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Communication

Structural Evolution of Household Energy Consumption: A China Study

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Abstract: Sustainable energy production and consumption is one of the issues for the sustainable development strategy in China. As China's economic development paradigm shifts, household energy consumption (HEC) has become a focus of achieving national goals of energy efficiency and greenhouse gas reduction. The information entropy model and *LMDI* model were employed in this study in order to analyse the structural evolution of HEC, as well as its associated critical factors. The results indicate that the information entropy of HEC increased gradually, and coal will be reduced by clean energies, such as natural gas and liquefied petroleum gas. The information entropy tends to stabilize and converge due to rapid urbanization. Therefore, from the perspective of environmental protection and natural resource conservation, the structure of household energy consumption will be optimized. This study revealed that residents' income level is one of the most critical factors for the increase of energy consumption, while the energy intensity is the only driving force for the reduction of HEC. The accumulated contribution of these two factors to the HEC is 240.53%

and −161.75%, respectively. It is imperative to improve the energy efficiency in the residential sector. Recommendations are provided to improve the energy efficiency-related technologies, as well as the standards for the sustainable energy strategy.

Keywords: household energy consumption; sustainable development; information entropy; *LMDI* model

1. Introduction

With the rapid economy development, household energy consumption (HEC) has been continuously rising in China. The total amount of HEC more than doubled between 1990 and 2012, from 157.99 million to 396.66 million tce (tonnes of coal equivalent). Meanwhile, the annual energy consumption per capita increased from 139.2 kgce (kilograms of coal equivalent) to 293.8 kgce with an annual growth rate of more than 3.45% during the same period [1]. For the total energy consumption, the annual growth rate was as high as 4.28%. Moreover, the industrial energy consumption increased from 675.78 million tce in 1990 to 2524.63 million tce in 2012. This was higher than that of the total energy consumption. The acceleration of industrialization in China leads to the increase of energy consumption and rapid urbanization. The urbanization rate reached 52.57%, with a growing number of residents moving from rural areas to urban areas in 2012. The average annual energy consumption of urban residents was 1.4-times that of rural residents in 2012 due to different lifestyles in China [2]. HEC in urban areas also surged since the 2000s. HEC accounted for 10% of the total energy consumption in China [3]. This would likely increase along with the increase of the average income level, standard of living and associated access to home appliances, housing, *etc.* For example, the number of air-conditioners per 100 urban households increased from 0.34 in 1990 to 70.4 in 2012 [1]. To satisfy the growing demand of urban residents, a number of energy-intensive sectors have gained rapid growth in the last decade. These sectors include building materials, iron and steel and flat glass. It is undoubted that HEC contributes to the growth of the total energy consumption, either directly or indirectly. However, China's energy policies do not pay adequate attention to the efficiency of the residential sector compared with the efforts in the industrial sector. For example, "The 12th Five-year Guideline for Economic and Social Development" specified that energy consumption per unit of GDP should decline 16% in the future compared with the level of 2010, with little discussion on the household energy efficiency [4]. On the other hand, HEC could directly affect the total energy consumption and energy structure. The experience of developed countries demonstrates that with the continuous increase of HEC, the current situation of energy efficiency remains severe, even if the structural adjustment of industry is completed [5]. It is of strategic importance and practical significance to study the energy policies of the residential sector.

HEC has drawn a growing level of attention from academics. It is well recognized that the residential energy consumption depends on a number of factors, such as family size, average income, appliance ownership, lifestyle, physical characteristics of houses and the human behaviour of energy consumption [6]. For example, York [7] analysed the influence of population and economic factors on HEC in the EU. Fang *et al.* [8] examined the impact of various research variables on HEC, such as population increase, production facility, life-style and living standard. Schultz [9] and Hansla *et al.* [10]

analysed the psychological basis of energy consumption behaviour and investigated its influence on consumption behaviour. Reinhard *et al.* [11] and Egmond *et al.* [12] focused on the impact of technical efficiency, average income and revenue on the HEC. Therefore, the main factors influencing HEC include income level, energy structure, demographic characteristics and energy efficiency.

Some models and methods have been employed to analyse the most critical factors that affect HEC. Structural decomposition analysis (*SDA*) is one of the most widely employed approaches to identify the magnitude of predetermined driving factors for changes in observed energy indicators [13]. Ang concluded that the Logarithmic Mean Divisia Index (*LMDI*) method was the preferred method, due to its theoretical foundation, adaptability, ease of use and result interpretation, along with some other desirable properties in the context of decomposition analysis [14]. At present, the vast majority of empirical studies have utilized the *LMDI* method to quantitatively identify the relative impact of different factors on the changes in energy consumption [15]. Some other models were also employed to analyse the energy and environmental issues. For instance, Stern *et al.* [16] proposed the value-belief-norm theory and explained the formation of environmental behaviour through the role of environmental values, beliefs and subjective norms. Huang and Jin [17] developed the Smooth transition regression (*STR*) model and studied the impact of urbanization on HEC based on empirical data. Lenzen *et al.* [18] employed a comparative multivariate analysis model to analyse the requirements of household energy in Australia, Brazil, Denmark, India and Japan. Geng *et al.* [19] used the information entropy theory to analyse the structural evolution of HEC and concluded that the real disposable income was closely associated with the energy consumption per capita. This method provided an innovative approach to describe the complexity and chaos of the energy consumption system, which consists of a number of factors.

In addition, HEC can be divided into direct and indirect energy consumption. The former means the direct purchase and consumption of energy commodities for residents, such as cooking, lighting and heating fuel and electricity consumption [20].The latter refers to the energy consumed by non-energy goods and services for residents. Biesiot and Noorman [21] revealed that the indirect consumption of household energy was much higher than the direct consumption. Ala-Mantila *et al.* [22] concluded that indirect emissions dominate the direct emission at all income and urbanity levels. Furthermore, daily decisions of locating, moving and consuming also make a difference, which indicates that green growth cannot be achieved without profound changes in private consumption. Household direct energy consumption can be retrieved from the related statistical yearbook. On the contrary, household indirect energy consumption needs to be calculated with models, such as input-output analysis. Considering the availability of data required and the scope of this research, HEC in this research refers to direct energy consumption.

In summary, previous studies predominately focused on the structure, model development and critical factors of the HEC. There is lack of systematic investigation, which takes both the evolution of the structure and critical factors of HEC into consideration. Based on the analysing principles of HEC evolution with information entropy, the contribution of each individual driving factor to energy efficiency was examined. These findings provide useful inputs for the development of future policy instruments aiming for higher household energy efficiency.

2. Methods

2.1. Information Entropy Model

Originating from the thermodynamic theory, the concept of entropy has been widely applied in a variety of disciplines and sectors since the middle of the last century [23,24]. This includes information entropy [25], management entropy [26], economy entropy [27–29] and environmental entropy [30,31], which leads to the development of the nonlinear science theory.

Information entropy theory was introduced by Shannon in 1948, which is a measure of the average information value of a stochastic system [28]. In a system, a higher orderly degree means greater information value contained and less information entropy. The energy consumption system is an open and nonlinear system. It involves a frequent exchange of energy, material and information with other systems. The structure of energy consumption evolved spontaneously and irreversibly due to the continuous impacts of both the external disturbance and internal fluctuation. These characteristics of energy consumption system are in conformity with established assumptions of a dissipative structure system. Therefore, information entropy can be used to analyse the structural evolution of HEC. In this model, greater information entropy means a more complex system of the HEC structure. It has also been employed successfully to evaluate the structural revolution of land use in cities due to consistent dimensions of land area in different studies [25,32]. However, the contents of energy consumption vary significantly in the existence forms, types and units of different energy sources. In order to make it applicable for analysing energy consumption, it is imperative to unify the units of energy for the utilization of the information entropy model. The method is as follows:

It is assumed that *m* kinds of energy were consumed, and the amount of each kind of energy can be converted to H_1, H_2… H_m kgce. The proportion of energy *i* to the total energy consumption is $P_i = \frac{H_i}{H}, H = \sum H_i$, $\sum P_i = 1$. According to information theory, information entropy can be defined as Equation (1) if the dimension of energy is unified.

$$S = -\sum_{i=1}^{m} P_i \ln P_i \qquad (1)$$

As shown in Equation (1), the information entropy is minimum ($S_{\min} = 0$) when there is only one kind of energy in the system. On the other hand, the information entropy is maximum if $H_1 = H_2 = \cdots = H_m$, namely, $S_{\max} = \ln m$. Therefore, the value of information entropy is between 0 and $\ln m$, reflecting the complexity of the structure of HEC.

$$E = -\sum_{i=1}^{m} P_i \ln P_i / \ln m \qquad (2)$$

$$D = 1 - E \qquad (3)$$

In Equation (2), *E* is named the equilibrium degree, which is defined as the ratio of information entropy to maximum entropy. The data range is $E \in [0,1]$. The higher the *E* value, the smaller the difference in the proportion of each kind of energy is to the total energy consumption. Meanwhile, *D* in Equation (3) is defined as the dominance degree of the system, which reflects the level of energy consumption dominated by one or several kinds of energy. This is contrary to *E* defined in Equation (2).

S represents the complexity of the energy consumption structure, while *D* and *E* describe the quality difference and structural pattern among various energies.

2.2. LMDI Model

The index decomposition method has been widely used to identify influential factors. It was introduced to the energy discipline in the late 1970s [33]. At present, *LMDI* was usually employed in the research of energy consumption and carbon emissions, which involves the industrial sector, energy type, population, economy and other factors [34]. It is well recognized that the direct consumption of household energy is associated with a number of factors, such as economic condition, energy structure, population characteristics and energy efficiency [3]. Therefore, the *LMDI* model was employed in this study to conduct a quantitative analysis on the relationship between HEC and the aforementioned factors (see Equation (4)).

$$\mathrm{E}=\sum_{\mathrm{i}} E_i = \sum_{\mathrm{i}} P\frac{Y}{P}\frac{E}{Y}\frac{E_i}{E} = \sum_i PRIS \tag{4}$$

where *P*, *Y* and *E* represent population, resident income and energy consumption, respectively; E_i is the*i* kind of energy; *R* is income per capita, representing the economic level of residents; *I* is the intensity of HEC, representing energy efficiency; *S* is the energy structure.

The logarithm and time *t* derivation was taken for Equation (4), and Equation (5) was obtained.

$$\frac{d\ln E}{dt} = \sum_i w_i(t)\times(\frac{d\ln \mathrm{P}}{dt}+\frac{d\ln R}{dt}+\frac{d\ln I}{dt}+\frac{d\ln S}{dt}) \tag{5}$$

The integral was taken for Equation (5), and Equation (6) was obtained.

$$\int_0^t \frac{d\ln E}{dt}dt = \sum_i \int_0^t w_i(t)\times(\frac{d\ln \mathrm{P}}{dt}+\frac{d\ln R}{dt}+\frac{d\ln I}{dt}+\frac{d\ln S}{dt})dt \tag{6}$$

According to the definite integral value theorem, Equation (7) can be derived by Equation (6).

$$\frac{E^t}{E^0} = \exp(\sum_i w_i(t^*)\ln\frac{P^t}{P^0})\times\exp(\sum_i w_i(t^*)\ln\frac{R^t}{R^0})\times\exp(\sum_i w_i(t^*)\ln\frac{\mathrm{I}^t}{I^0})\times\exp(\sum_i w_i(t^*)\ln\frac{S^t}{S^0}) \tag{7}$$

The logarithmic mean function as the weight proposed by Ang can be expressed as Equation (8) [14].

$$w_i(t^*) = \frac{(E_i^t - E_i^0)/(\ln E_i^t - \ln E_i^0)}{(E^t - E^0)/(\ln E^t - \ln E^0)} \tag{8}$$

Equation (8) is substituted into the Equation (7), obtaining Equation (9).

$$\frac{E^t}{E^0} = \exp[\ln(\frac{E^t}{E^0})] \tag{9}$$

Based on additional decomposition, Equation (10) was obtained. Equation (9) was substituted into Equation (10). As a result, Equation (11) to Equation (14) were obtained.

$$\Delta\mathrm{E}_{\mathrm{tot}} = E^t - E^0 = \Delta\mathrm{E}_{\mathrm{pop}} + \Delta\mathrm{E}_{\mathrm{act}} + \Delta\mathrm{E}_{\mathrm{int}} + \Delta\mathrm{E}_{\mathrm{str}} \tag{10}$$

$$\Delta\mathrm{E}_{\mathrm{pop}} = \sum_i \frac{E_i^{\mathrm{t}} - E_i^0}{LnE_i^t - LnE_i^0} Ln(\frac{P^t}{P^0}) \tag{11}$$

$$\Delta E_{act} = \sum_i \frac{E_i^t - E_i^0}{LnE_i^t - LnE_i^0} Ln(\frac{R^t}{R^0}) \tag{12}$$

$$\Delta E_{int} = \sum_i \frac{E_i^t - E_i^0}{LnE_i^t - LnE_i^0} Ln(\frac{I^t}{I^0}) \tag{13}$$

$$\Delta E_{str} = \sum_i \frac{E_i^t - E_i^0}{LnE_i^t - LnE_i^0} Ln(\frac{S_i^t}{S_i^0}) \tag{14}$$

where ΔE_{tot} represents the contribution of all factors to the direct consumption of household energy. ΔE_{pop}, ΔE_{act}, ΔE_{int} and ΔE_{str} are defined as demographic effects, the effects of residents' income level, the effects of energy consumption intensity and the effects of the structure of HEC, respectively. This method is employed for the analysis of the critical factors of the HEC structure.

3. Results and Discussion

3.1. Results and Discussion of Information Entropy

Based on the data from the China Statistical Yearbook [1], the structural proportion of energy consumption was calculated (see Table 1). Values of the information entropy, equilibrium degree and dominance degree of the structure of HEC per capita are shown in Table 1, Figures 1 and 2, respectively.

It could be observed from Figure 1 and Table 1 that the proportion of coal decreased dramatically from 92.11% in 1990 to 39.45% in 2011, while the information entropy increased gradually from 0.392 to 1.402 in the same period. Based on the response of the shrinking of coal in the energy consumption structure, the proportion of natural gas and electricity increased 26.33% and 13.76%, respectively. This indicated that the structure of HEC was markedly disordered. Although coal still makes up the majority of primary energy consumption currently, it has been gradually reduced by electricity, natural gas, liquefied petroleum gas and renewable energy. From the perspective of environmental protection and natural resource conservation, the energy consumption structure in the residential sector is optimized.

This is generally in line with the economic rules. As Chenery pointed out, economic development means structural transformation [35], which is two-fold, *i.e.*, the upgrading of the existing industrial structure and the improvement of the urbanization level. There is a certain level of regularity on the changes of energy consumption structure due to the evolution of the economic structure and spatial structure. For example, with the speeding up of urbanization and industrialization, the proportion of natural gas in HEC in European and American countries accounts for more than 50% [19]. Based on the experience from the developed countries and the ambitious energy projects, such as the "west-east natural gas transmission project" and the "China-Russia natural gas pipeline project", the structure of HEC in China will be changed significantly [36]. Natural gas and electricity will dominate the energy consumption in the residential sector in the future. Correspondingly, the evolution of the structure of HEC will be accelerating until the charging curve of information entropy becomes stable and convergent with the acceleration of urbanization. Thereafter, HEC will enter a virtuous and stable development stage.

Table 1. Structure proportion and information entropy for HEC in China from 1990 to 2011.

Year	Coal (%)	Electricity (%)	Kerosene (%)	Liquefied Petroleum Gas (%)	Natural Gas (%)	Coal Gas (%)	*S*	*E*	*D*
1990	92.11	3.26	0.83	1.50	1.33	0.96	0.392	0.219	0.781
1991	90.99	3.69	0.75	1.96	1.35	1.25	0.435	0.243	0.757
1992	89.17	4.74	0.72	2.53	0.93	1.9	0.494	0.276	0.724
1993	87.46	5.45	0.63	3.04	1.42	2.01	0.553	0.308	0.692
1994	83.63	6.82	0.67	4.19	1.73	2.96	0.674	0.376	0.624
1995	82.66	7.55	0.54	5.55	1.57	2.13	0.688	0.384	0.616
1996	74.90	9.73	0.66	9.13	2.04	3.55	0.893	0.498	0.502
1997	71.21	11.18	0.68	9.80	2.09	5.04	0.98	0.547	0.453
1998	68.25	11.96	0.82	11.04	2.36	5.56	1.047	0.584	0.416
1999	66.33	12.67	0.84	11.06	3.28	5.83	1.095	0.611	0.389
2000	64.88	13.69	0.85	11.29	3.35	5.95	1.121	0.626	0.374
2001	63.45	14.92	0.85	11.02	4.21	5.54	1.15	0.642	0.358
2002	61.41	15.89	0.41	12.18	4.48	5.63	1.172	0.654	0.346
2003	60.10	16.88	0.38	12.68	4.57	5.39	1.188	0.663	0.337
2004	58.17	17.44	0.23	13.75	5.34	5.07	1.214	0.678	0.322
2005	56.24	19.87	0.21	12.77	5.93	4.98	1.238	0.691	0.309
2006	52.64	21.59	0.20	13.08	7.13	5.36	1.292	0.721	0.279
2007	47.33	24.2	0.09	13.58	9.26	5.53	1.356	0.757	0.243
2008	44.74	26.41	0.10	12.21	11.02	5.53	1.378	0.769	0.231
2009	43.31	28.43	0.09	12.14	11.18	4.85	1.374	0.767	0.233
2010	41.28	28.38	0.09	11.26	13.63	5.37	1.403	0.783	0.217
2011	39.45	29.59	0.17	11.85	15.09	3.86	1.402	0.782	0.218

Notes: *S* stands for information entropy; *E* stands for equilibrium degree; *D* stands for dominance degree.

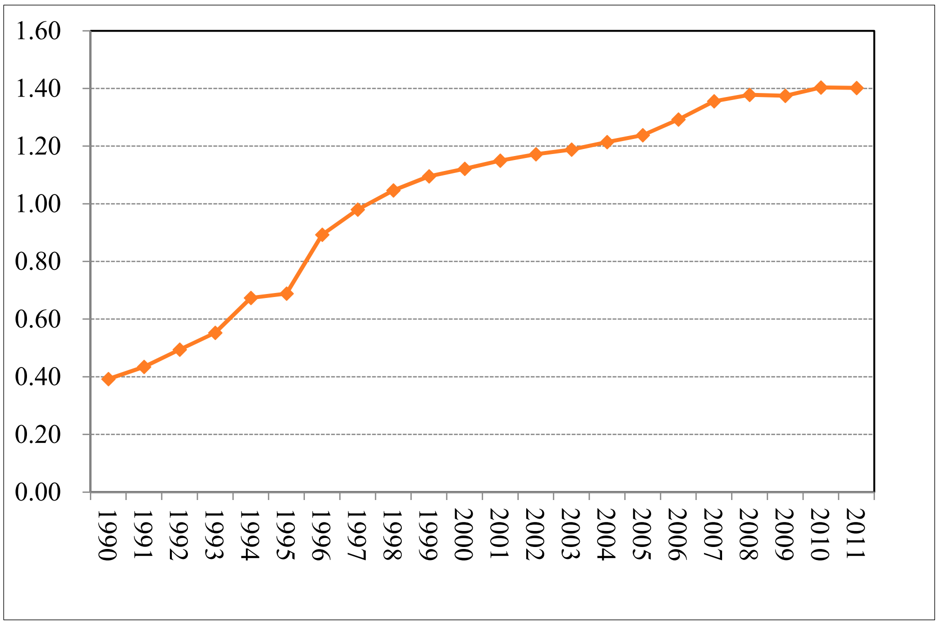

Figure 1. The trend for *S* of HEC in China from 1990 to 2011.

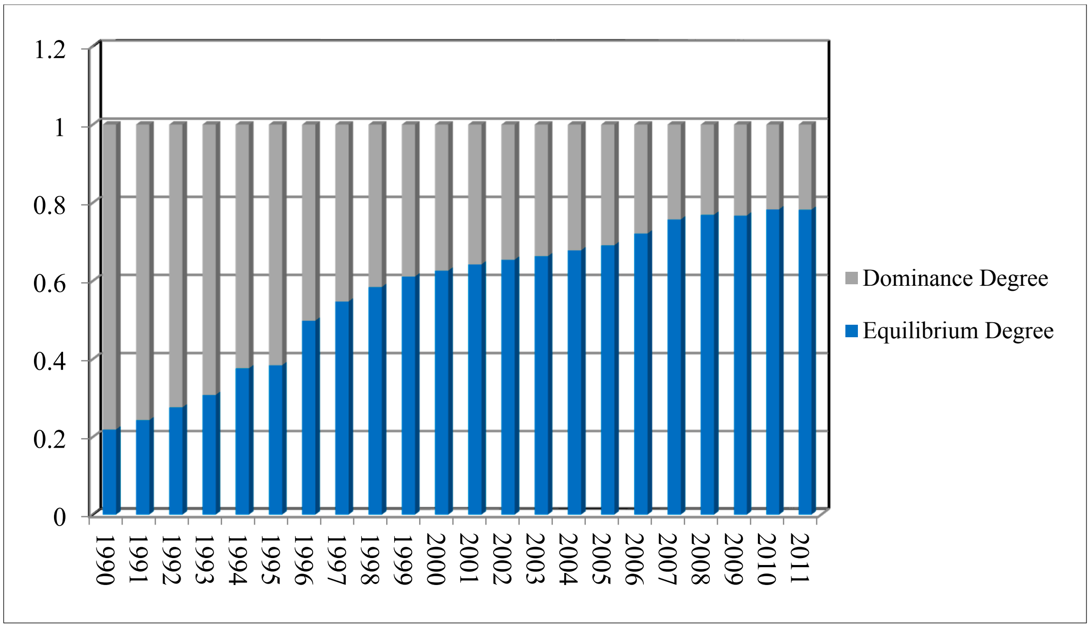

Figure 2. The trend for *E* and *D* of HEC in China from 1990 to 2011.

3.2. Results and Discussion of LMDI Model

Based on the statistics data from the China Statistical Yearbook, the statistical results of HEC in China from Zhao *et al.* [37] and Equations (5)–(9), the results of *LMDI* analysis are presented in Table 2.

Table 2. Results of HEC in China based on the *LMDI* model.

Year	ΔE_{pop}	ΔE_{act}	ΔE_{int}	ΔE_{str}	ΔE_{tot}
1991–1992	160.57	1033.22	−1777.78	−205.71	−789.7
1992–1993	150.46	784.95	−1544.81	−16.67	−626.07
1993–1994	142.43	850.93	−1162.76	−73.74	−243.14
1994–1995	132.67	676.82	−977.49	89.89	−78.11
1995–1996	122.43	881.21	−2313.43	−120.92	−1430.71
1996–1997	108.51	531.95	−1099.91	−166.20	−625.65
1997–1998	95.75	610.38	−707.94	−15.93	−17.74
1998–1999	86.84	774.09	−590.90	18.18	288.21
1999–2000	81.88	572.46	−537.89	−22.33	94.12
2000–2001	77.62	831.65	−697.81	439.03	650.49
2001–2002	75.47	1221.91	−518.70	−379.83	398.85
2002–2003	77.03	1045.50	697.16	63.37	1883.06
2003–2004	87.49	1221.72	915.13	72.34	2296.68
2004–2005	98.52	1531.38	−349.92	38.45	1,318.43
2005–2006	95.42	1773.25	−464.34	−16.82	1387.51
2006–2007	101.31	2292.09	−721.01	32.53	1704.92
2007–2008	105.68	1798.64	−1311.81	40.66	633.17
2008–2009	106.04	2495.35	−1381.95	113.33	1332.77
2009–2010	111.05	2263.15	−1048.64	138.89	1464.45
Total	2017.17	23,190.65	−15,594.8	28.52	9641.54

As shown in Table 2, the accumulated contribution of demographic effects to HEC is 2017.17 from 1991 to 2010. The accumulative contribution rate was about 21%, implying that population is one of main driving factors for the growth of HEC. From 1991 to 2002, demographic effects became lower due to the decrease of the annual population incremental rate. Thereafter, demographic effects increased smoothly. The contribution rate of demographic effects to HEC was 6.88%, 5.94%, 16.69%, 7.96% and 7.58% from 2006 to 2010. This indicated that the influence of demographic effects on household energy is limited if population is under control. These findings are basically the same as the conclusion of Fu *et al.* [38], Lenzen *et al.* [18,39] and Munksgaard *et al.* [40].

As shown in Table 2, all values for the effect of residents' income level were positive, which showed a direct impact on energy consumption. The accumulative contribution of residents' income level is 23,190.65 with a contribution rate of 240.53%. This indicated that the effect of residents' income level is one of the most critical driving factors for HEC, which proved the research conclusion of Mehrara [41] and He *et al.* [42]. With rapid economic development and the acceleration of urbanization, the residents' income will be further increased. Therefore, this is an issue that the government must pay attention to with respect to achieving a balance between the goals of income growth and energy savings. Economic development should not be achieved without the consideration of energy savings and environmental protection.

Most values for the effect of energy consumption intensity are negative from 1991 to 2010. Its accumulative contribution to the HEC was −15.5948 with a contribution rate of −161.75%. This indicated that the effect of energy consumption intensity is the key driving force to reduce HEC. However, the K-B hypothesis proposed by Khazzoom [43] and Brookes [44] discussed the rebound effect for the first time. They argued that energy efficiency improvements cannot reduce energy demand as much as expected [45,46]. The energy rebound effect was confirmed by some other studies [47–52]. A recent study showed that the residential household energy rebound effect aroused by efficiency improvement is comparatively small in China [52]. It is essential to continue adhering to the existing energy strategy and conservation routine in the macro perspective. With the implementation of policy instruments, such as carbon tax, subsidy policy for clean energy and ladder price for electricity consumption, the rebound effect can be restrained in the future [52]. It is a complex system to enhance household energy efficiency, which covers various aspects relevant to the daily activities of residents, such as housing, food, appliances, trips, *etc.* Residents should be encouraged to use energy-saving products. Energy-efficient policies should be designed to influence the behaviour of different energy consumers in both urban and rural areas, especially in the residential sector [53]. This could be achieved by market regulation or price regulation. For example, the government should strengthen urban infrastructure planning for the supply of district heat and gasification, as well as the necessary solar energy facilities [54,55]. In addition, China should implement different subsidy policies for energy-efficient home appliances between urban and rural regions to ensure the effectiveness of the future energy-efficient subsidy program. Secondly, the level of energy-saving technologies and energy efficiency standard of products should be improved to provide residents with better energy-efficient products. Thirdly, efforts are required to enhance the public awareness of sustainability issues and associated energy-efficient measures. It is necessary to cultivate proper living habits and energy-saving awareness, such as green transportation, green travel and sustainable consumption. Lastly, accelerating the transformation of the energy structure towards clean and low carbon, it is necessary to develop new and renewable energies, as well as clean energies, such as natural gas. Due to the gap between energy reserves and energy supply in China, it is necessary to import more natural gas in the future. The goals for new and renewable energy development have been established in China, *i.e.*, contributing to 15% of the total primary energy consumption by 2020. From 2011 to 2030, the newly added hydropower, wind power, solar power and nuclear power will surpass 1 billion kW, in which nuclear power will occupy 15%–20% [36]. With the development of new energy, renewable energy and low-carbon energy, China will reduce the reliance on traditional fossil fuel and consequently improve the environmental performance, as well as the energy sustainability [56].

The accumulative contribution and contribution rate of the effect of energy structure are 0.2852 and 2.96%, respectively. The annual contribution rate in the last four years was 1.91%, 6.42%, 8.50% and 9.48%, respectively. Although it has increased year by year, the effect of energy structure was not the main factor responsible for the growth of HEC based on the analysis of information entropy. As a result, the proportion of natural gas and electricity to the total energy consumption will increase, and the coal-dominated energy mix will be transformed step by step [17]. To sum up, the transformation of the energy consumption structure is inevitable as an outcome of urbanization. It is not feasible to achieve the goal of reducing the amount of HEC simply by reducing the effect of the energy structure.

4. Conclusions

The information entropy and equilibrium degree of the energy consumption structure gradually increasedfrom1991–2010 in China, while the dominance degree decreased in China. Similar to the developed countries, the structural evolution of HEC is inevitable, as coal will be reduced by using cleaner energy step by step. According to the analysis of the *LMDI* model, the accumulative contribution rate of demographic effects, the effect of energy consumption intensity, the effect of residents' income level and the effect of energy structure are 20.92%, 240.53%, −161.75% and 2.96%, respectively. This indicated that residents' income was the key driving factor to increase HEC, while the effect of energy intensity was the only driving factor to reduce the amount of HEC. Considering the acceleration of China's industrialization and urbanization, the economy will further develop, and residents' income will also increase. Therefore, enhancing the household energy efficiency is an important way to control the rapid growth of HEC effectively. From the perspective of sustainable energy policies, the government should enact specific plans and measures to improve the household energy efficiency. The level of energy-saving technologies and energy efficiency standards should be improved. Energy-saving awareness and consumption habits of the public should also be motivated via both incentives and penalties. New energy, renewable energies and low-carbon energy should be further promoted. It is crucial to formulate relevant new and renewable energy development planning. This helps to reduce the utilization of traditional fossil fuel, as well as to improve the energy efficiency and environmental performance of the residential sector.

HEC is a complex social system, which is associated with a number of uncertainties. For instance, it is well recognized that HEC is a social behaviour, which is based on the constitution of the family and their relationships. As a result, HEC is affected by a number of sociological factors, such as the awareness and attitudes toward energy consumption, which is difficult to quantify. Although *LMDI* is an established model to quantitatively identify the relative impact of different factors on the changes in energy consumption, however, due to different focuses, those sociological factors are not taken into consideration in *LMDI*. This has resulted in a certain degree of uncertainty. Similarly, all statistics were drawn from the Chinese Statistic Yearbook, which are the most reliable data in China. However, a certain level of biases exists due to errors during the data acquisition process. Consequently, uncertainties exist in every individual influencing factor. For instance, the income per capita (*R*) is significantly affected by the government policies due to the transition period of the economic system in China. This uncertainty associated with incomes will lead to uncertainties of energy consumption by household. In addition, related energy development plans were released in order to promote renewable energy development. However, the original targets may not be followed during the execution of plans. Therefore, there are uncertainties associated with the energy production and consumption. Indeed, making future projections based on historical data inherently carries a lot of uncertainties. In summary, HEC is a complex system that is associated with uncertainties. Future research opportunities exist to quantitatively analyse the impacts of these uncertainties in the HEC.

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Author Contributions

The study was designed by Qingsong Wang and Xueliang Yuan. The data from yearbooks and professional websites were retrieved by Ping Liu, Rujian Ma and Ruimin Mu. The results were analysed by Xingxing Cheng and Qignsong Wang. The literature related to the research was reviewed by Xueliang Yuan. Model design and English corrections were undertaken by Jian Zuo.

Conflicts of Interest

The authors declare no conflict of interest.

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