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What is Currently Driving the Growth of China's Household Electricity Consumption? a Clustering and Decomposition Analysis

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Abstract: The rapid growth of household electricity consumption is threatening the sustainable development of China's economy and environment because of its impacts on the operation efficiency of the electric power system. To recognize the driving factors of the consumption growth and offer policy implications, based on the consumption-related data of 2015 and 2016, this research used the rank sum ratio (RSR) method to divide China's 30 provinces into 5 groups and a logarithmic mean Divisia index (LMDI) algorithm to decompose the composition growth of each group into the quantitative contribution of each driving factor. The following conclusions were drawn from the empirical analysis. (1) The Yangtze basin is the most vigorous region of consumption growth and should be principally monitored. (2) Climate conditions have a remarkable impact on consumption growth and should be a key consideration when making differentiated household electricity policies. (3) The rebound effect has already appeared in a few of the most developed regions. Electricity price is an effective measure in dealing with this effect. (4) The improvement of the income level is the most important driving factor for consumption growth. (5) For provinces with high growth vitality, the change in the burden level of electricity expenditure prompts consumption growth. However, for provinces with low growth vitality, the situations are opposite. (6) The impacts of electricity price and population on consumption growth are negligible.

Keywords: household electricity consumption; driving factor; RSR clustering; LMDI decomposition; China

1. Introduction

The rapid growth of household electricity consumption is threatening the sustainable development of China's economy and environment. Thus, this study aims to identify the driving factors of consumption growth and to offer policy implications in guiding the development of China's electric power system.

At present, China has the world's largest electric power system. In 2018, China's installed power generation capacity was 1.90 billion kW and generated 7.11 trillion kWh, approximately accounting for 27.4% and 25.4% of the world's total, respectively [1]. Electricity generated by fossil energies has always accounted for the single largest part of the country's total, given that China has abundant coal resources and has been building a considerable amount of coal-fired power plants [2]. Since the foundation of the People's Republic, China's share of electricity generated by fossil energies has never been less than 70% [1]. At present, thermal power plants consume 37.3% of China's fossil energies and emit 40.9%, 32.8%, 36.7%, 16.3%, and 31.4% of CO_2, SO_2, NO_x, industrial dust, and waste gas of the country's total, respectively [3–5]. These plants are the largest fossil energy consumers and pollution sources of China.

Since the second half of 2014, China has transformed the previous high-speed extensive development mode into a "new normal," characterized by lowering economic growth, upgrading its industrial structures, and converting the motivating force of economic growth from key elements and investment into innovation to realize the sustainable development of economy and environment [6]. In this new normal development mode, households have become a major factor in raising China's electricity consumption with the slowdown of the growth of the industrial electricity demand. In the past four years, although the households' consumption share did not exceed 15%, they contributed 30% of China's electricity consumption growth [7].

The rapid growth of household electricity significantly impacts China's sustainable development. First, this phenomenon lowers the efficiency of electricity generation. Compared with the industry, the electric load of the household has a larger peak–valley rate ((peak load–valley load)/valley load). Generally, electricity cannot be stored in a large scale. Thus, additional reserve capacity is required to maintain a balanced supply and demand at any time with the share increase in household electricity consumption. In China, this role is generally played by thermal power plants. To satisfy the requirements of the dispatch department of the grid company, these units should frequently start and stop or remain in the state of spinning reserve for a long time. Evidently, this approach reduces the electricity generation efficiency of thermal power plants [8]. Second, it increases transmission loss. Transmission loss is inevitable given that the transmission line is not superconductive. On average, 6.7% of electricity is lost during transmission in China [9]. As China's household electricity supply adopts low voltage with long transmission length, and its line quality is poor, this part of line loss rate generally exceeds 15%, which is much higher than the average. The rapid increase in household electricity consumption inevitably raises the loss rate of electricity transmission. Third, it adds the operating cost of industrial and commercial enterprises. China has implemented a cross-subsidy system for electricity prices to manifest the superiority of the social system since the People's Republic was founded in 1949. That is, it sets a low electricity price for households and high electricity prices for industrial and commercial enterprises [10]. The cost of industrial and commercial enterprises in the cross-subsidy system continues to increase with the sheer increase in household electricity consumption. This research aims to identify the driving factors of China's household electricity consumption growth and offer policy implications to mitigate these impacts.

This research is structured as follows. Following the introduction, Section 2 reviews the literature related to this research. Section 3 introduces the methodology and data source. Section 4 presents the empirical results. Section 5 discusses these results. Finally, Section 6 summarizes the key findings and provides the policy implications of the research.

2. Literature Review

2.1. Driving Factor Selection

In theory, population is the basis of household electricity consumption. Evidently, if the people in a region disappear, then the household's electricity consumption will not also exist. Furthermore, some studies have recently confirmed that energy consumption presents different patterns because people in rural and urban areas have various living conditions and habits [11,12]. Thus, populations in rural and urban areas are selected as the potential driving factors of China's household electricity consumption growth.

The wealth level, which is generally measured by per capita disposable income, should also be considered when analyzing China's household electricity consumption. Mcneil and Letschert [13] adopted the econometric parameterization method to analyze the relationship between income and residential electricity consumption in developing countries. They found that the rate of appliance ownership increases with income. This phenomenon is a major factor of the growth of residential electricity consumption in developing countries. He and Reiner [14] used the statistical method to confirm the correlation between China's household electricity demand and income. They also found that electricity consumption patterns differ between the rural and urban households. Yin et al. [15] and Khanna et al. [16] also drew similar conclusions. As a result, the income level is also considered in this research as a potential driving factor.

The same as most of the other commodities, the household electricity demand is affected by its price. Meng et al. [17] used a three-dimensional model to decompose the growth of China's household electricity consumption per capita. They found that because China has maintained low prices for household electricity based on large-scale subsidies, the price is, in general, not a major factor for the increase in the consumption level during the period of 2001–2014. Khanna et al. [16] also confirmed this result. Therefore, aside from the implementation of the tiered price [18,19], the Chinese government has increased the overall price level for household electricity in recent years [9]. This research measures the current actual impact of price on the change of the household electricity consumption.

Furthermore, given the various climate conditions and many different living habits, China's energy consumption generally presents different patterns among regions because of its vast area [20]. For this reason, this study initially performed a clustering analysis of China's provinces in terms of the growth pattern of household electricity consumption, and then recognized the driving factors of the consumption growth in each group.

2.2. Clustering and Decomposition Methods

The *K*-means iterative algorithm [21] is a classic clustering method. It sets several original clustering centers and adjusts the center locations and clustering results by iteration. This method suits large clustering objects and can rapidly obtain the clustering results. However, this research only has 30 clustering objects (provinces), and outliers may well exist because of the complicated natural and social environment. Thus, ascertaining original clustering centers is difficult. The technique for order preference by similarity to ideal solution (TOPSIS) [22] algorithm can deal with small-sample clustering problems. It calculates the distance between two clustering objects and generates a dendrogram based on the distance results. The dendrogram can offer clustering results after setting the group number. The limitation of the TOPSIS method is that it does not consider the relative importance of the indicators. That is, all characteristic indicators should have equal importance for the clustering results. When clustering China's provinces based on the growth pattern of household electricity consumption, not all indicators (e.g., growth speed of consumption, population, income, and electricity price) are equally important. The rank sum ratio (RSR) [23] algorithm is also a small-sample clustering method that originated from the comprehensive evaluation. Its unique rank assignment method can distinguish the relative importance of the indicators and overcome the impacts of the outliers. Thus, this method is used for the clustering analysis in this research.

At present, there have been some research works on the changes in energy consumption over time in households. Xu and Ang [24] proposed a hybrid model and used it to decompose the changes of the residential energy consumption of Singapore. Their research focused on the impacts of family conditions (e.g. room and number of appliances), but the macroconditions (e.g. income and electricity price levels considered in this research) were not considered. Nie and Kemp [25] also conducted a similar analysis using China's data. Zhang et al. [26] investigated the difference of residential energy consumption between urban and rural areas. González et al. [27] analyzed the factors behind the change in aggregate energy consumption in the EU-27, and identified differences between member states. These research works offered policy implications based on the comparison, not the analysis of consumption changes of a region itself.

In the current research, a decomposition model is required to identify the driving factors of China's household electricity consumption growth. At present, data envelopment analysis and Malmquist productivity index (DEA-MPI) [8,28], Laspeyres index decomposition [29], and logarithmic mean Divisia index (LMDI) decomposition [30] are widely used. DEA-MPI is generally used to decompose the changes of relative efficiency of the same objects (e.g., industrial sectors in a country [8] or companies in the same industry [28]). Hence, it is not suitable for this research. The Laspeyres index and LMDI decomposition methods have similar functions in most cases, but the latter is generally preferred in decomposition analysis because of its superiority in theoretical foundation, adaptability, ease of use and result interpretation, and some other desirable properties in the context [31]. As a result, the LMDI decomposition method is selected in this research.

3. Methods and Materials

3.1. RSR Clustering Method

Essentially, the RSR analysis comprehensively evaluates the performance of each clustering object and ascertains the group it belongs to according to the evaluation score [23]. It usually includes the following process: indicator grade recognition, rank assignment, RSR calculation, probability distribution calculation, fitting equation estimation, and object clustering [32]. This research followed this process to perform the clustering analysis of the considered provinces.

3.2. LMDI Decomposition Algorithm

The LMDI decomposition algorithm uses a multiplication equation as the starting point and the logarithmic mean algorithm to ensure the completeness of the decomposition results [30,31]. Following this idea, this research decomposed the changes of household electricity consumption into the contributions of electricity price level (C_1), burden level of electricity expenditure (C_2), income level (C_3), and population (C_4).

3.3. Rebound Effect

The energy rebound effect refers to the discrepancy between the actual and expected energy-savings [33]. Specifically, the improved energy efficiency gives rise to not only a decrease in energy consumption but also reduction in energy prices. However, lower price increases energy consumption to some extent, thereby causing the rebound effect [34]. Figure 1 shows the economic basis of electricity rebound effect caused by price change.

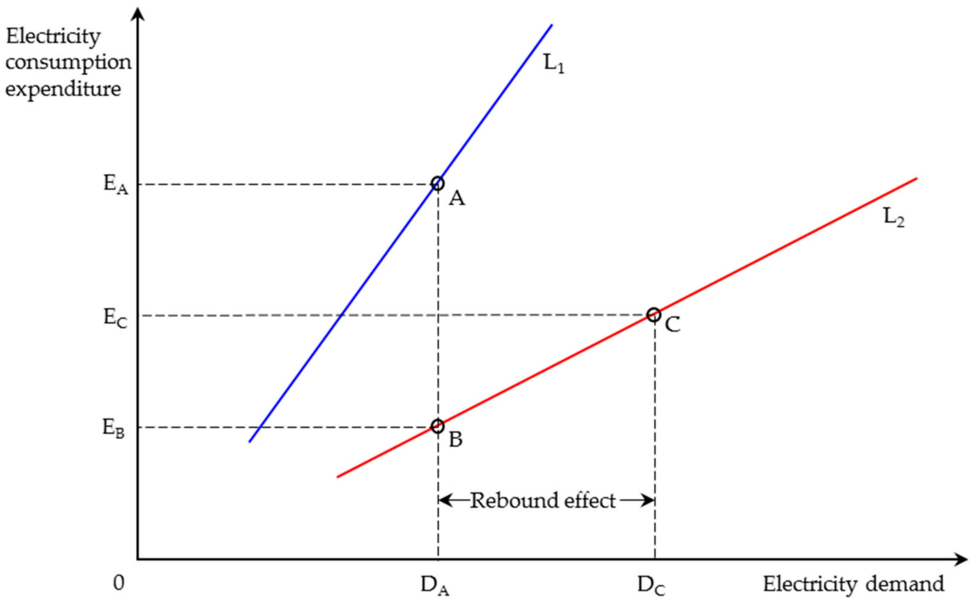

Figure 1. Electricity rebound effect caused by price change.

In Figure 1, line 1 (L_1) and line 2 (L_2) denote two different electricity price levels ($L_1 > L_2$). Initially, when the electricity price level is L_1, the household electricity demand is D_A and the corresponding electricity consumption expenditure is E_A. When the electricity price is decreased to L_2, the corresponding electricity consumption expenditure is E_B. However, because of the decrease in the electricity price, the households consume more electricity and finally reach D_C. Evidently, $(D_C - D_A)$ is the electricity rebound caused by price change.

3.4. Data Selection

As mentioned in the Introduction, the provincial data are used in this research. Among all China's provinces, only Taiwan is uncontrolled by the Chinese central government. Hong Kong and Macao are special administrative regions with far more autonomy than the other provinces. For these reasons, these regions were not considered in the present research. Meanwhile, Tibet's energy consumption was extremely small, thus its energy related values were not published in the statistical yearbook. Thus, Tibet was also excluded from our research.

The household electricity consumption data were selected from the "Energy Balance" table of each province in the *China Energy Statistical Yearbook*. Population and per capita disposable income data were obtained from the "Total Population by Urban and Rural Residence and Birth Rate, Death Rate, Natural Growth Rate by Region" and "Per Capita Disposable Income of Urban/Rural Households by Region" tables in the *China Statistical Yearbook* [3], respectively. The mean electricity price data were offered by the *Regulation Report on National Electricity Prices 2017* [9]. The households have become a major driver of China's electricity growth in 2015, and the latest available data are obtained from 2016. Thus, the data used in this research are from these two years. Table 1 lists all selected data.

Table 1. Household electricity consumption, population, per capita disposable income, and mean electricity price of considered provinces in 2015 and 2016.

Province	Household Electricity Consumption		Population				Per Capita Disposable Income				Mean Electricity Price	
			Urban		Rural		Urban		Rural			
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Beijing	17.5	19.5	18.8	18.8	2.9	2.9	52.9	57.3	20.6	22.3	495.1	494.8
Tianjin	8.7	9.3	12.8	13	2.7	2.7	34.1	37.1	18.5	20.1	503.3	503.7
Hebei	37.2	39.5	38.1	39.8	36.1	34.9	26.2	28.3	11.1	11.9	510.7	510.2
Shanxi	16	17	20.2	20.7	16.5	16.1	25.8	27.4	9.5	10.1	493.2	491.9
Inner Mongolia	12.8	13.9	15.1	15.4	10	9.8	30.6	33	10.8	11.6	470.9	472.2
Liaoning	23	24.3	29.5	29.5	14.3	14.3	31.1	32.9	12.1	12.9	512.4	513.4
Jilin	10.7	11.2	15.2	15.3	12.3	12	24.9	26.5	11.3	12.1	534.8	531.9
Heilongjiang	16.8	17.3	22.4	22.5	15.7	15.5	24.2	25.7	11.1	11.8	521.2	521.6
Shanghai	18.6	21.8	21.2	21.3	3	2.9	53	57.7	23.2	25.5	571.3	572.9
Jiangsu	52.9	62	53.1	54.2	26.7	25.8	37.2	40.2	16.3	17.6	517.6	519.6
Zhejiang	44.3	51.7	36.5	37.5	18.9	18.5	43.7	47.2	21.1	22.9	556.1	558.9
Anhui	25.1	30.1	31	32.2	30.4	29.8	26.9	29.2	10.8	11.7	569.2	572.7
Fujian	34.5	38.1	24	24.6	14.4	14.1	33.3	36	13.8	15	551.5	557.2
Jiangxi	18.4	21	23.6	24.4	22.1	21.5	26.5	28.7	11.1	12.1	618.2	620.5
Shandong	50.3	55.4	56.1	58.7	42.3	40.8	31.6	34	12.9	14	536.7	538.6
Henan	41.4	42.5	44.4	46.2	50.4	49.1	25.6	27.2	10.9	11.7	563.2	563.7
Hubei	27.9	31.5	33.3	34.2	25.3	24.7	27.1	29.4	11.8	12.7	579.5	573.5
Hunan	32.9	38.7	34.5	35.6	33.3	32.2	28.8	31.3	11	11.9	607	607.8
Guangdong	84.6	90.4	74.5	76.1	34	33.9	34.8	37.7	13.4	14.5	645.6	648.2
Guangxi	25.1	27	22.6	23.3	25.4	25.1	26.4	28.3	9.5	10.4	562.9	557.7
Hainan	5	5.4	5	5.2	4.1	4	26.4	28.5	10.9	11.8	632.1	632.3
Chongqing	13.8	16.4	18.4	19.1	11.8	11.4	27.2	29.6	10.5	11.6	537.3	533.8
Sichuan	34.1	39.3	39.1	40.7	42.9	42	26.2	28.3	10.3	11.2	523.3	523.3
Guizhou	19.8	21.8	14.8	15.7	20.5	19.9	24.6	26.7	7.4	8.1	485.4	484.2
Yunnan	21.7	19.5	20.6	21.5	26.9	26.2	26.4	28.6	8.2	9	472	468
Shaanxi	18.8	21.1	20.5	21.1	17.5	17	26.4	28.4	8.7	9.4	507.1	506.3
Gansu	7.7	8.4	11.2	11.7	14.8	14.4	23.8	25.7	6.9	7.5	511.8	522.5
Qinghai	2.3	2.5	3	3.1	2.9	2.9	24.5	26.8	7.9	8.7	405.8	404
Ningxia	2.4	2.6	3.7	3.8	3	3	25.2	27.2	9.1	9.9	457.2	462.7
Xinjiang	8	8	11.2	11.6	12.5	12.4	26.3	28.5	9.4	10.2	533.6	530.9

Units of household electricity consumption, population, per capita disposable income, and mean electricity price are billion kWh, million people, thousand yuan, and yuan per thousand kWh, respectively.

4. Results

4.1. RSR Clustering Result

Using the data in Table 1, the rank assignment of each indicator in each province was calculated and listed in Table 2.

Table 2. Assigned rank of each driving factor and rank sum ratio (RSR) for each province.

Province	Household Electricity Consumption	Population		Per Capita Disposable Income		Mean Electricity Price	RSR
		Urban	Rural	Urban	Rural		
Beijing	20	8.8	22.8	16.9	15.9	16.4	0.559
Tianjin	7.5	10.8	20.8	18.6	16.6	15.4	0.498
Hebei	7.5	21.3	8.8	14.9	13.9	16.6	0.461
Shanxi	9	13.3	16.3	12.1	12.1	17.3	0.445
Inner Mongolia	14	11.3	17.8	13.8	13.4	14.4	0.47
Liaoning	6	8.3	22.3	11.9	12.4	14.6	0.419
Jilin	5	9.8	15.8	12.9	12.6	18.1	0.412
Heilongjiang	4	9.3	19.5	12.4	11.9	15.4	0.402
Shanghai	27	10.3	17.3	18.9	18.9	14.1	0.591
Jiangsu	26	11.8	9.3	14.6	15.4	13.4	0.502
Zhejiang	25	13.8	11.8	15.3	15.1	12.9	0.521
Anhui	30	18.3	16.8	16.4	15.6	12.6	0.609
Fujian	19	12.8	18.3	16.1	16.9	12.4	0.53
Jiangxi	23	17.3	13.3	15.9	17.1	13.6	0.556
Shandong	17	22.3	8.3	14.1	14.1	13.9	0.498
Henan	3	20.8	12.3	12.6	13.6	15.4	0.431
Hubei	22	14.3	14.3	17.9	13.1	19.1	0.559
Hunan	28	15.8	9.8	17.4	16.1	14.9	0.566
Guangdong	11	12.3	21.8	17.1	16.4	13.1	0.509
Guangxi	12	15.3	20.3	13.1	18.1	18.9	0.542
Hainan	16	17.8	10.8	14.4	17.4	15.9	0.512
Chongqing	29	18.8	10.3	18.1	19.1	18.4	0.631
Sichuan	24	19.8	15.3	15.6	17.9	16.1	0.604
Guizhou	18	22.8	11.3	18.4	18.5	17.3	0.59
Yunnan	1	21.8	13.8	17.6	18.5	18.6	0.507
Shaanxi	21	16.3	12.8	13.4	14.9	16.9	0.529
Gansu	15	19.3	14.8	15.3	12.9	11.9	0.494
Qinghai	13	16.8	18.8	19.1	17.6	17.6	0.572
Ningxia	10	14.8	19.5	13.8	14.6	12.1	0.471
Xinjiang	2	20.3	21.3	16.6	14.4	17.9	0.513

In Table 2, considering that the growth speed of household electricity consumption is evidently the most important positive indicator for the growth pattern, this indicator is classified into Grade 1. Population is the direct basis of household electricity consumption and identified as a positive Grade 2 indicator. Compared with population, income and electricity price are less important and therefore placed in Grade 3. Electricity price is a negative indicator because its increase curbs the household electricity consumption growth. In addition, considering that population and electricity consumption scales differ among provinces, this research used the growth rate as the basis of rank assignment. The *RSR* of a province is then obtained by calculating the mean of the rank assignment results of each indicator [32]. These results are also listed in Table 2.

Following the clustering process, the RSR values in Table 2 are listed in Table 3 in an ascending sort order. The accumulative frequency, quantile for normal distribution, probit values, and the following equation was obtained:

$$RSR = 0.212 + 0.06 \cdot Probit. \quad (1)$$

Table 3. Sorted RSR, accumulative frequency, quantile for normal distribution, Probit, and fitted RSR for each province.

Province	RSR	Accumulative Frequency	Quantile for Normal Distribution	Probit	Fitted RSR
Heilongjiang	0.402	3.3	−1.8	3.2	0.401
Jilin	0.412	6.7	−1.5	3.5	0.421
Liaoning	0.419	10	−1.3	3.7	0.434
Henan	0.431	13.3	−1.1	3.9	0.445
Shanxi	0.445	16.7	−1	4	0.454
Hebei	0.461	20	−0.8	4.2	0.461
Inner Mongolia	0.47	23.3	−0.7	4.3	0.468
Ningxia	0.471	26.7	−0.6	4.4	0.474
Gansu	0.494	30	−0.5	4.5	0.48
Tianjin, Shandong	0.498	35	−0.4	4.6	0.488
Jiangsu	0.502	40	−0.3	4.8	0.496
Yunnan	0.507	43.3	−0.2	4.8	0.501
Guangdong	0.509	46.7	−0.1	4.9	0.507
Hainan	0.512	50	0	5	0.511
Xinjiang	0.513	53.3	0.1	5.1	0.516
Zhejiang	0.521	56.7	0.2	5.2	0.522
Shaanxi	0.529	60	0.3	5.3	0.526
Fujian	0.53	63.3	0.3	5.3	0.532
Guangxi	0.542	66.7	0.4	5.4	0.537
Jiangxi	0.556	70	0.5	5.5	0.543
Beijing, Hubei	0.559	75	0.7	5.7	0.552
Hunan	0.566	80	0.8	5.8	0.562
Qinghai	0.572	83.3	1	6	0.569
Guizhou	0.590	86.7	1.1	6.1	0.578
Shanghai	0.591	90	1.3	6.3	0.588
Sichuan	0.604	93.3	1.5	6.5	0.602
Anhui	0.609	96.7	1.8	6.8	0.621
Chongqing	0.631	99.2*	2.4	7.4	0.656

* This result is calculated by $[1 - 1/(4 \times 30)]$.

The fitting results to the RSR values were obtained by inputting the probit values into Equation (1). These results are also listed in Table 3.

This research divides the considered provinces into five groups. According to the RSR method [32], 3.2, 4.4, 5.6, and 6.8 correspond to probit thresholds. Then, the range of fitted RSR for each group was obtained by inputting these thresholds into Equation (1). Table 4 lists the clustering results for all considered provinces obtained by the ranges of fitted RSR. The results of fitted RSR are listed in Table 3.

Table 4. Clustering results for all considered provinces.

Group	Range of Probit	Range of Fitted RSR	Province
1	$(-\infty, 3.2)$	<0.403	Heilongjiang
2	[3.2, 4.4)	[0.403, 0.475)	Jilin, Liaoning, Henan, Shanxi, Hebei, Inner Mongolia, Ningxia
3	[4.4, 5.6)	[0.475, 0.548)	Gansu, Tianjin, Shandong, Jiangsu, Yunnan, Guangdong, Hainan, Xinjiang, Zhejiang, Shaanxi, Fujian, Guangxi, Jiangxi
4	[5.6, 6.8]	[0.548, 0.620]	Beijing, Hubei, Hunan, Qinghai, Guizhou, Shanghai, Sichuan
5	$(6.8, +\infty)$	>0.620	Anhui, Chongqing

4.2. Factor Decomposition Result

The quantitative contribution of each driving factor in each province for the household electricity consumption growth was obtained using the data in Table 1 and the LMDI decomposition algorithm, listed in Table 5.

Table 5. Quantitative contribution of each driving factor in each province for the household electricity consumption growth.

Group	Province	C_1	C_2	C_3	C_4
1	Heilongjiang	−14.4	−524.1	1106.6	−58.1
2	Jilin	59.4	−188.2	758.8	−79.9
	Liaoning	−46.1	35.7	1337.4	−27
	Henan	−32.8	−2460.4	3363.6	229.5
	Shanxi	42.2	−218.7	1145.5	80.9
	Hebei	40.9	−1486.8	3554.3	231.6
	Inner Mongolia	−35.7	−72	1100.1	47.7
	Ningxia	−29.4	−45.7	209.3	25.7
3	Gansu	−165.5	75.7	749.1	30.7
	Tianjin	−7.3	−302.8	773.3	86.9
	Shandong	−185.8	−49.3	4811.1	533.9
	Jiangsu	−220	4165.2	4919.7	165
	Yunnan	173.5	−4675.8	2116.8	125.5
	Guangdong	−342.1	−2436.7	7407.5	1201.3
	Hainan	−2	−42.3	480.1	34.2
	Xinjiang	39.7	−914.5	716.9	127.9
	Zhejiang	−244	3034.9	4090.1	439.1
	Shaanxi	30.3	395.3	1759.8	104.7
	Fujian	−370.4	481.1	3170.1	329.2
	Guangxi	240.8	−762.4	2214.5	227.1
	Jiangxi	−73.5	710.4	1821.2	111.8
4	Beijing	12.7	542.9	1487.4	17
	Hubei	307.3	494.9	2660.9	166.9
	Hunan	−46.4	2503.8	3407.9	−5.3
	Qinghai	10.6	−88	237.2	20.1
	Guizhou	54.4	−463.6	2302.8	146.5
	Shanghai	−58.7	1472.2	1764.9	41.6
	Sichuan	−0.7	1468.1	3464.7	257.9
5	Anhui	−167.7	2337.9	2528	231.9
	Chongqing	99.8	836.6	1494.2	159.4

The unit is million kWh.

Table 5 shows the quantitative impacts of driving factors on the change in the household electricity consumption. For example, −14.4 in line 2, column 3 indicates that because of the increase in electricity price, the household electricity consumption in Heilongjiang decreased by 14.4 million kWh during 2015–2016.

5. Discussion

5.1. Geographic Distribution Analysis

Table 4 lists the clustering results. To observe the geographic distribution of each group, the map of China was colored accordingly (only the considered provinces were included) with different gray levels (Figure 2).

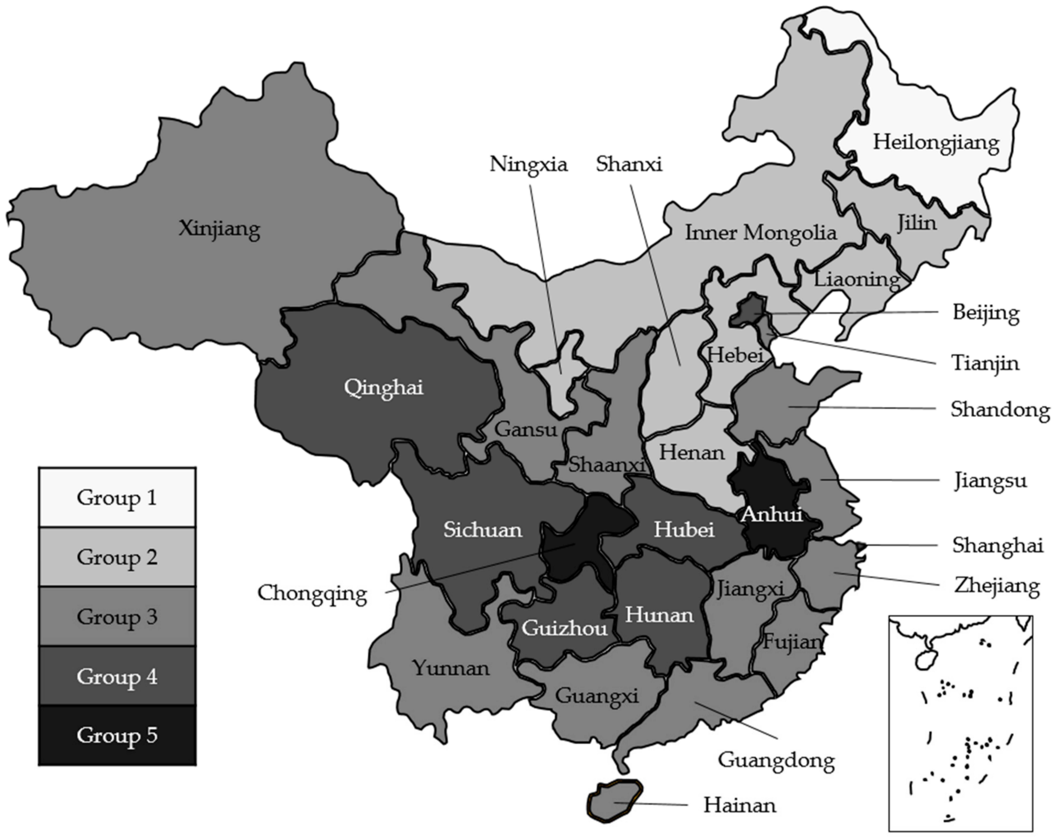

Figure 2. Geographic distribution of growth pattern of household electricity consumption of the considered provinces.

Figure 2 reveals an interesting phenomenon. The growth pattern of household electricity consumption of different provinces tend to relate to their geographic distributions. In general, except for a few outliers, the northern provinces tend to have small RSRs (Groups 1 and 2). In fact, the smallest 10 RSRs are from north China. Instead, the southern provinces have large RSRs (Groups 3, 4, and 5), and the Yangtze basin (Qinghai, Sichuan, Chongqing, Hubei, Hunan, Anhui, and several neighbor provinces of them) has the largest RSR. In accordance with the RSR clustering process, a large RSR score indicates high growth speed of electricity consumption, population, per capita disposable income, and stable electricity price. That is, provinces with large RSRs have large growth vitality of household electricity consumption. In this sense, south China has a larger growth vitality of household electricity consumption than north China, and the Yangtze basin is the most vigorous region. Considering the huge potential of consumption growth, to maintain the stable and economic running condition of the electric power system, this region should be principally monitored.

Figure 2 also shows that the neighboring provinces tend to be in the same group, particularly those at similar latitudes. Except for a few outliers, Figure 2 presents several geographic distribution belts. For example, Jilin, Liaoning, Hebei, Inner Mongolia, Shanxi, and Ningxia belong to Group 2. The provinces at similar latitudes have similar climate conditions; thus, this condition has an important impact on the growth of household electricity consumption.

5.2. OutlierAanalysis

As shown in Table 3 and Figure 2, the RSR of Beijing and Shanghai is significantly larger than that of its neighbors. Thus, they have a larger growth vitality of household electricity consumption. Using the statistics listed in Table 1, Table 6 shows the indicator comparison of Beijing, Shanghai, and other considered provinces.

Table 6. Indicator comparison of Beijing, Shanghai, and other considered provinces.

Province	Household Electricity Consumption		Population				Per Capita Disposable Income				Mean Electricity Price	
			Urban		Rural		Urban		Rural			
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Beijing	17.5	19.5	18.8	18.8	2.9	2.9	52.9	57.3	20.6	22.3	495.1	494.8
Shanghai	18.6	21.8	21.2	21.3	3	2.9	53	57.7	23.2	25.5	571.3	572.9
Mean value of other provinces	24.9	27.4	26.2	27	21	20.5	28.4	30.7	11.3	12.2	532.8	533.3

Units of household electricity consumption, population, per capita disposable income, and mean electricity price are billion kWh, million people, thousand yuan, and yuan per thousand kWh, respectively.

Table 6 shows that Beijing and Shanghai have similar indicator values. However, compared with other provinces, they have much higher urbanization rate, income level, and growth speed of household electricity consumption. The former two indicators are decided by the social–economic conditions, but wherefrom does the high growth speed of household electricity consumption originate? The rebound effect can explain this phenomenon.

The electricity rebound effect differs among China's different regions [35]. The household electricity consumptions of underdeveloped regions are used for the basic needs; hence, they are not sensitive to the price changes. Moreover, for the same province, as the urban regions have a higher income level (Table 1), they have a significant rebound effect.

As the most developed regions of China, Beijing and Shanghai have the best conditions for electricity rebound effect. From 2015 to 2016, the nominal electricity price changed slightly. However, because of the high-speed growth of income, the actual electricity price (price/income) decreased greatly. In fact, the actual electricity price of these two regions decreased by 7.8% and 8.1% in this period. Promoted by the rebound effect, these household electricity consumptions increased by 11.8% and 17.4%. Therefore, the rebound effect is a major driver of the household electricity consumption growth of China's most developed regions. In China, the income levels of some cities (e.g., Shenzhen, Guangzhou, and Tianjin) are rapidly approaching Beijing and Shanghai. It can be predicted that the rebound effect will be a major driver for the household electricity consumption growth in these regions. Considering that this part of consumption growth is sensitive to price changes, the Chinese government can select this measures to deal with this effect.

5.3. Driving Factor Analysis

Table 5 demonstrates the quantitative contribution of each driving factor to the change in household electricity consumption in each province. The mean contribution values in each group and total provinces were calculated to analyze the contribution difference of the driving factors among groups (Figure 3).

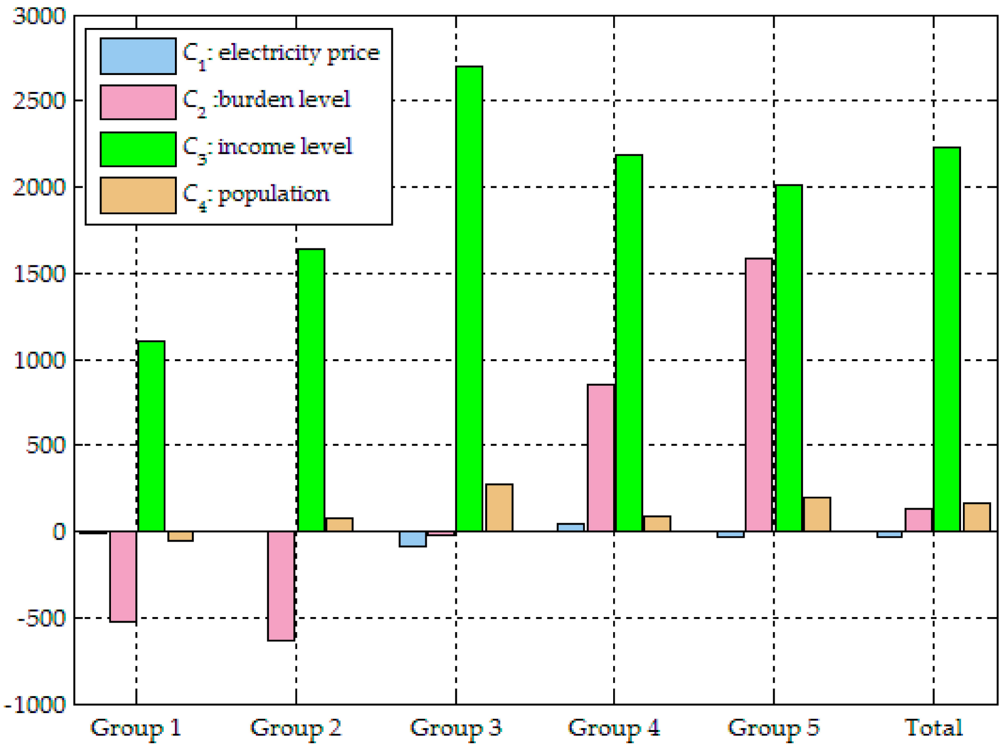

Figure 3. Mean quantitative contribution of each driving factor in each group and the total provinces.

Figure 3 shows that C_3 (income level) is the most important driving factor in all provinces. In fact, the household electricity consumption of all the considered provinces increased by 74.9 billion kWh (Table 1), and C_3 contributed 67 billion kWh (89.5%) (Table 5). This part of growth can be explained by appliance increase with the improvement of the income level [13]. Hence, increasing the energy efficiency of the household appliance is an important policy direction to mitigate this impact. In comparison with C_3, the impact of C_2 (burden level of electricity expenditure) differs among groups. Specifically, C_2 presents negative impacts for provinces with low growth vitality of household electricity consumption. That is, the growth speed of the household electricity consumption expenditure is lower than the income. For these regions, electricity is a necessity for households and not a luxury. However, for provinces with high growth vitality of household electricity consumption, the situations are the opposite. As a result, differentiated cross-subsidy policies should be considered. For provinces with low and high growth vitalities, the subsidy should be increased and decreased, respectively. The impacts of C_1 (electricity price) and C_4 (population) are negligible for most considered provinces. This means that, because electricity price and population changed very slightly, they did not cause the significant changes of household electricity consumption.

6. Conclusions

This research used the RSR method to perform the clustering analysis of China's provinces based on household electricity consumption characteristics, and an LMDI decomposition algorithm to recognize the driving factors of the consumption growth of each group. The following implications are drawn from the empirical analysis.

(1) The growth vitality of household electricity consumption of a region is highly related to its geographical location. Generally, compared with the north province, South China has a larger growth vitality, and the Yangtze basin is the most vigorous region. China should pay attention to the consumption growth of vigorous regions.

(2) The neighboring provinces at similar latitudes tend to have similar growth vitality of household electricity consumption. This finding implies that climate conditions significantly affect household

electricity consumption. This result should be a key consideration when making differentiated household electricity policies.

(3) The rebound effect has already appeared in a few of the most developed regions. This effect becomes increasingly significant with the development of China's economy. Electricity price is an effective measure for the Chinese government in dealing with this effect.

(4) The improvement of income level is the most important driving factor for the growth of China's household electricity consumption. At present, it contributes approximately 90% of the consumption growth. To mitigate this part of growth, increasing the energy efficiency of the household appliance is an important policy direction.

(5) The impact of the burden level of electricity expenditure varies among regions. This factor prompted the consumption growth of provinces with high growth vitality for household electricity consumption. However, for provinces with low growth vitality, the situations are the opposite. The Chinese government should increase the cross-subsidy of provinces with low growth vitality, and decrease the cross-subsidy of provinces with high growth vitality.

(6) Because electricity price and population changed very slightly, the impacts of them on household electricity consumption growth are negligible.

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References

1. National Bureau of Statistic of China. Statistical Bulletin on National Economic and Social Development 2018. Available online: http://www.stats.gov.cn/tjsj/zxfb/201902/t20190228_1651265.html (accessed on 28 May 2019). (In Chinese)
2. Meng, M.; Mander, S.; Zhao, X.; Niu, D. Have market-oriented reforms improved the electricity generation efficiency of China's thermal power industry? An empirical analysis. *Energy* **2014**, *114*, 734–741. [CrossRef]
3. National Bureau of Statistics. *China Statistical Yearbook (2016–2018)*; China Statistics Press: Beijing, China, 2018.
4. National Bureau of Statistics. *China Statistical Yearbook on Environment (2016–2018)*; China Statistics Press: Beijing, China, 2018.
5. IPCC. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available online: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html (accessed on 29 May 2019).
6. Li, C.; Zhang, X. Renminbi Internationalization in the New Normal: Progress, Determinants and Policy Discussions. *China World Econ.* **2017**, *25*, 22–44. [CrossRef]
7. National Energy Administration. Total Electricity Consumption Increased 8.5% in 2018. Available online: http://www.nea.gov.cn/2019-01/18/c_137754978.htm (accessed on 29 May 2019). (In Chinese)
8. Meng, M.; Fu, Y.; Wang, X. Decoupling, decomposition and forecasting analysis of China's fossil energy consumption from industrial output. *J. Clean. Prod.* **2018**, *177*, 752–759. [CrossRef]
9. National Energy Administration. Regulation Report on National Electricity Prices 2017. Available online: http://www.nea.gov.cn/2018-10/09/c_137519800.htm (accessed on 31 May 2019). (In Chinese)
10. Ye, Z.; Wu, Y.; Zhang, X.; Liu, S.; He, J. Research on the Inclining Block Tariffs Scheme for Solving Cross-subsidy under Demand Response—Based on the Perspective of Maximizing Social Welfare. *Chin. J. Manag. Sci.* **2019**, *27*, 149–159. (In Chinese)
11. Wang, Q.; Yang, X. Urbanization impact on residential energy consumption in China: The roles of income, urbanization level, and urban density. *Environ. Sci. Pollut. Res.* **2019**, *26*, 3542–3555. [CrossRef]
12. Jiang, L.; Chen, X.; Xue, B. Features, Driving Forces and Transition of the Household Energy Consumption in China: a Review. *Sustainability* **2019**, *11*, 1186. [CrossRef]

13. Mcneil, M.A.; Letschert, V.E. Forecasting Electricity Demand in Developing Countries: a Study of Household Income and Appliance Ownership. Available online: https://www.researchgate.net/publication/228619092_Forecasting_Electricity_Demand_in_Developing_Countries_A_Study_of_Household_Income_and_Appliance_Ownership (accessed on 4 June 2019).
14. He, X.; Reiner, D. Electricity demand and basic needs: Empirical evidence from China's households. *Energy Policy* **2016**, *90*, 212–221. [CrossRef]
15. Yin, H.; Zhou, H.; Zhu, K. Long-and short-run elasticities of residential electricity consumption in China: a partial adjustment model with panel data. *Appl. Econ.* **2015**, *48*, 2587–2599. [CrossRef]
16. Khanna, N.Z.; Guo, J.; Zheng, X. Effects of demand side management on Chinese household electricity consumption: Empirical findings from Chinese household survey. *Energy Policy* **2016**, *95*, 113–125. [CrossRef]
17. Meng, M.; Wang, L.; Shang, W. Decomposition and forecasting analysis of China's household electricity consumption using three-dimensional decomposition and hybrid trend extrapolation models. *Energy* **2018**, *165*, 143–152. [CrossRef]
18. Wang, C.; Zhou, K.; Yang, S. a review of residential tiered electricity pricing in China. *Renew. Sustain. Energy Rev.* **2017**, *79*, 533–543. [CrossRef]
19. Fu, X.; Zeng, X.J.; Feng, P.; Cai, X. Clustering-based short-term load forecasting for residential electricity under the increasing-block pricing tariffs in China. *Energy* **2018**, *165*, 76–89. [CrossRef]
20. Zhang, P.; Wang, X.; Zhang, N.; Wang, Y. China's energy intensity target allocation needs improvement! Lessons from the convergence analysis of energy intensity across Chinese Provinces. *J. Clean. Prod.* **2019**, *223*, 610–619. [CrossRef]
21. Adhau, S.P.; Moharil, R.M.; Adhau, P.G. K-Means clustering technique applied to availability of micro hydro power. *Sustain. Energy Technol. Assess.* **2014**, *8*, 191–201. [CrossRef]
22. Niu, D.; Li, S.; Dai, S. Comprehensive Evaluation for Operating Efficiency of Electricity Retail Companies Based on the Improved TOPSIS Method and LSSVM Optimized by Modified Ant Colony Algorithm from the View of Sustainable Development. *Sustainability* **2018**, *10*, 860. [CrossRef]
23. Cheng, L.; Song, Y.; Fang, X.; Zuo, Y.; Weng, Y.; Pu, Y.; Bai, Y. Analysis of the Allocation of Nursing Human Resources in China Based on Rank Sum Ratio Method (In Chinese). *Chin. Hosp. Manag.* **2019**, *39*, 74–76.
24. Xu, X.Y.; Ang, B.W. Analysing residential energy consumption using index decomposition analysis. *Appl. Energy* **2014**, *113*, 342–351. [CrossRef]
25. Nie, H.; Kemp, R. Index decomposition analysis of residential energy consumption in China: 2002–2010. *Appl. Energy* **2014**, *121*, 10–19. [CrossRef]
26. Zhang, M.; Song, Y.; Li, P.; Li, H. Study on affecting factors of residential energy consumption in urban and rural Jiangsu. *Renew. Sustain. Energy Rev.* **2016**, *53*, 330–337. [CrossRef]
27. González, F.P.; Landajo, M.; Presno, M.J. Multilevel LMDI decomposition of changes in aggregate energy consumption. a cross country analysis in the EU-27. *Energy Policy* **2014**, *68*, 576–584. [CrossRef]
28. Liu, D. Evaluating the multi-period efficiency of East Asia airport companies. *J. Air. Transp. Manag.* **2017**, *59*, 71–82. [CrossRef]
29. Cheng, S.; Wu, Y.; Chen, H.; Chen, J.; Song, M.; Hou, W. Determinants of changes in electricity generation intensity among different power sectors. *Energy Policy* **2019**, *130*, 389–408. [CrossRef]
30. Yang, H.; Ma, X. Uncovering CO_2 Emissions Patterns from China-Oriented International Maritime Transport: Decomposition and Decoupling Analysis. *Sustainability* **2019**, *11*, 2826. [CrossRef]
31. Ang, B.W. Decomposition analysis for policymaking in energy: Which is the preferred method? *Energy Policy* **2004**, *32*, 1131–1139. [CrossRef]
32. Sun, Z.; Wang, L. *Comprehensive Evaluation Method and Its Application in Medicine*; People's Medical Publishing House: Beijing, China, 2014. (In Chinese)
33. Berkhout, P.H.G.; Muskens, J.C.; Velthuijsen, J.W. Defining the rebound effect. *Energy Policy* **2000**, *28*, 425–432. [CrossRef]

34. Wang, Z.; Lu, M.; Wang, J.C. Direct rebound effect on urban residential electricity use: An empirical study in China. Renew. *Sustain. Energy Rev.* **2014**, *30*, 124–132. [CrossRef]
35. Wen, F.; Ye, Z.; Yang, H.; Li, K. Exploring the rebound effect from the perspective of household: An analysis of China's provincial level. *Energy Econ.* **2018**, *75*, 345–356. [CrossRef]