Energy 201 (2020) 117719

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Factors influencing China's non-residential power consumption: Estimation using the Kaya–LMDI methods

Shan Jiang [a, b, *], Yongnan Zhu [a, b], Guohua He [a, b], Qingming Wang [a, b], Yajing Lu [c]

[a] China Institute of Water Resources and Hydropower Research, State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, 100038, Beijing, China
[b] China Institute of Water Resources and Hydropower Research, Department of Water Resources, 100038, Beijing, China
[c] Beijing Water Science and Technology Institute, Beijing, China

ARTICLE INFO

Article history:
Received 4 October 2019
Received in revised form
22 April 2020
Accepted 24 April 2020
Available online 25 April 2020

Keywords:
Non-residential power consumption
Economic growth
Kaya-LMDI
Energy saving
Influencing factor

ABSTRACT

Electric power plays an important role in the economic development of a nation and in improving human life. Since China is the world's largest electricity consumer, an understanding of the factors influencing the growth in the consumption of electricity would help Chinese leaders design appropriate energy savings strategies and economic policies. Using the Logarithmic Mean Divisia Index (LMDI) method based on the Kaya identity, this study takes China's non-residential power consumption from 2007 to 2016 as its research subject and decomposes the influencing factors into population size, economic development, regional economic structure, regional industrial structure, and electricity consumption intensity. We find that economic growth is the main factor influencing the growth of non-residential power consumption, mostly in the eastern region; moreover, the increased intensity of power consumption inhibits the growth of non-residential power consumption, with the suppression effect being more significant in the secondary industry. Population growth plays a small role in promoting electricity consumption. Regional economic structure has a negative effect on power consumption, showing a significant difference between provinces. From these results, regional differences and industrial structure are factors to be considered for the development and management of electricity. Therefore, technological innovation and management need to be strengthened, with focus on industrial structure adjustment and promotion of energy conservation technology in the central and western regions.

1. Introduction

Electricity is the foundation of economies and human life [1], with the consumption of electricity having high impact on energy transition in global economies [2]. However, in recent years, weak global economic recovery, the continuous promotion of energy and resources savings, and improved energy efficiency have enhanced or decreased the primary energy and electricity consumption of some major economies [3]. Because electricity plays a fundamental role in energy production, a better understanding of the impact mechanism of power consumption has great significance for improving efficiency, controlling the growth rate, and maximizing economic benefit, which have always been the focus of international research [4].

The remarkable increase in China's electricity consumption in order to support its economic growth has made China the world's largest power consumer. According to the June 2018 BP Statistical Review of World Energy, the total electricity production in 2017 was only 2.8% higher than that in 2016. As the world's leading electricity producer, China has contributed the largest increase ever in 2017: 6495.1 TWh of electric power; this was 6.2% higher than its 2016 production, and 25.4% more than the rest of the world's production. However, China' electricity generation from coal accounted for 72% of its total generation in 2017, according to the National Bureau of Statistics. Its electricity consumption is targeted to grow by 3.6–4.8% over the period of its 13th Five-Year Plan for Electricity Power Development (2016–2020) [5]. China's economy has entered "a new normal," introducing major changes in terms of growth rate, development model, economic structure, and growth

* Corresponding author. China Institute of Water Resources and Hydropower Research, State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, 100038, Beijing, China.
E-mail address: jiangs@iwhr.com (S. Jiang).

https://doi.org/10.1016/j.energy.2020.117719
0360-5442/

Nomenclature

LMDI	Logarithmic Mean Divisia Index
GDP	Gross Domestic Product
IDA	Index Decomposition Analysis
IPCC	Intergovernmental Panel on Climate Change
Q	The CDP
Y	The per capita GDP
S_i	The economic contribution of i province in China
M_{ij}	The economic contribution of j industry in i province
U_{ij}	The electric power intensity of j industry in i province
ΔE	Total electricity consumption change
ΔP	Population effect
ΔY	Economic development effect
ΔS	Regional economic structure effect
ΔM	Regional industrial structure effect
ΔU	Electricity intensity effect
r	Contribution rate

drivers, and making it worth to estimate the influencing factors of electricity consumption and control it.

The consumption of electricity, as the main component of energy use, has been increasing in tandem with the high rate of economic growth [6]. Osman et al. indicated a long-run equilibrium relationship between electricity consumption and economic growth in the Gulf Cooperation Council countries [7]; however, an inconsistency was reported between economic growth and electricity consumption in China, probably due to an increase in inventory, fixed capital, or industrial power consumption [8], or inventory investment adjustment shock and electricity consumption structural shock on the deviation [9]. Furthermore, Liu et al. found that at the aggregate level, there is a unidirectional causality running from economic growth to electricity consumption [10]. These studies indicate a significant relationship between power consumption and economic growth, but with several factors influencing electricity consumption. Previous studies proposed many determinants of electricity consumption in Jordan from 1986 to 2015, such as GDP, electricity prices, population, urbanization, economic structure, and aggregate water consumption [11]. Fobi et al. suggested that developing economies show rapid growth in the number of customers with electricity access [12]. Karanfil et al. [13] found that the electricity consumption–growth nexus is highly sensitive to regional differences, country income levels, urbanization rates, and supply risks, using panel unit root, cointegration, and causality tests and considering 160 countries for causality. Zaman et al. [14] found that the determinants of electricity consumption in Pakistan cointegrated, with the influx of foreign direct investment, income, and population growth positively related to electricity consumption. Extant studies show various influencing factors, differing by country, economy, and level of economic development. However, there is a need for studies that examine electricity consumption at the national level, because little is known about how changes in customer behavior affect electricity consumption in the different regions of a country.

Numerous scholars in this field use causality tests to explain the characteristics of electricity consumption. Bah et al. [15] used the Toda and Yamamoto Granger causality test to estimate a vector autoregressive model in level variables; this test reduced the risk of wrongly identifying the order of integration. They found no causality between electricity consumption and economic growth. Jamil et al. [44] found a unidirectional causality from economic activity to electricity consumption in Pakistan using the Johansen maximum likelihood approach; this method involved two likelihood ratio tests based on trace and maximum eigenvalue statistics. However, these studies could conduct only cointegration analysis. The most common method to analyze the influencing factors of research objectives is factor decomposition; this method decomposes factors considering the target direction and degree [16]. Index Decomposition Analysis (IDA) is similar to the index number theory in economics which consistency in aggregation and perfect decomposition are particularly important. Van Megem et al. [17] used multilevel IDA in a comparative framework to disentangle the effects of changes in economic structure, overall economic activity, and structure-corrected energy intensity on electricity consumption in Geneva and Switzerland, to find effective national energy efficiency policies in place since 2001.

LMDI is an important branch of IDA, with features such as no residuals or residual values, total decomposition, ease of use, and multiplication decomposition with addition [18,19]. In terms of energy analysis, Lu et al. [20] decomposed the changes in total energy consumption in the construction industry using the LMDI model, and suggested that the area, structure, population, value and energy intensity are key influencing factors. Belloumi and Achour [21] identified the influencing factors of transportation energy consumption, and measured their corresponding contributions, in Tunisia using the LMDI model. They indicated that, overall, economic output, transportation intensity, population scale, and transportation structure have a positive effect on energy consumption, whereas energy intensity has a negative effect. Chong et al. [22] used an LMDI decomposition method to analyze the energy consumption growth in Guangdong Province, finding GDP per capita and population growth to be dominant factors influencing consumption growth. LMDI analysis has been widely used to explain changes in electricity-related CO_2 emission changes. Chong et al. [23] introduced an LMDI decomposition method based on energy allocation analysis. They indicated that population, GDP per capita, and energy intensity are still the main factors influencing changes in energy-related CO_2 emissions in Malaysia, thus suggesting the increasing influence of technical driving factors. De Oliveira-De Jesus [24] studied the effect of electricity generation capacity factors and evolution on carbon emission intensity in Latin America and the Caribbean. Chen et al. [25] analyzed the factors affecting CO_2 emissions in the OECD countries, and showed that energy intensity and per capita GDP are the main influencing factors. In terms of water resources management, Zhang et al. [26] used the LMDI decomposition method and showed that the crop-planting scale, cropping pattern, irrigation quota, and irrigation efficiency of different crops are the influencing factors of agricultural water use in the Heihe River basin of China. Yao et al. [27] decomposed the temporal-spatial differences in water intensity into intensity and structure effects in the Yangtze River Economic Zone, to find that industrial water intensity and industrial structure can reduce the water intensity.

Therefore, an analysis of the influencing factors of electric power consumption growth based on LMDI can help improve electricity efficiency and allow policymakers to control the growth of electricity consumption. Fang et al. [28] studied the influencing factors of China's electricity consumption using the ST-LMDI model, which is the LMDI model integrating spatial and temporal analyses into a single analytical framework, to indicate that economic growth has a strong impetus for power consumption whereas technological progress can effectively curb it. Using the LMDI method, Achão et al. [29] showed that activity, structure and intensity affects caused electricity consumption of the Brazilian residential sector from

1980 to 2007. González [30] and Inglesi-Lotz [31] also applied the same method to analyze electricity consumption in Spain and South Africa. From the extant research, the main influencing factors of electricity consumption are economic growth, industrial structure, and technological advancement, irrespective of the regional heterogeneity in electricity consumption changes. This is of great significance for a country like China that has a large gap in social and economic development, it is necessary to study the effects of regional heterogeneity on electricity consumption changes.

For China to maintain a sustained and rapid economic growth, it needs to analyze the characteristics and differences of its sectoral electricity consumption. Understanding the influencing factors and characteristics of power consumption based on the LMDI model can be helpful to design appropriate energy savings strategies. In view of the large differences in economic development of China's regions and power efficiency of its different industries, this paper applies the Kaya identify and combines the LMDI model to decompose the influencing factors of the growth of power consumption into population size, economic development, economic structure, industrial structure, and intensity of electricity consumption for three industry types across the 31 Chinese provinces. In contrast to the extant studies, this paper decomposes the influencing factors of China's non-residential power consumption at the national, provincial, and sectoral levels from 2007 to 2016, to explore the dependence of the regional and sectoral development on the non-residential power consumption, and thus make the policy recommendations more reasonable and accurate.

The remainder of this paper is structured as follows: Section 2 introduces the economy development and power consumption in China. Section 3 presents the method and data used, and decomposes the influencing factors of non-residential power consumption based on the Kaya-LMDI model. Section 4 decomposes non-residential power consumption year by year from 2007 to 2016, and analyzes the effect of influencing factors on non-residential power consumption in different provinces and the industrial structure. Section 5 discusses the reasons for the difference in non-residential power consumption between the eastern, central, and western region. Finally, Section 6 concludes the paper and presents policy implications.

2. Electricity consumption and economic growth

As Fig. 1 shows, the economic development of China indicates a steady and progressive trend. Its GDP has increased by approximately 7.4 times in the past 20 years, at an average annual growth rate of 10.5%. With the development of new industries and formats, China's power consumption increased from 1134.2 TWh in 1997−5974.7 TWh in 2016, that is, by 5.3 times, at an average growth rate of 8.7%. However, both the GDP and electricity consumption of China increased significantly during this period, but the growth rate of GDP was higher than that of electricity consumption. While the growth rate of consumption in China has slowed down since 2007, showing an average rate of 6.2%, the economic growth rate of China has increased slightly. A similar trend can be seen between economic growth and electricity consumption.

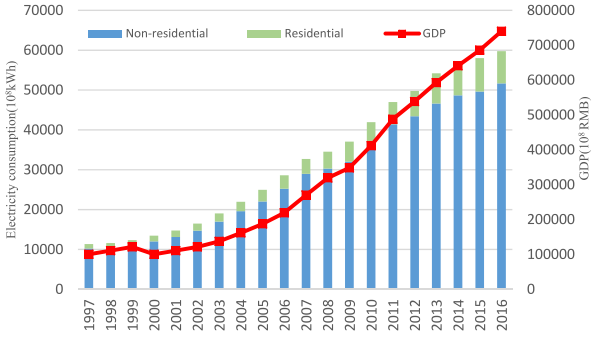

Fig. 1. Electricity consumption and GDP in China during 1997−2016.

From the electricity consumption structure of China, non-residential power consumption, included the primary, secondary and tertiary industrial power consumption, accounted for approximately 90% and 86.5% of the total power consumption in 1997 and 2016, respectively, thus playing a leading role in China's increased electricity consumption. As Fig. 2 shows, the China provinces show great differences, with those consuming more electricity concentrated in the eastern region, such as Hebei, Jiangsu, and Guangdong. Provinces in the western region account for more than 80% of the non-residential power consumption; these include Shanxi, Xinjiang, and Ningxia provinces.

This study considers the Chinese mainland, which includes 31 provinces, autonomous regions, and municipal cities, and performs a quantitative analysis of the influencing factors of non-residential power consumption in different regions from 2007 to 2016. According to the Chinese National Bureau of Statistics, the western region comprises 12 provinces—Sichuan, Chongqing, Gui zhou, Yunnan, Xizang, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, and Neimongol; the central region comprises eight provinces—Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan; and the eastern region comprises 11 provinces—Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Hainan, and Guangdong.

3. Method and data

3.1. Method

3.1.1. Kaya identity for influencing factors

The Kaya identity was introduced by Yoichi Kaya in 1989, and is widely used to study the influencing factors of the energy economy and environment because of its simple structure and easy-to-understand concept [32]. Robalino-López et al. used Kaya components to analyze the convergence process of CO_2 emissions per capita in 10 South American countries [33]. The Fourth Assessment Report of the IPCC also used the Kaya to identify the influencing factors of greenhouse gas emissions [34]. Cicea et al. [35] used an econometric model along with Kaya identity to analyze the environmental efficiency of investments in renewable energy. Gudipudi et al. [36] applied the urban Kaya relation to examine the intrinsic factors determining the emission efficiencies of large cities. This study accordingly considered five influencing factors of electricity consumption growth in three production industries across 31 provinces of China, to obtain the Kaya identity model as follows:

$$E = \sum_{ij} E_{i,j} = \sum_{i,j} P \frac{Q}{P} \frac{Q_i}{Q} \frac{Q_{i,j}}{Q_i} \frac{E_{i,j}}{Q_{i,j}} = \sum_{i,j} P \cdot Y \cdot S_i \cdot M_{i,j} \cdot U_{i,j}, \quad (1)$$

where subscript i represents the province, i = 1,2, … … 31, and j represents the type of production industry, j = 1,2,3 [the primary industry includes farming, forestry, animal husbandry, and fishery; the secondary industry includes construction, manufacturing (durable and nondurable goods manufacturing), utilities (electricity, gas, and water), and mining; and the tertiary industry includes wholesale and retail trade, transportation and warehousing, information, finance and insurance, real estate and rental and leasing,

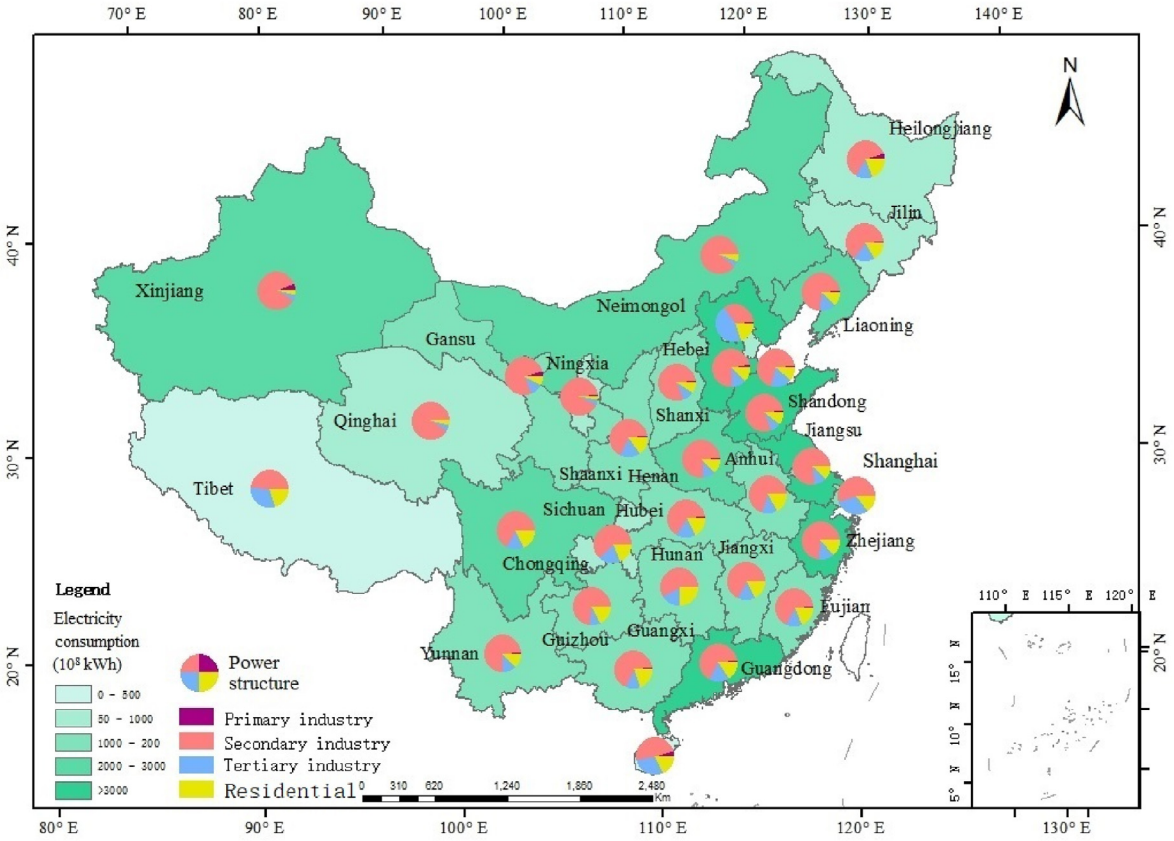

Fig. 2. Electricity consumption and structure in China (2016).

professional and business services, educational services, health care and social assistance, arts, entertainment and recreation, accommodations and food services, and the government].

In Eq. 1 E represents the total industrial electricity consumption; $E_{i,j}$ represents the electricity consumption of j industry in i province; P stands for total population; Q is the GDP; Q_i is the total GDP of i province; and $Q_{i,j}$ is the j industrial production value of i province. Furthermore, $Y = Q/P$ is the per capita GDP representing the economic development index; $Si = Q_i/Q$ the economic contribution of i province in China, representing the regional economic structure index; $M_{ij} = Q_{ij}/Q_i$ the structure of production, representing the regional industrial structure; and $U_{ij} = E_{ij}/Q_{ij}$ the electric power intensity of j industry in i province, representing the technical index.

3.1.2. LMDI method of electricity consumption growth in three industries

According to the Kaya identity, the influence on electricity consumption can be divided into five parts. This study follows Ang et al. [18,19,37], to build the LMDI-I model, which can be described as

$$\Delta E = E^t\text{-}E^0 = \Delta P+\Delta Y+\Delta S+\Delta M+\Delta U, \tag{2}$$

Where E_t and E_0 represent the total electric power consumption for non-resident in periods T and 0, respectively, and ΔP, ΔY, ΔS, ΔM, and ΔU represent the population effect, economic development effect, regional economic structure effect, regional industrial structure effect, and electricity intensity effect, respectively. This study uses the LMDI-I addition model decomposition, which can be calculated as follows:

$$\Delta P = \sum_{i=1}^{31}\sum_{j=1}^{3}\frac{\left(E_{ij}^t - E_{ij}^0\right)}{\left(lnE_{ij}^t - lnE_{ij}^0\right)} ln\left(\frac{P^t}{P^0}\right) \tag{3}$$

$$\Delta Y = \sum_{i=1}^{31}\sum_{j=1}^{3}\frac{\left(E_{ij}^t - E_{ij}^0\right)}{\left(lnE_{ij}^t - lnE_{ij}^0\right)} ln\left(\frac{Y^t}{Y^0}\right) \tag{4}$$

$$\Delta S = \sum_{i=1}^{31}\sum_{j=1}^{3}\frac{\left(E_{ij}^t - E_{ij}^0\right)}{\left(lnE_{ij}^t - lnE_{ij}^0\right)} ln\left(\frac{S_i^t}{S_i^0}\right) \tag{5}$$

$$\Delta M = \sum_{i=1}^{31}\sum_{j=1}^{3}\frac{\left(E_{ij}^t - E_{ij}^0\right)}{\left(lnE_{ij}^t - lnE_{ij}^0\right)} ln\left(\frac{M_{ij}^t}{M_{ij}^0}\right) \tag{6}$$

$$\Delta U = \sum_{i=1}^{31}\sum_{j=1}^{3}\frac{\left(E_{ij}^t - E_{ij}^0\right)}{\left(lnE_{ij}^t - lnE_{ij}^0\right)} ln\left(\frac{U_{ij}^t}{U_{ij}^0}\right) \tag{7}$$

1) Population effect (ΔP). While the growth of population leads to large explorations of resources, the safe and stable supply of electricity is closely related to the population and resources. How to match electricity consumption with the population

trends has become a focal issue. ΔP is the effect of population growth.

2) Economic development effect (ΔY). With the constant rise in economic development and living standards, people demand higher electricity supply and reliability. Electricity consumption and the social economy depend and rely on each other to move forward. ΔY represents the effect of economic development on electricity consumption.
3) Regional economic structure effect (ΔS). As a large developing nation, China faces a major issue in the process of economic development, that is, the economic development of the different regions is not balanced. Therefore, ΔS is one factor to be considered as affecting electricity consumption.
4) Regional industrial structure effect (ΔM). The industrial structure affects economic growth and the staying power, besides seriously affecting the quality of economic development. This is an important factor of regional economic development. Therefore, ΔM indicates the regional industrial structure effect on electricity consumption.
5) Electricity intensity effect (ΔU). Improving the efficiency in end use of electric power can contribute to the goal of saving energy and optimizing electricity utilization. ΔU evaluates the effect of the technology efficiency improvement of various sectors on electricity consumption.

3.1.3. Contribution rate

Contribution rate is an indicator of economic benefit. It is the ratio of effective or useful results to total consumption, that is, the ratio of output to input, or income to cost [38]. In this paper, contribution rate (r) illustrates the ratio of electric power consumption change due to influencing factors (Δ) to the total electricity consumption change (ΔE) in the production industry from base year 0 to target year t.

$$r = \frac{\Delta}{\Delta E} \times 100\% \tag{8}$$

3.2. Data

The study period chosen is 2007–2016, with the total population, gross national product, GDP, and industrial added value of each province obtained from the China Statistical Yearbook; the values for different years are converted to the constant price of 2007. The provincial and industrial electricity consumption levels are derived from the Compilation of Statistics on the Power Industry. The relevant indexes are explained as follows:

(1) Population data: The resident population data reflect the demographic status of a region more accurately. This paper considers resident population as an index.
(2) Economic data: The three industrial added values of each province are adjusted to the constant 2007 price to eliminate the influence of price factors; GDP is the sum of the three adjusted industrial added values.
(3) Electricity consumption data: The electricity consumption of each province is divided into non-residential and residential electricity. This paper focuses on non-residential power consumption, including primary, secondary, and tertiary industries.

4. Results

4.1. Influencing factors of non-residential power consumption based on the Kaya-LMDI model

We use the LMDI-I addition model to analyze the influencing factor effects on the non-residential electricity consumption changes from 2007 to 2016, such as the population, economic development, regional economic structure, regional industrial structure, and electricity intensity effects. From Fig. 3, population and economic development showed a positive effect on non-residential power consumption for the study period, while and economic development was the primary factor for non-residential power consumption growth from the perspective of maximum value. After three decades of reform and opening up, China was maintaining its high-speed economic development, but its growth rate began to decline in 2008 on account of the international economic environment and, worst of all, the 2008 American economic crisis. In order to address its financial crisis, China set out on a proactive fiscal and loose monetary policy, and thus expanded its domestic demand, maintained a stable economic environment, and took an economic uptrend. However, this was affected by the international economic development as well as internal self-regulation policy factors, and the economic growth rate slowed down after 2008. Furthermore, along with the changing economy, the non-residential power consumption changed accordingly. Moreover, the growth of China's total population slowed down, thus contributing feebly to power consumption.

Conversely, the increase in electricity efficiency could reduce electricity use. This was one main factor restraining the growth of non-residential power consumption. Especially, the 11th Five-Year Plan's single control (of only energy intensity) was upgraded to comprehensive control over both energy intensity and total energy consumption under the 12th Five-Year Plan, and this "double control" action (of both total energy consumption and intensity) was finally implemented in the 13th Five-Year Plan. The main purpose was to improve energy efficiency by forcing the transformation of the economic development mode and promoting continuous optimization and upgrading of the industrial structure, hindering the growth of power consumption to a large degree. The regional industrial structure has a feeble negative effect on power consumption; this effect is gradually strengthened through industrial restructuring by the local government. Regional economic structure has the weakest effect; it is gradual and negative owing to the narrowing economic development gap among the eastern, central,

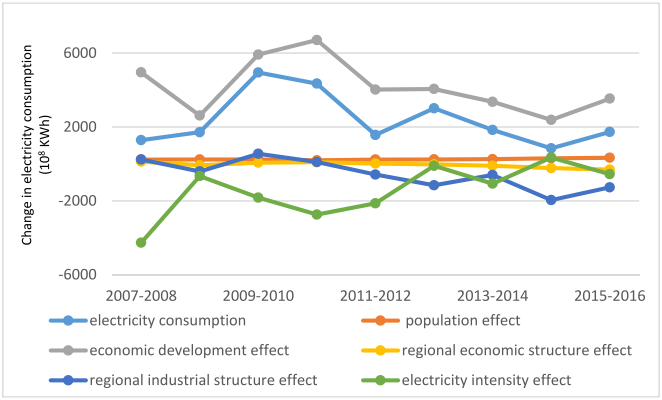

Fig. 3. The effect of different factors based on the LMDI-I addition model.

and western regions.

4.2. Decomposition of non-residential power consumption by time scale

From Eqs. (2)–(7), the national non-residential power consumption increased by 2143 TWh during the 2007–2016 period (see Table 1). The consumption increased by 3770.6 TWh as a result of economic development, and by 220.2 TWh as a result of increased population size. The r of economic development and population size are 176% and 10.3%, respectively. Adjustments to regional economic and industrial structures reduced the non-residential power consumption by 234.5 TWh and 416.2 TWh, respectively. The optimization of power consumption intensity in different industries also decreased the non-residential power consumption by 1408.2 TWh; the r of power consumption intensity was −65.7%. Growth in economic development and population size during the different periods have always increased the non-residential power consumption. However, in 2014–2015, electricity consumption intensity generally inhibited non-residential power consumption, with the regional industrial structure and economic structure effects changing from promotion to inhibition in 2011 and 2012, respectively. However, the impact was relatively small.

4.3. Regional analysis of non-residential power consumption

From Table 2, the effects of electric power decomposition factors show provincial differences, with the non-residential power consumption of Shandong increasing the most, by 271.6 TWh, followed by Guangdong, where consumption increased by 165.5 TWh; the growth in non-residential power consumption in Tibet was insignificant. While the provinces showed large differences in non-residential power consumption growth, population size and economic development remained the main influencing factors of increased non-residential power consumption; economic development contributed the most to non-residential power consumption in Guangdong and Jiangsu. Except for in Liaoning, the optimization of power consumption intensity had a negative effect, indicating that improved power consumption efficiency is the main factor curbing the growth of non-residential power consumption. The final consumption of Jiangsu province is 245 times that of Tibet, indicating great differences in the regional power consumption intensity, which in turn inhibits industrial power consumption growth; this is related to the electricity efficiency of different industries.

Non-residential power consumption in the eastern, central, and western regions of China increased by 1806.7, 454.9, and 601.4 TWh, respectively. In most provinces of the eastern region, such as Shandong, Guangdong, Zhejiang, Liangning, and Hebei, the non-residential power consumption increased by more than 100 TWh. Economic development is the influencing factor of power consumption growth in the eastern, central, and western regions. The increase in non-residential power consumption due to economic development completely offset the inhibiting effects of regional industrial structure and power consumption intensity optimization. Regional economic structure has a subtle negative effect on non-residential power consumption from 2007 to 2016, with large differences between provinces. While the regional economic structure of most provinces in the eastern advanced region restrained the growth of non-residential power consumption, for example, the Liaoning, Guangdong, and Zhejiang provinces, that of most provinces in the central and western region showed a positive effect on non-residential power consumption. Thus, economic development of the central and western regions depended strongly on electricity.

4.4. Industrial structure analysis of non-residential power consumption

The non-residential power consumption growth from 2007 to 2016 due to regional industrial structure and power consumption intensity differs by industrial type. Regional industrial structure led to a consumption decreases of 20.1 TWh in the primary industry, a consumption decreases of 501.7 TWh in the secondary industry, and a consumption increase of 105.6 TWh in the tertiary industry. Thus, regional industrial structure obviously inhibits the increase in electricity consumption in the secondary industry. Adjusting the primary industrial structure has little effect in restraining the growth of industrial power consumption, whereas increasing the tertiary industry promotes electricity consumption. As regards the variation trend due to regional industrial structure in the three industry types, the secondary industry curbed the consumption of power the most after 2011, while the tertiary industry promoted

Table 1
Decomposition factor effect of non-residential power consumption in China from 2007 to 2016.

Year		ΔE	ΔP	ΔY	ΔS	ΔM	ΔU
Change in non-residential power consumption (10^8 KWh)	2007–2008	1283.13	235.52	4954.49	122.87	237.71	−4267.46
	2008–2009	1713.96	238.18	2616.00	−74.55	−407.49	−658.18
	2009–2010	4946.35	243.56	5918.29	64.81	546.31	−1826.63
	2010–2011	4344.63	191.95	6705.72	91.37	100.74	−2745.14
	2011–2012	1565.61	235.61	4023.79	17.57	−577.42	−2133.93
	2012–2013	3009.69	242.07	4056.89	−27.69	−1157.28	−104.3
	2013–2014	1837.83	255.96	3359.03	−103.50	−601.02	−1072.64
	2014–2015	841.50	302.79	2381.57	−229.11	−1959.15	345.40
	2015–2016	1728.01	329.95	3534.22	−309.63	−1269.28	−557.25
	2007–2016	21429.69	2201.97	37706.02	−234.49	−4161.99	−14081.8
r (%)	2007–2008	100	18.4	386.1	9.6	18.5	−332.6
	2008–2009	100	13.9	152.6	−4.3	−23.8	−38.4
	2009–2010	100	4.9	119.6	1.3	11.0	−36.9
	2010–2011	100	4.4	154.3	2.1	2.3	−63.2
	2011–2012	100	15.0	257.0	1.1	−36.9	−136.3
	2012–2013	100	8.0	134.8	−0.9	−38.5	−3.5
	2013–2014	100	13.9	182.8	−5.6	−32.7	−58.4
	2014–2015	100	36.0	283.0	−27.2	−232.8	41.0
	2015–2016	100	19.1	204.5	−17.9	−73.5	−32.2
	2007–2016	100	10.3	176.0	−1.1	−19.4	−65.7

Table 2
Decomposition factor effect on the non-residential power consumption of each province in China from 2007 to 2016 (Unit: 10^8 KWh).

Region	Provinces	ΔE	ΔP	ΔY	ΔS	ΔM	ΔU
Eastern region	Beijing	411.99	38.42	657.97	−45.76	−71.61	−167.02
	Tianjin	120.85	32.24	552.03	113.77	−99.71	−477.48
	Hebei	1006.32	129.31	2214.27	−384.38	−176.97	−775.90
	Liaoning	1165.18	83.39	1427.91	−495.23	−264.72	413.83
	Shanghai	393.92	61.69	1056.40	−231.37	−232.85	−259.94
	Jiangsu	860.76	206.90	3542.88	235.83	−592.14	−2532.71
	Zhejiang	1513.90	146.55	2509.51	−262.73	−352.45	−526.97
	Fujian	906.45	66.27	1134.82	129.71	14.13	−438.47
	Shandong	2716.47	194.23	3325.99	−189.28	−562.51	−51.95
	Guangdong	1655.41	213.64	3658.40	−345.92	−344.45	−1526.27
	Hainan	115.55	8.84	151.38	23.04	−15.44	−52.27
Central region	Shanxi	642.33	81.84	1401.33	−365.23	−454.16	−21.44
	Jilin	202.37	26.39	451.92	1.27	8.78	−285.98
	Heilongjiang	207.41	34.85	596.75	−155.65	−250.86	−17.68
	Anhui	603.45	57.41	983.02	175.70	51.89	−664.57
	Jiangxi	437.00	37.26	638.03	88.42	−23.86	−302.86
	Henan	1459.46	117.34	2009.26	−70.10	−218.36	−378.67
	Hubei	587.52	63.19	1082.14	253.73	15.64	−827.18
	Hunan	409.59	50.35	862.14	161.20	5.91	−670.01
Western region	Neimongol	406.03	95.99	1643.77	20.39	−83.61	−1270.52
	Guangxi	411.15	45.88	785.67	97.67	54.94	−573.01
	Chongqing	439.56	30.59	523.85	166.44	−34.02	−247.31
	Sichuan	856.41	74.53	1276.17	147.11	−40.04	−601.35
	Guizhou	406.51	44.61	763.94	300.69	10.37	−713.10
	Yunnan	525.24	51.14	875.79	95.30	−71.15	−425.84
	Tibet	18.85	1.22	20.86	4.09	3.01	−10.34
	Shaanxi	967.34	47.21	808.46	157.91	−27.69	−18.55
	Gansu	464.77	42.99	736.19	−35.04	−172.68	−106.69
	Qinghai	243.16	23.83	408.07	61.41	−29.27	−220.88
	Ningxia	489.98	35.00	599.40	131.21	−32.22	−243.42
	Xinjiang	784.73	58.85	1007.71	−18.68	−175.89	−87.25

power consumption.

Consumption intensity reduced the consumption of power by 51.9 TWh, 1202.4 TWh, 153.9 TWh, respectively, in the three industry types (see Table 3). Improvement in efficiency of the secondary industry contributed most to reducing electricity consumption, while improvement in power consumption intensity in the primary industry contributed little to curbing power consumption. As regards the change in power consumption due to optimization of electricity consumption intensity in the three industry types, the increase in efficiency of electricity consumption in the tertiary industry suppressed the growth of non-residential power consumption from 2007 to 2016. Besides, in 2012–2013 and 2014–2015, the efficiency of electricity consumption in the secondary industry contributed the most to reducing non-residential power consumption.

5. Discussions

5.1. Non-residential power consumption in China

Economic development is the most important influencing factor for the growth of electricity consumption, with a similar trend between electricity consumption of the industry and economic growth, but with no synchronization, which is consistent with Zhang et al. [39]. They show that the deviation between electricity consumption and economic growth is in line with the general laws of economic development. Furthermore, intensity of power consumption holds back the power consumption growth rate; this agrees with the findings of Yu et al. [40] based on input-output analysis. In terms of industrial structure, the effect of change in the secondary industry is more than that in the primary and tertiary industries. Zhang et al. further indicate diversity and aggregation in the secondary industry [1].

Table 3
Decomposition factor effect of industrial structure on non-residential power consumption China from 2007 to 2016 (Unit: 10^8 KWh).

Year	Regional industrial structure effect			Electricity intensity effect		
	Primary industry	Secondary industry	Tertiary industry	Primary industry	Secondary industry	Tertiary industry
2007–2008	−28.00	281.17	−15.46	−114.48	−3916.97	−236.01
2008–2009	−16.48	−516.44	125.42	0.21	−649.72	−8.67
2009–2010	−26.20	648.99	−76.47	−114.78	−1527.30	−184.55
2010–2011	−41.68	134.28	8.14	−103.77	−2503.38	−137.98
2011–2012	−4.38	−714.98	141.94	−109.65	−1943.65	−80.63
2012–2013	−38.45	−1427.87	309.04	−33.18	225.91	−297.04
2013–2014	−21.94	−727.97	148.89	−65.41	−763.36	−243.87
2014–2015	−9.54	−2336.56	386.95	−2.21	618.43	−270.82
2015–2016	−28.02	−1520.57	279.31	14.75	−515.80	−56.20
2007–2016	−201.33	−5016.56	1055.89	−519.25	−12023.60	−1538.95

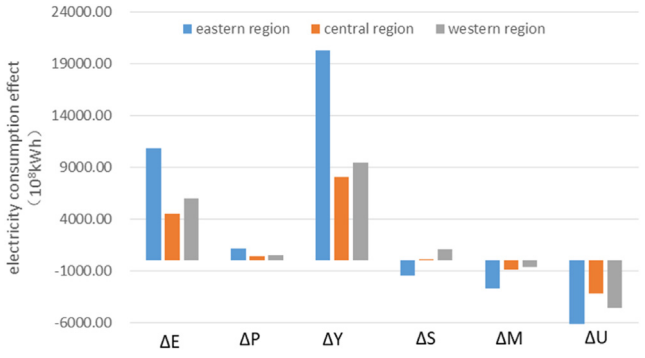

Fig. 4. Decomposition factor effect of electric power consumption growth in the eastern, central, and western regions.

5.2. Decomposition factor effect in the eastern, central, and western regions

Economic development is the decisive factor in the growth of non-residential power consumption in the three regions (seen in Fig. 4), with the economic development effect on electricity consumption growth largest in the eastern region, followed by the western region. The smallest effect is in the central region. This is related to the rapid economic development of the eastern region. The lower initial economic levels of the western provinces have great potential for development. The effect of electricity consumption intensity was greater than that of regional industrial structure optimization in the three regions. The economic structure of the eastern region suppressed its non-residential power consumption, which is related to the ongoing decline in its share of total income; the regional economic structural effects in the central and western regions promoted the growth of non-residential power consumption, because the central and western regions accelerated in development as the gap between China's regional economies narrowed down.

5.3. The effect of industrial structure and power consumption intensity in regions

From Fig. 5, the industrial structure gradually adjusted itself, with the primary and secondary industries adjusting to the tertiary industry. This explains why a negative effect on the growth of non-residential power consumption in the primary and secondary industries led to growth in the tertiary industry. The regional industrial structure effect has hindered the growth, with the largest impact in the eastern region, followed by the central region. The smallest impact is in the western region. For the secondary industry, the eastern and western regions have greater inhibitory effect, indicating that the efficiency of power consumption in the secondary industry has gained attention in the eastern and western regions. Similarly, improving the intensity of power consumption in the tertiary industry has a far more inhibitory effect on the growth of non-residential power consumption in the eastern region than in the central and western regions. The impact of consumption intensity in the three industrial types on the growth of non-residential power consumption is most significant in the eastern region, indicating that energy-saving technologies and management are strongly promoted there.

5.4. Implications for policy

China's economy is facing a period of slow economic growth, but the local economies maintain rapid growth. The economy of the eastern region particularly shows an overall stable and superior situation, resulting in increased non-residential power consumption. Lack of primary energy resources in the eastern area has made it important to convert the northwest coal resources and the southwest hydropower resources into power resources and transport them to the eastern region, where electricity is scarce. China will vigorously develop renewable energy and adjust the energy structure of electric power to achieve low carbon and the sustainable development, as a result that renewable installed capacity and electricity generation accounts for 38.3% and 26.7% in 2018, respectively [41]. However, the growth rate of wind and solar power consumption are slower than the rate of wind and solar installed capacity due to curtailment issues [42,43]. Expanding the West–East Power Transmission scale will ensure that the eastern region's future electricity demand is met. The 13th Five-Year Plan for Power Development (2016–2020) has set the target to enhance the power transmission capacity from 1.4×10^8 kW in 2015 to 2.7×10^8 kW in 2020 [5]. Simultaneously, the western region's share of the national economy has gradually increased, bringing more pressure on the region to produce more electric power to meet the region's power needs. Thus, the positive effect of an increase in non-residential power consumption has been highlighted in the western region, and it is necessary to reduce the proportion

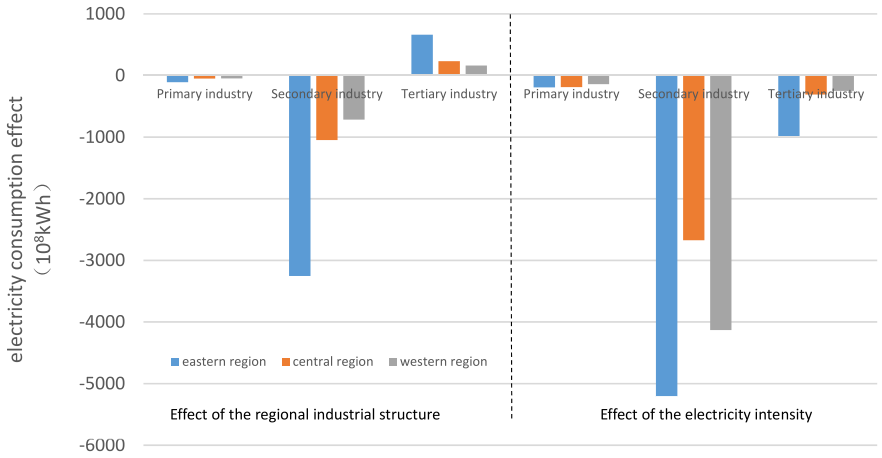

Fig. 5. Industrial differences in the decomposition factor effect on power consumption growth in 2007–2016.

fossil-fuel power in some regions of the West with serious wind and solar energy curtailment problem.

6. Conclusions

As an important factor for economic development, economic scale expansion inevitably leads to increased power consumption. Connecting LMDI method with Kaya identity is an analytical approach, the reliability has been examined by previous studies in decomposing the influence factors of energy or environmental management in many countries. The availability of quality data is the requirement for good empirical analysis, Kaya-LMDI method is not only feasible applied in decomposition analysis of power consumption in China, but also can be easily reapplied in other countries with credible data. Moreover, this study explores the regional structure and industrial characteristics, as well as the regional industrial structure and power consumption intensity effect on China's non-residential electricity consumption. The main conclusions of the study are as follows:

The study decomposes the growth of non-residential power consumption in China into five factors, population size, economic development, regional economic structure, regional industrial structure, and electricity intensity, to find that economic growth and population size are the influencing factors of non-residential power consumption, increasing consumption by 3770.6 TWh and 2202 TWh, respectively. The growth due to rapid economic development and population increases has offset the negative effect of regional structure, industrial structure, and utilization efficiency.

Spatially, the growth of non-residential power consumption of the eastern region was 1.8 times that of the western region and 2.4 times that of the central region, with particularly higher consumption in Guangdong, Shandong, and Jiangsu provinces. Economic development effect led to a 2023 TWh increase in the eastern region. However, power consumption intensity showed a pronounced inhibitory effect, to the tune of 639.5 TWh.

The effects of regional industrial structure and power consumption intensity were generally greatest in the secondary industry, with positive and negative values determining the promotion and inhibition effects, respectively. Because of the increasing share of the tertiary industry, the regional industrial structure in the tertiary industry could influence the growth of non-residential power consumption by 66 TWh in the eastern region, 23 TWh in the central region, and 16 TWh in the western region.

The regional industrial structure effect could reduce the non-residential power consumption by a certain extent, but it was weaker than the power consumption intensity optimization effect, particularly in the secondary industry. Industrial structure can easily be adjusted to inhibit the growth of non-residential power consumption. In the long term, the regional industrial structure can be upgraded to reduce non-residential power consumption. In particular, it would be beneficial to optimize the economic structure, guide the industry to transform and upgrade from a high-energy-consuming secondary industry to a low-energy-consuming tertiary industry, encourage the development of high-value-added high-tech enterprises, and reduce overall power consumption.

Implementation of the Western Development and Rise of Central China strategies could increase the central and western regional economic proportions within the national economy. Economic development could increase the non-residential power consumption of the central and western regions. However, the spatial pattern of the Chinese economy has not changed, with less control on growth in the central and western regions than in the eastern region. The expansion of the West-to-East Power Transmission scale could bring more pressure on electricity production of the western region. Therefore, the central and western regions need to strengthen their technological and management capabilities in the field of energy conservation and consumption reduction.

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.

CRediT authorship contribution statement

Shan Jiang: Conceptualization, Writing - original draft, Writing - review & editing. **Yongnan Zhu:** Methodology, Formal analysis, Writing - review & editing. **Guohua He:** Formal analysis, Writing - review & editing. **Qingming Wang:** Formal analysis, Writing - review & editing. **Yajing Lu:** Visualization.

Acknowledgment

This research was supported by the International Science & Technology Cooperation Program of China (Grant No. 2018YFE0196000) and National Nature Science Fund of China (NSFC) (No. 51809282). The authors also thank the support from international Clean Energy Talent Program (iCET) from China Scholarship Council.

References

[1] Zhang C, Su B, Zhou K, Yang S. Analysis of electricity consumption in China (1990–2016) using index decomposition and decoupling approach. J Clean Prod 2019;209:224–35.
[2] World Energy Council. World Energy Issues Monitor 2018: Perspectives on the grand energy transition. the UK; 2018.
[3] Wu CF, Wang CM, Chang T, Yuan CC. The nexus of electricity and economic growth in major economies: the United States-India-China triangle. Energy 2019;188:116006.
[4] Zhang C, Zhou K, Yang S, Shao Z. On electricity consumption and economic growth in China. Renew Sustain Energy Rev 2017;76:353–68.
[5] NDRC, NEA. The electric power development planning "in 13th Five-Year" (2016-2020). the People's Republic of China; 2016.
[6] Deng C, Li K, Peng C, Han F. Analysis of technological progress and input prices on electricity consumption: evidence from China. J Clean Prod 2018;196:1390–406.
[7] Osman M, Gachino G, Hoque A. Electricity consumption and economic growth in the GCC countries: panel data analysis. Energy Pol 2016;98:318–27.
[8] Lin B, Wang Y. Inconsistency of economic growth and electricity consumption in China: a panel VAR approach. J Clean Prod 2019;229:144–56.
[9] Lin B, Liu C. Why is electricity consumption inconsistent with economic growth in China. Energy Pol 2016;(88):310–6.
[10] Liu D, Ruan L, Liu J, Huan H, Zhang G, Feng Y, et al. Electricity consumption and economic growth nexus in Beijing: a causal analysis of quarterly sectoral data. Renew Sustain Energy Rev 2018;(82):2498–503.
[11] Al-Bajjali SK, Shamayleh AY. Estimating the determinants of electricity consumption in Jordan. Energy 2018;147:1311–20.
[12] Fobi S, Deshpande V, Ondiek S, Modi V, Taneja J. A longitudinal study of electricity consumption growth in Kenya. Energy Pol 2018;(123):569–78.
[13] Karanfil F, Li Y. Electricity consumption and economic growth: exploring panel-specific differences. Energy Pol 2015;82:264–77.
[14] Zaman K, Khan MM, Ahmad M, Rustam R. Determinants of electricity consumption function in Pakistan: old wine in a new bottle. Energy Pol 2012;50:623–34.
[15] Bah MM, Azam M. Investigating the relationship between electricity consumption and economic growth: evidence from South Africa. Renew Sustain Energy Rev 2017;80:531–7.
[16] Adomian G. A review of the decomposition method in applied mathematics. J Math Anal Appl 1988;135(2):501–44.
[17] Van Megen B, Bürer M, Patel MK. Comparing electricity consumption trends: a multilevel index decomposition analysis of the Genevan and Swiss economy. Energy Econ 2019;83:1–25.
[18] Ang BW, Zhang FQ, Choi KH. Factorizing changes in energy and environmental indicators through decomposition. Energy 1998;23(6):489–95.
[19] Ang BW. Decomposition analysis for policymaking in energy: which is the

preferred method? Energy Pol 2004;32(9):1131–9.
[20] Lu Y, Peng C, Li D. Which activities contribute most to building energy consumption in China? A hybrid LMDI decomposition analysis from year 2007 to 2015. Energy Build 2017;165.
[21] Belloumi M, Achour H. Decomposing the influencing factors of energy consumption in Tunisian transportation sector using the LMDI method. Transport Pol 2016;52:64–71.
[22] Chong CH, Liu P, Ma L, Li Z, Ni W, Li X, et al. LMDI decomposition of energy consumption in Guangdong Province, China, based on an energy allocation diagram. Energy 2017;133:525–44.
[23] Chong CH, Tan WX, Ting ZJ, Liu P, Ma L, Li Z, et al. The driving factors of energy-related CO2 emission growth in Malaysia: the LMDI decomposition method based on energy allocation analysis. Renew Sustain Energy Rev 2019;115:109356.
[24] De Oliveira-De Jesus PM. Effect of generation capacity factors on carbon emission intensity of electricity of Latin America & the Caribbean, a temporal IDA-LMDI analysis. Renew Sustain Energy Rev 2019;101:516–26.
[25] Chen J, Wang P, Cui L, Huang S, Song M. Decomposition and decoupling analysis of CO2 emissions in OECD. Appl Energy 2018;231:937–50.
[26] Zhang S, Su X, Singh VP, Ayantobo OO, Xie J. Logarithmic Mean Divisia Index (LMDI) decomposition analysis of changes in agricultural water use: a case study of the middle reaches of the Heihe River basin, China. Agric Water Manag 2018;208:422–30.
[27] Yao L, Xu J, Zhang L, Pang Q, Zhang C. Temporal-spatial decomposition computing of regional water intensity for Yangtze River Economic Zone in China based on LMDI model. Sustainable Computing: Informatics and Systems 2019;21:119–28.
[28] Fang D, Hao P, Hao J. Study of the influence mechanism of China's electricity consumption based on multi-period ST-LMDI model. Energy 2019;170:730–43.
[29] Achão C, Schaeffer R. Decomposition analysis of the variations in residential electricity consumption in Brazil for the 1980–2007 period: measuring the activity, intensity and structure effects. Energy Pol 2009;37(12):5208–20.
[30] González PF, Moreno B. Analyzing driving forces behind changes in energy vulnerability of Spanish electricity generation through a Divisia index-based method. Energy Convers Manag 2015;92:459–68.
[31] Inglesi-Lotz R, Blignaut JN. South Africa's electricity consumption: a sectoral decomposition analysis. Appl Energy 2011;88(12):4779–84.
[32] Yang J, Cai W, Ma M, Li L, Liu C, Ma X, et al. Driving forces of China's CO2 emissions from energy consumption based on Kaya-LMDI methods. Sci Total Environ 2020;711:134569.
[33] Robalino-López A, García-Ramos JE, Golpe AA, Mena-Nieto A. CO2 emissions convergence among 10 South American countries. A study of Kaya components (1980–2010). Carbon Manag 2016;7(1–2):1–12.
[34] IPCC. Climate change 2007: mitigation of climate change. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, editors. Cambridge: Cambridge University Press; 2007.
[35] Cicea C, Marinescu C, Popa I, Dobrin C. Environmental efficiency of investments in renewable energy: comparative analysis at macroeconomic level. Renew Sustain Energy Rev 2014;30(2):555–64.
[36] Gudipudi R, Rybski D, Lüdeke MKB, Zhou B, Zhu L, Kropp JP. The efficient, the intensive, and the productive: insights from urban Kaya scaling. Appl Energy 2019;236:155–62.
[37] Ang BW, Liu FL, Chew EP. Perfect decomposition techniques in energy and environmental analysis. Energy Pol 2003;31(14):1561–6.
[38] Guo H, Hu J, Yu S, Sun H, Chen Y. Computing of the contribution rate of scientific and technological progress to economic growth in Chinese regions. Expert Syst Appl 2012;39(10):8514–21.
[39] Zhang C, Zhou K, Yang S, Shao Z. On electricity consumption and economic growth in China. Renew Sustain Energy Rev 2017;76:353–68.
[40] Yu M, Zhao X, Gao Y. Factor decomposition of China's industrial electricity consumption using structural decomposition analysis. Struct Change Econ Dynam 2019;51:67–76.
[41] Department of Energy Statistics, National Bureau of Statistics. People's Republic of China. China energy statistical Yearbook. China Statistics Press; 2019.
[42] Xia F, Lu X, Song F. The role of feed-in tariff in the curtailment of wind power in China. Energy Econ 2020;86:104661.
[43] Tang N, Zhang Y, Niu Y, Du X. Solar energy curtailment in China: status quo, reasons and solutions. Renew Sustain Energy Rev 2018;97:509–28.
[44] Jamil F, Ahmad E. The relationship between electricity consumption, electricity prices and GDP in Pakistan. Energy Pol 2010;38(10):6016–25.