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Decomposition and Analysis of Household Electricity Consumption Inequality in China

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Abstract: Achieving equal electricity distribution among households is crucial to equal access to socioeconomic opportunities and hence shared prosperity in China. This paper studies the inequalities in household electricity consumption with the Theil index. It overcomes the drawbacks of using the Gini and Atkinson's indexes in previous studies in this area. It provides insight into the inter- and intra-regional and urban-rural inequalities with inequalities decomposed with Theil's method. Comparisons are made between the results for electricity and private consumption inequality, with possible explanations for the findings. The findings can substantiate several arguments. First, high income and personal consumption inequalities may not accompany substantial electricity consumption disparities. The latter is not solely reliant on economic well-being as the region's development and modernization may help universalize electrification when enlarging private consumption inequality. Second, inter-regional inequality is less significant for the overall disparity in electricity consumption than personal consumption inequality. The expansion and reform of the power industry in recent decades may explain the difference. Third, the climate also impacts electricity consumption and inequality. In cold regions, electricity expenditures can be rendered more unequal by the different choices of heating mode and appliance. Finally, industrialization, urbanization, and local development may explain the urban-rural electrical and private consumption disparity. Due to its natural and agricultural resources and early railway construction, the Northeast avoided growth in inequity after urbanization, in contrast to the East, Central, and West.

Keywords: Theil index, regional inequality, urban-rural disparity, measurement of inequality, electricity consumption, economic inequality

1. Introduction

Following the announcement that the country had eradicated absolute poverty, measured against the daily consumption threshold of $2.3 for each person per day, China's authorities set the target of achieving shared prosperity by 2035 in 2021. Despite the achievements in the past decades in poverty eradication, inequalities in income, resources, and services still pose fundamental threats to social welfare and the achievement of shared prosperity. The products of economic growth in recent decades have yet to be equally shared across the population. The wealthiest decile in China receives 43.4% of

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total income, compared to 13.7% earned by the bottom half of the population, rendering China one of the countries with the worst dispersion of income worldwide [1]. China still has 180 million poor people using the World Bank's $5.5 daily consumption threshold for upper-middle-income economies [2].

Enhancing shared prosperity in China entails not only the reduction of inequality in monetary terms but also the provision of equal access to socioeconomic opportunities and resources. A rise in energy use in China accompanies the fast development of the economy. China witnessed a ten-fold increase in its CO2 emission per capita since 1990, reaching 7.6 tonnes in 2019 [3], and rendered itself the world's largest CO2 emitter, whose annual emission exceeds that of the U.S. and the E.U. combined [4]. However, the increased energy use has yet to ensure universal access to energy for households. 18.9% of the Chinese population suffers from energy poverty [5]. Increasing equality in energy consumption has evolved into a sustainability goal encompassing economic, social, and environmental objectives.

In light of the shift of priority from speed to the quality of development, the promotion of shared prosperity emphasizes the reduction of urban-rural and regional inequalities [6]. The first step to combating regional and urban-rural disparities in the country is to understand the extent of these inequalities and the distribution pattern of income and resources. This paper is purposed to investigate the size of imbalances in the use of electricity, a representative type of energy, household income, and private consumption at the micro level, and to illustrate results for inequalities decomposed into inter-regional and intra-regional disparities, as well as urban-rural inequality. It compares results to those of private consumption inequality. It attempts to provide quantitative answers to and analyze the reasons behind the questions as follows.

What are the current levels of inequality in electricity consumption and income or private consumption in China and different regions?

How much of such inequalities is contributed by inter-regional inequality (or intra-regional inequality)?

How much of such inequalities is contributed by urban-rural inequality (or inequalities within the urban and rural areas)?

2. Literature Review

China has a large variability in resource endowment and economic prosperity across its regions. For several reasons, it is essential to understand the inequality level in energy distribution under the current scenario. First, energy consumption, or public utility provision, is one crucial aspect of social welfare. It plays a decisive role in citizens' socioeconomic opportunities and quality of life [7]. Some literature has studied energy inequality in parallel with income inequality to examine the regional level of equality and provided possible policy suggestions [8,9]. Second, the energy or electricity consumption disparities can indicate economic inequality. Some studies claim that electricity consumption is related to the disparity of various development aspects, such as income and gender inequality [9,10]. Electricity consumption from some specific devices reflects the utility received by the residents and measures the energy service flow from durable goods. Third, household energy use is a critical contributor to carbon emissions. It can also be studied as a part of the carbon footprint inequalities [11-13].

Like income or consumption inequality, energy inequality is often measured using the Gini coefficient and Lorenz curve. Estimating the Gini coefficient of electricity consumption by depicting Lorenz curves with data from Zhejiang Province in China, Wu, Li, and Wei [10] revealed a more significant inequality measure than income or expenditure inequality. At the same time, Rosas-Flores, Gálvez, and Zayas [7] analyzed the cost allocation for the primary fuel types in Mexican households. They found a slight trend toward an uneven distribution of modern fuels. Moreover, Wu, Zheng, and

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Wei [11] examined the many dimensions of energy inequality with the Lorenz curve and Gini coefficient, ranking the level of inequality by energy type, end-use activities, and regions of China. Xu, Han, and Lv examined the geographic and demographic factors for household carbon inequality with Shapley decomposition and the Lorenz curve and Gini index [12].

Nevertheless, the widely employed measures have limitations. Notifying that the Gini index embodies the subjective judgment about the weight a society attached to inequality, Schlör, Fischer, and Hake adopted Atkinson's index based on social welfare function (SWF) to measure the inequality of household usage of energy in Germany [8]. Such measure introduces the concept of marginal utility and the parameter epsilon, ε, an indicator of inequality aversion or the perceived trade-off of social justice against economic efficiency. Similarly, Sun et al. adopted the same method to measure the inequality of public utility products (electricity, gas, and water) in different categories of Chinese cities [9].

However, despite the ability to quantify the inequality, Atkinson's method does not provide an absolute value of the level of inequality at a particular time. The literature in this field has not agreed on the most accurate way to determine the value of ε. Schlör, Fischer, and Hake [8] introduced five scenarios with various ε values (0.1, 0.5, 1, 1.5, and 2), resulting in five different values of Atkinson's index. In contrast, Sun et al. introduced seven, with epsilon equal to 0.5, 1.0, 1.2, 1.5, 2, 2.5, and 5.0. A society's aversion to inequality, like other variables in the SWF, such as income or consumption level, should be a determined value at a fixed point in time [9]. The choice of epsilon value is arbitrary, leading to the risk of underestimation or exaggeration of the level of inequality.

Moreover, neither the Gini nor Atkinson's index has enabled the studies above to decompose the value of inequality level, nor did the researchers suggest at what administrative level the public agencies should take actions to aid the inequality. To my best knowledge, such decompositional Theil index analysis has scarcely been used at a micro level with a focus on household energy usage. Theil indices were previously decomposed into intra- and inter-group inequality to analyze the contributions of the different Kaya factors, namely energy intensity, emission coefficient, energy structure, and population [14-16]. Some other studies adopted the method to assess the nationwide inter-regional emission inequality [17,18] or a particular region [19,20] across different sectors and end-uses.

3. Methodology and Data

3.1. The Theil Index

The Theil index is a measure with various desirable properties for this study. Theil draws analogies from probability distributions and derives the Theil index for inequality analysis from calculating information entropy [21].

$$T = \sum_{i=1}^{n} h(\frac{1}{n}) - \sum_{i=1}^{n} s_i\, h(s_i) = \frac{1}{\mathrm{n}}\sum_{\mathrm{i=1}}^{\mathrm{n}} \frac{\mathrm{y_i}}{\bar{\mathrm{y}}}\, log\left(\frac{y_i}{\bar{y}}\right) \quad (1)$$

s_i is a reinterpretation of the probability of an event, denoted by i, in the entropy theory. It represents the share of the individual or household i in total income (consumption) of n people or families. The $\bar{y}$ and y_i are the mean income and the income of the person or household i.

McGregor, Smith, and Wills propose the axiomatic approach as a formal structure for the design and selection of inequality measures with five generally agreed principles of measurement of inequality [22]. The five fundamental axioms generally agreed upon include:

1. Anonymity principle: the distribution is left unchanged by any income switch between individuals within the population.

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2. Scale invariance: any proportional change in all incomes will not alter the measure for the population.

3. Population replication: all else equal, any proportional change in the population leaves the level of inequality unchanged.

4. Pigou-Dalton principle: inequality is reduced when any income redistribution occurs from a relatively wealthy individual to a poorer one.

5. Diminishing principle of transfer: with any given income differences, any transfer between individuals reduces inequality more when it happens at higher income levels than at lower ones.

The Theil index is among the approaches that satisfy all five axioms above. Moreover, Bourguignon suggests that Theil's measure is zero-homogenous decomposable for the inequality in that the weights of the intra-group inequalities sum to a constant in the total disparities [23]. The decomposition is expressed as follows.

$$T_{total} = T_{inter} + T_{intra} = \sum_{i=1}^{g} S_i * log \frac{S_i}{P_i} + \sum_{i=1}^{g} S_i * T_i \quad (2)$$

T_{total}, the total degree of inequality, the sum of T_{inter} and T_{inter} , the inter- and intra-group inequality, respectively. g denotes the number of groups, which equals 4 for cross-region analysis and 2 for urban-rural analysis. S_i represents the share of total electricity or private consumption of group i in the population, while P_i stands for the faction of group i in the population. T_i is the Theil index of the group i calculated with the formula (1). The proportions of the people for different regions and the urban and rural areas used here to estimate S_i are computed concerning the provincial data released by the China National Bureau of Statistics for 2014 [24]. The intra-regional inequality reflects the difference in the usage of a type of energy across households in each region. In contrast, the interregional inequality indicates the difference in electricity use between the areas. Similarly, urban-rural inequality reflects the gap between the urban and rural in energy use, whereas intra-area inequality measures such inequality across all urban or rural households.

3.2. Data

This study is based on the database collected by the Chinese Residential Energy Consumption Survey (CRECS), a micro-level household survey. The survey is undertaken by the Department of Energy Economics at the Renmin University of China (RUC), involving 3863 families from 85 cities, 127 districts and counties, and 28 provinces, municipalities, or autonomous territories. The face-to-face study looks at the demographics and economics of the selected families, as well as how they consume and spend money on various energy sources [25].

In this study, intra-regional and inter-regional inequality analysis of energy use is performed by dividing the whole country into four regions in the light of different official economic development strategies, namely the East with the Eastern Development Strategy, the Central with the Rise of Central China, the Northeast with the design of the Northeast Revitalization, and the West with the strategy of the Western Development. The basic overview of the four regions and the rationale behind the categorization is provided in Appendix 1. The calculations and analysis hereafter are performed with the data from CRECS 2014, the latest survey conducted in 2015, summarised in the Chinese Household Energy Consumption Report 2016 [25].

4. Results and Discussion

Table 1 shows the results for the overall electricity consumption, private household consumption, and income levels, as well as the level of inequality among the Chinese regions. The results echo those of the earlier studies in that the imbalances are lower in energy consumption than in private consumption.

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At the same time, the inequality in the latter is lower than that of household income [8,26]. The results could be explained by the fact that household consumption involves the expenditure on necessities that are insensitive to variations in economic status. That electricity itself is a type of necessity.

Notably, the variation of the Theil index for electricity consumption between the regions follows a different pattern than those of private consumption and income. Eastern China has the highest income and consumption inequality levels but the lowest electricity consumption inequality. The electrification disparity cannot be explained solely by income or consumption disparities. Alternatively, the diffusion of electricity provision appears relevant to the industrialization and modernization of the local economy. Among the four regions, electricity consumption equality shares the same ranking as the share of secondary and tertiary industries combined in the regional GDP. Eastern, Central, Northeast, and Western China proportions were 93.46%, 88.90%, 88.08%, and 87.50%, respectively [24]. The universal power supply, grid system, equipment maintenance, and continuous service provision regarding residential consumption in remote areas entail decent infrastructure, technology, and government spending.

Table 1: Average level and Theil index among regions.

Regions	Electricity Consumption		Private consumption		Household Income	
	Mean value	Theil Index	Mean value	Theil Index	Mean value	Theil Index
Eastern	1398.67	0.2307	52547.39	0.5965	107838.39	0.9105
Central	1044.52	0.2496	24984.05	0.4800	47463.41	0.4600
Northeast	964.50	0.2855	32293.78	0.4386	49501.85	0.3930
Western	916.30	0.3451	25688.87	0.5115	46730.18	0.8094
Total	1142.32	0.2803	36517.07	0.6103	71033.79	0.8693

Inter-regional inequality has less explanatory power for electricity consumption than for private consumption inequality. The ratio between the highest (Eastern) and the lowest (Western) regional electricity consumption is 1.53, while the ratio for personal consumption is 2.3. That can be attributed to the reforms and programs in the electricity sector in recent decades. The state dismantled the State Power Corporation in 2002 to end the monopoly of the power industry, setting up new operators with dispersed locations, including two power grid companies and five electricity generation corporations, each owning less than 20% of the domestic market [27]. The reform enabled new operators to have regional service delivery foci and increased market competition to rationalize pricing. Besides optimizing market operation, the state launched the West-East Power Transmission Project to expand capacity and improve the spatial distribution of power supply. The project constructed new coal bases and hydroelectric dams in western China and built three transmission corridors connecting the border of the west and east coast in the south, central, and north [28]. As a result, the new capacities benefited a wide range of regions along the corridors. Several actions have rendered electricity a relatively universal commodity across areas.

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Table 2: The inter- and intra- regional Theil Index for electricity and private consumption in China.

Regions	Theil (Inter-regional)		Theil (Intra-regional)		Total
	Value	Contribution	Value	Contribution	
Electricity Consumption	0.0168	6.00%	0.2635	94.00%	0.2803
Private Consumption	0.0615	10.38%	0.5308	10.38%	0.5923

For the urban-rural inequalities, Table 3 shows that the rural area has a higher level of electricity consumption inequality, while the urban area has a higher private consumption inequality. The difference, again, can be explained by the industrialization and modernization of the economy. The rural area of the Northeast has a notably high level of electricity consumption inequality in disproportion to its level of automation and economic well-being. One possible explanation is the mode of heating and climate. The lengthy and cold winter results in high and long-lasting demand for heating for 5–6 months per year in northeastern China. Among the respondents of the CRECS 2014, 22 out of 232 northeastern rural respondents are covered by central heating, which charges separate heating fees from other types of energy expenditures. Household-independent heating systems cover the others. They can choose between different energy types, such as electricity, gas, coal, and biomass. The vast demand for heating exaggerates the differences in electricity consumption between central and household heating and between household heating with and without electricity.

Table 3: Mean values and Theil indices for different regions' electricity and private consumption in the urban and rural areas.

	Electrical consumption				Private consumption			
	Urban		Rural		Urban		Rural	
Regions	Mean	Theil	Mean	Theil	Mean	Theil	Mean	Theil
Eastern	1512.66	0.2019	984.24	0.3052	58406.49	0.5663	28442.70	0.6477
Central	1218.17	0.1930	888.53	0.2878	31468.40	0.4402	18916.12	0.4610
Northeast	979.29	0.2103	945.06	0.3877	36090.46	0.4594	27266.69	0.3767
Western	1072.21	0.2983	809.94	0.3689	32588.30	0.4580	21042.64	0.5187
Total	1301.54	0.2289	887.73	0.3351	45282.66	0.5624	22850.78	0.5068

Table 4 demonstrates the Theil indices and the contribution of urban-rural inter- and intra-group disparities for each of the four regions. Two types of consumption share the same ranking of group inequality across the four areas. Eastern and Central China have the highest urban-rural disparities in electricity consumption. The Theil indices for the between-group difference are 0.0179 and 0.0125, contributing 7.76% and 5.01% to the total gap, respectively. The Northeast has a surprisingly low level of between-group measure at 0.0001, explaining merely 0.05% of the actual inequality in electricity consumption.

The mode of industrialization can explain the vast gap between different regions in terms of urban-rural differences. The Northeast followed a decentralized path in the early phase of its automation

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and experienced the fall of the urban economy. With over half of China's oil reserves, one-sixth of its natural gas reserves, 68% of its oil shale reserves, and a quarter of its iron ore reserves, the Northeast is dotted with resource-based cities and towns as a result of early exploitation since the early twentieth century [29,30]. While the urban area attracted a large proportion of the labor force to the manufacturing, construction, and mining industries, the rural population benefited from the vast and fertile land and forest resources. The railway system connecting all cities and the majority of surrounding villages enabled the rural area to be integrated into the economic development of the cities [31]. Immediately after the People's Republic of China's establishment, the Northeast became the center of the national industry during the planned economy era. The region produced 12.36% of the GDP, 22.88% of industrial output, and 9.65% of agricultural production with 7% of the population, becoming the center of Chinese industry that supports the whole country's development. However, since 1978, the economic transition to a market economy has resulted in 29 the demise of many state-owned enterprises. The industries in Northeast China have suffered a severe impact, further narrowing the gap between the agricultural and non-agricultural populations [32].

On the other hand, the rest of China followed a centralized path of industrialization. Since the transition from the planned economy, automation has been concentrated in the eastern coastal cities and a few big inland cities. Then migration trends from inland to coast and rural to urban began. The process renders particular large cities endowed with disproportionate capital and human resources [33]. Even the East, with most of the country's coastal provinces, exhibits a wide internal urban-rural gap in private consumption. The East, Central, and Western results are consistent with Mishra and Agarwal's [34] results, indicating that the urbanization process widens the urban-rural gap. The rate of urbanization from high to low is 63.72%, 60.94%, and 47.42% for the East, Central, and West, respectively [24], following the same sequence as the level of inequality between urban and rural.

Table 4: Decomposition of Theil index of electricity and private consumption among regions in China.

Regions	Consumption type	Between urban and rural		Within urban and rural		Total
		Value	contribution	Value	contribution	
Eastern	electricity	0.0179	7.76%	0.2128	92.24%	0.2307
	private	0.0468	7.85%	0.5496	92.15%	0.5965
Central	electricity	0.0125	5.01%	0.2371	94.99%	0.2496
	private	0.0313	6.53%	0.4487	93.47%	0.4800
Northeast	electricity	0.0001	0.05%	0.2854	99.95%	0.2855
	private	0.0100	2.28%	0.4286	97.72%	0.4386
Western	electricity	0.0099	2.86%	0.3352	97.14%	0.3451
	private	0.0233	4.56%	0.4882	95.44%	0.5115
Total	electricity	0.0171	6.09%	0.2632	93.91%	0.2803
	private	0.0531	8.70%	0.5572	91.30%	0.6103

5. Conclusion and Limitations

This study has comprehensively analyzed the level and pattern of inequality in energy consumption, measured by expenditure on electricity with the Theil index, and compared it with private consumption. There are several findings. First, a region with high income and personal consumption disparities does not always have high energy or electricity consumption disparities. It means that the latter is not entirely dependent on differences in economic well-being. It could be related to the degree of industrialization and modernization of the regional economy, which facilitates the universal electrification of the region. Second, inter-regional inequality contributes less to the overall disparity in electricity consumption than private consumption inequality. It could result from the development

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and reform of the power sector in recent decades, which have promoted the diffusion of electricity in less developed regions. Third, the climate is also a factor that impacts electricity consumption and inequality. In cold areas, electricity expenditures can be rendered unequal by choice of heating mode and appliance. Finally, the urban-rural gap in electricity and private consumption might be related to the paths of industrialization and urbanization, and local development. In contrast to the East, Central, and West, the Northeast has avoided growth inequality following its urbanization thanks to its natural and agricultural resources and the early development of railway transportation.

There are several limitations to this study. First, it may have underestimated the explanatory power of inter-regional inequality. The figure shows that the inter-regional inequality is substantially lower than the intra-regional. Some other studies show converse results [33]. It is due to the size of the research units in this study. The four regions of this study each have different development and economic modes. For example, within the East region of this study, some southern cities are characterized by export-oriented manufacturing dominated by privately owned small businesses.

In contrast, some northern counterparts are dominated by heavy industry controlled by state-owned enterprises. Due to the large size of the groups, more inequality can be contained by the within-group component. Second, the energy consumption level measured only by electricity expenditure may need to be more inclusive. Electricity consumption contributed to only 45.36% of total residential energy consumption. However, It could be hard to define what should be included. Natural gas is another commonly used energy type. However, natural gas consumption could be more sensitive to the variation of climate types. Therefore, it could lead to an inaccurate measure of energy inequality for large countries with varying climate types across regions, like China.

Moreover, some types of energy are simply alternatives when clean points are unavailable. A poor household in a remote area may burn lump coal when electricity is not available. The increased spending narrows their gap with affluent families in energy expenditure, but it does not mean that the inequality in well-being is alleviated.

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Appendix

Appendix 1: Detailed economic information on the regions of China.

	Provinces, Autonomous Regions, and Municipalities Included	Regional Features and Rationale for Categorization	Population and Percentage of the National Population (million)	Urbanization Rate (% in 2014)	GDP per capita (CNY in 2014)
Eastern	Beijing, Tianjin, Hebei, Zhejiang, Jiangsu, Shandong, Guangdong, Fujian, and Hainan	It is the coastal area of China, with a highly superior geographical location. It holds the leading position in the market economic development and open-up. It is the most developed region of China	537.39 39.11%	63.72%	65062.52
Central	Jiangxi, Hubei, Hunan, Anhui, Henan, and Shanxi	It is the transportation centre linking various parts of the country. A highly dense population supports the development of energy raw materials, agriculture, and manufacturing sectors. It is faced with the challenge of industrial upgrading and structural adjustment.	360.77 26.25%	49.76%	38437.72
North east	Liaoning, Heilongjiang, and Jilin	Industrialisation and urbanisation started early. It relies on agriculture and heavy industry today. The common issues of exhaustion of natural resources and weakening development entail industrial upgrading.	106.08 7.72%	60.94%	54175.90
Western	Guangxi, Yunnan, Sichuan, Chongqing, Tibet, Gansu, Ningxia, Shaanxi, Inner Mongolia, Qinghai, and Xinjiang	It has 70% of the territory with 27% of the population of China and a few cities as regional centres, faced with the small and narrow market and concentrated poverty in the remote areas.	369.93 26.92%	47.42%	37325.16

Source: China National Bureau of Statistics (2015)