged levels in Eq. (3). Two asymptotic critical bounds are used to test for co-integration when the independent variables are I(d). The lower value is used if the regressors are I(0), and the upper value for I(1) regressors. If the F-statistic exceeds the upper limit of the critical value, a long run relationship exists regardless of the order of integration, I(0) or I(1). If the F-statistic falls below the lower critical values, the null hypothesis of no co integration is sustained. However, if the statistic falls between these two bounds, the inference would be inconclusive. When the order of integration among the variables is known, and if all of them are I(1), then the decision is made based on the upper bound. Similarly, if all the variables are *I(0)*, then the decision is made based on the lower bound. If variables are co integrated, the conditional long run model can be obtained from the reduced from solution of Eq. (3) and the variables in their first difference are jointly equal to zero, i.e. $\Delta x = \Delta y = \Delta z = 0$. Thus,

$$y_t = \partial_0 + \partial_2 x_t + d_3 z_t + v_t \tag{4}$$

where $\partial_0 = -\lambda_1/\lambda_2$; $\partial_2 = \lambda_3/\lambda_2$; $\partial_3 = \lambda_4/\lambda_2$ and v_t is the random error. The long run coefficients in Eq. (3) are estimated by OLS. If co-integration exists among the variables, then the error correction model can be represented by the following reduced form equations.

$$\Delta y_t = \sum_{i=1}^{p} \lambda_i \Delta y_{t-1} + \sum_{j=1}^{m} \beta_i \Delta y_{t-j} + \sum_{k=1}^{n} \beta_k \Delta y_{t-k} + \eta ECT_{t-1} + \omega_t \tag{5}$$

$$\Delta LEM = \partial_0 + \partial_{FUE}\Delta FUE + \partial_{REN}\Delta REN + \partial_{GDP}\Delta GDP + \partial_{POP}\Delta OP + \eta ECM_{t-1} + \omega_t \tag{6}$$

Goodness of fit of the ARDL model, diagnostic and stability test are conducted to assess serial correlation, functional form, normality and heteroscedasticity associated with the model.

The stability test is conducted using the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares of recursive residuals (CUSUMsq) (Figs. 3, 4). In addition, the Chow Forecast Test is used to examine the reliability of ARDL model (Table 6).

4 Results and discussion

4.1 Time series properties of data

Prior to employing the ARDL co integration approach, it may be useful to test the order of integration of each series by applying the Ng-Perron procedure (Jain and Ghosh 2013). The application of Ng-perron is to enhance the power of several tests that have been shown to have small size distortions as well as to provide far more robust to size distortions when the residuals have negative serial correlation. The results in Table 1 suggest non-stationarity in the level (unit root); but difference stationary [no unit root, I(1)]. The purpose is to determine the order of integration because the (ARDL) bounds testing approach to co integration becomes applicable only in the presence of I(0) or I(1) variables, that is, being stationary/integrated at the level form or at first difference. Thus, the assumption of bounds testing will collapse in the presence of I(2) variable (Shaheet al. 2007).

The study conducts unit root tests on the variables included in the regression by employing the Ng perron test at 1, 5 and 10% levels of significance. The null hypothesis is that unit root problem exists, that is, $\partial_1 = \partial_2 = \partial_3 = \partial_4 = \partial_5 = 1$ against the alternative hypothesis that there exists no unit root problem that is, $\partial_1 = \partial_2 = \partial_3 = \partial_4 = \partial_5 < 1$. The results show that all variables are integrated of orders one. This implies that the series are non-stationary at levels but are stationary at first difference [I(1)].

Table 4 Statistical output for residual ADF unit root test

Variable	None	Intercept	Intercept and Trend	Inference
Random term	t-statistic	t-statistic	t-statistic	OI Lag
	−4.3163*	−4.2584*	−4.2642*	I(0) [1]

IO order of integration

*, ** and *** denote the significant at 1, 5 and 10% levels, respectively

4.2 Bounds test approach to co-integration

According to Engle and Granger (1987) and Narayan and Narayan (2010), when testing for co-integration, the following conditions are stated: If the F-statistic value falls above the upper bound critical value, a conclusive inference is drawn that co-integration exists without prior knowledge of whether the series were I(0) or I(1). Alternatively, if the calculated F-statistic value falls below the lower critical bound value, the null hypothesis of no co-integration is not rejected irrespective of whether the series were I(0) or I(1). Contrary to this, if the estimated F-statistic value falls within the range of the lower and upper critical bounds, a conclusive inference cannot be reached unless there is a prior knowledge about the series of whether they were I(0) or I(1).

Pesaran et al. (2011) and Engle and Granger (1987) provided the critical values of lower and upper bounds to be compared to the estimated F-statistic of the ARDL model. The bounds test results show that the F-statistic values of CO_2 emission (11.7546), fossil fuel energy consumption (6.7597), and renewable energy consumption (6.0991) exceed the upper critical limits. The F-statistic value of population (1.8560) falls below the lower critical bound at 5% indicating lack of co-integration when population is the dependent variable. On the other hand, the F-statistic value of GDP (4.3182) falls within the range of the lower and upper critical bounds at 5% validating the inconclusiveness of the result. The summary of the bounds test co-integration is that a long run equilibrium relationship exists with three co-integrating vectors.

Added to the bounds long run relationship is the test of residual non-stationary in Table 4 to support the co-integration test of the ARDL. The null hypothesis is that there is unit root among the residuals, hence, no co-integration. The alternate hypothesis on the other hand is that there is no unit root in the residuals, hence, co-integration exists.

The co-integration regression produced the residual which is then tested using the Augmented Dickey Fuller test with ‘none’, intercept’ and ‘trend & intercept’. The residual values at all the stages support the rejection of the null hypothesis and inference is drawn that the residual values obtained from co-integration regression are free from unit root, hence, co-integration exists among the variables of CO_2 emissions, fossil fuel, renewable energy, GDP and population.

Furthermore, a specified number of symptomatic tests are carried out on the chosen ARDL models. At a comprehensive level, the selected ARDL models succeeded the number of the symptomatic tests. Table 4 summarizes the results of the estimated F-statistic values together with the symptomatic tests results. The normality test of residuals indicated by Jarque–Bera value shows that the residuals are distributed normally. The Ramsey-Reset test of model formulation indicates that the preferred models are not mis-specified. The ARCH (autoregressive conditional heteroskedasticity) test confirms that the models do not contain any ARCH problem, hence, the models are homoscedastic. In addition, the null hypothesis of serial correlation among the residuals is not rejected by the Lag rangier Multiplier of Breusch–Godfrey indicating that the residuals are free from autocorrelation up to order two. Conclusively, the outcome of the diagnostic checks shows that the selected ARDL models are properly fit for the bounds co-integration analysis.

4.3 Short and long run estimated coefficients

The short and long run analysis in Table 5 shows that fossil fuel consumption, renewable energy consumption, economic growth and population influence emissions at 1, 5 and 10% levels of significance.

Table 5 Statistical output for parsimonious model (long-run and short-run analysis)

Variables	Coefficient	Standard error	t-statistic	Probability
Short run coefficients				
Constant	54.4259	35.8260	1.5191	0.1430
$LFUE_t$	−0.7650*	0.2488	−3.0742	0.0055
$InGDP_t$	0.5290*	0.1679	3.1497	0.0046
$InPOP_t$	5.9912***	2.9043	1.9684	0.0617
$InREN_t$	−1.3898***	0.6065	−1.7448	0.0950
$ECM_{(t-1)}$	−1.7342*	0.4948	−3.6574	0.0014
Long run coefficients				
Constant	−159.4195	158.8482	−1.0035	0.3223
$LFUE_t$	0.4850*	0.04407	11.0062	0.0000
$InGDP_t$	0.0160	0.0031	0.5086	0.6141
$InPOP_t$	1.1351*	0.3911	2.9016	0.0063
$InREN_t$	−0.2841	0.9965	−0.0400	0.9683
$R^2 = 0.8316$	Adjusted $R^2 = 0.7245$			
F-statistic = 7.7636	DW = 2.2638			

*, ** and *** indicate significance of the variables at 1, 5 and 10% significance level (data and analysis results are available upon request from authors)

Table 6 Statistical output for sensitivity test (Eqs. 3, 6)

Model no.	Serial correlation	ARCH test	Normality test	Heteroscedasticity	Ramsey Reset
Long-run	1.4119 (0.2862)	1.7649 (0.3405)	1.9965 (0.3685)	3.4198 (0.4902)	0.0929 (0.9265)
Short-run	2.6972 (0.3679)	0.1279 (0.7227)	2.6997 (0.3578)	1.3182 (0.2787)	1.0850 (0.2922)

The probability-values are given in parenthesis. (a) Lagrange multiplier test of residual serial correlation. (b) Ramsey's RESET test using the square of the fitted values. (c) Based on a test of skewness and kurtosis of residuals. (d) Based on the regression of squared residuals on squared fitted values. (e) Jarque–Bera normality test

Renewable energy consumption impacts are negative by reducing emission and ensuring environmental quality in China. A 1% increase in renewable energy consumption decreases emissions by 1.389 and 0.2841% in the short and long run respectively as shown in Table 6. The results are in line with the findings of (Mathiesen et al. 2011; Riti and Shu 2016; Riti et al. 2017a; He and Wang 2012) in terms of the effect of renewable energy consumption and energy efficiency on environmental degradation. The plausibility of the findings lies with the sign and significance of the coefficient of renewable energy consumption both in the short and long runs. The negative and statistical reliability of the coefficient of renewable energy consumption indicates that it contributes to greenhouse gas emission reduction, hence, climate change mitigation. The finding that renewable energy reduces greenhouse gas emissions is in line with the efforts by the Chinese ministry of environment to reduce incidence of climate change impacts in the country. This effort gave rise to the renewable energy programme initiated in the country.

The sign of the coefficient of fossil fuel energy consumption is negative in the short run but turns out to be positive in the long run. A 1% increase in fossil fuel energy consumption contributes 0.765% to CO_2 emissions in the negative direction. Long-run analysis shows that a 1% increase in fossil fuel energy consumption contributes 0.485% rise in CO_2 emissions. This notion (fall in the effect of fossil fuel energy consumption on CO_2 emission) shows efficiency and technological change in the process of production and consumption in the long run. Generally, the results in the light of environment–energy thesis can be vindicated since China has a large population and their major source of energy comes from fossil fuels of coal (69% in Table 1).

Economic growth (GDP) effects on the environment (CO_2 emission) on the other hand show a diminishing trend from short run to long run. In the short run, a 1% rise in GDP contributes 0.529% rise in CO_2 emissions. However, in the long run, the effects of GDP decrease from 0.529 to 0.016%. This is a confirmation that the environmental carbon Kuznets curve (ECKC) hypothesis holds in China when CO_2 emission is used for environmental degradation. In addition, the results are in line with the findings of (Ahmed et al. 2013; Riti et al. 2017a, b) in terms of the economic existence of EKC.

Population variable shows increasing and positive effects on CO_2 emission. A 1% increase in population contributes 5.99 and 1.135% to CO_2 emission in the short and long run respectively. Just like GDP, population effects diminish in the long-run confirming the existence of environmental population Kuznets curve (EPKC).

On the overall, the analyses of the short and long runs confirm the dynamic interaction of the variables and agreed with the energy-growth-environment led thesis where fossil fuel consumption, economic GDP and population lead to environmental degradation while renewable energy consumption ensures environmental quality. The fall in the effects of the three variables (Economic growth, fossil fuel and population) on CO_2 emission is a confirmation of the EKC phenomenon in China.

4.4 Diagnostic analysis result

Table 6 displays the diagnostic test result of both short and long run regression specifications. The result shows that the model is free from autocorrelation and ARCH problems. The model specification test of Ramsey-Reset shows that the model is without specification bias. The normality test shows that the residuals are normally distributed and are homoscedastic. The short run stability of the model, investigated by CUSUM and CUSUMsq test on the recursive residuals are shown in Figs. 3 and 4. The test suggests that the parameters are stable since the statistics fall within the critical bands of the 5% confidence interval.

At 5% level of significance indicated by the two straight lines, the models demonstrate stability both in the short and long run. The line within the critical bounds represents the results of both the short-and long-run analyses and imply that the coefficients of error correction model is free from autoregressive conditional heteroscedasticity and serial correlation.

The long run diagnostic test result is also displayed in Table 6. The tests passed the econometric complications of autocorrelation of the residuals, symmetrical distribution of the residuals, non-constancy of the mean and variance of the residuals and specification bias. On the basis of this findings, the model is deem fit for policy implications in terms environment–growth–energy linkage.

4.5 Direction of causality within VECM

In this section, Granger causality procedure within the vector error correction model (VECM) is applied to analyze the causal link at least in one of the directions. Caution must be exercised when applying Granger causality analysis in the first difference via vector auto-regression (VAR) due to the chances of obtaining bias results when co-integration exists among the variables. However, this problem can be resolved by including an error correction term which helps to capture the long run relationship among the variables (Engle and Granger 1987). The following is the Granger causality specification augmented by an error correction term formulated as a bi-variate path order VECM:

$$\begin{pmatrix} \Delta LEM \\ \Delta LFUE \\ \Delta LREN \\ \Delta LGDP \\ \Delta LPOP \end{pmatrix} = \begin{pmatrix} K_1 \\ K_2 \\ K_3 \\ K_4 \\ K_1 \end{pmatrix} + \sum_{i=1}^{P} \begin{pmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \vdots & \vdots \\ d_{m1} & \cdots & a_{mn} \end{pmatrix} + \begin{pmatrix} \delta_1 ECM_{t-1} \\ \delta_2 ECM_{t-1} \\ \delta_3 ECM_{t-1} \\ \delta_4 ECM_{t-1} \\ \delta_5 ECM_{t-1} \end{pmatrix} + \begin{pmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{pmatrix} + \begin{pmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \\ \eta_4 \\ \eta_5 \end{pmatrix} \tag{7}$$

The first difference operator is denoted by Δ, while the ECM represents the error correction mechanism derived from long run co-integrating relationship via ARDL model; Ci (i = 1…5) are intercepts; and η_i (i = 1…5) are serially uncorrelated stochastic terms with zero means. The directions of the Granger causality are provided by the VECM and divided into short run and long run. The Chi square statistic or the partial F-statistic captures the short run causality while the significant lagged error correction model including t-statistic provides long run directions for Granger causality. The determination of the existence of co-integration among the variables in the ARDL model presents an interesting platform to conduct the Granger causality test. This will further provide a vivid picture to policy makers on policy implications of the environment–growth–energy nexus.

Table 7 displays both short and long run Granger causality results. The long run causality shows that there is long run relationship among the variables in all the VECMs. The speed of adjustment to the long run of CO_2 emission equation is 173.42% in the

Table 7 Statistical output for VECM Granger causality

SR causality						LR causality t-statistics
Chi square statistic or partial F-statistics						
	$\sum \Delta LEM_{t-i}$	$\sum \Delta LFUE_{t-i}$	$\sum \Delta LGDP_{t-i}$	$\sum \Delta LPOP_{t-i}$	$\sum \Delta LREN_{t-i}$	ECM_{t-1}
ΔLEMt	–	2.8806** [0.0615]	3.0934** [0.0502]	3.6326** [0.0265]	3.0629** [0.0439]	−1.7342* [−3.0642]
ΔLFUEt	4.5114* [0.0001]	–	8.8591* [0.0000]	−2.6031** [0.0146]	−3.5451** [0.0271]	−0.8338** [−2.2170]
ΔLGDPt	11.5660* [0.0001]	5.8442* [0.0080]	–	3.1749** [0.0584]	6.4278* [0.0054]	−0.0577** [−4.7921]
ΔLPOPt	2.5108 [0.1065]	3.3049** [0.0533]	1.1951 [0.2432]	–	−2.1578** [0.0407]	−0.0246* [−2.0032]
ΔLRENt	1.5951 [0.2220]	6.9077* [0.0039]	7.0892* [0.0012]	1.86990 [0.1729]	–	−0.2203* [−5.0906]

SR short run, *LR* long run

*, ** and *** denote the significance at the 1, 5 and 10% level, respectively

presence of short run distortions. Fossil fuel energy consumption equation on the other hand shows a speed of adjustment that hovers around 83.38% if the system exposes to shocks in the short run. Renewable energy consumption has a speed of convergence of 22.03% to the long run. The speed of convergence of GDP and population are relatively slow at 5.77 and 2.46% respectively. In summary, the Granger causality test shows long run directions of causality in all the series.

The short run Granger causality results present interesting findings. There is unidirectional causality from fossil fuel to CO_2 emission suggesting growth hypothesis. GDP and CO_2 emission have bidirectional causality in the short run. Renewable energy however does granger-cause CO_2 emission in the short run where a uni directional causality runs from renewable energy to CO_2 emission confirming the growth hypothesis. One interesting phenomenon in line with our hypothesis is the uni directional causality from both energies to CO_2 emission and bidirectional causality between GDP and both energies. This implies that renewable energy ensures environmental quality in favour of growth while fossil fuel energy ensures growth at the expense of the environment. In addition, as income (GDP) increases, there is the tendency to increase the consumption of both energies. Population also shows a uni directional causality to CO_2 emission. The long run economic growth of China has been aided by energy consumption coupled with the growing labour supply leading to both higher output and emissions. All the long run causality tests survive a 1% level of significant except fossil fuel energy and GDP which are significant at the 5% level.

5 Conclusion and implications for policy

Economic growth, energy consumption especially fossil fuel and greenhouse gas emissions in China have been rising together over the past several years. Exploring the dynamic relationship among these variables has a lot of policy implications to policy makers and governments alike. This paper examines the long run relation among the series of disaggregated energy consumption (fossil and renewable), population, and economic growth and CO_2 emissions for China. The study shows special relevance due to the possible interrelations among the series with implications for energy, growth, population, emissions and climate change policies. The primary concern is that, China is a major economy in transition especially in the region of East Asian, and witnessing comparatively high rate of economic growth and rising greenhouse gas emissions.

Results from the analysis confirm the effects of fossil fuel, GDP and population to be detrimental to the environment. Although the effects of these variables are harmful to the environment in the short run, long run analysis validates the ECKC, Environmental fuel Kuznets curve (EFKC) and EPKC hypothesis in China. Renewable energy promotes efficient output and a healthy environment. Therefore, the twin objectives of ensuring growth and environmental quality can be achieved via the development and consumption of renewable energy and energy efficiency. This can as well help policy makers formulate the right public policies.

This paper is viewed as an evaluation of China's energy, growth and environmental policy to lend credence to reducing greenhouse gas emissions by supporting the utilization of renewable energy as alternative efficient energy source to non-renewable which is contained in the 2030 renewable energy road map. The findings that economic growth and energy Granger causing each other in both short and long runs is an indication of their interdependence. There is the need for a clear articulated and established sustainable energy policy. Otherwise, the plan to actualize the goal of vision 2030 might be a mirage as well produce negative impact on the environment in the long term.

The findings that non-renewable energy of fossil fuel leads to increase in greenhouse gas emissions but renewable energy consumption has the capacity to reduce greenhouse gas emissions in the long run offer some hopes. For China to achieve the triple sustainable development goals of economic, social and environmental, a higher proportion of the required energy must be from efficient and renewable energy source. China could benefit from the two-angled policy i.e. encourage renewable infrastructural development as well as continue the current policy of energy efficiency to address the carbon restriction concerns. In the long run, attention should be placed on venturing in renewable energy sources and endorse other energy savings' schemes ranging from energy mix and other mitigation options. The inability to address these needs may necessarily bring difficulties in achieving the declared objectives of vision 2030. In addition, the economy might as well become totally fossil fuel energy-dependent with persist greenhouse gas emissions. The long term objective should be the adoption of sustainable energy efficiency in the overall energy consumption.

This research helps fill the knowledge gap in energy policy in terms of energy mix which decomposed the relative effects of disaggregated energy consumption not only on economic growth as in the case of previous but studies on greenhouse gas emissions and climate change mitigation process. The research also helps fill the knowledge gap in the environmental impacts created by the concurrence of the energy commission which has limited scope of environmental conservation and management systems. Therefore, there is a great need to plunge into energy efficiency, develop the technical efficiency of energy conversion, production and transmission; alternating more non-renewable fuels with renewable ones. This would help to reverse the adverse effects of energy generation and consumption on the environment.

In conclusion, future directions on this and related topic should focus on a complete spatial planning and cost analysis of renewable energy and efficiency financing. In addition, climate policy effectiveness required to mitigate climate change and ensure sustainable green environment should be verified.

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References

Ahmed, K., Shahbaz, M., Qasim, A., Long, W.: The linkages between deforestation, energy and growth for environmental degradation in Pakistan. Ecol. Indic. **49**, 95–103 (2013)

Al-Mulali, U., Saboori, B., Ozturk, I.: Investigating the environmental Kuznets curve hypothesis in Vietnam. Energy Policy **76**, 123–131 (2015)

Bach, T.: Human rights in a climate changed world: the impact of COP-21, Nationally Determined Contributions, and National Courts. Vt. L. Rev. **40**, 001 (2016)

Belis, D., Joffe, P., Kerremans, B., Qi, Y.: China, the United States and the European Union: multiple Bilateralism and Prospects for a New Climate Change Diplomacy. Carbon Clim. Law Rev. **9**, 203–218 (2015)

Blazey, P., He, X.: China's past, present and future approach to climate change. East Asia's Renewed Respect for the Rule of Law in the 21st Century: The Future of Legal and Judicial Landscapes in East Asia, 215 (2015)

Burck J., Bals, C., Rossow, V.: The Climate Change Performance Index: Results. Germanwatch, Berlin. http://germanwatch.org/en/download/13625.pdf (2014)

Cai, F., Lu, Y.: Population change and resulting slowdown in potential GDP growth in China. China World Econ. **21**, 1–14 (2013)

Cao, W., Bluth, C.: Challenges and countermeasures of China's energy security. Energy Policy **53**(2013), 381–388 (2013)

Change, I.P.C.: Mitigation of climate change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007)

Chen, Z.M., Chen, G.: Demand-driven energy requirement of world economy 2007: a multi-region input–output network simulation. Commun. Nonlinear Sci. Numer. Simul. **18**, 1757–1774 (2013)

Ciuriak, N., Ciuriak, D.: Climate change and the trading system: implications of the trans-pacific partnership. Available at SSRN 2692272 (2015)

Demirbaş, A.: Biomass resource facilities and biomass conversion processing for fuels and chemicals. Energy Convers. Manag. **42**, 1357–1378 (2001)

den Elzen, M., Fekete, H., Höhne, N., Admiral, A., Forsell, N., Hof, A.F., Olivier, J.G., Roelfsema, M., van Soest, H.: Greenhouse gas emissions from current and enhanced policies of China until 2030: can emissions peak before 2030? Energy Policy **89**(2016), 224–236 (2016)

Dong, X., Yu, B., Brown, M., Zhang, Y., Kang, M., Jin, Y., Zhang, X., Ulgiati, S.: Environmental and economic consequences of the overexploitation of natural capital and ecosystem services in Xilinguole League, China. Energy Policy **67**, 767–780 (2014)

Eia, U.: Annual Energy Outlook 2013, pp. 60–62. US Energy Information Administration, Washington (2013)

Energy Research Institute National Development and Reform Commission, ERINDRC: Renewable energy roadmap for China in 2030. Renewable Energy and Energy Efficiency Partnership (REEEP) Funded Project. https://www.reeep.org/ (2011)

Engle, R.F., Granger, C.W.: Co-integration and error correction: representation, estimation, and testing. Econom. J. Econom. Soc. **55**, 251–276 (1987)

Feng, W., Cai, Y., Gu, B.: Population, policy, and politics: how will history judge China's one-child policy? Popul. Dev. Rev. **38**, 115–129 (2013)

Fischer-Kowalski, M., Hausknost, D.: Large scale societal transitions in the past. Europe Working Paper **55** (2014)

Grubb, M., Sha, F., Spencer, T., Hughes, N., Zhang, Z., Agnolucci, P.: A review of Chinese CO_2 emission projections to 2030: the role of economic structure and policy. Clim. Policy **15**, S7–S39 (2015)

Gunn, G.C.: The hungry dragon: how China's resource quest is reshaping the world. J. Contemp. Asia **45**(1), 180–183 (2015)

Hamit-Haggar, M.: Greenhouse gas emissions, energy consumption and economic growth: a panel cointegration analysis from Canadian industrial sector perspective. Energy Econ. **34**, 358–364 (2012)

Hannam, P.M., Liao, Z., Davis, S.J., Oppenheimer, M.: Developing country finance in a post-2020 global climate agreement. Nat. Clim. Change **5**, 983–987 (2015)

Hansen, A.D., Altin, M., Iov, F.: Provision of enhanced ancillary services from wind power plants–examples and challenges. Renew. Energy **97**, 8–18 (2016)

He, G., Bluemling, B., Mol, A.P., Zhang, L., Lu, Y.: Comparing centralized and decentralized bio-energy systems in rural China. Energy Policy **63**, 34–43 (2013)

He, J., Wang, H.: Economic structure, development policy and environmental quality: an empirical analysis of environmental Kuznets curves with Chinese municipal data. Ecol. Econ. **76**, 49–59 (2012)

Hong, Z.: China and ASEAN: Energy Security, Cooperation and Competition. ISEAS-Yusof Ishak Institute, Singapore (2015)

Huang, Y.: Policy experimentation and the emergence of domestic voluntary carbon trading in China. East Asia **30**, 67–89 (2013)

Jain, A., Ghosh, S.: Dynamics of global oil prices, exchange rate and precious metal prices in India. Resour. Policy **38**, 88–93 (2013)

Jalil, A., Feridun, M.: The impact of growth, energy and financial development on the environment in China: a cointegration analysis. Energy Econ. **33**(2011), 284–291 (2011)

Kang, L.: Energy self-sufficient eco-village: utilization of wind energy. http://www.theseus.fi/handle/10024/78440 (2014)

Karali, N., Xu, T., Sathaye, J.: Reducing energy consumption and CO_2 emissions by energy efficiency measures and international trading: a bottom-up modeling for the US iron and steel sector. Appl. Energy **120**, 133–146 (2014)

Kaygusuz, K.: Energy for sustainable development: a case of developing countries. Renew. Sustain. Energy Rev. **16**, 1116–1126 (2012)

Korsbakken, J.I., Peters, G.P., Andrew, R.M.: Uncertainties around reductions in China [rsquor] s coal use and CO_2 emissions. Nat. Clim. Change **6**, 687–690 (2016)

Krewitt, W., Nienhaus, K., Kleßmann, C., Capone, C., Stricker, E., Graus, W., Hoogwijk, M., Supersberger, N., Winterfeld, U.V., Samadi, S.: Role and potential of renewable energy and energy efficiency for global energy supply. https://epub.wupperinst.org/frontdoor/index/index/docId/4032 (2012)

Li, J., Wang, X.: Energy and climate policy in China's twelfth five-year plan: a paradigm shift. Energy Policy **41**, 519–528 (2012)

Lindner, S., Liu, Z., Guan, D., Geng, Y., Li, X.: CO_2 emissions from China's power sector at the provincial level: consumption versus production perspectives. Renew. Sustain. Energy Rev. **19**(2013), 164–172 (2013)

Liu, F., Klimont, Z., Zhang, Q., Cofala, J., Zhao, L., Huo, H., Nguyen, B., Schoepp, W., Sander, R., Zheng, B.: Integrating mitigation of air pollutants and greenhouse gases in Chinese cities: development of GAINS-City model for Beijing. J. Clean. Prod. **58**, 25–33 (2013a)

Liu, Z., Guan, D., Crawford-Brown, D., Zhang, Q., He, K., Liu, J.: Energy policy: a low carbon road map for China. Nature **500**, 143–145 (2013b)

Lütkepohl, H.: Forecasting nonlinear aggregates and aggregates with time-varying weights. Jahrbücher für Nationalökonomie und Statistik **231**, 107–133 (2011)

Masini, A., Menichetti, E.: Investment decisions in the renewable energy sector: an analysis of non-financial drivers. Technol. Forecast. Soc. Chang. **80**, 510–524 (2013)

Mathiesen, B.V., Lund, H., Karlsson, K.: 100% renewable energy systems, climate mitigation and economic growth. Appl. Energy **88**, 488–501 (2011)

Menegaki, A.N.: Growth and renewable energy in Europe: benchmarking with data envelopment analysis. Renew. Energy **60**, 363–369 (2013)

Meng, J., Liu, J., Guo, S., Li, J., Li, Z., Tao, S.: Trend and driving forces of Beijing's black carbon emissions from sectoral perspectives. J. Clean. Prod. **30**, 1 (2015)

Metz, B., Davidson, O., Bosch, P., Dave, R., Meyer, L.: IPCC: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY (2007)

Milne, M.J., Gray, R.: Whither ecology? The triple bottom line, the global reporting initiative, and corporate sustainability reporting. J. Bus. Ethics **118**(1), 13–29 (2013)

Ming, Z., Ximei, L., Yulong, L., Lilin, P.: Review of renewable energy investment and financing in China: status, mode, issues and countermeasures. Renew. Sustain. Energy Rev. **31**, 23–37 (2014)

Morse, E.L., Jaffe A.M.: Strategic energy policy: challenges for the 21st. Century. James A. Baker III Institute for Public Policy Rice University (2011)

Murata, A., Liang, J., Eto, R., Tokimatsu, K., Okajima, K., Uchiyama, Y.: Environmental co-benefits of the promotion of renewable power generation in China and India through clean development mechanisms. Renew. Energy **87**, 120–129 (2016)

Narayan, P.K., Narayan, S.: Carbon dioxide emissions and economic growth: panel data evidence from developing countries. Energy Policy **38**, 661–666 (2010)

Ng, S., Perron, P.: LAG length selection and the construction of unit root tests with good size and power. Econometrica **69**, 1519–1554 (2001)

Outlook, A.E.: Energy information administration. Department of Energy. http://www.eia.doe.gov/oiaf/aeo/index (2010)

Pachauri, R.K., Allen, M., Barros, V., Broome, J., Cramer, W., Christ, R., Church, J., Clarke, L., Dahe, Q., Dasgupta, P.: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014)

Panwar, N.L., Kaushik, S.C., Kothari, S.: Role of renewable energy sources in environmental protection: a review. Renew. Sustain. Energy Rev. **15**(3), 1513–1524 (2011)

Pesaran, M.H., Shin, Y., Smith, R.J.: Bounds testing approaches to the analysis of level relationships. J. Appl. Econom. **16**, 289–326 (2011)

Pirotta, F., Ferreira, E., Bernardo, C.: Energy recovery and impact on land use of Maltese municipal solid waste incineration. Energy **49**, 1–11 (2013)

Rafindadi, A.A.: Revisiting the concept of environmental Kuznets curve in period of energy disaster and deteriorating income: empirical evidence from Japan. Energy Policy **94**, 274–284 (2016)

Riti, J.S., Shu, Y.: Renewable energy, energy efficiency and eco-friendly environment (R-E^5) in Nigeria. Energy Sustain. Soc. **6**(1), 1–16 (2016)

Riti, J.S., Song, D., Shu, Y., Kamah, M.: The contribution of Energy use and financial development by source in climate change mitigation process: a global empirical perspective. J. Clean. Prod. **148**, 882–894 (2017a)

Riti, J.S., Song, D., Shu, Y., Kamah, M.: Decoupling CO_2 emission and economic growth in China: is there consistency in estimation results in analyzing environmental Kuznets curve? J. Clean. Prod. (2017b). doi:10.1016/j.jclepro.2017.08.117

Rockström, J., Sachs, J.D., Öhman, M.C., Schmidt-Traub, G.: Sustainable development and planetary boundaries. Background Research Paper Submitted to the High Level Panel on the Post-2015 Development Agenda. Paris, New York: Sustainable Development Solutions Network (2013)

Saidur, R., Rahim, N., Islam, M., Solangi, K.: Environmental impact of wind energy. Renew. Sustain. Energy Rev. **15**, 2423–2430 (2011)

Shahbaz, M., Hye, Q.M.A., Tiwari, A.K., Leitão, N.C.: Economic growth, energy consumption, financial development, international trade and CO_2 emissions in Indonesia. Renew. Sustain. Energy Rev. **25**, 109–121 (2013)

Shahe, E.M., Shilpi, F., Alam, M.I.: Economic liberalization and price response of aggregate private investment: time series evidence from India. Can. J. Econ./Revue canadienne d'économique **40**, 914–934 (2007)

Shaw, C.: Choosing a dangerous limit for climate change: public representations of the decision making process. Glob. Environ. Change **23**, 563–571 (2013)

Siali, M., Flazi, S., Stambouli, A.B., Fergani, S.: Optimization of the investment cost of solar based grid. Renew. Energy **97**, 169–176 (2016)

Sovacool, B.K., Brown, M.A.: Competing dimensions of energy security: an international perspective. Annu. Rev. Environ. Resour. **35**, 77–108 (2010)

Sovacool, B.K., Kryman, M., Laine, E.: Profiling technological failure and disaster in the energy sector: a comparative analysis of historical energy accidents. Energy **90**(2015), 2016–2027 (2015)

Tampakis, S., Tsantopoulos, G., Arabatzis, G., Rerras, I.: Citizens' views on various forms of energy and their contribution to the environment. Renew. Sustain. Energy Rev **20**, 473–482 (2013)

Tan, X., Zhao, Y., Polycarp, C., Bai, J.: China's overseas investments in the wind and solar industries: trends and drivers. World Resources Institute Working Paper (2013)

Tian, H., Cheng, K., Wang, Y., Zhao, D., Lu, L., Jia, W., Hao, J.: Temporal and spatial variation characteristics of atmospheric emissions of Cd, Cr, and Pb from coal in China. Atmos. Environ. **50**, 157–163 (2012)

Tiwari, A.K., Shahbaz, M., Islam, F.: Does financial development increase rural-urban income inequality? Cointegration analysis in the case of Indian economy. Int. J.Soc. Econ. **40**, 151–168 (2013)

Tuana, N., Cuomo, C.J.: Climate change—editors' introduction. Hypatia **29**, 533–540 (2014)

Valli, V.: The Economic Rise of China and India. Accademia University Press, Turin (2015)

Wandesforde-Smith, G., Denninger Snyder, K., Hart, L.A.: Biodiversity conservation and protected areas in China: science, law, and the obdurate party-state. J. Int. Wildlife Law Policy **17**, 85–101 (2014)

Wang, B., Liang, X.J., Zhang, H., Wang, L., Wei, Y.M.: Vulnerability of hydropower generation to climate change in China: results based on Grey forecasting model. Energy Policy **65**(2014), 701–707 (2014)

World Bank Data (World Development Indicators). (2016). http://data.worldbank.org/indicator/; http://data.worldbank.org/data-catalog/world-development-indicators. Accessed 6 Sept 2016

Wu, Y.K., Lee, C.Y., Chen, C.R., Hsu, K.W., Tseng, H.T.: Optimization of the wind turbine layout and transmission system planning for a large-scale offshore windfarm by AI technology. Ind. Appl. IEEE Trans. **50**, 2071–2080 (2014)

Yang, M., Patino-Echeverri, D., Yang, F., Williams, E.: Industrial energy efficiency in China: achievements, challenges and opportunities. Energy Strategy Rev. **6**, 20–29 (2015)

Yuan, J., Kang, J., Yu, C., Hu, Z.: Energy conservation and emissions reduction in China progress and prospective. Renew. Sustain. Energy Rev. **15**, 4334–4347 (2015)

Zhang, W., Yang, S.: The influence of energy consumption of China on its real GDP from aggregated and disaggregated viewpoints. Energy Policy **57**(2013), 76–81 (2013)

Zhang, X., Karplus, V.J., Qi, T., Zhang, D., He, J.: Carbon emissions in China: how far can new efforts bend the curve? Energy Econ. **54**, 388–395 (2016)

Zhi, Q., Sun, H., Li, Y., Xu, Y., Su, J.: China's solar photovoltaic policy: an analysis based on policy instruments. Appl. Energy **129**, 308–319 (2014)

Zhou, N., Fridley, D., Khanna, N.Z., Ke, J., McNeil, M., Levine, M.: China's energy and emissions outlook to 2050: perspectives from bottom-up energy end-use model. Energy Policy **53**, 51–62 (2013)