Analysis of China's Electricity Price and Electricity Burden of Basic Industries under the Carbon Peak Target before 2030

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***Abstract*—The Chinese government is deepening reformation of electricity prices during the 14th Five Year Plan period and has set a carbon emission reduction target of reaching carbon peak before 2030. In this context, will the carbon emission target influence electricity pricing and will electricity price influence competitiveness of Chinese main industries are two questions needing to be answered. This paper compares China's electricity price level with the selected major countries in the world, and four typical industries are selected to evaluate their electricity burden respectively. Then, the correlation between residential electricity price and industrial electricity price and the influencing factors is analyzed, from the perspectives of scale, structure and technology. According to the model obtained by regression analysis, the electricity price level and corresponding residential and industrial electricity burden in 2025 and 2030 are forecasted.**

***Index Terms*—Electricity burden, industrial electricity price, regression analysis, residential electricity price.**

I. Introduction

DURING the 13th Five-Year Plan period, China has steadily promoted electric power system reform and basically formed a power market system dominated by medium and long-term trading. Electric power spot market trials have been carried out in eight regions, whilst construction of power ancillary service markets has been promoted in five regional power grids [1]. In China's current electricity pricing mechanism, retail price is differentiated according to user classification and voltage level [2]. In general, the retail price can be ranked from low to high, respectively for agricultural, residential, large industrial, and general industrial and commercial users. However, many empirical studies have shown there is still a widespread phenomenon called cross-subsidy in China's current electricity pricing mechanism [3], [4]. Cross-subsidy in electricity prices refers to a phenomenon that electricity prices cannot reflect power supply costs and user preferences under government intervention, so some consumers pay less than their power supply costs, and the difference is compensated by other consumers [5], [6]. Specifically, the industrial electricity subsidizes residential electricity, whilst high voltage electricity subsidizes low voltage electricity, resulting in unclear commodity attributes of electric power and social deadweight loss [7].

In fact, due to higher network loss and labor cost, the retail price of residential electricity should be higher than of industrial electricity [8]. Compared with developed countries and regions in the world, the overall electricity price in China is at a relatively low level, as well as the ratio of residential electricity price to industrial electricity price [9], [10].

At present, industrial electricity consumption still occupies the dominant position in China's power consumption structure, which is significantly different from a "low proportion of industrial electricity consumption" in developed countries. In 2019, industrial and residential electricity consumption in China accounted for 67.72% and 14.21% of the total social electricity consumption, respectively [11]. Considering the power demand elasticity for industrial users is higher than of residential users, further reducing industrial electricity price will lead to increase of electricity demand of industrial users. Consequently, carbon emission from power production side will rise significantly, which is contrary to the target of carbon emission peak and carbon neutrality in China [12], [13]. In China's pilot carbon trading markets, calculation of carbon emissions is divided into direct emissions from fossil fuel use and indirect emissions from electricity consumption. According to the historical experience of carbon trading markets in other countries, carbon tax policies can significantly affect the electricity burden of electricity-intensive industries (EIIs) [14]. On one hand, EIIs may use fossil fuels as raw materials to produce direct carbon emissions, and cost will be directly settled with EIIs; on the other hand, electricity consumption of EIIs will produce indirect carbon emissions, and corresponding increased power supply cost will eventually be transferred to the EIIs through the retail price.

The dilemma between electricity price reform and carbon emission reduction targets can be learned from experience of developed market economy countries or regions such as the European Union and the United States. They not only have a relatively stable and mature power market, but also have rich theoretical and practical experience in carbon cap and trade [15]. International carbon trading markets, such as the European Union Emission Trading System (EU-ETS) [16] and

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the Regional Greenhouse Gas Initiative (RGGI) [17], include power enterprises in the scope of carbon control and emission. Due to full marketisation of electricity of these developed countries, a carbon tax can be transmitted to the user side to a certain extent, and electricity price mechanism can reflect the carbon emission and clean energy consumption signals of their energy system. In addition, electricity price is also a signal of the economic, social and technological environment of a certain country. Consequently, manufacturing countries or third-world countries similar to China, such as India and Brazil, also have some reference value in terms of electricity price levels. Therefore, guiding suggestions for the future trend of electricity prices in China can be obtained by studying the electricity price mechanism of major countries of the world [18].

In this context, this paper studies the future trend of residential electricity price and industrial electricity prices in China. The major contributions are summarized as follows:

- Current electricity price mechanism in China is compared with the international electricity price level.
- Electricity burden of residential users and industrial users are evaluated based on purchasing power parity and the law of one price, respectively. Among them, the steel industry, cement industry, plastic industry and electrolytic aluminum industry are selected as four typical EIIs in China.
- Pearson correlation analysis is adopted to analyze the correlation between electricity price in major countries of the world and various influencing factors.
- Based on a linear regression analysis, forecast values of residential and industrial electricity prices in China in 2025 and 2030 are obtained, as well as electricity burden of EIIs at that time.
- Electricity price forecasts of Vietnam and Laos, which are third world countries in Asia with China, are also given.

The remainder of this paper is organized as follows: Section II introduces current electricity price mechanism in China and makes a comparison with major countries in the world. Section III assesses electricity burden of residential and industrial users, respectively. In Section IV, correlation analysis is presented and electricity price in China in 2025 and 2030 is predicted. Conclusions are given in Section V.

II. China's Current Electricity Price and International Level Comparison

In this section, electricity retail price of residential users and industrial users is taken as the main research object to analyze the current electricity pricing mechanism in China. Subsequently, electricity price in China is compared with the international major countries.

A. Current Electricity Price Mechanism in China

Current residential and industrial electricity prices in China mentioned in Section II are, respectively, from the latest data published on the official websites of State Grid of all provinces and municipalities until August 2021.

1) Residential Electricity Price in China

To encourage residential users to conserve electricity, and ensure fairness to low-income households, China is implementing a pricing policy called increasing-block electricity tariffs or step tariffs for residential users, in which electricity consumption is divided into three blocks [19]. The first block covers about 80% of residential electricity consumption and the corresponding electricity price should maintain a low level to ensure people's well-being. The second block covers about 95% of residential electricity consumption and the corresponding price should be increased by no less than 0.05 CNY/kWh compared to the first block. The third block is expected to encourage energy conservation and emission reduction, and it is priced 0.3 CNY/kWh higher than the first block.

Taking the first block's tariff as an example, Table I shows residential electricity price level of each province and municipality in China through the color shade of the map.

TABLE I
Residential Electricity Prices by Province and Municipality in China

Province/municipality	Residential electricity price (CNY/kWh)
Anhui	0.5653
Beijing	0.4883
Fujian	0.4983
Gansu	0.51
Guangdong	0.6258
Guangxi	0.5283
Guizhou	0.4556
Hainan	0.6083
Hebei	0.52
Henan	0.56
Heilongjiang	0.51
Hubei	0.558
Hunan	0.588
Jilin	0.525
Jiangsu	0.5283
Jiangxi	0.6
Liaoning	0.5
Nei Mongol	0.5
Ningxia	0.6008
Qinghai	0.3771
Shandong	0.5469
Shanxi	0.477
Shanxi	0.4983
Shanghai	0.617
Sichuan	0.5224
Taiwan	0.68
Tianjin	0.49
Xizang	0.49
Xinjiang	0.24
Yunnan	0.45
Zhejiang	0.538
Chongqing	0.52

The first block's tariff for residential users varies from 0.24 CNY/kWh (Xinjiang) to 0.68 CNY/kWh (Taiwan). On the whole, residential electricity prices in southeastern China are generally higher than those in western and northern China.

2) Industrial and Commercial Electricity Price in China

In China, a two-part tariff policy is fully implemented for large industrial electricity consumption, as well as for relatively large scale general industrial and commercial electricity consumption in some areas. This policy divides large-scale industrial electricity prices into three parts, namely the basic electricity price, kilowatt-hour-based electricity price, and power factor clause. Considering electricity consumption and load rate respectively, the two-part tariff policy can not only promote rational and efficient allocation of power resources, but also reduce power supply cost [20].

Table II shows charge rate of electricity consumption at 1–10 kV voltage level for large industrial users, whilst Table III displays charge rate for general industrial and commercial users less than 1 kV voltage grade.

TABLE II
LARGE INDUSTRIAL ELECTRICITY PRICES BY PROVINCE IN CHINA

Province/municipality	Large industrial electricity price (CNY/kWh)
Anhui	0.6198
Beijing	0.677
Fujian	0.5559
Gansu	0.45
Guangdong	0.5346
Guangxi	0.6261
Guizhou	0.5417
Hainan	0.6302
Hebei	0.5394
Henan	0.6105
Heilongjiang	0.5858
Hubei	0.6117
Hunan	0.6437
Jilin	0.5866
Jiangsu	0.6068
Jiangxi	0.6193
Liaoning	0.5286
Nei Mongol	0.647
Ningxia	0.469
Qinghai	0.3582
Shandong	0.6086
Shanxi	0.548
Shanxi	0.5502
Shanghai	0.671
Sichuan	0.6242
Taiwan	0.57
Tianjin	0.679
Xizang	/
Xinjiang	0.363
Yunnan	0.532
Zhejiang	0.6217
Chongqing	0.6057

It can be seen that, charge rate for large industrial users in Table II varies from 0. 3582 CNY/kWh (Qinghai) to 0.679 CNY/kWh (Tianjin), and retail price for general industrial and commercial users ranges from 0.4101 CNY/kWh (Yunnan) to 0.85 CNY/kWh (Taiwan). Generally speaking, overall electricity price level of large industry and general industry and commerce in eastern China is higher than in western China.

Due to lack of market-based pricing and large-scale cross-subsidies, residential electricity price in China is lower than industrial electricity price, which is mainly reflected in the electricity transmission and distribution price. The cross-subsidy electricity pricing strategy is not a unique phenomenon in China. It also exists in development history of power industry in other countries. In the early stage of China's development, cross-subsidy electricity pricing did play an important role in promoting economic development of rural areas, encouraging energy conservation of industrial and commercial users, and reducing electricity burden of residential and agricultural users. However, with continuous progress of economic development and power market reform, net loss of social welfare caused by electricity price signal distortion has been more harmful than good.

TABLE III
GENERAL INDUSTRIAL AND COMMERCIAL ELECTRICITY PRICES BY PROVINCE IN CHINA

Province/municipality	General industrial and commercial electricity price (CNY/kWh)
Anhui	0.6198
Beijing	0.75
Fujian	0.5959
Gansu	0.6043
Guangdong	0.6218
Guangxi	0.662
Guizhou	0.5787
Hainan	0.6957
Hebei	0.5644
Henan	0.6125
Heilongjiang	0.7165
Hubei	0.6907
Hunan	0.7003
Jilin	0.7222
Jiangsu	0.6664
Jiangxi	0.6311
Liaoning	0.6379
Nei Mongol	0.647
Ningxia	0.4883
Qinghai	0.4303
Shandong	0.6226
Shanxi	0.5309
Shanxi	0.6237
Shanghai	0.724
Sichuan	0.6485
Taiwan	0.85
Tianjin	0.6768
Xizang	0.658
Xinjiang	0.4578
Yunnan	0.4101
Zhejiang	0.6964
Chongqing	0.6578

B. Comparison with International Electricity Price

There are significant differences in electricity pricing mechanisms in different countries. On one hand, electricity pricing mechanisms are affected by economic, political, environmental and other factors. On the other hand, mechanisms change with progress of electricity market reforms. To illustrate complexity and differences of the electricity price mechanisms, USA, UK and Japan are selected to briefly introduce their electricity price mechanisms.

Electricity prices in USA are rather complex for the vast territory and independence between states [21]. Electricity pricing mechanism can be divided into three categories: first category is areas where the power sector is dominated by vertically integrated public utilities, second category is areas where only the wholesale market introduces liberalization, and third one is areas where both the wholesale market and retail market are fully liberalized. At present, the electricity market in the UK is fully liberalized and implements a market mechanism known as the British Electricity Trading and Transmission Arrangements (BETTA) [22]. Under the BETTA, electricity wholesale price and profit of electricity suppliers are allocated by market competition, whilst transmission and distribution prices are determined by regulatory agencies. Nowadays, the electricity retail market in Japan has been fully liberalized [23]. Retail price is restricted to be lower than administered price of the General Electricity Utilities (GEU), whilst transmission and distribution prices are determined by incremental costs.

This section mainly compares residential and industrial electricity price levels between China and other countries. A total of 19 typical countries in the world, including China, are selected, and selection criteria comprise the following aspects. The first category is developing countries with strong comprehensive strength and have experienced electricity market reforms and gained successful experience before China, including Argentina, Brazil and Turkey. The second category is developed countries with a high degree of electricity market liberalization, and typical representatives are USA, UK, German and Italy. Such countries have sufficient experience in the reconstruction, privatization, regulation, and competition of electricity market reforms. The third category is countries with a relatively high proportion of renewable energy in their energy structures, including France, Colombia and Brazil. This category of countries has important reference significance for China, which requires continuous increase in the proportion of renewable energy power generation. The fourth category is manufacturing countries similar to China, including India and Japan. These countries consume considerable electricity in energy-intensive industries and may compete with China for certain industrial products. The fifth category is third world countries with relatively backward economic and power market development, such as Vietnam and Laos. These countries reflect early characteristics of the power market and are also classified as reference countries to ensure integrity of sample selection. It should be noted that some countries may have above-mentioned multiple characteristics, such as Brazil.

The average residential electricity price and industrial electricity price of these typical countries are shown in Figs. 1 and 2, respectively [24], [25].

Residential electricity price in China ranks at the lower

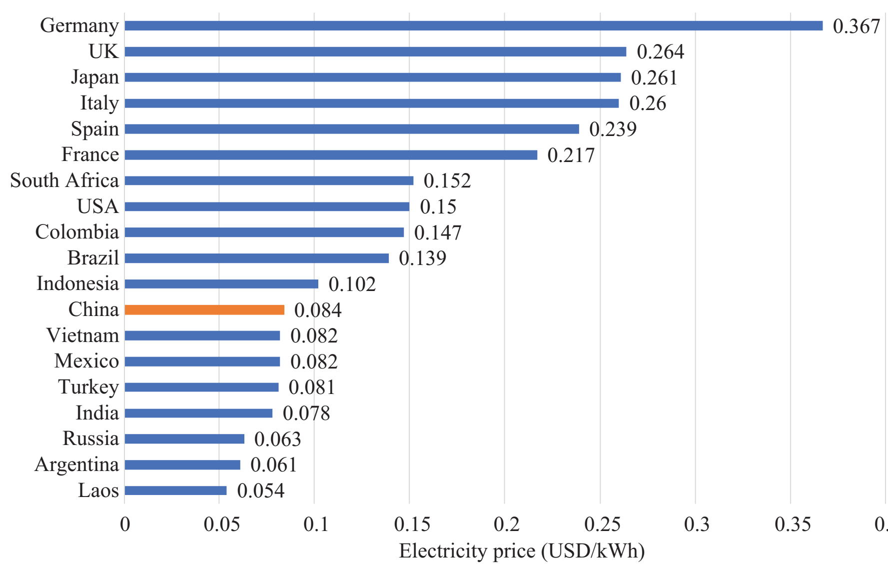


Fig. 1. Residential electricity prices in typical countries.

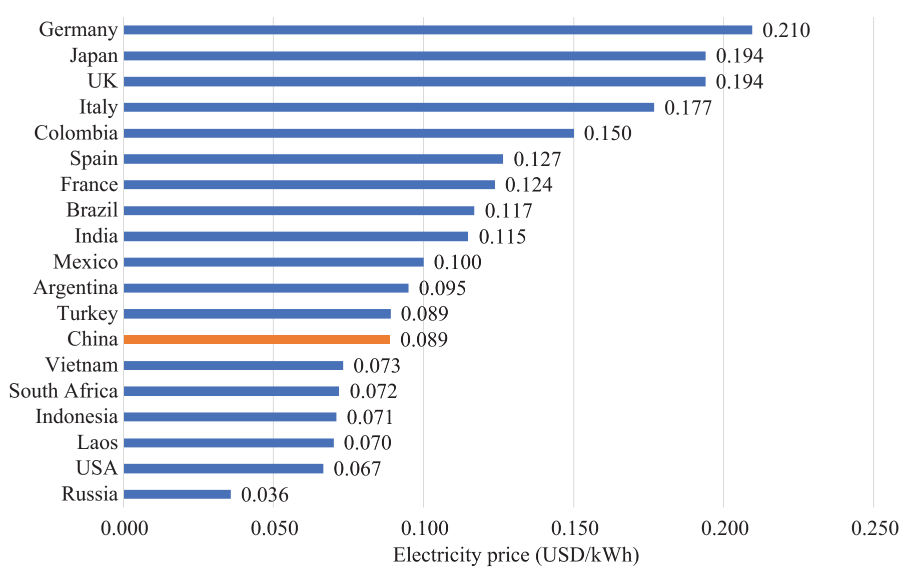


Fig. 2. Industrial electricity prices in typical countries.

middle level of these typical countries. In terms of industrial electricity price, China is lower than developed countries with a high proportion of clean energy, but on a par with manufacturing countries such as Turkey and Indonesia.

III. Assessment of Electricity Burden of Households and Typical Industries

A. Assessment of Households' Electricity Burden

Since the economic level varies among different countries, electricity price based on exchange rate cannot accurately reflect electricity burden of households. Therefore, residential electricity price of each country is converted according to their price level indices, and the electricity price can then be analyzed under purchasing power parity [26].

The relationship between electricity price based on exchange rate and the electricity price based on purchasing power parity is shown in (1):

$$p_{\mathrm{ppp}} = p_{\mathrm{er}}/PLI \tag{1}$$

where p_{er} and p_{ppp} denote electricity price based on exchange rate and purchasing power parity, respectively; *PLI* refers to price level indices and specific values are given in [27]. Specifically, price level indices are ratios of purchasing power parities to market exchange rates, which can provide a measure of differences in general price levels of countries.

As shown in Fig. 3, after eliminating difference of purchasing power of typical countries, residential electricity price in China is the lowest, about 0.138 international dollar/kWh. This price is not only lower than developed countries, but also lower than other third world countries.

B. Assessment of Electricity Burden of Typical Industries

According to the "China Energy Statistical Yearbook 2020" released by the Chinese government, industrial electricity consumption in China accounts for more than 76% of total electricity consumption of the society [11]. Furthermore, as the largest manufacturing country in the world, China's manufacturing electricity consumption occupies more than 67% of total industrial electricity consumption. Due to large electricity consumption in manufacturing industries, electricity price level has a significant impact on their electricity burden. Meanwhile, the law of one price reveals the basic link between domestic commodity prices and exchange rates and is applicable to energy-intensive and trade-intensive industrial products.

In view of the above, through research on the status quo of China's manufacturing industry, this paper selects four electricity-intensive and high-trade-intensity industries as representatives of China's manufacturing industries, namely the steel industry, cement industry, plastic industry and electrolytic aluminum industry.

This section introduces the electricity burden of four selected industries, which is defined as the proportion of electricity costs relative to their total production costs. In addition, introduction in this section serves as the basis for analysis of industrial electricity burden changes under forecast electricity prices in Section IV-B.

1) Steel Industry

Nowadays, most global steel production capacity is concentrated in China, India, Japan and the United States. As shown in Fig. 4, in 2019, total steel production in China was 996 million tons, accounting for 53.31% of global steel production, ranking first in the world [28].

Steel production process mainly includes integrated route (blast furnace and basic oxygen furnace) and recycling route (electric arc furnace). Electricity cost accounts for about 1.06% of total production cost of integrated route. For recycling route, electricity cost takes up 7.87% because 50% of its energy consumption comes from electricity [29].

2) Cement Industry

Cement industry is a traditional industry with high energy consumption, high pollution and resources. As the largest cement producer in the world, China's output in 2020 reached

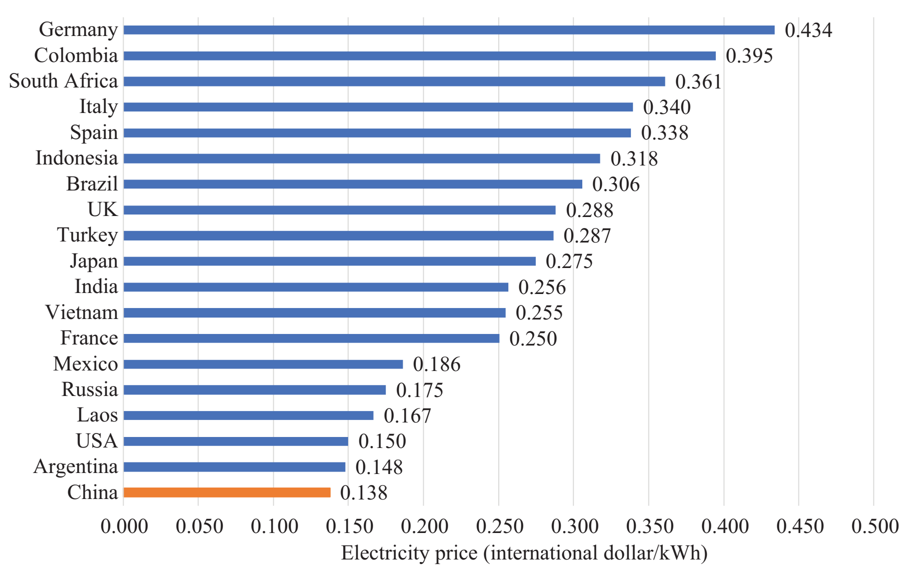


Fig. 3. Residential electricity prices based on purchasing power parity in typical countries.

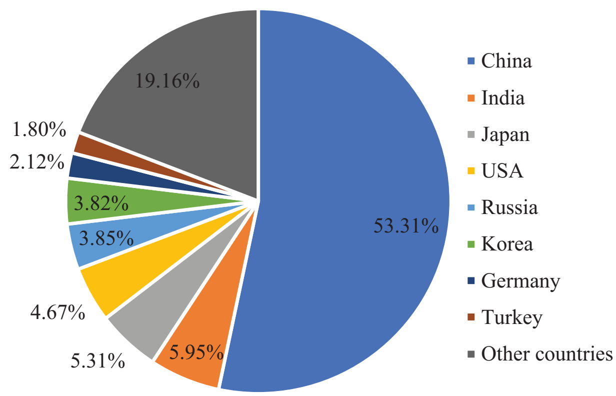


Fig. 4. Share of global steel production in 2019.

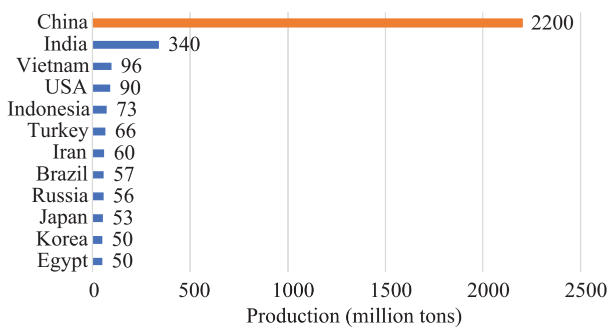


Fig. 5. Output of the global major cement producers in 2020.

2.2 billion tons, accounting for 53.66% of the global total output, as shown in Fig. 5 [30].

In China, raw materials, fuel power, depreciation, labor and other manufacturing costs account for 27%, 47%, 12% and 14% of total production cost of cement [31]. According to a research report released by the JRC, electricity costs take up more than half of energy cost of cement production in China, accounting for about 21% of total production cost [32].

3) Plastic Industry

In 2019, the world produced a total of 368 million tons of plastic. As the largest plastic producer in the world, plastic production of China occupies 31% of global market share, as shown in Fig. 6 [33].

Plastic products can be divided into polypropylene (PP),

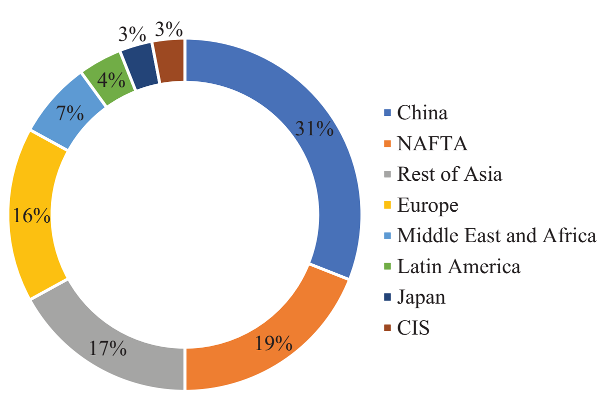


Fig. 6. Output of the global major plastic producers in 2020.

polyethylene (PE) and polyvinyl chloride (PVC) by category. PVC industry is electricity-intensive in China and is mainly produced by calcium carbide route and ethylene route around the world. Limited by resource conditions of rich coal, lean oil and poor gas, PVC is mainly produced by calcium carbide route in China, which consumes large amounts of electricity both in the production process itself and in preparation of calcium carbide with coke [34]. As shown in Fig. 7, electricity consumption for production of one ton of PVC is about 5,450 to 5,650 kWh, which accounts for about 52% of total cost [35].

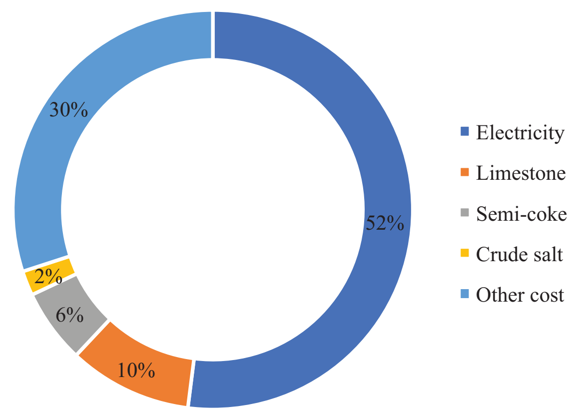


Fig. 7. Cost structure of PVC produced by calcium carbide route.

4) Electrolytic Aluminum Industry

As shown in Fig. 8, China is the largest aluminum producer in the world, with a total production capacity of 37.337 million tons in 2020 [36].

Production cost of electrolytic aluminum mainly includes energy, raw materials, labor and other expenses. In China, electricity cost is the most important cost of electrolytic aluminum production; production of one ton of electrolytic aluminum consumes about 13500 kWh electricity, accounting for about 34% of total cost of electrolytic aluminum production [37].

IV. Correlation Analysis of Residential and Industrial Electricity Price

A. Screening of Influencing Factors

To explore development law of electricity price, a total of 19 countries mentioned in Section I are selected as research objects, starting from the five influencing factors of scale effect (per capita GDP, per capita power generation), structural effect (low-carbon electricity), and technology effect (energy intensity, final to primary energy ratio).

Original data of each country are shown in Table IV and data sources include the OECD data [27], Our World in Data [38], World Bank open data [39], Knoema [40], IEA data [41], Global petrol prices [25], and IMF [42].

The definitions of five influencing factors in Table IV are as follows:

Per capita GDP is a financial metric that breaks down a country's economic output per person and is calculated by dividing GDP of a nation by its population. Per capita power generation is an energy-related metric that breaks down a

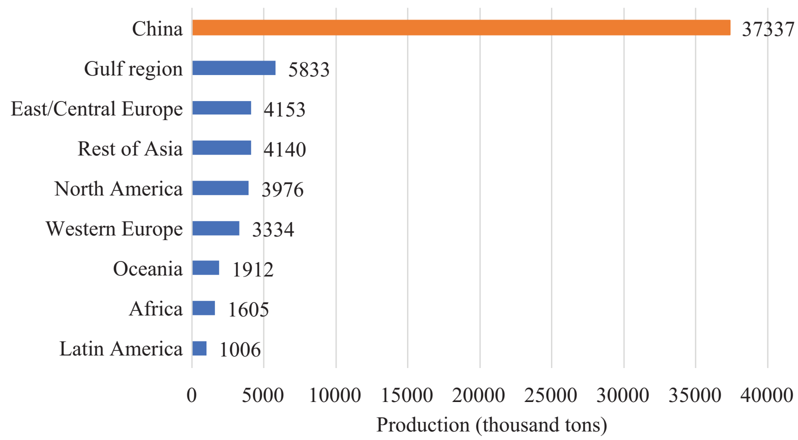


Fig. 8. Output of global major electrolytic aluminum producers in 2020.

TABLE IV
RAW DATA FOR THE 19 COUNTRIES STUDIED

Country	Residential electricity price (USD/kWh)	Industrial electricity price (USD/kWh)	Per capita GDP (USD)	Per capita power generation (kWh)	Final to primary energy ratio	Energy intensity (kWh/USD)	Low-carbon electricity
USA	0.150	0.067	63416	12309.57	67.69%	1.49	40%
Germany	0.367	0.210	45733	6834.94	69.26%	0.96	56%
France	0.217	0.124	39907	7888.21	62.07%	1.04	91%
Spain	0.239	0.127	27132	5611.28	73.35%	1.06	66%
Italy	0.260	0.177	31288	4588.83	76.23%	0.84	43%
UK	0.264	0.194	40406	4628.48	68.10%	0.86	59%
Brazil	0.139	0.117	6783	2884.43	79.29%	1.18	86%
Argentina	0.063	0.095	8555	3003.33	71.99%	1.21	32%
Japan	0.261	0.194	40146	7474.44	65.33%	1.13	31%
India	0.078	0.115	1965	998.49	66.05%	1.10	25%
Mexico	0.082	0.100	8421	2384.09	63.70%	1.15	25%
Colombia	0.147	0.150	5336	1614.35	69.54%	0.82	69%
South Africa	0.152	0.072	5067	3843.45	44.89%	2.27	11%
Turkey	0.081	0.089	8548	3550.85	73.81%	1.06	43%
Indonesia	0.102	0.071	3922	1048.99	75.27%	0.76	17%
Russia	0.063	0.036	10037	6974.97	63.54%	2.41	41%
Vietnam	0.082	0.073	3499	2812.32	81.91%	1.50	31%
China	0.084	0.089	10484	5346.21	61.65%	2.09	34%
Laos	0.054	0.07	2626	4708.86	67.42%	1.85	56%

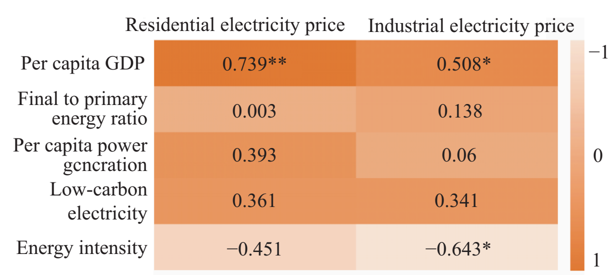
country's power generation per person and is calculated by dividing total power generation of a nation by its population. Final primary energy ratio is the percentage of primary energy which reaches final end-user and is obtained by dividing end-use final energy over primary energy. Energy intensity is measured as primary energy consumption per unit of GDP and is measured in kilowatt-hours per USD in this paper. Low-carbon electricity is sum of electricity from nuclear and renewable sources (including solar, wind, hydropower, biomass and waste, geothermal and wave and tidal).

It should be pointed out that each column of data in Table IV is standardized when conducting Pearson correlation analysis and subsequent linear regression analysis.

Pearson correlation analysis is adopted to study the relationship between residential and industrial electricity prices and the above influencing factors, and results are shown in Fig. 9.

1) Related Factors of Residential Electricity Price

According to Fig. 9, residential electricity price is only significantly correlated with per capita GDP. Correlation value between residential electricity price and per capita GDP is 0.739, showing a significance level of 0.01, which indicates there is a significant positive correlation between residential electricity price and per capita GDP.



Note: ** and * indicate significance at the level of 1% and 5%, respectively.

Fig. 9. Pearson correlation analysis results.

2) Related Factors of Industrial Electricity Price

According to Fig. 9, industrial electricity price is significantly correlated with per capita GDP and energy intensity. Correlation value between industrial electricity price and per capita GDP is 0.508, and shows a significance level of 0.05, indicating there is a significant positive correlation between industrial electricity price and per capita GDP. Correlation value between industrial electricity price and energy intensity is −0.643 and shows a significance level of 0.01, indicating there is a significant negative correlation between industrial electricity price and energy intensity.

B. Regression Analysis of Residential and Industrial Electricity Price

Based on screening results of influencing factors in Section IV, this section conducts a regression analysis of residential electricity price and industrial electricity price, respectively.

1) Linear Regression Analysis of Residential Electricity Price

Per capita GDP and residential electricity price are taken as the independent variable and dependent variable, respectively. After standardising parameters in Table IV, linear regression analysis is carried out using SPSS, and results are obtained as shown in Table V.

The relationship between residential electricity price and per capita GDP obtained from Table V is shown in (2):

$$p_r = 0.117 + 0.702 \times GDP_{\mathrm{pc}} \tag{2}$$

where p_r represents residential electricity price, and GDP_{pc} refers to per capita GDP.

In Table V, R square equals 0.546, which means that variable per capita GDP can explain 54.6% of the variation of residential electricity price. The model also passes the F-test ($F = 20.442$, $P = 0.000 < 0.01$), which indicates that per capita GDP will definitely have an impact on residential electricity prices. The regression coefficient of per capita GDP is 0.702 ($t = 4.521$, $P = 0.000 < 0.01$), which means that per capita GDP will have significant positive impact on residential electricity prices.

2) Linear Regression Analysis of Industrial Electricity Price

Per capita GDP and energy intensity are taken as independent variables and industrial electricity price is the dependent variable. Results of linear regression analysis are shown in Table VI.

The relationship between industrial electricity price, per capita GDP and energy intensity obtained from Table VI is shown in (3):

$$p_i = 0.524 + 0.344 \times GDP_{\mathrm{pc}} - 0.517 \times EI \tag{3}$$

where p_i represents industrial electricity price, and EI refers to energy intensity.

In Table VI, R square equals 0.536, which means that per capita GDP and energy intensity can explain 53.6% of the changes in industrial electricity price. The model passed the F-test ($F = 9.258$, $P = 0.002 < 0.05$), indicating that at least one of per capita GDP and energy intensity will have an impact on industrial electricity price. The multicollinearity test shows that all VIF values in the model are less than 5, which means there is no collinearity problem. In addition, value of D-W is near 2, indicating the model does not have autocorrelation and there is no correlation between sample data.

In terms of regression coefficient, value of energy intensity was −0.517 ($t = -3.099$, $p = 0.007 < 0.01$), while value of per capita GDP is 0.344 ($t = 2.063$, $p = 0.056 > 0.05$). Therefore, energy intensity has significant negative impact on industrial electricity price, while per capita GDP has no impact on industrial electricity price.

After excluding per capita GDP, regression analysis is conducted, and results are shown in Table VII.

The model obtained according to Table VII is shown in (4):

$$p_i = 0.650 - 0.608 \times EI \tag{4}$$

TABLE V
RESULTS OF LINEAR REGRESSION ANALYSIS BETWEEN RESIDENTIAL ELECTRICITY PRICE AND PER CAPITA GDP

Parameter	Unstandardized coefficient		Standardized coefficient	t	p	VIF	R square	Adjusted R square	F
	B	Standard error	Beta						
Constant	0.117	0.063	–	1.846	0.082	–	0.546	0.519	F(1, 17) = 20.442, p = 0.000
Per capita GDP	0.702	0.155	0.739	4.521	0.000**	1			
D-W: 2.056									

TABLE VI
LINEAR REGRESSION ANALYSIS RESULTS OF INDUSTRIAL ELECTRICITY PRICE, ENERGY INTENSITY AND PER CAPITA GDP

Parameter	Unstandardized coefficient		Standardized coefficient	t	p	VIF	R square	Adjusted R square	F
	B	Standard error	Beta						
Constant	0.524	0.094	–	5.588	0.000**	–	0.536	0.478	F(2, 16) = 9.258, p = 0.002
Per capita GDP	0.344	0.167	0.364	2.063	0.056	1.075			
Energy intensity	−0.517	0.167	−0.547	−3.099	0.007**	1.075			
D-W: 2.002									

TABLE VII
LINEAR REGRESSION ANALYSIS RESULTS OF INDUSTRIAL ELECTRICITY PRICE AND ENERGY INTENSITY

Parameter	Unstandardized coefficient		Standardized coefficient	t	p	VIF	R square	Adjusted R square	F
	B	Standard error	Beta						
Constant	0.65	0.078	–	8.355	0.000**	–	0.413	0.379	F(1, 17) = 11.968, p = 0.003
Energy intensity	−0.608	0.176	−0.643	−3.460	0.003**	1			
D-W: 2.081									

In Table VII, R square equals 0.413, which means that variable energy intensity can explain 41.3% of variation of industrial electricity price. The model also passes the F-test ($F = 11.968$, $p = 0.003 < 0.05$), which indicates that energy intensity will definitely have an impact on industrial electricity prices. Regression coefficient of energy intensity is -0.608 ($t = -3.460$, $p = 0.003 < 0.01$), which means that energy intensity will have significant negative impact on industrial electricity prices.

3) Electricity Burden Forecasting for Residential and Industrial Users

Based on potential of GDP growth capacity in China, it is estimated China will maintain an average annual growth rate of 4.7% to 4.9% in the next 15 years to achieve the main targets for economic and social development in the 14th Five-Year Plan period and long-term targets for 2035 [43]. According to trend analysis of the seventh national census, population of China is expected to peak between 2025 and 2030 [44]. Therefore, by 2025 and 2030, per capita GDP of China will reach USD 14,359.46 and USD 18,152.92, respectively. These two values are then standardized based on maximum and minimum values of per capita GDP in Table IV. According to the regression model of residential electricity price, China's residential electricity price in 2025 and 2030 will reach 0.135USD/kWh and 0.149USD/kWh respectively, increasing by 60.64% and 76.79% compared with 2020.

Achieving China's target of "carbon emission peak before 2030 and carbon neutrality before 2060" requires not only increasing use of renewable energy, but also reducing energy intensity. According to research in [45], to achieve China's nationally determined contribution (NDC) target and carbon reduction commitments by 2030, energy intensity should be reduced by no less than 14% during the 14th and 15th Five-Year Plans. In 2020, China's GDP was 10.15986 trillion CNY, and energy consumption was 4.97714 million tons of standard coal, equivalent to 0.374 kWh/CNY per unit of GDP, or 1.832 kWh/USD at purchasing power parity in 2020. If average annual decline rate of energy intensity is 3%, China's energy intensity in 2025 and 2030 will be 1.573 kWh/USD and 1.351 kWh/USD, respectively. These two values are then standardized based on the maximum and minimum values of energy intensity in Table IV. According to the regression model of industrial electricity price, in 2025 and 2030, China's industrial electricity price will reach 0.097USD/kWh and 0.111USD/kWh respectively, increasing by 8.62% and 24.58% compared with 2020.

Based on assessment results of electricity burden in Section III, changes in electricity burden of steel, cement, plastics and electrolytic aluminum industries are shown in Table VIII.

TABLE VIII
ELECTRICITY BURDEN OF TYPICAL INDUSTRIES UNDER PREDICTED ELECTRICITY PRICE

Typical industry	2025	2030
Steel industry (recycling route)	0.69%	1.96%
Cement industry	1.81%	5.16%
Plastic industry (PVC by calcium carbide route)	4.48%	12.78%
Electrolytic aluminum industry	2.93%	8.36%

Referring to the judgment standard on impact of carbon prices on industry competitiveness of the European Union, this paper judges the electricity burden of industries whose electricity cost exceeds 5% of total production cost is heavy. Thus, by 2030, change of industrial electricity price will have significant impact on China's cement industry, plastic industry (PVC by calcium carbide route), and electrolytic aluminum industry, resulting in a heavy electricity burden.

In view of the fact that Southeast Asian countries are important partners of China's "One Belt, One Road" initiative, this paper attempts to provide some useful suggestions for their future electricity prices, and takes Laos and Vietnam, which border China, as examples [46], [47]. According to data of the World Bank, average per capita GDP growth rates of Vietnam and Laos in the recent five years are 5.99% and 4.30%, respectively [48], [49]. In terms of energy intensity, according to Lao PDR energy outlook 2019, energy intensity of Laos is expected to maintain a downward trend of 1.4% in the next 20 years [50]. Energy intensity of Vietnam has remained stable in recent years according to data released by IEA. Combined with regression analysis model of electricity price, residential electricity price in Vietnam is expected to reach 0.100 USD/kWh and 0.106 USD/kWh in 2025 and 2030, respectively. As for Laos, residential electricity price will reach 0.095 USD/kWh and 0.098 USD/kWh, respectively, in 2025 and 2030, and industrial electricity price will reach 0.087 USD/kWh and 0.095 USD/kWh, respectively.

V. CONCLUSION

Current electricity price mechanism in China has the issue of cross-subsidies, and a carbon trading mechanism is still not completely launched, which causes the electricity price cannot fully reflect power supply cost, user preference and environmental cost. To explore the trend of China's electricity price under the dual objectives of electricity reform and carbon emission reduction, this paper selects some major countries in the world as benchmarks. First, residential price and industrial price in China's current electricity price mechanism are evaluated. Second, correlation between electricity price and various influencing factors is analyzed by Pearson correlation analysis. Subsequently, residential electricity price and industrial electricity price model are obtained by linear regression analysis. Results indicate that per capita GDP will definitely have an impact on residential electricity prices, whilst energy intensity will definitely have an impact on industrial electricity prices. Based on regression model, residential and industrial electricity prices of China in 2025 and 2030 are predicted, respectively. Results show the predicted industrial electricity price in 2030 will have a significant impact on China's cement industry, plastic industry (PVC by calcium carbide route), and electrolytic aluminum industry, resulting in increase of electricity burden by 5.16%, 12.78% and 8.36%, respectively. This paper also presents a number of suggestions on electricity price development in Southeast Asian countries, which are important partners of China's "One Belt, One Road" initiative. Limited to the length of this paper, only Laos and Vietnam are researched.

Certainly, in addition to electricity price level, political and environmental factors, profitability and demand price elasticity of different electricity consumers also have an impact on their electricity burden, which will be studied in our future work.

In general, future pricing of residential electricity prices and industrial electricity prices in China should conform to development of China's economic and social environment. Reasonable electricity price adjustment and industry subsidy policies are also needed to alleviate impact of electricity price adjustment on industries with high-cost intensity.

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