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Review

Features, Driving Forces and Transition of the Household Energy Consumption in China: A Review

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Abstract: Household energy consumption has been a major contributor to the increase in global energy demand and carbon emission, and the household sector has also become one of the most crucial factors shaping the management of developments towards sustainability. However, there is still a knowledge gap regarding the household energy consumption in China. Due to the vast territory and the differences among regional conditions, it is critical to conduct a systemic review to illustrate the overall situation as well as the detailed mechanisms of the household energy consumption in China. By employing both qualitative and quantitative methods, two key features of the household energy consumption in China are presented; one is regarding the total amount and the structure of the household energy consumption, and the second is the significant urban-rural gap. The driving forces are investigated from the perspective of external determinants and internal determinants, which consist of seven key factors; finally, the transition roadmap towards the sustainable energy system for the household level are presented based on the text analysis from the four key policy documents. Weaknesses in the current research on the energy geography of household level also exist, such as the lack of single factor research and the lack of integration and comprehensive analysis. Therefore, future studies need to strengthen the research of regional household energy consumption structure, spatial-temporal process, and its motivation mechanism, and sustainable development of energy, so as to explore space-social structure of household energy consumption and spatial-temporal interaction.

Keywords: energy transition; household energy consumption; spatial pattern; China

1. Introduction

Energy sustainability is one of the core topics for addressing sustainable development goals toward 2030 and is also critical in tackling climate change [1,2]. For example, the United Nations *Transforming our World: the 2030 Agenda for Sustainable Development* (SDG 2030) says that "a world where human habitats are safe, resilient and sustainable and where there is universal access to affordable, reliable and sustainable energy", and therefore "ensure access to affordable, reliable, sustainable and modern energy for all" is emphasized as Goal 7 among the total 17 SDGs [1]. The Paris Agreement, which has been signed by 195 UNFCCC (United Nations Framework Convention on Climate Change) members as of November 2018, aims to keep the increase in global average temperature to well below 2 °C above pre-industrial levels [2], and the energy sector is at the heart of the response to implementing the Paris Agreement [3]. For instance, the estimated global CO_2 emissions due to human activities reached 41 gigatons in 2017 [4], while the energy-related CO_2 emissions reached 32.5 gigatons [5], and accounted for 79.3% of the total global CO_2 emissions. The energy sector also

plays an important role in improving regional environmental quality, especially for preventing and controlling the local air pollution and cross-regional transfer of pollutants [6]. For example, the NO_2 and secondary derivatives originating from coal and petroleum fuels can generate acidic sediments that can impact forests, soil, and freshwater ecosystems [7], and that is also why "accelerating energy structure adjustment and increasing the supply of clean energy" is taken as one of the 10 measures specified in the *Air Pollution Control Program* issued by the State Council of China in 2013 [8].

The residential sector has been a main energy consumption sector [3,5,9], and the energy consumption in residential sector includes the energy used for heating, cooling, lighting, water heating, and consumer products, but excludes the energy used for transportation uses. Generally, residential energy consumption accounts for 10–50% of all sectors at the state level and about 25–30% at the global level [9,10]. Furthermore, it contributed about 17% of the global CO_2 emissions [5]. For example, on average, the residential sector accounted for about 25% of the total energy consumption in the EU in 2016, and contributed more than about 23% of the GHG (greenhouse gases) emissions [10], and in the US, the residential sector consumes more than 20% of total energy demand [11], while in some developing countries, such as in China, the residential sector accounts for 12.4% of total energy use, while the industry accounts for more than 66.6% [12].

Households have become one of the most crucial factors shaping the management of developments towards sustainability. With the rapid economic development, the household energy consumption has contributed to an increasing proportion of energy consumption [13], and is now a significant source of the growth of both global energy demand and carbon emissions [14,15]. A study shows that the residential energy consumption grows by 1.4%/year and will increase by 48% from 2012–2040. Specifically, in the non-OECD (OECD: Organization for Economic Cooperation and Development) nations, the residential energy use is expected to increase by 2.1% per year, and in OECD countries by about 0.6% per year [16]; furthermore, both China and India continue to lead world residential energy demand growth, mainly as a result of the fast economic growth [16].

In China, the household energy consumption is growing faster than that of the industrial sector since 2011 [17]. By comparison, in 2015, the energy consumption of industrial sector decreased by 1.15%, while the residential sector rose by 6.11% [18] and continues to grow, for instance, to about 12.9% in 2017 [12]. Inspired by the experiences from the pioneer countries in energy transition, such as Germany, the residential sector always plays a critical role for addressing long-run energy sustainability as well as for responding to climate change [19,20]. For example, since the energy transition took off in 2000, energy consumption of the households in Germany reduced by 10%, while in the United States it increased by 20% over the past 20 years [21]. Furthermore, German households used less than one third of the power compared with the US, and also less than other industrialized countries such as France and the UK [21,22].

Energy consumption in the residential sector is mainly affected by household income, energy prices, residential location, household characteristics, and energy-related policies [16,23]. Therefore, the type and amount of household energy consumption have different performance within and across regions and countries [24]; also, understanding the spatial pattern and the underlying drivers of variations of the household energy consumption thus helps to identify challenges and opportunities and provide advice for future policy measures [25]. In China, due to the vast territory and the differences among regional social, environmental, and economic conditions, households have quite different energy use performance [23], such as a result in inequality [26]. Therefore, under such a circumstance, it is critical to conduct a systemic review to illustrate the overall situation as well as the detailed mechanisms of the household energy consumption in China. After this introductory section, the rest of the paper is structured as follows: Section 2 contains a literature review which aims to identify the knowledge gap regarding household energy consumption in China, and an analytical framework is also presented for mapping out the technique route; Section 3 presents the methods and the data used in this study; in Sections 4 and 5, the key features and driving forces are presented

respectively; and Section 6 contains the argument of the transition towards a sustainable energy system. At last, the conclusion is presented in Section 7.

2. Literature Review and Analytical Framework

Curbing levels of energy consumption has been of interest to policymakers since the 1973 and 1979 geopolitical turmoil [27]. Currently, the growing global energy consumption puts increasing pressure on local environmental pollution and global climate change, while the share of households' energy consumption in total energy utilization is substantial [9,10], because households play an increasingly important role in energy consumption and mitigating climate change not only by pro-environmental behaviors but also by acting as a social- economic unit [28]. Therefore, policies targeting the household are becoming more critical. For example, since the household energy consumption in Germany accounts for 26% of the total energy consumption [29], many regulations directly target private households [17], and in the Netherlands, in order to reduce household energy consumption, the *Third National Energy Efficiency Action Plan* introduces a set of incentives and regulations applicable for all the locations of the country [30]. Given the fact that at the regional level, notable differences are observed among the main regions worldwide, a varied, and not a unique, global energy policy should be recommended and applied [31]. Nevertheless, just as we mentioned in the introduction, one of the critical bases for making the precise energy policy is to have a more profound and overall understanding on the energy system coupled with household development, particularly for the developing countries. However, such kind of knowledge gaps still exist.

Many previous studies have explored the different features of the household energy consumption at the local level, national level, or international level, which were conducted by the international organization or scientific communities. The U.S. (United States) is the country with the highest household energy consumption in the world, indicated by a survey conducted in 18 countries and regions including both developed and developing samples, such as the U.S., Canada, Australia, France, South Korea, China, India, Malaysia, Thailand, Vietnam, and Japan [24]. A report from the WEC (World Energy Council) presented that the global average electricity consumption for households was roughly 3500 kWh in 2010. However, in comparison, the average US household in 2010 used about 20 times more than the typical Nigerian household, and 2–3 times more than a typical European household, in detail, 11,700 kWh for a US typical household, 4600 kWh in the UK, and around 1300 kWh in China [32]. The EIA (U.S. Energy Information Administration) 2015 Residential Energy Consumption Survey (RECS) indicated that households account for 55% of the energy used in buildings, and many U.S. households rely on a variety of sources to meet their home energy needs. For instance, in 2015, 75% of U.S. households used more than one source of energy [33]. Herein, we would like to highlight that the RECS play a vital role in offering the detailed data for uncovering the household energy consumption in the U.S., for example, to investigate the household energy intensity trends [34], household fuel poverty [35], or uncover the factors affecting household-level wood energy consumption [36]. Since the first survey conducted in 1978, the 14th RECS covered more than 5600 households, to represent the 118.2 million households [33,34].

As a low-carbon development leader at the global level, many studies regarding the household energy consumption have been conducted in the EU (European Union) level as well as in its member countries. Both *Eurostat* and the *EEA* (European Environment Agency) provide very detailed public accessible data, such as the energy products used in the residential sector and the use of energy products in households by purpose [37–39]. For example, the EEA reports that the household energy consumption of the EU has declined by 8% over the 2005–2016 period [37], but increased both in 2015 (by 4%) and in 2016 (by 3%) compared with 2014 and 2015, respectively [38], and most of the final energy consumption in the residential sector in EU is covered by natural gas (37.1%), followed by the electricity (24.5%) and renewables (16.0%) [39]. A study on the determinants of the regional level household energy consumption from the European perspective found that there are common determinants and those that are dependent on the regions' level of development [40], for instance,

11 out of 28 EU Member States use mainly renewable energies for heating their home. For example, 72.2%, 65.2%, and 59.8% of the households in Portugal, Croatia, and Slovenia, respectively, have the most substantial proportion of energy consumption for heating covered by renewables [39]. Therefore, it was suggested that the authorities have opportunities to improve efficiency by generating regional-specific demand-side energy efficiency programs and measures [40].

It has been widely recognized that household energy consumption is a complex issue sorely linked to the multitude of inter-related factors [41,42], because of the differences of the local natural climate-environmental conditions, the household features or the social-economic situations, and so on [16,23], even though the weights of the same factor may be different varies from spatial levels to temporal scales. For example, a study by Blazquez et al. found that households located in colder zones tend to use more energy than those in warm zones [43], while another study conducted by Stoppok et al. concluded that household energy consumption is extraordinarily diverse and to some extent independent of climate conditions based on the IEA (International Energy Agency) data [44]. However, some other studies indicated that the residential sector's energy consumption exhibits distinct sensitivities to climate as compared to the industrial and transportation sectors [45], and wind speed and precipitation serve as crucial predictors of climate-sensitive load [46]. Furthermore, the findings from the Chinese Residential Energy Consumption Survey (CRECS 2013) also illustrated the importance of geographic differences to household energy consumption, for instance, between hotter and colder climates [47].

Actually, the energy consumption in households may be understood as the interaction of the multifaceted and synergic interplay between a socio-economic and a contextual domain at a higher level of scales, for example, a study conducted by *Borozan* which focused on the European regional-level household energy consumption determinants found that there are common energy consumption determinants at the household level, and some determinants are dependent on the regions' level of development [40]. Even so, quite a number of frameworks serving as the epistemology of household energy consumption have been developed [48], and these frameworks have metamorphosed from being purely disciplinary ones to being integrated frameworks comprising variables [49], and various technical, behavioral, and policy level interventions are available for reducing residential energy consumption [50]. Moreover, some new interesting but less noticeable research points regarding household energy consumption are also appearing—for example, the energy consumption in unoccupied households. Anderson et al. found that the average dorm room consumed 30.2% of all electrical energy use while vacant, and household energy use while unoccupied ranged from under 4% to over 80% [51], and such findings could provide insight into the operational efficiency of buildings and offer an approximation of the amount of energy that could be saved from improvements in occupant behavior without occupants having to make changes to their behavior in a manner that could potentially negatively affect his/her comfort [51–53]. That is also why the human dimensions are being recognized to play a role that is as significant as that of technological advances [53].

During the past decades, particularly in the last ten years, many studies have been conducted to investigate the household energy consumption in China, for example, to quantify the energy consumption per household [54–56] the urban-rural differences [57,58], driving forces and policy investigation [59,60], energy-related carbon emissions and indoor environmental quality [61,62], the energy accessible and livelihood [63], and so on. For example, early in 1996, Wang and Fend conducted a survey of 3240 rural households in six different regions, presenting that the energy consumption per household accounts for 700–1200 kgce (kgce stands for kilogram of coal equivalent), 40–60% of which is used for cooking, and 60–90% of total household energy consumption is in the form of biomass [54]. In 2002, another study conducted in Sheyang County of Jiangsu province based on a survey of 384 households in 12 villages indicated that energy consumption per household was around 970 kgce (294 kgce per capita times family size 3.3 person), while straws amounted to 56.5%, coal 9.9%, electricity 10.9%, firewood 14.4%, biogas 2.4%, LPG (Liquefied petroleum gas) 5.9%, and kerosene 0.02% [55]. Another survey of 1450 households in 26 Chinese provinces conducted by Zheng et al. in

2012 showed that a typical Chinese household in 2012 consumed 1426 kgce, and they found that the energy sources of urban and rural households are entirely different [56]. A survey of 556 households in Sichuan province conducted by Chen further suggested that the decision maker characteristics, the demographic structure of rural families, income level, arable land owned, and household location are all crucial factors affecting the process of household energy transition [63]. Even though many such studies have been conducted, many of them have been primarily focused on the building energy consumption in large cities and rural areas, and do not reflect the current situations of the household energy consumption in China.

There is still a knowledge gap regarding the household energy consumption in China, particularly in presenting an overall and systematic review concerning the spatial distribution and patterns and influencing and driving actors, as well as the features of the Chinese household energy consumption to international readers, Chinese domestic communities, and stakeholders, given the fact that most of the proviso studies are isolated or independent research with a focus on a special region, sector, or single perspective. For example, concerning the spatial levels which were investigated, we found that, currently, the main research areas mainly focus on the north and northwest of China, especially the ethnic minority areas, and few attentions have been paid to northeastern and southern China. For instance, to the best of our knowledge, we find that, till now, the provincial-level studies have mainly covered Inner Mongolia Autonomous Region (Inner Mongolia) [64,65], Gansu province [62,66–68], Tibet Autonomous Region (Tibet) [68,69], and Yunnan Province [70,71], and it seems that there is almost no detailed investigation conducted in Guangxi Zhuang Autonomous Region and Hainan province. Perhaps, as most of the colleagues or readers know, compared with the RECS in the U.S. [33], the most well-known corresponding project in China is the CRECS (the Chinese Residential Energy Consumption Survey), which is led by Prof. Dr. Zheng from Renmin University of China. The feature of the surveys is to collect very detailed information on household energy use behaviors [72], and such a big project only could cover part of China's 34 province-level administrative regions during its three rounds surveys, for instance, the CRECS conducted from December 2012 to March 2013 covered 1450 households from 26 provincial administrative regions [56], and in 2014, they completed the survey of 3404 households from 12 provincial administrative regions [73]. Therefore, it will make sense to conduct a review regarding household energy consumption in China. Therefore, an analytical framework (Figure 1) is proposed, with an aim to fill in the knowledge gap as we argued: firstly, the "features" of the household energy consumption including the overall structures and sources mix were presented, after that, the "driving forces" that are influencing and driving the household energy consumption in China are figured out, and finally, the sustainable transition of the household energy consumption will be summarized and proposed. During the analysis process of "features," "driving forces," and "transition," some international comparative analysis on the relevant components are also presented.

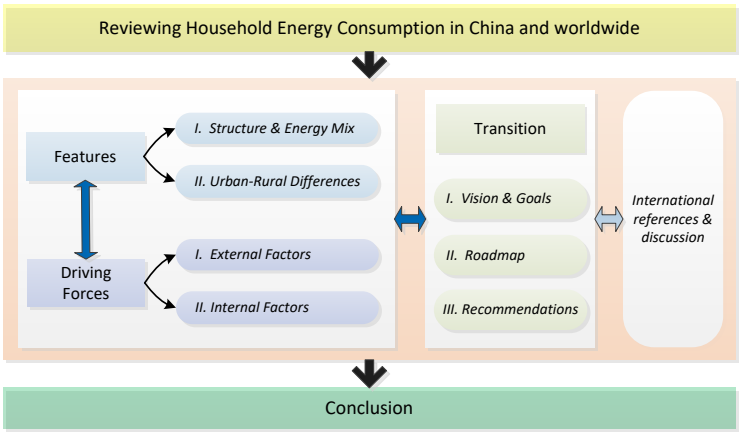

Figure 1. Analytical framework.

3. Methods and Data

Generally, a combination of qualitative and quantitative methods was used in this study to investigate and present the situation of the household energy consumption in China. We undertake a text analysis as a tool for analyzing the key literature which focused on the research on household energy consumption, which involves the deflection of texts incorporated into the analysis, determining which object will be considered in the analysis, coding, and interpreting the results. The literature database consists of three main parts: 1) articles from the WoS (Web of Science) database, 2) papers from the CNKI (China National Knowledge Infrastructure) database, and 3) the reports or datasheets from the Google search. Regarding the WoS part, keywords of "household energy"/"residential energy" plus "China" were used for topic-based literature searching in the database of WoS Core Collection (timespan 2000–2018) [74], and then two further methods were employed to refine the publications to 648 articles: one is to limit document types as "article" and "review", and the second is to exclude the categories in pure technology development or pure fundamental subjects, such as journal "Chemistry Physical", "Nursing", and so on. After that, the abstract of these 648 articles are checked one by one by authors and their trained research assistants, and finally, 96 articles are left and put into the literature database.

However, given the fact that all of these 96 articles are from academic communities, and they are all presented in English, two further steps are then conducted for completing the literature database: the first step is to use the CNKI [75] database for searching the literature published in peer-reviewed Chinese journals by employing the keyword "household energy consumption" in Chinese characters, and after the abstract-based screening, a total of 43 papers published during 2000–2018 are finally selected; the second step is to use the Google [76] for searching the independent reports or datasheet either in Chinese or in English, which were not published in peer-reviewed journals, for example, the Report of the Chinese Residential Energy Consumption which was published online in Chinese [73], and the report of *Energy Efficiency in Buildings in China: Policies, Barriers, and Opportunities*, which was produced by the DIE (German Development Institute) in English [77].

At the same time, during the process of building the literature database, the CiteSpace software [78] was also employed for identifying the key journals and linkages between the keywords clusters from the literature [79]. The most apparent advantage of CiteSpace is that it allows scholars to investigate the specific research areas by analyzing the citations, co-citations, and geographical distribution, thus drawing a very useful conclusion [80]. For example, based on the CiteSpace analysis, we could figure out the key journals which published the papers under the keywords of "household energy consumption" plus "China," for example, the key journals are *Energy Policy*, *Renewable, and Sustainable Energy Reviews*, and so on. Of course, we have to mention that not of all this literature is finally referred to in this paper.

Various models and formulas are employed for conducting quantitative analysis in this study, for example, the carbon emission from household energy consumption and the spatial correlation analysis of the provincial-level household energy consumption. However, the detailed methods will not be introduced here, but will be presented or referred to in the corresponding sections by using either a reference or detailed presentation. The data we used are mainly from published statistical books or international reports, and some data are extracted from the literature which have been clearly marked as references in the corresponding text, for example, the national aggregate data on energy statistics are mainly derived from the various issues of China Statistical Yearbook and China Energy Statistical Yearbook [12], and the China Energy Databook v.9.0 [81], and the household level data are mainly derived from previous studies such as the Chinese Residential Energy Consumption survey [72] and our survey conducted in 2017 and 2018.

4. Features

As we discussed in the literature review section, quite a lot of studies have been conducted for investigating the household energy consumption in China, however, most of them are mainly focused

on a special component or sector, such as the electricity sector or the rural area, and therefore lack a systemic description and analysis of the features of China's household energy consumption.

The first key feature of the household energy consumption in China is that the total amount of energy consumption has risen sharply in the household sector but is accompanied by rapid adjustments in the energy mix. During the past 60 years, China's energy consumption has increased from 131 million tons oil equivalent in 1965 to 3,014 million tons oil equivalent in 2015, with the gross domestic product (GDP) increasing from 172 billion Chinese Yuan (RMB) to 67,670 billion RMB [82], while the residential energy consumption has grown even more rapidly, for instance, increasing from 167 Mtce (million tons of coal equivalent) in 2000 to 501 Mtce in 2015 [12], with an average growth rate of 7.60% during the past 15 years. Specifically, during that period, the household kerosene consumption has an average annual decreased rate of 5.88%, from 0.79 million tons to 0.28 million tons. Globally, there is also a small level of kerosene used in the residential sector, but it shows a decreasing trend, given improved electricity access and policies to replace kerosene as a cooking fuel, given its negative impacts on air quality and health [83]. That is also why the household natural gas and electricity consumption in China shows an average annual growth rate of 17.51% and 11.6%, respectively, which was followed by the heat (9.75%) and LPG (7.53%), and the household gas consumption showed an increase from 12.6 billion cubic meters (BnCM) in 2000 to 184 BnCM in 2008, decreasing to 80 BnCM in 2015 [12].

Biomass is also a significant source of energy in China today, particularly widely used by rural households traditionally. Biomass accounts for about 13% of primary energy consumption in China, and in some rural areas is about 22 % in 2000 [84]. Recently, the CRECS study indicated that in 2014 the biomass shared about 27.2% of total China's household energy consumption, with an average amount of 295.11 kgce per household [85]. In the rural areas, an early study by Wang and Fend showed that biomass accounted for 60–90% of total energy used by rural households in China between 1987 and 1991 [54], while another survey conducted in 2012 by Zhang et al. found that in 2012, bioenergy accounts for 18% of their total energy consumption in rural area of three Chinese provinces, including Zhejiang, Guizhou, and Shanxi [57]. Actually, the estimated theoretical biomass energy resource in China is about 5 billion tons coal equivalent, and China is only using 5 percent of its total biomass potential [86]. However, given the fact that almost all the bioenergy is used in traditional stoves, a sustainable policy for bioenergy use must be further considered and benefit local households, for example, in Sichuan province, located in southwest China [87].

In terms of the residential energy consumption by fuel in China, a study from the China Energy Group at the Lawrence Berkeley National Laboratory [81] also found that the total consumption amount has increased from 90 Mtce in 1980 to 288 Mtce in 2014 (Figure 2), with an average annual growth of 3.48%. However, the share of each energy source has a different performance, for example, the consumption amount of coal decreased from 115.7 Mtce in 1980 to 92.53 Mtce in 2014, with an average annual decrease rate of 0.67%. However, its share decreased sharply from 91.8% in 1980 to 17.0% in 2014, while at the same period, in contrast, the consumption amount of electricity increased from 10.52 terawatt hours (TWh) to 717.6 TWh, with an average annual decrease rate of 13.65%, and its share increased rapidly from 1.4% in 1980 to 22.7% in 2014. Such a changing trend was also found in other developed countries, for example, in the UK, the fuel mix has also significantly changed during 1970-2014: coal consumption decreased from 39% to 1%, while the natural gas and electricity increased from 24% to 63%, and 18% to 25%, respectively [84]. The IEA study (World Energy Outlook 2016) indicated that both China and other developing Asian countries account for almost two-thirds of global residential demand growth in electricity in 2040, underpinned by continued urbanization [88]. Even though the average amount of energy consumption in China's household is much lower compared with the other countries, for instance, only 1087 Kgce in China (2014), and 3038 Kgce in the USA (2012), 2113 Kgce in UK (2012), 2192 Kgce in Germany (2012) and 3170 Kgce in Estonia (2012) [85], in the context of rapid urbanization and the new development strategy of rural revitalization in China, the residential energy consumption has a great potential and possibility to continue growing.

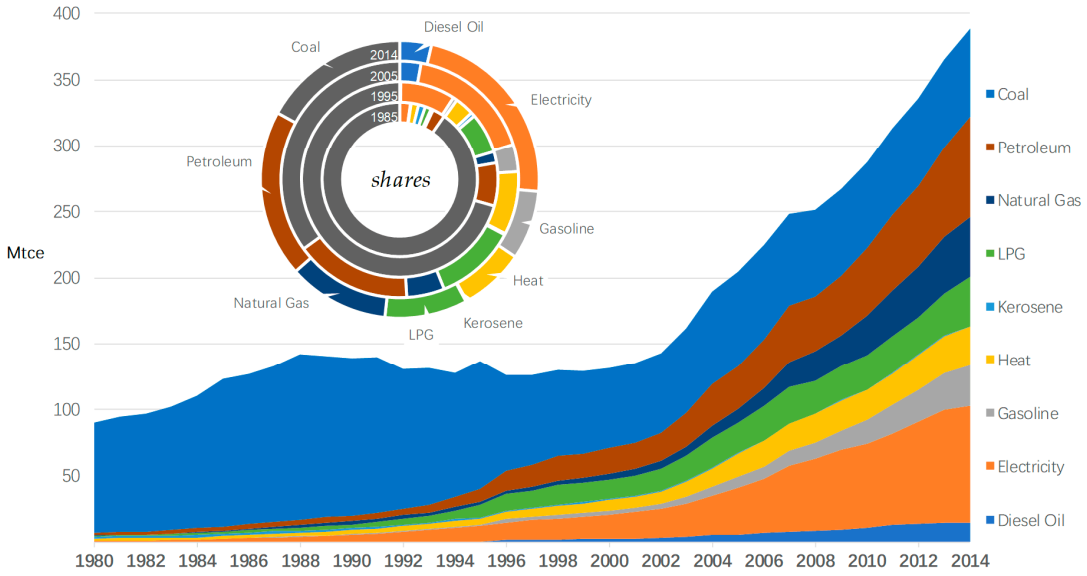

Figure 2. Residential Energy Consumption by Fuel in 1980–2014 (data source: Lawrence Berkeley National Laboratory, China Energy Databook Version 9.0).

The second key feature of the household energy consumption in China is the significant increasement difference and gap between urban and rural areas. In fact, urban–rural differences and regional gap are long-standing problems in China [88,89] and result in a considerable number of studies from different perspectives towards the long-run sustainability, such as poverty and income inequality [90]. As one of the key indicators measuring sustainability, "access to electricity," which refers to "*the percentage of people in a given area that have relatively simple, stable access to electricity*", plays a vital role in sustainable development [91]. Globally, around 1.2 billion people do not have access to electricity [92], and about 95% of them located in Africa and Asia [93]. From an international comparison, the relative gap of the "access to electricity" between urban and rural China seems better than other developing countries. For example, according the data from the World Bank under the subject of "sustainable energy for all" [94], as shown in Figure 3, in 1990, the rates of the "access to electricity" in the rural areas of China, Brazil, India, South Africa, and Bangladesh are 89.7%, 55.4%, 29.7%, 35.1%, and 4.0%, respectively, while that in urban areas is 99.3%, 97.5%, 82.8%, 59.3%, and 8.5%, respectively. In comparison, at that time, the value of this indicator in both rural and urban area of the U.S., UK, and Germany are all 100%. In 2008, the rate of the "access to electricity" in urban China achieves 100%, and then five years later, in 2013, it meets 100% in rural China.

In terms of the residential energy consumption per capita in China, in 1980, that in rural China was about 60 Kgce, while in urban areas it was only 332 Kgce, with more than 5.5 times. However, during the past almost 40 years, the residential energy consumption per capita in rural China has increased to 390 Kgce in 2016, but that in urban China remains almost stable, with an average of 395 Kgce, only 1% higher than that in rural area (Figure 4) [95]. Except for a temporary drop during 1996–1999, the residential energy consumption per capita in rural China witnesses overall solid growth, with an annual rate of 5.34%. Based on the first comprehensive survey of residential energy consumption in China, Zheng et al. stated that a typical Chinese household in 2012 consumed 1426 Kgce, while the average household energy consumption in an urban household is 1503 kgce/year, with per capita consumption of 651 kgce/year, and in rural households, the average total energy consumption is 1097 kgce/year, with per capita consumption of 445 kgce/year [56], which provided a quite different conclusion regarding the gap between urban and rural households compared with result based on the NBS data. Moreover, frankly speaking, it seems that it is quite difficult for us to offer a reliable and common recognized explanation.

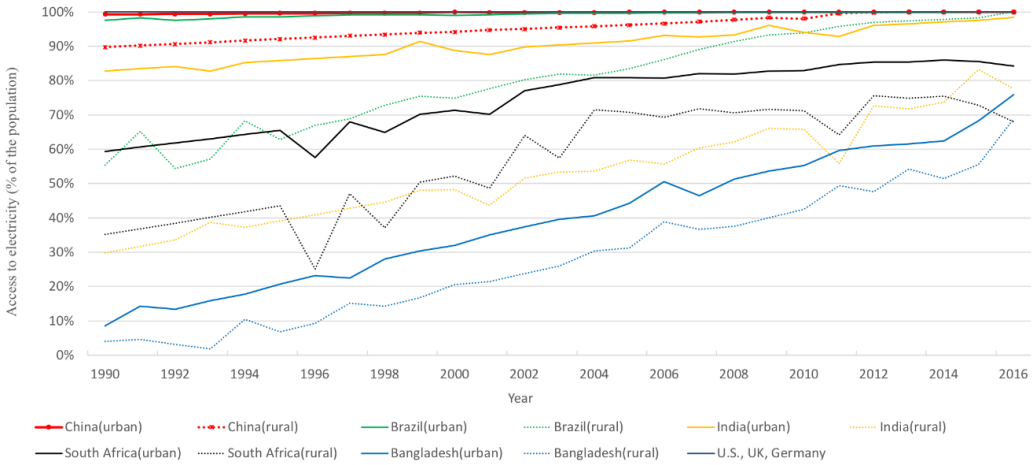

Figure 3. Access to electricity (% of the population) in 1990–2016 (data source: World Bank, Sustainable Energy for All, http://databank.worldbank.org/).

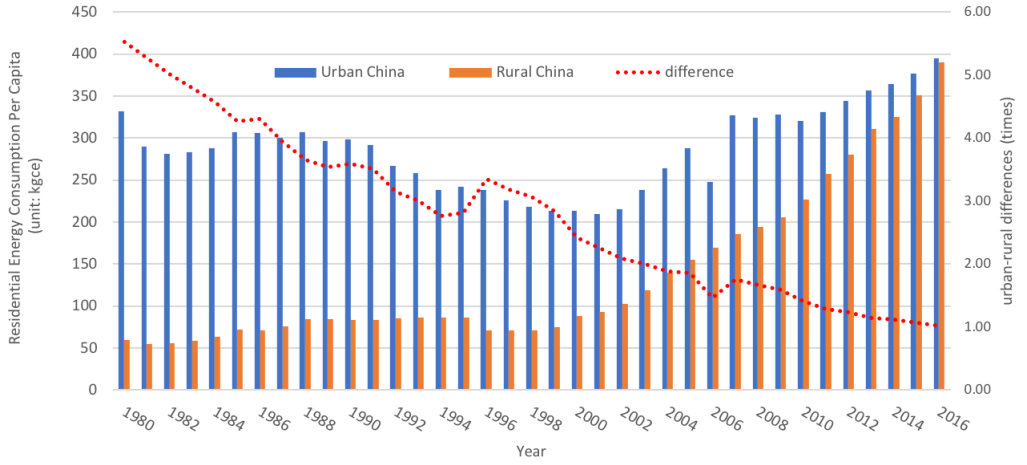

Figure 4. Residential energy consumption per capita in urban and rural China (data source: NBSC, China Energy Statistical Yearbook 2017).

Given the fact that China has over 600 million people living in rural areas, as well as an over 7% annual growth rate of per capita income during the past 40 years [12], the rural household energy consumption pattern has experienced a dramatic transition in terms of energy quantity, mix, and final demand. Rural household energy is primarily from biomass sources. In some ethnic minority areas in Gansu and Yunnan, rural residents still use traditional biomass energy resources like firewood as their major energy source. In these areas, commercial energy sources like coal and electricity are not used as alternative energy sources [96]. The residential energy source in the rural area of northeastern Yunnan is primarily firewood, which accounts for up to 90% of energy needs. Consumption of renewable energy sources such as solar energy, marsh gas, and hydroelectric contributes only 5% [97]. In Tibet and Inner Mongolia, the energy sources that farmers and herdsmen use for production are mainly traditional biomass, such as dung and firewood [98]. Even though residential energy consumption in rural China is undergoing a transition from traditional biomass energy to modern commercial energy, for example, Yao et al. (2012) [99] and Zhang et al. (2009) [100] found that there is a substantial energy transition underway from solid fuel to commercial energy and biogas, the tradition biomass energy will continue dominating energy sources in rural areas [47].

In comparison, in urban households, energy use is mainly from coal, liquefied petroleum gas, and electricity. Coal has long been a dominant type of energy, but its proportion is decreasing; natural gas consumption is rapidly growing, and the consumption of liquefied petroleum gas and electricity is

also increasing. A study based on an online survey undertaken in 31 regions of China (not including Hong Kong, Macao, or Taiwan) in 2015 indicated that, apart from electricity, natural gas is used in 56% of urban households, and furthermore, in about 20% of urban households, electricity has become the predominant fuel thanks to the electrification program [101]. Globally, the different features of energy use between urban-rural households also performed in some developing countries (such as Zimbabwe, India, etc.) [56]. Regarding China's case, more efforts should be made to fill the gap between urban and rural China, for addressing sustainability in the long run.

5. Driving Forces: Determinants and Performance

Projections of household energy demand over the coming decades, or at least until 2030, are critically important to understanding and anticipating future resources requirements and environmental impacts, as well as achieving the low-carbon oriented sustainable transition [102,103]. Thus, a systemic understanding of the driving forces would be very valuable by offering fundamental knowledge, for example, for improving the institutional instruments by strengthening policy-making [104] or promoting social acceptance of public during the transition process [105]. Literately, various methods have been employed to investigate the determinants and performance of household energy consumption, and the main stream methods which are widely used include decomposition analysis (DA), input-output analysis (I/O), multiple regression, and material/energy flow approaches (ME/FA). Generally, the methods of DA, I/O, and multiple regression are usually used alone or in combination at the macro level, while the ME/FA approach is usually applied by combining with a field survey at the micro-unit level, such as a typical household. For example, by applying the DA method, Wachsmann et al. identified the driving forces determining the changes in household energy use in Brazil from 1970 to 1996, finding that lifestyles, consumption patterns, and income are the main factors [106], Cellura et al. found that the driving forces the indirect energy consumption related to Italian household's consumption include energy intensity effect, emission intensity effect, Leontief and final demand effects [107], and by applying the non-parametric test (Chi-square), Uhunamure et al. found that household income, educational level and employment status, cultural norms, and values are among the key determinants of the energy preference scale [108].

Obviously, we can find that there are different terms used for indicating the driving forces in the household energy consumption, for example, the indices of driving forces' determinants could be divided as "indirect factors" and "direct factors" from the perspective of influencing route [47,107] "socioeconomic factors" and "technical factors" from the perspective of the characters [81,109], or "external factors" and "inner factors" if the household was taken as an organic unit [68,102]. In our study, the reviewing analysis of the driving forces is conducted and presented from the perspective of "external factors" and "internal factors", which mainly because we consider the household energy consumption as a kind of individual decision-making, which means the household makes choices that maximize their well-being or utility under the constraints they face [110,111].

External driving forces are those kinds of legislation, location, or events that influence the energy consumption from the outside of the household, which means that even though the external environment occurs outside of a household, it can have a significant influence on the current as well as the future structure and growth trend of the household energy consumption, as well as the long-term sustainability. Factors indicating the external driving forces of the household energy consumption in China mainly consist of energy-environment policy (E1), geographical location (E2), socioeconomic situation (E3), and the energy accessibility (E4). However, the internal driving forces usually consist of the household income and livelihood strategy (I1), family size (I2), end-use behavior (I3), which mainly either reflects the characters of the household self or is generally under control by the household. Please see Table 1. Herein, we have to point out that some other indicators are also proposed and studied in some literature, such as urbanization [112]. For example, Fan et al. found that urbanization contributes 15.4% to the increase in residential energy consumption during 1996–2012 in China [113], however, such an indicator is kind of a comprehensive index which could be further decomposed into

policy sector (E1) or categorized as socioeconomic situation (E3) [114]. Therefore, those indicators are not listed here but will be discussed in the corresponding sections.

Table 1. Critical determinants for driving household energy consumption.

Category	Determinants
External	energy-environment policy (E1) geographical location (E2) socioeconomic situation (E3) energy accessibility (E4)
Internal	household income and livelihood strategy (I1) family size(I2) end-use behavior(I3)

During the past 30 years, policy has always played a critical role in China's social-economic development [115], which is the same regarding its impacts on household energy consumption. Key policies that are driving the household energy consumption in China mainly include the "new normal urbanization policy" [113,114], "returning farmland to forests/grasses program" [116], "natural forest protection program" [117], and "grazing prohibition and enclosure" [64,118], which mainly reduce the biomass energy consumption in China, particularly in the north and northwestern rural regions, and "rural electrification program" [119] which mainly improves the shares of the electricity consumption in rural China. Internationally, these policies could offer good experiences for other developing countries, for instance, the Chinese model of rural electrification projects could serve as an inspiration for other developing countries [120].

Both geographical location and socioeconomic situation are important for driving the household energy consumption in China. For example, the total household energy consumption of northern China was 1.82 times than that of southern China, in detail, 888 kgce per household per year in southern China and 1,616 kgce in northern China. The energy was used for heating in northern China but mainly used for cooking in southern China [85]. Electricity was the primary type of energy consumed in southern China, while in northern China coal was the primary energy source and, on average, took up over 10.75% in household consumption, which was nearly ten times that of southern China. There were large differences in household energy consumption in different regions within the same administrative region. For example, in Gansu province, the structure of household energy consumption of Tianshui city differed significantly from that of Gannan, which is another city-level prefecture in Gansu. In Tianshui, coal (for heating) was the primary energy source (over 50%), and biomass energy was mainly from straw, while in Gannan over 65% of households use dung as a household energy source [66,67].

Energy Cost is an important factor influencing the resident choice of an energy source. High prices of advanced energy techniques mean a higher threshold cost for residents to use them [121]. The higher the cost of an energy source, the lower the probability that residents will use it [122]. Energy prices have little influence on the decision to use coal, whereas price can significantly impact the use of energy sources like liquefied petroleum gas and solar energy [123]. In Hebei, Hunan Province, and Xinjiang households, liquefied petroleum gas is the most sensitive to price changes, followed by firewood and straw. A study shows that every time the energy price index increases by 1%, the probability that households will choose traditional non-commercial energy increases 3-fold [121]. However, energy price fluctuations have a different influence on the energy consumption of residents of different income levels when the other conditions remain the same. Energy price adjustment policies might have different effects on the household energy consumption of different regions and significantly affect the total household energy consumption and energy consumption structure of China. For example, the increase of household electricity on the households in Guangdong might have a greater impact than on the residents in economically less developed provinces [124]. Therefore, one should consider differences in spatial elements and take appropriate measures when developing energy consumption

guiding policies. This will more effectively encourage residents to change their traditional energy consumption pattern and help ensure efficient resource utilization.

Energy accessibility is a major factor influencing the types of energy consumed by various provinces in China. Regional natural resource access can impact the spatial pattern of household energy consumption [125]. Biomass energy is more accessible with a low cost of collection in rural areas, and firewood/straw is the dominant rural household energy source there. Urban household energy is mainly pipeline and bottled gas. The area under cultivation has a significantly positive effect on the use of firewood and straw as energy in rural houses, while a larger cultivated area means that straw forms a higher proportion of the energy sources for rural families. Energy is more accessible in plain regions than mountain areas, where the household energy consumption structure is diversified with a selection of commercial energy sources. Non-commercial energy based on firewood is most common [126]. Energy delivery conditions like transportation and power grids have determined whether an energy source can be accessed and the cost of accessing it. Although commercial energy consumption has increased in the rural area, household energy consumption will still depend on local biomass energy for the foreseeable future [127]. In this context, the types and amounts of resources will be closely associated with household energy consumption in various regions. With improved household economic conditions and infrastructure, higher energy accessibility, and upgrading of rural energy consumption structure, it is advisable to guide and promote household energy consumption structure to transform from a simple structure to one which is diversified and of high quality [128].

Household income is a major economic factor influencing energy consumption decisions. Energy consumption increases by an average of 7% with each 1% increase in household income, for example, every 1% increase of per capita income of rural residents corresponds to a 19.2 kgce per capita increase of energy consumption in Jilin Province, 4.04 kgce in Jiangsu province, and 38.17 kgce in Inner Mongolia [64], while in Shaanxi Province, energy consumption increases by 0.26% and the proportion of household commercial energy increases by 5% for every 1% increase of household income [129]. Families with different income levels show significant differences in energy choices. Families with higher income levels are more likely to prioritize comfort when choosing energy sources. With lower income levels, however, economic efficiency is the principal factor [13]. Income level does not have an obvious influence on the use of firewood, straw, and coal. It does have a significantly negative influence on the use of marsh gas and a significant influence on electricity, liquefied petroleum gas, solar energy, and total energy consumption [130].

Family characteristics, such as family size and average educational level, are also important factors influencing household energy consumption. A larger family size corresponds to higher food and energy consumption. Family size is positively correlated with total household energy consumption. For each additional family member, energy consumption increases by 8% in Jiangsu and Jilin [131]. For example, in rural areas, larger families tend to choose non-commercial energy sources with lower costs or no cost due to their increased total energy consumption [132]. Household electrical appliances and heating energy are shared by family members, leading to scale economy effect. Therefore, family size is negatively correlated with energy consumption per capita. Energy consumption per capita declines as family size increases [133]. For example, the per capita consumption will decline by 28.1 kg standard coal (electricity), 97.17 kg standard coal (coal), 30.93 kg standard coal (liquefied petroleum gas), 76.64 kg standard coal (traditional biomass energy), and 10.78 kg standard coal (renewable energy) for every additional member of a rural family in Beijing. In the rural families of Jilin and Jiangsu, each additional family member corresponds to a per capita decline of energy consumption by 0.458 kg and 0.243 kg standard coal, respectively [133]. Education level shows a significant positive correlation with household energy consumption. Usually, the higher the education level, the greater the probability a family will use renewable energy. In contrast, families with less education are more likely to use traditional biomass energy [132]. Therefore, the average household education level helps increase the proportion of commercial energy residents use and optimizes the energy consumption structure [134].

6. The Transition towards a Sustainable Energy System

Sustainable transition of household energy consumption has been proposed as a key strategy in China's current development policies, including the *13th Five-year Plan for Energy Development* (2016–2020) (abbr. FPED) [135], *Energy Development and Strategic Action Plan* (2014–2020) (abbr. EDSAP) [136], *Action Plan of Energy Technology Innovation* (2016–2030) (abbr. APETI) [137], and the *Energy Supply and Consumption Revolution Strategy* (2016–2030) (abbr. ESCRS) [138]. As we see, both FPED and EDSAP are short-term plans which will be expired in 2020, and the latter two documents, APEIT and ESCRS, are long-term plans. In addition, the main focus of the ESCRS remains in line with the EDSAP, however, it set up new and higher targets for future, for example, in 2030 primary energy consumption should be controlled within 6 billion tons, and non-fossil fuel in the energy mix should be higher than 20%. In any case, based on the text analysis from those four policy documents, the main goal of the energy transition at household level would be concluded as "green, clean, low carbon, and all accessible", which actually mainly reflects the context of SDG 2030 and the Paris Agreement. The key methods of the energy transition at the household level are summarized as shown in Table 2.

Table 2. Key methods of the household-level energy transition.

Category	Key Methods	Policy Document
Energy Service	Universal Service of energy. Realizing the convenience of basic energy service and narrow the gap in electricity consumption between urban and rural residents.	Five-year Plan for Energy Development (FPED) (2016–2020)
	Improve the fair allocation of energy resources and emergency response mechanisms to ensure the basic energy needs of urban and rural residents.	FPED (2016–2020)
	Improve property management and professional services. In 2030, the rural areas will realize in establishing commercialized energy service system.	Energy Supply and Consumption Revolution Strategy (ESCRS) (2016–2030)
Energy Supply	Promote energy replacement by electricity, and use the storage energy for heating in the new energy-rich areas.	FPED (2016–2020)
	Improve energy infrastructure. Coordinate the upgrading of power grids and the replacement of electricity to meet the electricity substitution in residential heating.	FPED (2016–2020)
	Implement the urban gasification projects. By 2020, urban residents will use natural gas.	Energy Development and Strategic Action Plan (EDSAP) (2014–2020)
	Develop small hydropower and other renewable energies in a rural area, promote the efficient use of non-commercial energy, and strengthen rural energy conservation.	EDSAP (2014–2020)
Energy Management	Implement the Energy Conservation Plan to ensure saving energy being a conscious action of the whole society.	EDSAP (2014–2020)
	Formulate urban comprehensive energy planning, and develop distributed energy.	EDSAP (2014-2020)
	Implement the "all line into one grid" plan, develop the smart household energy system.	Action Plan of Energy Technology Innovation (APETI) (2016–2030)
	Promotion of rural distribution network construction, solar photovoltaic power generation, and heat utilization.	ESCRS (2016–2030)
	Support residents to participate in clean energy production in various forms such as rooftop PV.	FPED (2016–2020)
Pilot Projects	Clean energy demonstration provinces, green energy cities (counties), and smart energy towns.	FPED (2016–2020)
	Building low-carbon smart town.	EDSAP (2014–2020)
	Demonstration of low-carbon communities, and near-zero carbon emission zones.	ESCRS (2016–2030)
	Building green household.	ESCRS (2016–2030)

However, given the fact that the characters of Chinese energy policy system are top-down, plus supply-side oriented market policies with limited public participation, even though the households are the policy targets, it is not easy to engage the public to be involved in the macro policy-making process as well as the implementation process at the meso level [17]. Therefore, the different policies targeting the residential energy sector are limited in the ability to realize policy aims, energy savings, energy efficiency, and renewable energy in the residential sector, which would form new barriers and challenges for a sustainable energy transition. However, China not only needs to develop local knowledge, but also needs the international expertise if it is to achieve long-term sustainability for example, learning from the experience from Germany [17], such as the outcomes from ENavi Project [139], which shows great potentials of the positive features of energy transition. For instance, the energy transition will be the largest modernization and infrastructure project of the next decades, and the national economy is forecasted to benefit from 2025 on. It also brings technology breakthroughs, which could have a dramatic cost reduction and sustain the global deployment.

7. Conclusions

China's energy transition is taking place under the double pressure of energy security concerning its still growing economy and environmental protection. The household sector plays a critical role in the overall target of China's energy revolution as well as for meeting the needs of sustainability in the long run. By applying the combination of qualitative and quantitative methods, valuable insights that fill the identified knowledge gap are presented, including the two key features of China's household energy consumption from the perspectives of the amount and structure and the significant urban-rural gap of China's household energy consumption, and seven key factors that drive the household energy consumption from the perspectives of external and internal determinants. We also argue that a solution towards a sustainable energy transition which aims to solve the problem based on the ensemble of previous studies from the literature review should be considered in policy making.

Regional household energy structure, temporal-spatial processes, and its driving mechanism and effect are all frontiers of current energy geographical studies. However, they are also difficult to study, largely due to a lack of integrated and interdisciplinary approaches. For this reason, quantitative studies from traditional perspectives do not accurately illustrate the correlative effects and mechanisms. For example, the natural environment and human activities both show spatial homogeneity and cultural heterogeneity in geographic regions that are subject to the joint influence of different cultures in the same environment. With the increase in multi-source geographic spatial data, identification of regional household energy consumption is possible. This technology reduces survey time and also produces more accurate results [140]. Studying household energy consumption and using innovative spatial data methodology will be significant for exploring the spatial–social pattern characteristics and the temporal–spatial interaction of household energy consumption. The resulting data will help provide solutions to a variety of complex problems facing resources, environment, and development.

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