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Economic growth, electricity consumption, and urbanization in China: A tri-variate investigation using panel data modeling from a regional disparity perspective

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ABSTRACT

This paper aims to examine the causal relations between economic growth, electricity consumption, and urbanization indicators. Heterogeneous panel data techniques are performed to help shed light on the importance of the heterogeneity among three economic regions within China from 2000 to 2017. Our results show that the three indicators are all stationary and cointegrated after the first difference. Heterogeneity of the Granger causality is found between these three variables varies across the eastern, central, and western economic regions in China. In the long run, the eastern region presents a similar trend as the national level that long-run Granger causality of the three variables is found. Conversely, there is a unidirectional long-run causal relationship from economic growth to electricity consumption in the central region, while there is a bi-directional long-run causal relationship between economic growth and electricity consumption in the western region in China. Our empirical findings highlight the "urbanization ladder" effect which implies that as development, urbanization factor in the eastern region may play a promotion role in the tri-variate system when the urbanization reaches a higher level, while it may lack the influence in the central and western regions of China. From a regional perspective, it is further indicated that the improvement of urbanization can be practical measures in the central and western parts of China in the long run.

1. Introduction

Economic growth and energy consumption have a close relationship (Ozturk, 2010), and the causality relationship between these indicators has been widely investigated (Chiou-Wei et al., 2008; Narayan and Prasad, 2008; Liddle and Lung, 2014; Kahouli, 2018). One of the Sustainable Development Goals of the United Nations is to have access to clean and modern energy by the year 2030 (UNDP, 2019). Compared with other kinds of energy, electricity is vital for development, which is linked to human development that comprises population, health, education, carbon dioxide emissions, agricultural productivity, and industrial production (Burney, 1995; Santos and Balestieri, 2018; Karsu and Kocaman, 2021). It is argued that increasing electricity consumption can provide a good platform for achieving sustainable growth (Lawal et al., 2020; Karsu and Kocaman, 2021).

Over the past four decades, China has witnessed continuous and rapid economic growth. Meanwhile, China has been the largest energy consumer in the world with total electricity consumption was 7111.8 Terawatt-hours in 2018, with a global share of 26.7% (British Petroleum Company, 2019). Thus, the topic of the relationship between energy consumption and economic growth in China caused wide concern (Zhen et al., 2008; Wang, 2014; Lin and Wang, 2019). Furthermore, the urban population in China grew dramatically with the urban population outnumbering that of rural areas in 2011 (National Bureau of Statistics of China, 2013). Demographic factors, such as urbanization rate has an important influence on economic growth (Zhen et al., 2008; Liu et al., 2016) and energy consumption (Zhang and Lin, 2012; Wang et al, 2014, 2016, 2014; Liu et al., 2017) in China. Accordingly, there is a dire need to examine the tri-variate causality relations between economic growth, electricity consumption, and urbanization in China.

Moreover, huge spatial disparities in economic growth, electricity consumption, and urbanization level have been observed among the eastern, central, and western economic regions of China from 2000 to

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Abbreviations

ADF test	Augmented Dickey Fuller test
DFE	Dynamic Fixed Effect estimator
EC	Electricity consumption per capita
GDP	Gross Domestic Product
IPS test	Im, Pesaran and Shin test
MG	Mean Group estimator
PMG	Pooled Mean Group estimator
UL	Urbanization level
VECM	Vector error-correction model

2017 (Fig. 1, see the three geographic divisions in section 3.3). As can be seen, the GDP in the eastern region grew the fastest among the three regions; even it reached twice that of the central region and three times that of the western region from 2005. Electricity consumption exhibited steady growth in the three economic regions and accelerated growth in the eastern region after 2009. Meanwhile, the urbanization rates showed huge disparities in the three regions as well. It can be found that the urbanization rates in the eastern region grow the fastest in the three regions.

Therefore, this study mainly focuses on the spatial disparities of the causal relationship between economic growth, electricity consumption, and urbanization by tri-variate modeling in China. To achieve this aim, heterogeneous panel models were employed to probe the long-term equilibrium relationships, temporal dynamic relationships, and Granger causality relationships at the national level and in three economic regions in China. The remainder of this paper is organized as

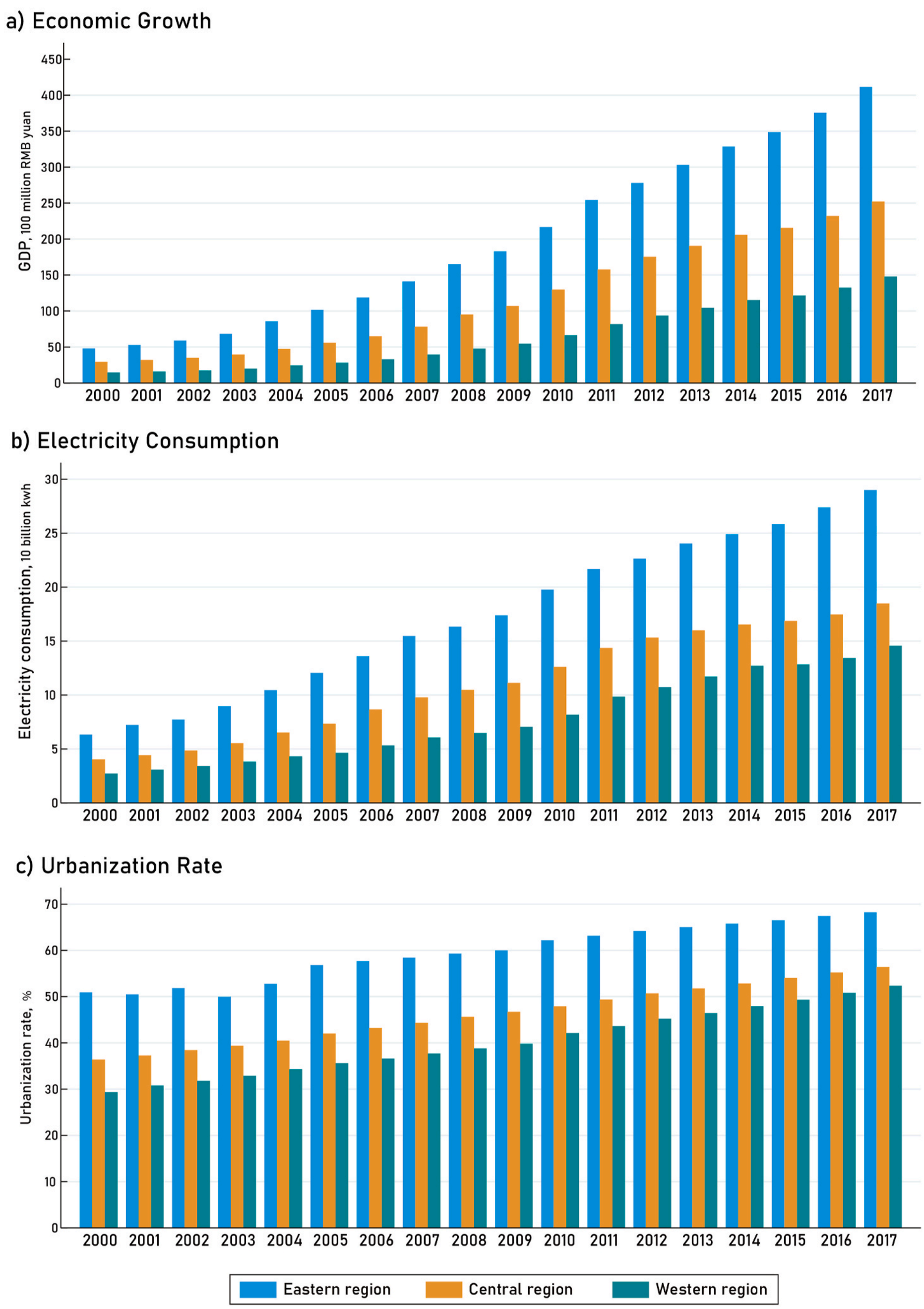

Fig. 1. Economic growth (a), electricity consumption (b), and urbanization levels (c) in the eastern, central, and western regions of China from 2000 to 2017.

follows: Section 2 provides a brief overview of the related literature; Section 3 describes the econometric methodology and data used in the study; Section 4 presents the results of panel unit root tests, panel cointegration tests, and Granger causality tests, followed by discussion in Section 5, and finally the conclusions in Section 6.

2. Literature review

Investigation of the causal relationships between economic growth, energy (electricity) consumption, and urbanization has important implications from theoretical, empirical, and policy standpoints. Hence, considerable literature can be found in this field. The literature review in this paper mainly focuses on these studies which identify a complex task and an active field of econometric research.

The relationship between energy consumption and economic growth, which has been widely investigated by numerous theoretical explorations as well as a large number of empirical investigations (Chiou-Wei et al., 2008; Lee and Chang, 2008; Narayan and Prasad, 2008; Narayan and Smyth, 2009; Wolde-Rufael, 2009; Wang et al., 2011; Kahouli, 2018; Alola et al., 2019; Bekun et al., 2020). Thus, there is a growing literature in this area, which find evidence of the relationship between these two indicators for countries with different economic structure and at different stages of economic growth (Chiou-Wei et al., 2008). One important point from these studies is that mixed results for both developed and developing countries were obtained. Furthermore, urbanization and its relationship with economic growth also showed mixed results. It was found that urbanization did not Granger-cause GDP per capita across countries for 1960–2000 (Bloom et al., 2008). In contrast, it was shown that urbanization was important and correlated with economic growth across countries of four income panels from 1971 to 2007 (Liddle, 2013). Further, the impact of urbanization on economic growth varied across countries at different income levels. For example, it was revealed that urbanization and economic growth either co-evolved in low-income and high-income countries, or else the two processes were decoupled for middle-income and Latin American countries (Liddle and Messinis, 2015).

Additionally, extensive studies have been conducted to probe the link between urbanization and energy consumption. For example, a significant relationship between urbanization and energy consumption was identified in several developing countries in Africa, Asia, and Latin America (Jones, 1991; Parikh and Shukla, 1995; Jorgenson et al., 2010; Liddle and Lung, 2014). Some studies confirmed the positive relationship between urbanization and energy consumption in some developed countries in Europe (York, 2007; Liddle and Lung, 2010). In addition, the link between urbanization and energy consumption exhibits complexity across countries. For instance, the urbanization associated with economic growth is caused by electricity consumption in the long run based on the Granger causality analysis (Liddle and Lung, 2014). Also, urbanization could lead to greater demand for energy consumption, thus, more and wealthier people with electricity access would lead to more energy and electricity consumption based on the study in residual electricity demand in Turkey (Halicioglu, 2007). Indeed, the link between urbanization and electricity consumption is especially relevant for China, the largest electricity consumer in the world. Therefore, the relation between energy use and urbanization is becoming an important issue in China (Zhang and Lin, 2012; Wang, 2014; Wang et al., 2014, 2016; Zhao and Wang, 2015; Fan et al., 2017; Liu et al., 2017). Mixed results have been obtained in China as well. For example, unidirectional causality running from urbanization to energy consumption was identified in China (Liu, 2009; Zhao and Wang, 2015). In contrast, a bi-directional causal relationship was found between urbanization and energy consumption in China (Wang et al., 2014; Liu et al., 2016).

Furthermore, some studies explored the causal relationships between economic growth, energy consumption, and urbanization in a multivariate framework based on the Granger-causality time series approach. For instance, a study of Turkey probed the causal relationship between energy consumption, energy prices, GDP, and urbanization, indicating a long-run causality running from GDP, energy prices, and urbanization to energy consumption (Halicioglu, 2007). Similarly, the causal relationship was found between energy consumption and urbanization with an additional variable GDP for Pacific Island countries, indicating a short-run Granger causality between energy consumption to urbanization and long-run Granger causality between these indicators (Mishra et al., 2009). Further, the long-run relationship between energy consumption, economic growth, and urbanization was found in Tunisia (Shahbaz and Lean, 2012), Angola (Solarin and Shahbaz, 2013), and several new emerging-market countries (i.e., Colombia, India, Indonesia, Kenya, Malaysia, and Mexico) (Bakirtas and Akpolat, 2018). In China, most previous studies focused on the relationships between energy consumption and economic performance at a national level, which demonstrated a cointegrating relationship amongst total energy consumption, population, economic growth, and urbanization with unidirectional Granger causality running from urbanization to total energy consumption (Liu, 2009; Zhao and Wang, 2015).

However, three gaps should be noted in the existing empirical literature. First, most of the studies were based on the country level, and there has been little empirical work on the spatial difference of the relationships in China. For example, Li et al. (2011) investigated the causal relationship between energy consumption and economic growth, and the difference between the eastern and western regions in China. Another study demonstrated the causal relationship between energy consumption and economic growth, and the difference between the eastern, central, and western regions in China (Zhang and Xu, 2012). Second, compared with energy consumption, the indicator of electricity consumption is often used due to its role in determining welfare and economic development (Kim, 2015). Nevertheless, few studies pay attention to the causal relationship between electricity consumption, economic growth, and urbanization. Third, most previous papers concentrated on the linkages between energy consumption and economic performance, but tri-variate modeling including urbanization has rarely been performed, especially in China. Hence, further studies on the causal relationship between economic growth, electricity consumption, and urbanization in regional aspects based on panel data modeling are necessary for China.

That is the motivation of this paper to propose a further examination of this issue. Heterogeneous panel data methods combining cross-sectional and time-series information in different regions can provide much more precise estimates of the cointegration vector (Mark and Sul, 2003). It is widely accepted that panel models are more efficient relative to time series models due to their higher degree of freedom (Hsiao, 2007). In addition, panel models have a better capacity to deal with more complex datasets relative to the time series models. In sum, the objective of this study is threefold. First, this paper aims to examine the long-run relationship between economic growth, electricity consumption, and urbanization in China by employing panel data at the provincial level over the period from 2000 to 2017. Second, we intend to detect the causal relationship and its direction between the three indicators and to investigate the spatial disparities of the causal relationship in three economic regions in China. Further, our sub-national level analysis aims to obtain insight into the direction of causality (or lack of causality) and the regional differences compared to the findings at the national level. Additionally, if such causality can be determined at the subnational level, it would be useful to explore whether the regional disparity of economic performance can be reduced through enhancing urbanization and electricity improvement in China.

3. Methodology and data

3.1. Methodology

Existing studies have demonstrated that the flow of causality in economic growth, electricity consumption, and urbanization may vary.

The theoretical link in modeling of the three variables is based on the following theoretical framework:

$$Y_t = f(EC_t, UL_t) \tag{1}$$

where Y_t refers to the real GDP per capita, EC_t is the electricity consumption per capita, and UL_t is the urbanization level. This model is followed by previous studies that included urbanization as one of the potential variables in the modeling of economic growth and energy consumption (Liu, 2009; Shahbaz and Lean, 2012; Solarin and Shahbaz, 2013). Hence, the focus of our research is to trace the evolution of the three variables nexus with the application of the heterogeneous panel data modeling to test unit roots, cointegration relations, and Granger causality. In the first step, the stationary of the variables is checked by using panel unit root tests. In the second step, the Pedroni cointegration test is applied to identify whether a long-term relationship between the set of integrated variables exists. In the third step, Granger causality is tested based on the vector error-correction model.

3.1.1. Panel unit root test

The test for the unit root of the panel data is performed based on the Augmented Dickey-Fuller (ADF) test (Im et al., 2003):

$$\Delta y_{it} = \rho_i y_{it-1} + \sum_{j=1}^{p_i} \gamma_{ij} \Delta y_{it-j} + X_{it}^{'} \delta + \varepsilon_{it} \tag{2}$$

In Eq. (2), $i = 1, \ldots, N$ represents cross-section units, $t = 1, \ldots, T$ represents times periods, $X_{it}^{'}$ denotes the exogenous variables (including the fixed effects and individual trend terms), and ε_{it} is the error term.

Further, the Im, Pesaran and Shin (IPS) test allows for a heterogeneous autoregressive unit root process (ρ_i) to vary across cross-sections (Im et al., 2003). The test estimates the ADF regressions for each unit and the *t*-statistics are averaged and adjusted to calculate the test statistics. The hypotheses for the IPS test are as follows:

$$H_0 : \rho_i = 0 \; for \; all \; i$$

$$H_1 : \rho_i = 0 \; for \; i = 1, 2, \ldots, N_1$$

$$\rho_i < 0 \; for \; i = N_1 + 1, N_1 + 2, \ldots, N$$

In the above tests, the lag order for the different terms (ρ_i) is allowed to vary across cross-sections, and the IPS test has a better finite sample performance (Im et al., 2003).

3.1.2. Panel cointegration test

After confirming the existence of panel unit roots, the Pedroni cointegration test is performed. Based on the Engle-Granger cointegration test (Engle and Granger, 1987), the Pedroni cointegration test allows for different intercepts and trend coefficients among the individual members of the panel, which can be used for heterogeneity in the autoregressive term (Pedroni, 2001). This method is different from traditional co-integration analysis applied on single cross-section time series. Besides, the Pedroni cointegration test assumes a single cointegrating vector, and several studies show that this technique is more powerful and efficient in heterogeneous panels than systems methods (e.g., the Larsson panel cointegration procedure) that aim to pin down the number of cointegrating vectors (Larsson et al., 2001; Banerjee et al., 2004; Wagner and Hlouskova, 2009). Therefore, the Pedroni cointegration test is employed to evaluate the long-term directions of causality between the variables examined in this paper.

Meanwhile, to test the null of no cointegration in heterogeneous panels, seven statistics are performed in this study, which include within dimension statistics (i.e., panel tests) and between dimension statistics (i.e., group tests) (Pedroni, 2000). The within dimension tests allow for common time factors and heterogeneity among panel members. The between dimension tests consider the heterogeneity of parameters across panel members. Seven test statistics in this study are performed as follows:

Within dimension (panel tests):

(a) Panel ν-statistic.
(b) Panel Phillips-Perron type *rho*-statistics.
(c) Panel Phillips-Perron type *t*-statistic.
(d) Panel ADF type *t*-statistic.

Between dimension (group tests):

(e) Goup Phillips-Perron type *rho*-statistics.
(f) Group Phillips-Perron type *t*-statistic.
(g) Group ADF type *t*-statistic.

The Pedroni cointegration test is performed based on the following model:

$$y_{it} = \alpha_i + \delta_i t + \beta_i X_{it} + e_{it} \tag{3}$$

In Eq. (3), α_i represents the intercept term; δ_i is the coefficient of trend effects; X_{it} denotes regressors, and β_i represents slope coefficients for each cross-section *i*. The variables y_{it} and X_{it} are assumed to be $I(1)$. To test the null hypothesis of no cointegration, the regression residuals e_{it} are calculated from Eq. (4) and examined if $\rho_i = 1$ in the auxiliary regression as follows:

$$e_{it} = \rho_i e_{it-1} + u_{it} \tag{4}$$

It showed that the panel ADF-statistic performs better than other statistics in finite samples by the comparison of the performance power (Örsal, 2007).

3.1.3. Panel Granger causality test

Granger causality tests can further detect the direction of the causal relationship (i.e., unidirectional or bi-directional) if there is a long-term relationship between two or more variables (Granger, 1969). Based on the vector error-correction model (VECM), the Granger causality could be used to test the causal relationships if variables are cointegrated. Hence, the Granger causality test is performed in this study to examine the causal relationship between economic growth, electricity consumption, and urbanization level. The test models are specified as follows.

$$\Delta EC = \alpha_{it} + \beta_{it} ect_{it-1} + \sum_{i=1}^{l} \omega_{it} \Delta EC_{it-1} + \sum_{i=1}^{l} \phi_{it} \Delta GDP_{it-1} + \sum_{i=1}^{l} \delta_{it} \Delta UL_{it-1} + \mu_{it} \tag{5}$$

$$\Delta GDP = \alpha_{it} + \beta_{it} ect_{it-1} + \sum_{i=1}^{l} \omega_{it} \Delta GDP_{it-1} + \sum_{i=1}^{l} \phi_{it} \Delta EC_{it-1} + \sum_{i=1}^{l} \delta_{it} \Delta UL_{it-1} + \mu_{it} \tag{6}$$

$$\Delta UL = \alpha_{it} + \beta_{it} ect_{it-1} + \sum_{i=1}^{l} \omega_{it} \Delta UL_{it-1} + \sum_{i=1}^{l} \phi_{it} \Delta GDP_{it-1} + \sum_{i=1}^{l} \delta_{it} \Delta EC_{it-1} + \mu_{it} \tag{7}$$

In Eqs. (5)–(7), Δ represents the lag operator; α_{it} is the intercept term; β_{it}, ω_{it}, ϕ_{it}, and δ_{it} are undetermined parameters; ect_{it-1} is the lagged error correction term in the cointegration test, which could be used to identify long-run causality between the variables. μ_{it} is the white noise error. The short-run causality effects are identified through the F-statistics on the lagged explanatory variable of the VECM. The significance of the lagged error-correction term is tested through *t*-statistics.

Three estimators are commonly used for dynamic panel data model estimation. One is the Mean Group (MG) estimator, which is the mean of the estimates. Another is the Dynamic Fixed Effect (DFE) estimator, which is the traditional pooled estimator, where the intercepts can differ across groups. In this paper, Pooled Mean Group (PMG) estimator is selected, for it considers both pooling and averaging. This estimator allows the long-run coefficients are constrained to be the same, while the short-run coefficients, the speed of adjustment, and error variances to differ freely across groups. The PMG estimator could estimate short-run dynamics and long-run adjustment processes simultaneously (Pesaran et al., 2004), which is based on Eqs. (4)–(6).

3.2. Variables and data source

3.2.1. Economic growth

Economic growth is considered an important factor that influences energy consumption (Kraft and Kraft, 1978) and the level of urbanization (Henderson, 2003). In this study, the real per capita GDP divided by the total population is selected as a proxy indicator for measuring economic growth at the provincial level in China for the 2000–2017 period (Table 1). In the current study, the real per capita GDP is presented in logarithmic form.

3.2.2. Electricity consumption

The time series data of the electricity consumption per capita is collected at the provincial level in China for the 2000–2017 period (Table 1). The electricity consumption data are from the energy balance sheet of the *China Energy Statistical Yearbooks*. In this study, per capita electricity consumption is expressed in terms of billion kilowatt-hours (kWh). Population data of permanent residents at the provincial level are from *China Population and Employment Statistics Yearbooks*. The per capita electricity consumption is expressed in logarithmic form as well.

3.2.3. Urbanization

The urbanization process mainly refers to the population shift from rural areas to urban areas (United Nations, 1997). Accordingly, the proportion of people living in urban areas is selected as a proxy indicator to measure the urbanization level in this study (Table 1). However, the urbanization level can not technically be integrated of order 1, i.e., $I(1)$, since such integrated variables must be unbounded. One method working with bounded time-series variables of urbanization level is to apply the logistic transformation (Wallis, 1987) and then employed in cointegration studies (Beine and Coulombe, 2006; Gustavsson and Österholm, 2012). In this study, the transformation equation of urbanization level can be expressed as follows:

$$UL = \ln\left(\frac{u\_it}{1 - u\_it}\right) \tag{8}$$

In Eq. (8), *UL* is the urbanization level which is unbounded above and below after logistic transformation. *u_it* refers to the initial urbanization level.

3.3. Spatial division of three economic regions in China

The provincial administrative units in China can be classified into three groups according to the economic geographical position, defined by the State Statistical Bureau of China ("http://www.stats.gov.cn/ztjc/tjzdgg/hsyjh1/yjhxsjlh/hsfx/201010/t20101015_69181.html,"). The three groups of spatial division in mainland China are the eastern, central, and western regions, respectively (Fig. 2). The eastern region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan provincial administrative units. The central region includes Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan provincial administrative units. The western region includes Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Ningxia, Qinghai, Xinjiang, and Tibet provincial administrative units. In the current study, Tibet, Hong Kong, Macau, and Taiwan are not included for the non-available data.

Table 1
Summary of the panel data of electricity consumption, economic growth, and urbanization level in China.

Indicator	Abbreviation	Unit
Real per capita GDP	GDP	RMB yuan
Electricity consumption per capita	EC	kWh/per
Urbanization level	UL	%

4. Results

4.1. Panel unit root tests

The IPS unit root tests were performed both with intercept and trend (C, T) and with intercept only (C) (Table 2), which indicated the presence of panel unit roots for economic growth, electricity consumption, and urbanization. The results further showed that all variables were stationary at the first difference rejecting the null hypothesis at a less 1% significance level (Table 2). The same conclusion can be drawn that whether the trend term was included, which indicated that the series was all $I(1)$. Thus, the cointegration test and VECM were further performed in this study to examine the long-run relationships between these variables.

4.2. Panel cointegration tests

The Pedroni cointegration analysis for all seven tests was performed (Table 3). It can be found that the ADF tests strongly rejected the null of no integration in the regressions in the three equations. Specifically, the results indicated a cointegrated relationship between economic growth, energy consumption, and urbanization. At the national level, both ADF tests rejected the null hypothesis of no cointegration at a 10% significance level, which can be identified in three equations. Furthermore, for the sub-samples, the cointegration test results were mixed. In the eastern region, two ADF tests showed cointegration at a 1% significance level in the UL equation, and one ADF test showed cointegration at a 5% significance level in both EC equation and GDP equation. In the central region, the panel ADF test found cointegration at a 10% significance level at three equations. In the western region, both ADF tests found cointegration at a 5% significance level in both GDP equation and UL equation, while panel *v*, panel *rho*, group *rho*, and group Phillips-Perron tests showed cointegration at a 10% significance level in the EC equation. In sum, it can be concluded that there was sufficient evidence to support the existence of cointegration in each region of China considering the selected panel was a small sample and the better power properties of the ADF tests.

4.3. Granger causality tests

The results of the VECM Granger causality can be divided into short and long runs since the series exhibits cointegration links (Table 4). In the short run, the results of the Granger causality test showed that in the period from 2000 to 2017, a short-term causal relationship existed between economic growth, electricity consumption, and urbanization. Specifically, a bi-directional positive Granger causal relationship can be found between electricity consumption and economic growth and between urbanization and economic growth. There was no Granger causality relationship between urbanization and electricity consumption.

Moreover, a significant and negative error-correction coefficient was evidence of long-run causality from the explanatory variable to the dependent variable. At the national level, in the long run, the significantly negative error correction term $ect(it\text{-}1)$ indicated that bi-directional causality exists between economic growth, electricity consumption, and urbanization. The error correction term $ect(it\text{-}1)$ for

Fig. 2. The spatial division of three economic regions in China with available panel data.

Table 2
Panel unit root tests.

Region	IPS test	GDP	EC	UL
Full samples	IPS-level (C)	0.985	0.293	0.001***
	IPS-1st diff (C)	<0.001***	<0.001***	<0.001***
	IPS-level (C,T)	0.998	0.320	<0.001***
	IPS-1st diff (C,T)	<0.001***	<0.001***	<0.001***
Eastern panel	IPS-level (C)	0.854	0.543	0.001***
	IPS-1st diff (C)	<0.001***	<0.001***	<0.001***
	IPS-level (C,T)	0.653	0.574	<0.001***
	IPS-1st diff (C,T)	<0.001***	<0.001***	<0.001***
Central panel	IPS-level (C)	0.983	0.952	0.037**
	IPS-1st diff (C)	<0.001***	<0.001***	<0.001***
	IPS-level (C,T)	0.998	0.916	0.241
	IPS-1st diff (C,T)	<0.001***	<0.001***	<0.001***
Western panel	IPS-level (C)	0.781	0.222	<0.001***
	IPS-1st diff (C)	<0.001***	<0.001***	<0.001***
	IPS-level (C,T)	0.607	0.281	<0.001***
	IPS-1st diff (C,T)	<0.001***	<0.001***	<0.001***

All tests are one-sided with the rejection region on the left-tail. *** denotes significance level at 1%.

ΔGDP was −0.304, which demonstrated that 30.4% of a deviation from the long-run equilibrium was eliminated in one period through changes in economic growth. The estimated coefficients for ΔEC and ΔUL were only −0.153 and −0.166, respectively, which demonstrated that the speed of adjustment of electricity consumption and urbanization level to the long-run equilibrium was slower than that of economic growth in the long run.

Furthermore, the causal relationships among economic growth, electricity consumption, and urbanization vary across three economic regions in China according to regional panel modeling. In the short run, economic growth was a Granger cause of electricity consumption and urbanization in the eastern region. In the central region, there was a bilateral Granger relationship between electricity consumption and economic growth, while there was a unilateral causal relationship from electricity consumption to urbanization. In the western region, there was a bilateral causal relationship between electricity consumption and economic growth, while urbanization was a Granger cause of economic growth. Urbanization presented no direct impact on electricity consumption.

In the long run, there was a bilateral causal relationship between the three indicators in the eastern region. Further, economic growth in the eastern region exhibited the highest speed to the long-run equilibrium than electricity consumption and urbanization (Table 4). In the central region, there was a unilateral causal relationship from economic growth to electricity consumption. In the western region, there was a bilateral causal relationship between economic growth and electricity consumption. Our empirical findings demonstrate that urbanization does not have a causal effect on economic growth and electricity consumption in the central and western regions in China.

5. Discussion

In this study, the relations between economic growth, electricity consumption, and urbanization were investigated at the national level and in each economic region in China. Specifically, cointegration and Granger causality tests were employed based on balanced panel data over the period 2000 to 2017. Based on the econometric findings and spatial disparities, several main points can be drawn and discussed further.

Firstly, according to this study, the long-run Granger causality of the three variables, i.e., economic growth, electricity consumption, and urbanization was identified in China. So far, previous empirical studies on the long-run causal relationship between GDP, energy consumption, and urbanization have mixed results based on such previous studies using different techniques, periods and samples of countries (Halicioglu, 2007) such as Pacific Island countries (Mishra et al., 2009) and Tunisia (Shahbaz and Lean, 2012). In China, Liu demonstrated a cointegrating relationship amongst total energy consumption, population, GDP, and urbanization with unidirectional long-run Granger causality running

Table 3
Panel cointegration tests.

Dependent variable	Panel cointegration test statistics	Full sample		Eastern panel		Central panel		Western panel	
		Statistic	*P*-value	Statistic	*P*-value	Statistic	*P*-value	Statistic	*P*-value
GDP	Panel v	−2.378	0.009	−2.483	0.007	−1.342	0.090	−1.107	0.134
	Panel rho	1.270	0.102	1.191	0.117	0.503	0.307	−0.664	0.253
	Panel t PP	−2.733	0.003	−2.002	0.023	−1.637	0.051	−3.281	0.001
	Panel t ADF	−2.141	0.016	−2.175	0.015	−1.476	0.070	−1.692	0.045
	Group rho	3.075	<0.001	2.339	0.010	1.683	0.046	0.514	0.304
	Group t PP	−2.219	0.013	−1.399	0.081	−1.013	0.155	−3.557	<0.001
	Group t ADF	−1.352	0.088	−1.272	0.102	−0.534	0.297	−2.797	0.003
EC	Panel v	−3.428	<0.001	−2.483	0.007	−1.636	0.051	−2.175	0.015
	Panel rho	−0.265	0.395	1.191	0.117	0.825	0.205	1.673	0.047
	Panel t PP	−7.646	<0.001	−2.002	0.023	−1.569	0.058	−0.962	0.168
	Panel t ADF	−2.186	0.014	−2.175	0.015	−1.531	0.063	−0.224	0.411
	Group rho	1.467	0.071	2.339	0.010	1.950	0.026	1.995	0.023
	Group t PP	−6.800	<0.001	−1.399	0.081	−1.201	0.115	−1.631	0.051
	Group t ADF	−3.148	<0.001	−1.272	0.102	−1.090	0.138	−1.153	0.125
UL	Panel v	−2.439	0.007	−1.505	0.066	−1.535	0.062	−1.107	0.134
	Panel rho	1.371	0.085	−0.798	0.212	0.421	0.337	−0.664	0.253
	Panel t PP	−4.399	<0.001	−7.472	<0.001	−2.537	0.006	−3.281	<0.001
	Panel t ADF	−1.834	0.033	−5.574	<0.001	−1.811	0.035	−1.692	0.045
	Group rho	3.062	<0.001	0.866	0.193	1.880	0.030	0.514	0.304
	Group t PP	−4.595	<0.001	−7.029	<0.001	−1.781	0.037	−3.557	<0.001
	Group t ADF	−2.993	<0.001	−4.359	<0.001	0.372	0.355	−2.797	0.003

Note: an intercept and trend are included in the cointegration equations.

Table 4
Granger causality test.

Region	Dependent variable	Direction of causality			
		Short run			Long run
		ΔGDP	ΔEC	ΔUL	ECT(it-1)
Full samples	ΔGDP	–	0.143***	0.173*	−0.304***
	ΔEC	0.370***	–	0.119	−0.153***
	ΔUL	0.347**	−0.294	–	−0.166***
Eastern panel	ΔGDP	–	0.076	0.028	−0.411***
	ΔEC	0.406***	–	0.007	−0.120***
	ΔUL	0.557*	−0.737	–	−0.432***
Central panel	ΔGDP	–	0.260***	0.226	−0.096
	ΔEC	0.428***	–	0.231	−0.131***
	ΔUL	−0.028	0.078*	–	−0.016
Western panel	ΔGDP	–	0.121***	0.374**	−0.225***
	ΔEC	0.302*	–	0.100	−0.267***
	ΔUL	0.079	0.037	–	0.012

from urbanization to total energy consumption over the period 1978–2008 (Liu, 2009). Further, Zhao and Wang revealed that there was a bi-directional Granger causal relationship between energy consumption and economic growth, and unidirectional causality running from urbanization to energy consumption and economic growth to urbanization with the period 1980–2012 in China (Zhao and Wang, 2015). In this study, electricity consumption was chosen as the main indicator which is different from the prior studies that selected total energy consumption as the major indicator. Our results manifested the long-run Granger causality of the three variables i.e., economic growth, electricity consumption, and urbanization from 2000 to 2017 at the national level of China. It is also different with the finding that a positive bilateral causal link between the intensity of electric power consumption and economic growth and urbanization and economic growth in China (Ahmad et al., 2020). Our findings indicate that the electricity consumption may play a different role which may exhibit a closer relation to economic growth and urbanization than total energy consumption. Moreover, the speed to the long-run equilibrium varies among these variables, in which economic growth exhibits the highest speed to the long-run equilibrium than electricity consumption and urbanization level.

Secondly, in the short run at the national level, a bi-directional positive Granger causal relationship can be identified between electricity consumption and economic growth and between urbanization and economic growth, while no Granger causality was detected between urbanization and electricity consumption according to our results. A previous study on the EU showed a short-run unidirectional panel causality running from GDP to energy consumption and urbanization to GDP (Kasman and Duman, 2015). It also exhibited that a short run panel Granger causality running from urbanization to energy consumption in Pacific Island countries (Mishra et al., 2009). In China, unidirectional Granger causality was detected running from urbanization to total energy consumption in the short run from 1978 to 2008 (Liu, 2009). Further, a bi-directional Granger causal relationship was identified between energy consumption and economic growth, and unidirectional causality running from urbanization to energy consumption and economic growth to urbanization from 1980 to 2012 in China (Zhao and Wang, 2015). Based on the current study, the Granger causal relationship was identified between energy consumption and economic growth, and between urbanization level and economic growth is analogous to the previous study (Zhao and Wang, 2015). But it is quite different from previous studies that no Granger causality was detected between urbanization and electricity consumption from 2000 to 2017 according to this study.

Thirdly, this study revealed the causalities between the three variables vary across sub-national areas in China, i.e., between eastern, central, and western regions during the study period. Given the huge differences among the three regions from east to west in terms of economic development, it is as expected for the causal relationships to differ across these regions in China. Based on our findings, in the short run, the difference of the causalities can be detected at the sub-national level, which demonstrated that economic growth led to higher electricity consumption both in the three regions in the short run, but it only showed in western and central regions vice versa. Generally, economic growth is linked with increased electricity consumption in three regions. Conversely, in the eastern region, where infrastructure construction is more complete than other parts of China, higher electricity consumption may not lead to economic growth. In western and central regions, infrastructure construction and industrialization are just in progress, which needs more energy, and higher electricity consumption can lead to economic growth. Further, electricity consumption promotes urbanization in the central region, and urbanization level promotes economic growth in the western region in the short run.

In the long run, a bilateral causal relationship between these three variables is found in the eastern region, which is consistent with the previous studies at the national level in China. The bi-directional positive Granger causality implies that economic growth, energy consumption, and urbanization level are jointly determined and affected at the same time in the eastern region in China. Since electricity consumption for the manufacturing and industrial sector is the predominant source of the total electricity consumption, higher electricity consumption implies more activities in these sectors which may lead to a higher level of urbanization and GDP. Nevertheless, it presents different relations that urbanization does not have a causal effect on economic growth and electricity consumption in the central and western regions of which development falls behind the eastern region in China. This indicates that urbanization has no significant impacts on economic growth and electricity consumption in the long run in the central and western regions. Liddle argued that urbanization has various effects on economic growth in the long run, which shows a strong negative impact for the poorest countries, a less negative to neutral impact for countries with moderate incomes, and a growth-promoting/reinforcing relationship for the countries with wealthier middle and highest income levels (Liddle, 2013). In addition, a previous study also finds that the impact of urbanization on economic growth varied from negative to neutral to positive for western-, intermediate-, and eastern-economic zone, respectively (Ahmad and Zhao, 2018), though there are certain differences in the classification of region division in this paper and the previous study.

Importantly, our results reveal the different co-integration and causality relations between the economic growth, electricity consumption, and urbanization in the eastern, central, and western regions of China with different development stages. This compound tri-variate system is found to reach an equilibrium in the eastern region of China in the long run. Conversely, the central and western regions lack the urbanization factor in the long run cointegration and causal relationships, indicating that urbanization does not have a causal effect on economic growth and electricity consumption in these regions of which development falls behind the eastern region. This finding underlines the "urbanization ladder" effect which implies that as development, urbanization has the potential to exhibit from negative, neutral to positive impacts on economic growth displaying an inverted-U relationship with economic growth (Liddle, 2013). Interestingly, a similar feature was found in China called the "development-based urbanization ladder effect" which means economic growth in more developed regions has a relatively more vigorous impact on urbanization, whereas the economic growth in less-developed regions promotes urbanization with less degree (Ahmad et al., 2020). According to our findings, the urbanization ladder effect can be extended to the tri-variate system, i.e., economic growth, electricity consumption, and urbanization, that the urbanization factor in the eastern region may play a promotion role in the tri-variate system when the urbanization reaches a higher level, while it may lack the influence in the central and western regions of China.

Several limitations in this paper should be noted. One of the limitations is that the structure of the economy and electricity consumption is not taken into consideration. For instance, the relations between renewable electricity consumption and economic growth have been investigated in some industrialized countries (Swain and Karimu, 2020; Azam et al., 2021; Ivanovski et al., 2021). For one thing, future studies should consider renewable and non-renewable electricity consumption to further understand the dynamic relations to economic growth and urbanization in China. For another, the economic structure should be also involved in the following studies since the construction of a modern economic system has become the strategic goal of the Chinese government. Second, the urban-rural gap was not investigated in this study. It will be interesting for future research to examine the difference in the tri-variate system between urban and rural areas in China either at the national level or a panel data framework. Moreover, environmental impacts and climate change relates to economic development, urbanization, and energy consumption based on recent studies (Adedoyin et al., 2020; Ahmad et al., 2021; Baloch et al., 2021; Liu et al., 2021; Nathaniel and Adeleye, 2021; Solarin et al., 2021), which indicate a study prospect that integration of the environmental sustainability and the tri-variate system involved in this study in the future.

6. Conclusions

In this study, the causal relations between economic growth, electricity consumption, and urbanization are investigated at the national level and in each economic region in China based on the panel data from 2000 to 2017. Several key points can be concluded. First, the results of unit root tests indicate that the variables are non-stationary, and the cointegration test further demonstrated that the panel data of the three regions are cointegrated. Then, the long-run Granger causality of the three variables is identified at the national level in China.

Second, this study reveals that the causalities between these three variables vary across sub-national areas in China. In the short run, only unidirectional causality running from economic growth to energy consumption and urbanization is identified in the eastern region. In the central region, economic growth is a Granger cause of electricity consumption and urbanization. In the long run, the eastern region shows a similar trend as the national level that the long-run Granger causality of the three variables is found. Conversely, there is a unilateral long-run causal relationship from economic growth to electricity consumption in the central region, while there is a bilateral long-run causal relationship between economic growth and electricity consumption in the western region in China.

Third, our empirical findings demonstrate that urbanization does not have a causal effect on economic growth and electricity consumption in the central and western regions of which development falls behind the eastern region in China. This finding underlines the "urbanization ladder" effect which implies that as development urbanization factor in the eastern region may play a promotion role in the tri-variate system when the urbanization reaches a higher level, while it may lack the influence in the central and western regions of China. Hence, taking steps to accelerate the urbanization process can be practical measures for further development in the central and western parts of China in the long run.

CRediT authorship contribution statement

Na Wang: Methodology, data compiling, Formal analysis, result interpolation. **Xiaodong Fu:** Methodology, result interpolation, Writing – review & editing. **Shaobin Wang:** Conceptualization, Methodology, data compiling, Formal analysis, result interpolation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Adedoyin, F., Ozturk, I., Abubakar, I., Kumeka, T., Folarin, O., Bekun, F.V., 2020. Structural breaks in CO2 emissions: are they caused by climate change protests or other factors? J. Environ. Manag. 266, 110628. https://doi.org/10.1016/j.jenvman.2020.110628.

Ahmad, M., Ahmed, N., Jabeen, M., Jabeen, G., Qamar, S., Chandio, A.A., Rehman, A., Rauf, A., 2020. Empirics on heterogeneous links among urbanization, the intensity of electric power consumption, water-based emissions, and economic progress in regional China. Environ. Sci. Pollut. Res. 27, 38937–38950. https://doi.org/10.1007/s11356-020-09939-y.

Ahmad, M., Jiang, P., Murshed, M., Shehzad, K., Akram, R., Cui, L., Khan, Z., 2021. Modelling the dynamic linkages between eco-innovation, urbanization, economic growth and ecological footprints for G7 countries: does financial globalization matter? Sustain. Cities Soc. 70, 102881. https://doi.org/10.1016/j.scs.2021.102881.

Ahmad, M., Zhao, Z.-Y., 2018. Empirics on linkages among industrialization, urbanization, energy consumption, CO2 emissions and economic growth: a heterogeneous panel study of China. Environ. Sci. Pollut. Res. 25, 30617–30632.

Alola, A.A., Bekun, F.V., Sarkodie, S.A., 2019. Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. Sci. Total Environ. 685, 702–709. https://doi.org/10.1016/j.scitotenv.2019.05.139.

Azam, A., Rafiq, M., Shafique, M., Zhang, H., Ateeq, M., Yuan, J., 2021. Analyzing the relationship between economic growth and electricity consumption from renewable and non-renewable sources: fresh evidence from newly industrialized countries. Sustain. Energy Technol. Assess. 44, 100991. https://doi.org/10.1016/j.seta.2021.100991.

Bakirtas, T., Akpolat, A.G., 2018. The relationship between energy consumption, urbanization, and economic growth in new emerging-market countries. Energy 147, 110–121. https://doi.org/10.1016/j.energy.2018.01.011.

Baloch, M.A., Ozturk, I., Bekun, F.V., Khan, D., 2021. Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: does globalization matter? Bus. Strat. Environ. 30, 176–184. https://doi.org/10.1002/bse.2615.

Banerjee, A., Marcellino, M., Osbat, C., 2004. Some cautions on the use of panel methods for integrated series of macroeconomic data. Econom. J. 7, 322–340. https://doi.org/10.1111/j.1368-423X.2004.00133.x.

Beine, M., Coulombe, S., 2006. Economic integration and the diversification of regional exports: evidence from the Canadian–U.S. Free Trade Agreement. J. Econ. Geogr. 7, 93–111. https://doi.org/10.1093/jeg/lbl022.

Bekun, F.V., Yalçiner, K., Etokakpan, M.U., Alola, A.A., 2020. Renewed evidence of environmental sustainability from globalization and energy consumption over economic growth in China. Environ. Sci. Pollut. Res. 27, 29644–29658. https://doi.org/10.1007/s11356-020-08866-2.

Bloom, D.E., Canning, D., Fink, G., 2008. Urbanization and the wealth of Nations. Science 319, 772. https://doi.org/10.1126/science.1153057.

British Petroleum Company, 2019. BP statistical review of world energy 2019. Lond. Engl. Br. Pet. Co.

Burney, N.A., 1995. Socioeconomic development and electricity consumption A cross-country analysis using the random coefficient method. Energy Econ. 17, 185–195. https://doi.org/10.1016/0140-9883(95)00012-J.

Chiou-Wei, S.Z., Chen, C.-F., Zhu, Z., 2008. Economic growth and energy consumption revisited—evidence from linear and nonlinear Granger causality. Energy Econ. 30, 3063–3076.

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

Fan, J.-L., Zhang, Y.-J., Wang, B., 2017. The impact of urbanization on residential energy consumption in China: an aggregated and disaggregated analysis. Renew. Sustain. Energy Rev. 75, 220–233. https://doi.org/10.1016/j.rser.2016.10.066.

Granger, C.W., 1969. Investigating causal relations by econometric models and cross-spectral methods. Econom. J. Econom. Soc. 424–438.

Gustavsson, M., Österholm, P., 2012. Labor-force participation rates and the informational value of unemployment rates: evidence from disaggregated US data. Econ. Lett. 116, 408–410.

Halicioglu, F., 2007. Residential electricity demand dynamics in Turkey. Energy Econ. 29, 199–210. https://doi.org/10.1016/j.eneco.2006.11.007.

Henderson, V., 2003. The urbanization process and economic growth: the so-what question. J. Econ. Growth 8, 47–71.

Hsiao, C., 2007. Panel data analysis—advantages and challenges. Test 16, 1–22. https://doi.org/10.1007/s11749-007-0046-x n.d. http://www.stats.gov.cn/ztjc/tjzdgg/hsyjh1/yjhxsjlh/hsfx/201010/t20101015_69181.html.

Im, K.S., Pesaran, M.H., Shin, Y., 2003. Testing for unit roots in heterogeneous panels. J. Econom. 115, 53–74.

Ivanovski, K., Hailemariam, A., Smyth, R., 2021. The effect of renewable and non-renewable energy consumption on economic growth: non-parametric evidence. J. Clean. Prod. 286, 124956. https://doi.org/10.1016/j.jclepro.2020.124956.

Jones, D.W., 1991. How urbanization affects energy-use in developing countries. Energy Pol. 19, 621–630.

Jorgenson, A.K., Rice, J., Clark, B., 2010. Cities, slums, and energy consumption in less developed countries, 1990 to 2005. Organ. Environ. 23, 189–204.

Kahouli, B., 2018. The causality link between energy electricity consumption, CO2 emissions, R&D stocks and economic growth in Mediterranean countries (MCs). Energy 145, 388–399. https://doi.org/10.1016/j.energy.2017.12.136.

Karsu, Ö., Kocaman, A.S., 2021. Towards the Sustainable Development Goals: a Bi-objective framework for electricity access. Energy 216, 119305. https://doi.org/10.1016/j.energy.2020.119305.

Kasman, A., Duman, Y.S., 2015. CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. Econ. Modell. 44, 97–103.

Kim, Y.S., 2015. Electricity consumption and economic development: are countries converging to a common trend? Energy Econ. 49, 192–202. https://doi.org/10.1016/j.eneco.2015.02.001.

Kraft, J., Kraft, A., 1978. On the relationship between energy and GNP. J. Energy Dev. 401–403.

Larsson, R., Lyhagen, J., Löthgren, M., 2001. Likelihood-based cointegration tests in heterogeneous panels. Econom. J. 4, 109–142.

Lawal, A.I., Ozturk, I., Olanipekun, I.O., Asaleye, A.J., 2020. Examining the linkages between electricity consumption and economic growth in African economies. Energy 208, 118363. https://doi.org/10.1016/j.energy.2020.118363.

Lee, C.-C., Chang, C.-P., 2008. Energy consumption and economic growth in Asian economies: a more comprehensive analysis using panel data. Resour. Energy Econ. 30, 50–65.

Li, F., Suocheng, D., Li, X., Quanxi, L., Wangzhou, Y., 2011. Energy consumption-economic growth relationship and carbon dioxide emissions in China. Energy Pol. 39, 568–574. https://doi.org/10.1016/j.enpol.2010.10.025.

Liddle, B., 2013. The energy, economic growth, urbanization nexus across development: evidence from heterogeneous panel estimates robust to cross-sectional dependence. Energy J. 34.

Liddle, B., Lung, S., 2014. Might electricity consumption cause urbanization instead? Evidence from heterogeneous panel long-run causality tests. Global Environ. Change 24, 42–51.

Liddle, B., Lung, S., 2010. Age-structure, urbanization, and climate change in developed countries: revisiting STIRPAT for disaggregated population and consumption-related environmental impacts. Popul. Environ. 31, 317–343.

Liddle, B., Messinis, G., 2015. Which comes first–urbanization or economic growth? Evidence from heterogeneous panel causality tests. Appl. Econ. Lett. 22, 349–355.

Lin, B., Wang, Y., 2019. Inconsistency of economic growth and electricity consumption in China: a panel VAR approach. J. Clean. Prod. 229, 144–156. https://doi.org/10.1016/j.jclepro.2019.04.396.

Liu, X., Kong, H., Zhang, S., 2021. Can urbanization, renewable energy, and economic growth make environment more eco-friendly in Northeast Asia? Renew. Energy 169, 23–33. https://doi.org/10.1016/j.renene.2021.01.024.

Liu, Y., 2009. Exploring the relationship between urbanization and energy consumption in China using ARDL (autoregressive distributed lag) and FDM (factor decomposition model). Energy 34, 1846–1854. https://doi.org/10.1016/j.energy.2009.07.029.

Liu, Y., Xiao, H., Lv, Y., Zhang, N., 2017. The effect of new-type urbanization on energy consumption in China: a spatial econometric analysis. J. Clean. Prod. 163, S299–S305. https://doi.org/10.1016/j.jclepro.2015.10.044.

Liu, Y., Yan, B., Zhou, Y., 2016. Urbanization, economic growth, and carbon dioxide emissions in China: a panel cointegration and causality analysis. J. Geogr. Sci. 26, 131–152.

Mark, N.C., Sul, D., 2003. Cointegration vector estimation by panel DOLS and long-run money demand. Oxf. Bull. Econ. Stat. 65, 655–680.

Mishra, V., Smyth, R., Sharma, S., 2009. The energy-GDP nexus: evidence from a panel of Pacific Island countries. Resour. Energy Econ. 31, 210–220. https://doi.org/10.1016/j.reseneeco.2009.04.002.

Narayan, P.K., Prasad, A., 2008. Electricity consumption–real GDP causality nexus: evidence from a bootstrapped causality test for 30 OECD countries. Energy Pol. 36, 910–918.

Narayan, P.K., Smyth, R., 2009. Multivariate Granger causality between electricity consumption, exports and GDP: evidence from a panel of Middle Eastern countries. Energy Pol. 37, 229–236.

Nathaniel, S.P., Adeleye, N., 2021. Environmental preservation amidst carbon emissions, energy consumption, and urbanization in selected african countries: implication for sustainability. J. Clean. Prod. 285, 125409. https://doi.org/10.1016/j.jclepro.2020.125409.

National Bureau of Statistics of China, 2013. China Statistical Yearbook 2012. China Statistics Press, Beijing.

Örsal, D.D.K., 2007. Comparison of panel cointegration tests. Econ. Bull. 3, 1–20. https://doi.org/10.18452/4048.

Ozturk, I., 2010. A literature survey on energy–growth nexus. Energy Pol. 38, 340–349. https://doi.org/10.1016/j.enpol.2009.09.024.

Parikh, J., Shukla, V., 1995. Urbanization, energy use and greenhouse effects in economic development: results from a cross-national study of developing countries. Global Environ. Change 5, 87–103. https://doi.org/10.1016/0959-3780(95)00015-G.

Pedroni, P., 2001. Fully modified OLS for heterogeneous cointegrated panels. In: Badi, H. B., Thomas, B.F., Carter Hill, R. (Eds.), Nonstationary Panels, Panel Cointegration, and Dynamic Panels, Advances in Econometrics. Emerald Group Publishing Limited, pp. 93–130.

Pedroni, P., 2000. Fully modified OLS for heterogeneous cointegrated panels. Adv. Econom. 15, 93–130.

Pesaran, H., Shin, Y., Smith, R., 2004. Pooled mean group estimation of dynamic heterogeneous panels. J. Am. Stat. Assoc. 94 https://doi.org/10.2307/2670182.

Santos, H.T.M. dos, Balestieri, J.A.P., 2018. Spatial analysis of sustainable development goals: a correlation between socioeconomic variables and electricity use. Renew. Sustain. Energy Rev. 97, 367–376. https://doi.org/10.1016/j.rser.2018.08.037.

Shahbaz, M., Lean, H.H., 2012. Does financial development increase energy consumption? The role of industrialization and urbanization in Tunisia. Energy Pol. 40, 473–479.

Solarin, S.A., Nathaniel, S.P., Bekun, F.V., Okunola, A.M., Alhassan, A., 2021. Towards achieving environmental sustainability: environmental quality versus economic growth in a developing economy on ecological footprint via dynamic simulations of ARDL. Environ. Sci. Pollut. Res. 28, 17942–17959. https://doi.org/10.1007/s11356-020-11637-8.

Solarin, S.A., Shahbaz, M., 2013. Trivariate causality between economic growth, urbanisation and electricity consumption in Angola: cointegration and causality analysis. Energy Pol. 60, 876–884.

Swain, R.B., Karimu, A., 2020. Renewable electricity and sustainable development goals in the EU. World Dev. 125, 104693. https://doi.org/10.1016/j.worlddev.2019.104693.

UNDP, 2019. Affordable and Clean Energy. United Nations Development Programme.

United Nations, 1997. Glossary of Environment Statistics, Studies in Methods. United Nations, New York, NY.

Wagner, M., Hlouskova, J., 2009. The performance of panel cointegration methods: results from a large scale simulation study. Econom. Rev. 29, 182–223. https://doi.org/10.1080/07474930903382182.

Wallis, K.F., 1987. Time series analysis of bounded economic variables. J. Time Ser. Anal. 8, 115–123.

Wang, Q., 2014. Effects of urbanisation on energy consumption in China. Energy Pol. 65, 332–339. https://doi.org/10.1016/j.enpol.2013.10.005.

Wang, Q., Wu, S., Zeng, Y., Wu, B., 2016. Exploring the relationship between urbanization, energy consumption, and CO2 emissions in different provinces of China. Renew. Sustain. Energy Rev. 54, 1563–1579. https://doi.org/10.1016/j.rser.2015.10.090.

Wang, S., Fang, C., Guan, X., Pang, B., Ma, H., 2014. Urbanisation, energy consumption, and carbon dioxide emissions in China: a panel data analysis of China's provinces. Appl. Energy 136, 738–749. https://doi.org/10.1016/j.apenergy.2014.09.059.

Wang, Yuan, Wang, Yichen, Zhou, J., Zhu, X., Lu, G., 2011. Energy consumption and economic growth in China: a multivariate causality test. Energy Pol. 39, 4399–4406.

Wolde-Rufael, Y., 2009. Energy consumption and economic growth: the experience of African countries revisited. Energy Econ. 31, 217–224.

York, R., 2007. Demographic trends and energy consumption in European Union Nations, 1960–2025. Soc. Sci. Res. 36, 855–872.

Zhang, C., Lin, Y., 2012. Panel estimation for urbanization, energy consumption and CO2 emissions: a regional analysis in China. Energy Pol. 49, 488–498. https://doi.org/10.1016/j.enpol.2012.06.048.

Zhang, C., Xu, J., 2012. Retesting the causality between energy consumption and GDP in China: evidence from sectoral and regional analyses using dynamic panel data. Energy Econ. 34, 1782–1789. https://doi.org/10.1016/j.eneco.2012.07.012.

Zhao, Y., Wang, S., 2015. The relationship between urbanization, economic growth and energy consumption in China: an econometric perspective analysis. Sustainability 7. https://doi.org/10.3390/su7055609.

Zhen, L., Yongchun, Y., Yuxiang, L., 2008. Difference among the growth of GDP and urbanization of the provinces and the cities in west China since the reform and opening-up. China Popul. Resour. Environ. 18, 19–26. https://doi.org/10.1016/S1872-583X(09)60017-6.