Environmental Science and Pollution Research (2021) 28:37741–37753
https://doi.org/10.1007/s11356-021-13329-3

RESEARCH ARTICLE

Natural gas consumption-economic output and environmental sustainability target in China: an N-shaped hypothesis inference

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Received: 22 December 2020 / Accepted: 3 March 2021 / Published online: 15 March 2021

Abstract

On one divide, energy types have been linked with the varying degree of environmental damage. Another perspective argued on the severity of the damaged base on per capita and/or population consumption pattern. As such, this study investigates the nexus of per capita natural gas consumption-carbon dioxide emissions and per capita income-carbon dioxide emissions in the case of the People of the Republic of China. This study objectively expanded to illustrate whether the N-shaped environmental Kuznets curve hypothesis holds in the case of China or not. The employed autoregressive distributed lag bound testing approach incorporated additional explanatory variables (urbanization) within the N-shaped EKC hypothesis over the period 1971–2018. Importantly, the results show an evidence of inverted N-shaped EKC relationship. In addition, the study posits a positive relationship between natural gas consumption and carbon dioxide emissions and between urbanization and carbon dioxide emissions. Thus, the study proposes renewable energy development and decongestion of the urban centers as a means of controlling global warming.

Keywords Natural gas consumption · Urbanization · Real income · Environmental degradation · People Republic of China

Introduction

While it is anticipated that natural gas in 2020 would generate about 10% of the People of the Republic of China's overall primary energy consumption, there is a report of a significant increase of 3.8% compared to the 6.2% overall initial energy consumed in 2014 (The Oxford Institute for Energy Studies, 2020). Additionally, it is expected that specific factors which among others includes seasonal weather disparities, natural gas, and unconventional energy price, infrastructure (gas-access-rate), resource endowment, priorities of public authorities (government), industry structure, income level, environmental awareness, and urbanization would influence the People of Republic of China's natural gas demand (The Oxford Institute for Energy Studies 2020). Without mixing words, it is paramount to state here that the drivers listed above tend to

Highlights

- Per capita income and environmental quality in China exhibit a "rise and fall" relationship.
- An inverted N-shaped environmental Kuznets curve hypothesis holds for China.
- Natural gas utilization hampers environmental quality in China.
- Increasing rate of urbanization is detrimental to the environment.

Responsible Editor: Ilhan Ozturk

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exhibit varying influence (effect) on the regional natural gas consumption at varying environments or places.

In addition, the role that natural gas plays in an economy such as the People of the Republic of China tends to shift either from contributing to the largest share of the growing energy demand or fill in for the existing energy supply from other non-renewable energy sources, specifically from fossil fuels. Overall, such substitution will largely rely on many factors, which include the possibility of having in place a secure and adequate energy supply, the relative prices of natural gas in contrast to other energy sources, and the environmental impacts that come with such energy sources. Furthermore, looking at the regional level, one of the main drivers of consumption of natural gas is the composition of the regional economy.

In an economy where the oil sector contributes to a larger share of the aggregate gross domestic product (GDP), such an economy expectedly tends to employ a larger share of natural gas in their industries. This is notwithstanding even when its portion (allotment) in aggregate natural gas consumption is experiencing a decline. With regard to the services-dominated economy, the consumption of natural gas in commercial and/or residential units is more important. Moreover, the household (residential) consumption of natural gas is significantly increasing in most nations, especially typical of the People of Republic of China with enhanced natural gas infrastructure, coupled with the growing urbanization. Also, household consumption of natural gas possesses a significant opportunity for the development of natural gas shortly, specifically in the developed nations of the world. On the other hand, according to Lasisi et al. (2020) and Saint Akadiri et al. (2020), cooling and heating consumption of gas is anticipated to rise in shoreline countries due to government economic policies that are enacted, specifically on reducing or curbing the usage of coal for power generation and the increasing disparities among valley and peak power insistence. Consequently, the consumption of natural gas becomes eminent both for commercial and/or residential usage.

The consumption and production of the natural gas of the People of the Republic of China over time have increased tremendously, see Table 1[1]. The People of the Republic of China in 2017 grasp 184 trillion cubic feet of confirmed natural gas reserves, ranked 10th position globally. This is also accounting for about 3% of the world's aggregate natural gas reserves of 6923 trillion cubic feet. Similarly, the People of the Republic of China have confirmed reserves corresponding to 21.9 times its yearly consumption. Consequently, the regions have more than 2 decades of natural gas in reserves.[2]

[1] The data reported is for until 2015, which is the latest year with complete data in all groups.

[2] At the current consumption levels, excluding unproven reserves. Source: Statistical Review of World Energy and Energy International Agency (EIA).

Table 1 Position of China natural gas

Indicators	Cubic ft in millions (MMcf)	World rank
Reserves	163,959,000	10th
Consumption	6,738,152	3rd
Production	4,559,626	8th
Exports	116,331	
Imports	2,282,597	
Deficits (annual)	− 2,178,526	
Net (imports)	2,086,265	

On consumption in 2017, the People of the Republic of China consume about 8,500,000 MMcf of natural gas, a statistic that positions the region 3rd globally in terms of the consumption of natural gas, controlling for about 6.4% of the global natural gas consumption of 132,290,211 MMcf. Furthermore, the regions use 16 cubic feet per capita natural gas per day or 5929 cubic feet per capital natural gas annually (statistic was built on 2017 population figure of 1,421,021,791). While on production as of 2015, the regions generate about 4,559,625.60 MMcf of natural gas annually, which put the country in 8th position on the world map. Lastly, on imports as of 2015, the region imports 31% of its natural gas consumed which amounts to 2,086,265 MMcf (Worldometer, 2020). In general, China is currently ranked as the world's largest importer of oil and gas ahead of the USA since 2017 (United States Energy International Agency 2018). Going by these statistics, it is obvious that the economy of the People of the Republic of China depends largely on the consumption and production of natural gas; hence, an expected impact of energy utilization on the country's environment via several economic activities is explainable. This motivates us to investigate the emissions impacts of per capita natural gas consumption and output in the case of the People of the Republic of China, via the N-shaped hypothesis.

The major objective of this study is to examine whether the N-shaped environmental Kuznets curve (EKC) hypothesis holds in the case of China or not. It is paramount to state here that the environment-economic growth nexus has been extensively studied in energy-environment-economic growth literature, while several drivers of environmental degradation have been investigated (Katircioğlu 2014; Alola et al. 2019b; Saint Akadiri et al. 2019a, 2019b; Eluwole et al. 2020). The EKC hypothesis as widely referred to proposes that environmental deterioration primarily increases with per capita income. According to Alola et al. (2020), an increase in per capita income (economic growth) causes demand for environmental quality, hence a reduction in environmental degradation. Consequently, in a situation whereby an inverted U-shaped EKC is confirmed, it would be that there is an environmental development, and this will be achieved over the long run even with an increase in economic growth. Thereby, human and economic activities would continue with the hope of sustaining a cleaner and sound environment either over the short run or over the long run (Stern 2004). Over time, a few researchers (Allard et al. 2018; Lorente and Álvarez-Herranz 2016 among others) have reexamined this relationship between environment and economic growth and reported that there is a possibility of N-shaped EKC relationships. The N-shaped EKC hypothesis proposes that environmental deterioration after a decline continues to rise again above a specific level of income. That is when the income level becomes tripled. This study is among the few studies that have examined whether there is an existence of an N-shaped EKC hypothesis or not, most especially in the case of the People of the Republic of China, incorporating urbanization and natural gas consumption as explanatory variables.

To achieve our research objective, this study makes use of annual frequency time series data such as carbon dioxide emissions, GDP per capita, natural gas consumption, and urbanization to ascertain the impact of emissions from per capita of natural gas and output within the N-shaped EKC hypothesis framework throughout 1971–2018 for China. The N-shaped EKC framework suggests that GDP, the square of GDP, and a cube of GDP determine environmental degradation, using an autoregressive distributed lag bound testing approach that produces short- and long-run estimates, efficient with partially integrated order of varies and also adequate when working with small sample size among other merits. Empirical results show that rather than the N-shaped hypothesis, the impacts of the GDPC (negative), the square GDPC (+), and the cube GDPC (−) on carbon emissions suggest an inverted N-shaped hypothesis in the case of China. The inverted N-shaped hypothesis implies that the growth of income per capita initially improves environmental quality and then damages the environment when income growth is doubled until the income growth is eventually tripled.

The other parts of the study are scheduled as follows: the “Theoretical background” section discusses theoretical background and literature review. In the “Data and methodological framework” section, we detailed data, its sources, and the methodology adopted for empirical analysis. The “Results and discussion” section discusses the results and elaborates the findings, while in the “Conclusion and policy recommendations” section, we conclude the study alongside policy suggestions.

Theoretical background

Economic growth and natural gas

The contributions of natural gas (NG) to the economic growth of different countries across the world have gained relevance particularly due to the depletion of the oil reserves of many oil monopolists, hence making natural gas an option that is viable for consideration given the unique role as a non-renewable energy source (Villada and Olaya 2013; Shahbaz et al. 2013a, 2013b; Apergis et al. 2010). Over the years, the development in the area of innovation and exploration has further increased the natural gas supplies to meet the demand for energy, which consequently translates, to expansion in economic growth in many countries of the world with this natural resource. Natural gas is known to be cleaner than oil as it emits 20% less carbon emission and coal with about 50% less carbon emission (citation). Besides, the long-term benefit it gives to the world in terms of ameliorating climate issues, its efficiency, and reliability is more appreciated than renewable energy (International Gas Union, 2010). The investment infrastructures needed to facilitate economic growth using gas-fired power plants require less construction time compared to coal-fired plants and nuclear facilities, which further allows for ease of doing business in the industry, such that investment decisions are taken given friendly business environment that will guarantee economic growth. Scholars have established a causal link between natural gas consumption and economic growth (Lee and Chang 2005; Zamani 2007; Isik 2010; Solarin and Shahbaz 2015; Saint Akadiri et al. 2019a) given that the demand for energy consumption has constantly increased especially for the case of natural gas and oil, which has also increased economic growth globally. NG has a track record of harnessing and boosting economic growth irrespective of the developmental stage in the economic ladder such an economy finds itself (Balsalobre-Lorente et al. 2019a).

The accruals generated from the proceeds of NG can be transmitted through a mechanism into economic growth. This can be achieved by utilizing the increased revenues from proceeds for investment in the public infrastructural architecture and consumption; these will serve as an incentive to induce and stimulate more economic activities that will eventually translate into economic growth. According to Basher and Fachin (2013), savings and investment are established to have a long-run relationship. Though over the years, they have been a considerable deviation from household consumption towards the industrial sector of NG exploration and exploitation due to technological advancement, which uses an approach that ensures high-efficiency low emission (HELE) strategy, which then increases the industrial sector consumption of NG. Furthermore, a deliberate attempt by the government to provide pipeline installation and subsidiaries also encourages the involvement of private sector investment significantly in growing the economy. These dynamics mitigates the low domestic savings faced by private investment, such that the NG revenue increases income which in turn induces higher savings through increases in investment and accumulation of capital which is vital for the expansion of the domestic economy with higher economic activities (Esfahani and Yousefi 2017; Ramey 2011).

Similarly, another perspective on the relationship between natural gas and economic growth can be observed from the price economy and structural adjustment. The price effect of NG consumption can significantly affect economic growth. From the microeconomic point of view, the price of NG will have a direct impact on the consumption and production of the industry and a greater effect on the energy-intensive industry. With changes in the materials used in production in the factories and commodities needed by the households relative to the other alternative energy sources, the utilization of more natural gas will be induced and used in the factory. This ultimately will alter the dynamics of livelihood and production, which will, in turn, affect and translate into the growth of the entire economy.

Environmental impact of natural gas

Economic growth is usually referred to as the persistent rise in the number of goods and services produced by a country at a given time. Although growth-energy nexus literature provides a general perspective of the growth model, the impact of disaggregated energy sources in productivity vis-à-vis economic development is increasingly illustrated in extant studies (Kraft and Kraft 1978; Soytas and Sari 2003; Alola and Yildirim 2019; Kose et al. 2020). However, the impact of energy on economic development has not come without an arguably negative consequence such as environmental degradation. In the literature, the impact of energy on the environment illustratively depends on whether the energy is from a conventional/traditional source(s) such as fossil fuel energy or clean energy sources (largely renewable and clean technologies) (Alola et al. 2019a; Bekun et al. 2019; Adedoyin et al. 2020b; Ibrahim and Alola 2020; Ike et al. 2020).

In specific, NG has been known to play a critical role in increasing the productivity of any nation endowed with natural resources. However, with the increase in output, an increase in per capita natural gas may be responsible for the increase in carbon emissions (Lee and Brahmasrene 2014; Balsalobre-Lorente et al. 2019a). Given the resource-intensive nature of natural gas in the industrial sector, it is safe to argue that NG consumption per capita may increase the negative externalities on the environment even while enhancing economic growth through the production and distribution activities of the NG. The production and distribution process of natural gas involves an increase in environmental degradation (Balsalobre-Lorente et al. 2019b). Based on the aforementioned, the environmental Kuznets curve framework will be employed to examine the relationship between economic growth and carbon dioxide emissions.

Kuznets (1955) maintained the position that the relationship between income per capita and income inequality can be described with a bell-shaped curve. So, the growth of per capita income increases income inequality initially; however, the income inequality declines after a certain threshold with increasing revenue. Grossman and Krueger (1991) subsequently did revisit this phenomenon by investigating the relationship between gross domestic product (GDP) and the environment. Likewise, there was an increase in environmental degradation in the first phase of growth but there was a decline in environmental pollution due to reaching a certain income level turning point (Stern 2003). This concept is being referred to as the environmental Kuznets curve in the literature.

An increase in pollution emissions in the industrialization era was common with the first and early stages of economic growth. What was important at this stage was the growth of output with little or no interest in the effect of such growth on the environment. Implying that increase in the production capacity will increase carbon emission, thereby increasing the level of pollution. Nevertheless, after a certain trajectory, there are levels of consciousness regarding the effect of economic activities on the environment; therefore, deliberate attempts are made to ensure a clean environment (Dinda 2004; Balsalobre-Lorente et al. 2018; Adedoyin et al. 2020a; Adedoyin et al. 2020a).

To further buttress the relationship between environmental degradation and income, Grossman and Krueger (1991) summarize the effect of this relationship from three standpoints. Firstly, the scale effect is known to harm the quality of the environment. The negative impact can be traced to the fact that an increase in production would require an increase in input. Consequently, increasing input will require more energy and other resources in an intensive manner. This will further result in more by-products and waste which will pollute the environment. Second is the composition effect, which explains the positive impacts of economic growth on the environment. With an increase in the income level, the economic structure is enhanced with efficient and effective techniques that ensure a reduction in environmental degradation with the use of energy-intensive production techniques. Finally, technical effects also have a positive influence on the environment. An increase in the income level will ensure robust research and sdevelopment (R&D) allocations. This will further promote technological advancement, which will enhance economic growth, and old and obsolete technologies will give way to modern technologies that will guarantee a clean environment (Grossman and Krueger 1991; Komen et al. 1997; Dinda 2004).

They have been several contradictory empirical results following rigorous exercise to test and analyze the EKC hypothesis using different datasets with various econometric techniques for several countries. These scholars include Grossman and Krueger (1991) being the first to analyze this hypothesis, then followed by Dinda (2004); Hu et al. (2018); Ozturk and Acaravci (2010); Panayotou (1993); Shafik and Bandyopadhyay (1992); Sharif et al. (2019); Stern (2004); Zhang and Meng (2019); and Barış-Tüzemen et al. (2020).

Related studies: a review

The natural gas consumption and economic growth nexus in recent times have taken center stage in the energy-growth literature. Extant studies have shown different relationships that exist between these variables of interest. Furuoka (2016) found that in the case of China and Japan, a unidirectional causality was observed between natural gas and economic growth, whereas bidirectional causality was evident in the Japanese case. Shahbaz et al. (2014) in their studies with the use of multivariate variables using the ARDL model confirmed that natural gas consumption played a significant role in enhancing economic growth in Pakistan. Ozturk and Al-Mulali et al. (2015) further confirmed in their study bidirectional causality between natural gas and economic growth in the long run. A Scholar like Balitskiy et al. (2016) predicated their study on the neoclassical growth model and selected 26 countries in the EU using panel data to determine the relationship between natural gas, energy efficiency, and economic growth. Furthermore, other researchers like Narayan et al. (2007), Bartleet and Gounder (2010), and Bekun et al. (2020) also investigated the relationship between these variables.

Jun (2015) in his study using China was able to ascertain the error correction model against natural gas consumption index, coal consumption index, and economic growth index. The result of this analysis revealed a long-term equilibrium between coal and natural gas consumption along with economic growth. Li (2012) validated the cointegrating relationship between natural gas consumption and economy with regard to 1949 to 2010 in the USA. Similarly, An-bing (2013) in his investigation using the error correction model and the cointegration theory into the nexus between natural gas consumption and economic growth in China from 1991 to 2011 confirmed that there is a unidirectional causality running from natural gas consumption to economic growth.

Further consideration of the relationship between natural gas consumption and economic growth as seen in literature reveals that there four groups to categorize this nexus. First is the use of the bivariate model to elucidate and validate the relationship between natural gas consumption and economic growth (Lim and Yoo 2012; Isik 2010). Secondly, is the use of a trivariate model that usually includes either the use of capital or labor to complement natural gas consumption and economic growth variables, to ascertain the nexus (Kum et al. 2012; Apergis and Payne 2010). Thirdly, the model was further modified to include trade indicators validating the nexus (Shahbaz et al. 2013b). Finally, the model introduces natural gas consumption along with other disaggregated groups of energy such as coal, electricity, oil, and solar (Yu and Choi 1985; Yang 2000; Aqeel and Butt 2001; Fatai et al. 2004; Lee and Chang 2005; Zamani 2007; Reynolds and Kolodziej 2008; Sari et al. 2008; Hu and Lin 2008; Asghar 2008; Apergis et al. 2010; Ighodaro 2010; Payne 2011; Adedoyin et al. 2020a; Etokakpan et al. 2020 d, e). Table 2 gives a summary of the natural gas consumption and economic growth literature review across many economies with contradictory decisions from empirical studies. Hence, no consistent conclusion has been reached though many of the results supported the feedback hypothesis.

Data and methodological framework

Data

This study used the following variables such as carbon emissions, GDP per capita, natural gas consumption, and urbanization to ascertain the impact of emissions from per capita of natural gas and output within the N-shaped EKC hypothesis framework throughout 1971–2018 for China. The N-shaped EKC framework suggests that GDP, the square of GDP, and a cube of GDP determine environmental degradation. Recently, due to policy formulation, forecasting, and the intention to reduce emissions variable bias, many additional variables have been introduced into the equation. On this note, energy consumption (natural gas) and urbanization variables are incorporated into the model as additional insights into the emissions (Al-Mulali et al. 2016; Al-Mulali and Ozturk 2015; Kasman and Duman 2015; Al-Mulali et al. 2015). On the strength of these studies, this model is considered as follows:

$$\begin{aligned}\ln\mathrm{CEM}_t = \alpha_1 + \alpha_2\ln\mathrm{GDPC}_t + \alpha_3\ln{\mathrm{GDPC}_t}^2 \\ + \alpha_4\ln{\mathrm{GDPC}_t}^3 + \alpha_5\ln\mathrm{NGC}_t + \alpha_6\ln\mathrm{URBP}_t \\ + \varepsilon_t\end{aligned} \tag{1}$$

From Eq. (1), CEM is the carbon dioxide emissions per capita (metric tons of oil equivalent of CO_2 by population), GDPC_t denotes the real GDP per capita as expressed in constant dollars 2010, ${\mathrm{GDPC}_t}^2$ is the square GDP per capita, ${\mathrm{GDPC}_t}^3$ is the cube GDP per capita, NGC_t represents the natural gas consumption per capita (tons of the oil equivalent of natural gas consumed divided by population), and URBP_t denotes the urbanization population ratio (urban population divided by total population). Environmental degradation is proxied by carbon emissions (CEM) expressed in metric tons per capita. The economic output is proxied by the gross domestic product (GDP) per capita (Constant USD 2010). The carbon emissions and natural gas dataset were sourced from the British Petroleum (BP) Statistical Review of World Energy (2020), whereas the population, urbanization, and GDP were obtained from World Development Indicators with the sample period between 1971 and 2018 (see Table 3).

Table 2 Natural gas-economic growth nexus literature summary

Author & year	Country	Period	Technique	Findings	Decision
Balsalobre-Lorente et al. (2019a)	Iran	1990Q1–2017Q4	ARDL, GC, BH	NG ↔ Y	Feedback
Furuoka (2016)	China	1980–2012	ARDL, GC, TY	NG → Y	Conservative
Shahiduzzaman and Alam (2014)	Australia	1970–2009	ARDL	NG ↔ Y	Feedback
Rafindadi and Ozturk (2015)	Malaysia	1971–2012	ARDL, BH, GC	NG ↔ Y	Feedback
Saboori and Sulaiman (2013)	Malaysia	1980–2013	ARDL, JML, GC	NG ↔ Y	Feedback
Lotfalipour et al. (2010)	Iran	1967–2007	TY	NG → Y	Conservative
Reynolds and Kolodziej (2008)	Soviet Union	1928–1987, 1988–1991, 1992–2003	GC	NG → Y	Conservative
Siddiqui (2004)	Pakistan	1970–2003	ARDL, HGC	NG x Y	Neutrality
Yu and Choi (1985)	USA, UK	1947–1974	GC	NG ← Y	Growth
Akadiri and Akadiri (2018)	Iran	1980–2013	ARDL, TY	Y x NG	Neutrality
Solarin and Ozturk (2016)	OPEC member countries	1980–2012	Panel GC	NG ↔ Y	Feedback
Bildirici and Bakirtas (2014)	Brazil, Russia, and Turkey	1980–2011	ARDL, JML, GC	NG ↔ Y	Feedback
Ozturk and Al-Mulali et al. (2015)	Gulf Cooperation Council (GCC) Countries	1980–2012	Pedroni cointegration test	NG ↔ Y	Feedback
Shahbaz et al. (2013b)	Pakistan	1972–2010	ARDL, JML, GC	NG → Y	Conservative
Apergis and Payne (2010)	67 countries	1992–2005	Pedroni cointegration	NG ↔ Y	Feedback
Hu and Lin (2008)	Taiwan	1973–2003	VECM	NG ← Y	Growth
Fatai et al. (2004)	New Zealand and Australia	1960–1999	ARDL, JML, TY	Y x NG	Neutrality
Hafeznia et al. (2017)	Iran	N/A	Descriptive statistics, Graphs	NG ↔ Y	Feedback
Balitskiy et al. (2016)	EU-26	1997–2011	Panel cointegration	NG↔ Y	Feedback
Dogan (2015)	Turkey	1995–2012	VECM, GC	NG ↔ Y	Feedback
Das et al. (2013)	Bangladesh	1980–2010	JML,GC	Y → NG	Growth
Ighodaro (2010)	Nigeria	1970–2005	VECM, JJ	NG → Y	Conservative
Sari et al. (2008)	US	2001–2005	ARDL, VECM	NG ← Y	Growth
Solarin and Lean (2016)	India and China	1965–2013	Hatemi-J, TYDL GC	NG ↔ Y	Feedback
Isik (2010)	Turkey	1977–2008	ARDL	NG ↔ Y	Feedback
Kum et al. (2012)	Korea	1991–2008	GC	NG ↔ Y	Feedback
Zamani (2007)	Iran	1967–2003	JML, VECM	NG ↔ Y	Feedback
Amadeh et al. (2009)	Iran	1973–2003	ARDL, VECM	NG ← Y	Growth
Lee and Chang (2005)	Taiwan	1954–2003	JML, WE	NG → Y	Conservative
Zamani (2007)	Iran	1967–2003	JML, VECM	NG ↔ Y	Feedback
Farhani et al. (2014)	Tunisia	1980–2010	ARDL, GC, JJ	NG ↔ Y	Feedback
Muhammad et al. (2012)	Pakistan	1972–2010	ARDL	NG → Y	Conservative
Pirlogea and Cicea (2012)	Romania	1990–2010	GC	Y x NG	Neutrality
Payne (2011)	USA	1949–2006	TY	Y → NG	Growth

Note the definition of the following abbreviations and notations: ↔, feedback causality; →, conservative causality; ←, growth causality; x, no causality; *N/A*, not available; *NG*, natural gas; *Y*, economic growth; *ARDL*, autoregressive distributed lag; *VECM*, vector error correction model; *GC*, Granger causality; *BH*, Bayer and Hanck; *JML*, Johansen's maximum likelihood; *JJ*, Johansen-Joselius cointegration; *TY*, Toda and Yamamoto and Luktkepohl; *TYDL*, Toda and Yamamoto and Dolado and Luktkepohl; *HGC*, Hsiao's Granger causality

Unit root test

The stationarity test is necessary for the early stage of the empirical analysis to ascertain the integration levels of the variables under consideration, and two different unit root tests were adopted for this study: augmented Dickey and Fuller (ADF) (1979) and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test (1992). The ADF test is necessary to eliminate the possibility of rejecting a true null hypothesis of non-stationarity. The KPSS test is needful as an alternative technique adopted for the ADF test for testing the null hypothesis to remove the deterministic trends to make it stationary. It is important to note that the KPSS test is stationary around a deterministic trend against the alternative of a unit root; this implies that the presence of a unit root is on the alternative as opposed to the null hypothesis for the ADF test.

ARDL model

The Pesaran et al. (2001) bound test technique was employed to validate the long-run relationship between output, natural gas consumption, and environmental degradation. The uniqueness of this technique rests on it applying to the independent variables that are integrated at order zero, $I(0)$, order one $I(1)$, or partially cointegrated. It has a single-equation setup that enhances its simplicity for easy understanding; hence, the dependent and independent variables can take on different lag lengths (Giles 2013).

The ARDL model is characterized by three stages namely (1) the unrestricted error correction model created to determine the long-run relationship among the variables of interest. (2) Should the variables be cointegrated, and then, the long-

Table 3 Data description, common statistics, and correlation matrix

Data description				
Variable	Code	Unit of measurement		Source
Carbon emissions	CEM	Metric tons		BP
Gross domestic product per capita	GDPC	Constant USD = 2010		WDI
Natural gas per capita	NGC	Metric tons		BP
Urbanization	URBP	Ratio of urban to population		WDI
Descriptive statistics				
	LnCEM	LnGDPC	LnNGC	LnURBP
Mean	7.840	6.882	− 17.976	− 17.458
Median	7.832	6.727	18.196	− 17.523
Maximum	9.152	8.956	− 15.560	− 16.974
Minimum	6.165	5.155	− 20.436	− 17.802
Std. deviation	0.904	1.210	1.125	0.256
Skewness	− 0.111	0.213	0.080	0.462
Kurtosis	2.035	1.702	2.752	1.928
Jarque-Bera	2.205 (0.332)	4.200 (0.122)	0.278 (0.870)	4.506 (0.105)
Observations	54	54	54	54
Correlation matrix				
Variable	LnCEM	LnGDPC	LnNGC	LnURBP
LnCEMC	1			
LnGDPC	0.980*	1		
LnNGC	0.960*	0.929*	1	
LnURBP	0.864*	0.938*	0.808*	1

Note: The CEM, LGDPC, NGC, and URBP are respectively the logarithm of carbon emissions, the logarithm of gross domestic product per capita, law and order, and socioeconomic factor. In addition, * represents the 1% statistical significant level

run coefficients are estimated. (3) The short-run coefficients and the error correction coefficients are therefore obtained. Hence, this study has its ARDL model as specified below:

$$\begin{aligned}\Delta \ln \mathrm{CEMC}_t = {} & a_{0Y} + \sum_{i=1}^{m} b_{1Y} \Delta \ln \mathrm{CEMC}_{t-i} \\ & + \textstyle\sum_{i=0}^{n} c_{2Y} \Delta \ln \mathrm{GDPC}_{t-i} \\ & + \textstyle\sum_{i=0}^{n} d_{3Y} \Delta \ln \mathrm{GDPC}^2_{t-i} \\ & + \textstyle\sum_{i=0}^{n} e_{4Y} \Delta \ln \mathrm{GDPC}^3_{t-i} \\ & + \textstyle\sum_{i=0}^{n} f_{5Y} \Delta \ln \mathrm{NGC}_{t-i} \\ & + \textstyle\sum_{i=0}^{n} g_{6Y} \ln \mathrm{URBP}_{t-i} + \varphi_{1Y} \ln \mathrm{CEMC}_{t-1} \\ & + \varphi_{2Y} \ln \mathrm{GDPC}_{t-1} + \varphi_{3Y} \ln \mathrm{GDPC}^2_{t-1} \\ & + \varphi_{4Y} \ln \mathrm{GDPC}^3_{t-1} + \varphi_{5Y} \ln \mathrm{NGC}_{t-1} \\ & + \varphi_{6Y} \ln \mathrm{URBP}_{t-1} + \varepsilon_t \end{aligned} \tag{2}$$

Here, a_{0Y} denotes the intercept and ε_{1t} stands for the error term. The first part of Eq. (2) has the error correction dynamics of the model, whereas the second part of the same equation captures the long-run relationship. The null hypothesis from the bounds test is expressed as follows: $\varphi_{1Y} = \varphi_{2Y} = \varphi_{3Y} = \varphi_{4Y} = \varphi_{5Y} = \varphi_{6Y} = 0$, implying that there is no long-run relationship among the variables of interest. On the other hand, an appropriate expression for the alternative hypothesis of the bounds test suggests that there is a long-run equilibrium relationship among the variables under consideration and represented as follows: $\varphi_{1Y} \neq \varphi_{2Y} \neq \varphi_{3Y} \neq \varphi_{4Y} \neq \varphi_{5Y} \neq \varphi_{6Y} \neq 0$.

With the knowledge of the long-run equilibrium relationship as seen among the variables of interest in Eq. (2), the ECM will be adopted to estimate the short-run and long-run coefficients. Also, consideration will be given to the speed of adjustment of the short-run values of the independent variables to the long-run equilibrium level of the dependent variable was estimated as well using the ECM model:

$$\begin{aligned}\Delta \ln \mathrm{CEMC}_t = {} & a_{0Y} + \sum_{i=1}^{m} b_{1Y} \Delta \ln \mathrm{CEMC}_{t-i} \\ & + \textstyle\sum_{i=0}^{n} c_{2Y} \Delta \ln \mathrm{GDPC}_{t-i} \\ & + \textstyle\sum_{i=0}^{n} d_{3Y} \Delta \ln \mathrm{GDPC}^2_{t-i} \\ & + \textstyle\sum_{i=0}^{n} e_{4Y} \Delta \ln \mathrm{GDPC}^3_{t-i} \\ & + \textstyle\sum_{i=0}^{n} f_{5Y} \Delta \ln \mathrm{NGC}_{t-i} \\ & + \textstyle\sum_{i=0}^{n} g_{6Y} \ln \mathrm{URBP}_{t-i} + \alpha \mathrm{ECT}_{t-1} + \varepsilon_t \end{aligned} \tag{3}$$

Here, ECT_{t-1} denotes the speed of adjustment to the long-run equilibrium level. Also, to further validate the robustness of the results, FMOLS, DOLS, and CCR were conducted in this study. Several diagnostic tests will be conducted to ascertain the goodness of fit of the ARDL model.

Results and discussion

Giving that the skewness of the variables from the descriptive statistics estimated is between − 0.5 and 0.5 (see Table 3), the estimated dataset is adjudged to be moderately symmetric. Besides, with 54 observations, all the series are also normally distributed. Importantly, there is a piece of statistically significant correlation evidence suggesting a significant relationship between the dependent variables and the explanatory variable (see Table 3). In Table 4, the result of the unit root suggests that the series are all stationary at most after the first difference. The aforementioned evidence provides a suitable ground after the cointegration investigation between carbon emissions, gross domestic product per capita, natural gas per capita, and urbanization in China. Interestingly, a priori evidence of a long-run relationship is perceived from the visual inspection of Fig. 1.

The long-run and short-run evidence

The result of long-run and short-run ARDL with the model ARDL (2, 2, 1, 2) is presented in Table 5. The model adjusts at a rate of 20.1% from short-term disequilibrium to stability. Except for the URBP (urbanization) which exerts a negative impact on carbon emissions, the impact of gross domestic per capita (GDPC) and natural gas per capita (NGC) on carbon emissions is both significant and positive in the long run and short run. The implication is that both increases in the GDPC (increase in individual income) and NGC (increase in per head consumption of natural gas) worsen the environmental quality in both immediate and long periods. However, the undesirable impacts from GDPC and NGC show improvement in the long run because the positive impact of GDPC and NGC decreases from 80.2 to 68.2% and 17.4 to 11.7% respectively.

Table 4 Unit root estimations

Variable	Level		First difference	
	C	*T*	*C*	*T*
ADF				
lnCEM	− 1.139	− 3.097	− 3.883*	− 3.936**
lnGDPC	1.286	− 3.923**	− 4.684*	− 5.063*
lnNGC	− 0.238	− 2.097	− 3.068**	− 3.025
lnURBP	− 1.058	− 3.737**	− 2.711***	− 1.847
KPSS				
lnCEM	0.869*	0.077	0.163	0.066
lnGDPC	0.872*	0.221*	0.730***	0.150
lnNGC	1.268*	0.183***	0.160	0.161***
lnURBP	1.258*	0.293*	0.637**	0.200**

Note: The asterisks *, **, and *** respectively indicate the 1%, 5%, and 10% statistical significance level. The LnCEM, LnGDPC, LnNGC, and LnURBP are the respective logarithmic values of the carbon emissions, gross domestic product per capita, the natural gas per consumption per capita, and urbanization. In addition, ADF is the augmented Dickey and Fuller (1979) unit root test while the KPSS is the Kwiatkowski et al. (1992) stationarity test

Corroborating the positive nexus of GDPC and carbon emission, Liu et al. (2015) and Liu et al. (2018) also found that income growth is detrimental to environmental quality in China. By employing the Gini coefficient as the income inequality, Liu et al. (2019) also found that there is a significant positive impact of the uneven spatial distribution of income on carbon emission in China. However, rather than employing carbon emissions as a proxy for environmental degradation, Wu et al. (2019) employed the different pollution levels of the pollutants SO_2, NO_x, and $PM_{2.5}$ and found that income growth mitigates the effect of the pollutants across the Chinese provinces. But, the perspective expressed in the study of Zhang and Zhao (2014) is that the impact of income on carbon dioxide emissions varies across the regions in China. In respect to urbanization, Sun et al. (2019) opined that urbanization aggravates environmental degradation while Liu et al. (2015) posited that population density leads to a decrease in pollutant emissions in China.

The robustness and diagnostic test

By applying the robustness estimation techniques with the FMOLS, DOLS, and CCR as indicated in the middle part of Table 5, the statistical evidence discussed above is further corroborated. For instance, the three estimation techniques support the statistically significant evidence that GDPC induces the emissions of carbon dioxide in China. Similarly, the techniques further confirmed and revealed that natural gas consumption per head is significant enough to cause more damage to the environment. Additionally, in the case of urbanization, the FMOLS and CCR also affirm that URBP is a good strategy to employ in reducing carbon emissions in China. Although the DOLS result suggested the same desirable impact, it is not statistically significant.

Additionally, the aforementioned results are further affirmed by applying series of diagnostic tests (see Table 5). For instance, the heteroskedastic test via the Breusch-Pagan Godfrey technique and the serial correlation test via the Breusch-Godfrey technique respectively affirmed that there is no concern of heteroskedasticity and serial correlation, which could have made the estimation spurious. Moreover, the Jarque-Bera statistics (0.115 with a p-value of 0.944) has further proven that the entire series are jointly normally

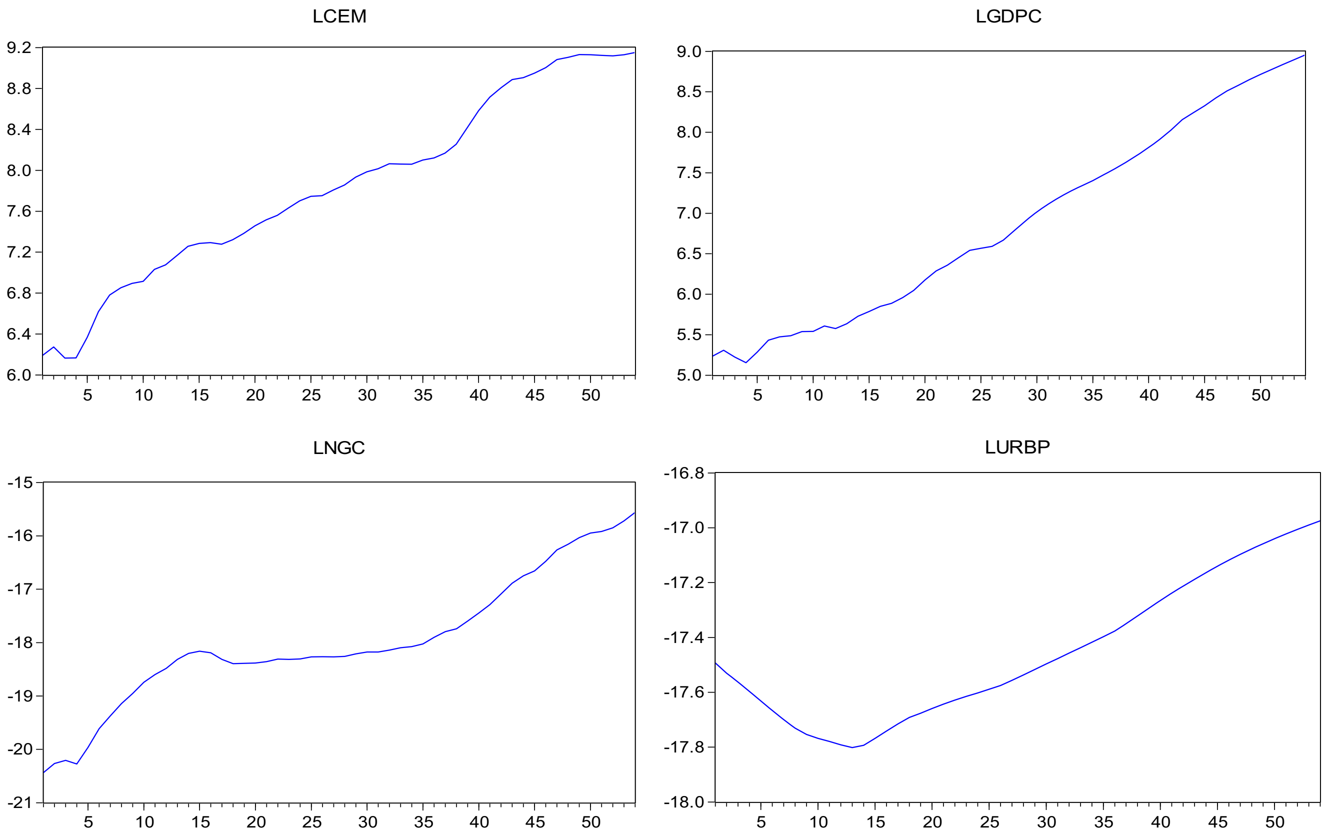

Fig. 1 The time series plot of the logarithmic of carbon emissions, gross domestic product, natural gas consumption, and urbanization

distributed. Also, the distribution is negatively skewed and while peaked given the skewness of − 0.094 and kurtosis of 3.133. These are not without the diagnosticlong-run and short-run statistical significant evidence through the *F*-statistics of thebound test and that of the Wald test.

The inverted N-shaped hypothesis

In investigating the N-shaped hypothesis, the FMOLS, DOLS, and CCR techniques are also employed (see the lower part of Table 5). The techniques were first employed with only constant and then with both constant and trend. Indicatively, while the income growth initially (the GDPC) exerts a negatively significant impact on carbon emissions, the impact of income growth on carbon emissions soon turned positive and significant (the square GDPC), and eventually, the income growth impact on carbon emissions became negative (the cube GDPC) again. Thus, rather than the N-shaped hypothesis, the implication of the impacts of the GDPC (negative), the square GDPC (+), and the cube GDPC (−) on carbon emissions suggest an inverted N-shaped hypothesis for the case of China. Moreover, similar statistical and significant evidence was obtained when the estimation approaches incorporate both constant and trend in the model.

The inverted N-shaped hypothesis implies that the growth of income per capita initially improves environmental quality and then damages the environment when income growth is doubled until the income growth is eventually tripled. By employing different environmental variables such as the CO_2, SO_2, wastewater, and waste solid emissions, both the time series and panel studies for the case of China have presented divergent statistical evidence of EKC (U-shaped), inverted U-shaped, and the N-type hypotheses (Kang et al. 2016; Wang, Han & Wang et al. 2016; Solarin et al. 2017; Sarkodie and Strezov 2018). Interestingly, the results from the estimations techniques present that both natural gas consumption per capita and urbanization aggravate environmental degradation.

Conclusion and policy recommendations

In this paper, we investigate the emissions impacts of per capita natural gas consumption and output in the case of the People of the Republic of China via the N-shaped hypothesis. The major objective of this study is to examine whether the N-shaped environmental Kuznets curve (EKC) hypothesis holds in the case of China or not. To achieve our research objective, this study makes use of annual frequency time series data such as carbon dioxide emissions, GDP per capita, natural gas consumption, and urbanization to ascertain the impact of emissions from per capita of natural gas and output within the N-

Table 5 The long- and short-run cointegration coefficient

Model A: ARDL (2, 2, 1, 2)						
	LnGDPC	LnNGC	LnURBP	LnURBP (− 1)	ECT (− 1)	
LR	0.682*	0.117**	− 0.780			
SR	0.802	0.174**	− 1.413	2.354**	− 0.201*	
Robustness evidence						
				I0 bound	I1 bound	
Bound test	*F*-statistics	4.268* (k = 3)	5%	3.23	4.35	
Wald test	*F*-statistic	18.365*		χ^2	91.827*	
Residual diagnostics						
Breusch-Godfrey SR-LM test			Breusch-Pagan-Godfrey *H* test			
χ^2 (*p*-value)		2.134 (0.343)	15.089 (0.129)			
Jarque-Bera	0.115 (0.944)		Kurtosis	3.133		
Skewness	− 0.094					
Robustness with FMOLS and CCR techniques						
	LnGDPC	LnNGC	LnURBP	Constant	*R*-square	
FMOLS	0.872*	0.1335*	− 1.361*	− 19.516*	0.992	
DOLS	0.696*	0.177	− 0.937	− 10.272	0.996	
CCR	0.877*	0.129**	− 1.377*	− 19.934*	0.992	
Model B: withthe N-shaped hypothesis						
	lnGDPC	LnGDPC2	LnGDPC3	LnNGC	LnURBP	Constant
FMOLS	− 5.275**	0.937*	− 0.052*	0.519*	0.619	36.914*
DOLS	4.135	− 0.337	0.004	0.486*	0.711	15.362
CCR	− 5.513**	0.948**	− 0.053*	0.542*	0.863***	41.766*
	lnGDPC	LnGDPC2	LnGDPC3	LnNGC	LnURBP	C (trend)
FMOLS	− 2. 561	0.623**	− 0.038*	0. 558*	0.626	30.34* (− 0.03*)
DOLS	3. 613	− 0.280	0.001	0. 480*	0.706	16.653 (0.009)
CCR	− 2.472	0.613**	− 0.038*	0.563*	0.698***	31.50* (0.03*)

Note: The FMOLS, DOLS, CCR, LR, SR, SR-LM, H, χ^2 are respectively the fully modified ordinary least square, dynamic least square, canonical cointegrating regression, long-run, short-run, serial correlation Lagrange multiplier, heteroskedasticity, and chi-square. The asterisks *, **, and *** are respectively the 1%, 5%, and 10% statistical significant levels

shaped EKC hypothesis framework throughout 1971–2018 for China. The N-shaped EKC framework suggests that GDP, the square of GDP, and a cube of GDP determine environmental degradation, using an autoregressive distributed lag bound testing approach that produces short- and long-run estimates, efficient with partially integrated order of varies and also adequate when working with small sample size among other merits.

Empirical results show that rather than the N-shaped hypothesis; the impacts of the GDPC (negative), the square GDPC (+), and the cube GDPC (−) on carbon emissions suggest an inverted N-shaped hypothesis in the case of China. The inverted N-shaped hypothesis implies that the growth of income per capita initially improves environmental quality and then damages the environment when income growth is doubled until the income growth is eventually tripled. From a policy standpoint, it is obvious that for the People of the Republic of China to have a clean and sustainable environment for the immediate and future generation-specific environment-economic growth, policies have to be designed based on the intensity of the environmental degradation and income level since environmental degradation in this region is output driven. Also, we suggest an alternative switch to renewable energy sources for consumption and production purposes. Energy-environment-economic growth policies that would promote energy-saving and -efficient technologies with little or zero emissions should be implemented. Lastly, natural gas consumption and urbanization appears to aggravate environmental degradation in the sampled country. Thus, government and policymakers in this region should intensify their efforts in replacing natural gas consumption with friendlier energy sources and the migration of people into the urban centers should be avoided and policy that would decongest the urban centers (as suggested by Alola et al. 2019a) should be out in place to promote a clean sustainable environment for the immediate and the generation to come.

Author contributions Andrew Adewale ALOLA: formal analysis, investigation, methodology, and corresponding; Mfonobong Udom ETOKAKPAN: writing-original draft and data curation; Seyi Saint AKADIRI: writing and conceptualization.

Data Availability Not applicable.

Declaration

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

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