Driving Forces of Direct Carbon Emission From Urban and Rural Household Energy Consumption in China

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Abstract. In China, economic growth stimulates urban expansion and rural household income and consumption expenditure. The study calculates direct carbon emission from the energy consumption of Chinese urban and rural household and applies LMDI (Logarithmic Mean Divisia Index) decomposition model to identify the driving forces that influence variations in residential direct carbon emission. The result shows that direct carbon emission of urban residents is always higher than that of rural and there is still a significant gap between them. Income lever effect and energy structure effect present positive impact on both urban and rural residential emission, while the emission intensity effect plays a negative role. In addition, population size plays positive effect on urban residential direct carbon emission, while negative role on rural. The study concludes with the policy implications.

1. Introduction

During the past decades, China has transformed from an agriculture country to an industry country successfully, which accompanied with the growth of carbon emission dramatically. China has become the biggest carbon emission country in the world since 2007 as well as consumed the largest amount of energy from 2010. Upon the global pressure of curtailing the carbon emission, China has realized that he should take some measures to diminish the carbon emission as a responsible country. The share of residential consumption in total consumption increases yearly. And residential energy consumption also accounts for a fairly large proportion of the total final energy consumption (IEA 2005). With the rapidly Chinese economic growth and improvement of living standards, the demand for energy from residents would also rise in future, which will inevitably induce the energy carbon emission. Under this background, there are more and more focus on the residential energy consumption, its influence on carbon emission and the driving forces behind it.

There are a variety of progresses on residential energy consumption carbon factors decomposition. Some researchers decomposed the influencing factors with different methodologies, such as LMDI, STRIPAT model [1,2]. In addition, a series of decomposed factors impact residential energy consumption carbon emission, such as energy intensity, income lever, wealth, population and energy consumption structure [3,5].

This study also deals with the residential energy consumption carbon emission. Different from prior studies, this study uses data containing 19 different kinds energy (raw coal, cleaned coal, other washed coal, briquettes, coke, coke oven gas, other gas, diesel oil, other coking products, crude oil, gasoline, kerosene, fuel oil, LFG, refinery gas, nature gas, other petroleum products, heat, electricity) consumed by residents and splits the total residential energy consumption into urban and rural side. We apply the LMDI methodology, which has the pro of the decomposition outcomes without unexplainable residual subjects, to quantify the factors that would affect the variations in residential energy consumption carbon emission.

The remainder of this paper is organized as follows, section 2 describes the LMDI models used in this study and the data source, section 3 applies LMDI to decompose factors driving Chinese residential direct carbon emission and the last part is the conclusion and policy applications.
2. The LMDI Model and Data Source

The study focuses on Chinese residential direct carbon emission from energy consumption like electricity, coal, nature gas and so on. Here residential energy consumption direct carbon emission is written as C.

2.1 LMDI deposition methodology

\[ C^d = \sum_k f_k E_k \]  

(1)

Here \( C^d \) is the amount of direct carbon emission from urban or rural residents, \( E_k \) is the amount that k kind energy is consumed by residents. \( f_k \) is the carbon emission index of k kind energy.

\[ f_k = V_k \times D_k \]  

(2)

Here \( V_k \) is average low heat value, \( D_k \) is carbon factor.

According to the Eq. 2, various energy carbon emission indexes are calculated, the outcomes are list in table 1.

<table>
<thead>
<tr>
<th>Energy</th>
<th>Raw coal</th>
<th>Cleaned coal</th>
<th>Other washed coal</th>
<th>Briquettes</th>
<th>Coke Oven gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>1.9885</td>
<td>2.5055</td>
<td>0.7954</td>
<td>1.9885</td>
<td>3.0589</td>
</tr>
<tr>
<td>Energy</td>
<td>Other gas</td>
<td>Diesel oil</td>
<td></td>
<td>Crude oil</td>
<td>Gasoline</td>
</tr>
<tr>
<td>CI</td>
<td>0.9855</td>
<td>3.1748</td>
<td>2.779</td>
<td>3.0819</td>
<td>3.0006</td>
</tr>
<tr>
<td>Energy Fuel oil</td>
<td>LFG</td>
<td>Refinery gas</td>
<td>Nature gas</td>
<td>Heat</td>
<td>Electricity</td>
</tr>
<tr>
<td>CI</td>
<td>3.0819</td>
<td>3.1693</td>
<td>2.6522</td>
<td>2.1867</td>
<td>0.118</td>
</tr>
<tr>
<td>Energy Other petroleum products</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CI</td>
<td>2.8221</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Upon table 1, the unit of nature gasoline is KG/m\(^3\), heat is T/GJ, and electricity is T/MWH, except that, the unit of rest energy carbon indexes is KG/KG.

The paper adopts LMDI to decompose the driving forces of residential direct carbon emission.

\[ C^d_r = \sum_i C^r_i = \sum_i \frac{C^r_i}{E^r_i} \times \frac{E^r_i}{Y^r_i} \times Y^r \times P^r = \sum_i U_i \times S_i \times I \times M \times P^r \]  

(3)

\( C^r_i \) means carbon emission from i kind energy consumed by urban or rural residents, \( E^r_i \) is the amount of i kind energy consumed by urban or rural residents, \( E^r \) is the total amount of energy consumed by urban or rural residents, \( Y^r \) is urban or rural residential income, \( P^r \) is the population size of urban or rural. Based on Eq. 3, we can find that the variation of carbon emission is determined by five factors, as carbon energy emission index \( U_i = \frac{C^r_i}{E^r_i} \), residential energy consumption structure \( S_i = \frac{E^r_i}{E^r} \), energy income intensity \( I = \frac{E^r}{Y^r} \), income lever \( M = \frac{Y^r}{P^r} \) and population size \( P^r \). Because of the lack of data, carbon energy emission indexes are all the same during study period. Under this situation, carbon emission indexes can not be decomposed. Thus, the study will neglect that factor. The rest four factors are decomposed by LMDI method, the decomposed equations are as follows:

The energy structure effect:

\[ \Delta C_s = \sum_i \frac{C^T_{i} - C^0_{i}}{\ln C^T_{i} - \ln C^0_{i}} \ln \left( \frac{S^T_{i}}{S^0_{i}} \right) \]  

(4)
Energy intensity effect:
\[ \Delta C_e = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left( \frac{I^T}{I^0} \right) \]  

(5)

Income Effect:
\[ \Delta C_{in} = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left( \frac{M^T}{M^0} \right) \]  

(6)

Population Effect:
\[ \Delta C_p = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left( \frac{P^T}{P^0} \right) \]  

(7)

Residential energy consumption structure substitution, which indicates residential energy consumption structure evolution, can be concluded from Eq. 4. Eq. 5 energy income intensity effect is related to a series factors, like energy-saving investment, technology improvement. Eq. 6 and Eq. 7 evaluate the effect from income per capita and population size on carbon emission respectively.

2.2 Date source


3. The Decomposition of Driving Factors Contribute to Residential Direct Carbon Emission

3.1 Chinese residential energy consumption direct carbon emission

As shown in fig.1, the amount of urban and rural residential direct carbon emission growth rapidly during the research period. The growth trend of them tends to be the same, but the amount of urban residential emission is always higher than that of the rural. The emission from urban and rural resident rise from 184.72, 67.32 million tons in 1998 to 667.51, 350.78 million tons in 2012 respectively, with the growth rate of 10% and 12.6%. Based on fig.2, there is also a significant gap between urban residential carbon emission per capita and that of rural. The amount of former one is nearly double as the later one. There are some factors contribute to this phenomenon, such as the unbalance economic development, large distance of income lever and consumption lever within them.

![Figure 1. Residential CO2 emission.](image1)

![Figure 2. Residential CO2 emission per capita.](image2)

3.2 Decomposition Results

According to the residential direct carbon emission calculated and equation (4)-(7), this study
decomposes the driving factors, the outcome are list in Tab 2. In order to the convenience of writing, _u and _r indicate urban and rural residents decomposition results, respectively.

Table 2. Decomposition results from Chinese urban and rural residential direct carbon emission.

<table>
<thead>
<tr>
<th>Variety Period</th>
<th>Energy intensity</th>
<th>Energy structure</th>
<th>Income lever</th>
<th>Population Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>∆Ce_u</td>
<td>∆Ce_r</td>
<td>∆Cs_u</td>
<td>∆Cs_r</td>
</tr>
<tr>
<td>1998-1999</td>
<td>-6.15</td>
<td>1.8</td>
<td>10.11</td>
<td>32.75</td>
</tr>
<tr>
<td>1999-2000</td>
<td>-14.87</td>
<td>-0.87</td>
<td>47.11</td>
<td>32.55</td>
</tr>
<tr>
<td>2002-2003</td>
<td>-0.42</td>
<td>-11.1</td>
<td>24.34</td>
<td>23.71</td>
</tr>
<tr>
<td>2003-2004</td>
<td>9.74</td>
<td>50.15</td>
<td>50.51</td>
<td>59.79</td>
</tr>
<tr>
<td>2004-2005</td>
<td>-61.05</td>
<td>-14.33</td>
<td>152.22</td>
<td>80.81</td>
</tr>
<tr>
<td>2005-2006</td>
<td>-49.01</td>
<td>-24.9</td>
<td>53.77</td>
<td>101.37</td>
</tr>
<tr>
<td>2006-2007</td>
<td>-111.88</td>
<td>-42.67</td>
<td>147.67</td>
<td>25.72</td>
</tr>
<tr>
<td>2007-2008</td>
<td>-9.97</td>
<td>-35.99</td>
<td>309.43</td>
<td>-8.16</td>
</tr>
<tr>
<td>2008-2009</td>
<td>-158.27</td>
<td>9.04</td>
<td>532.71</td>
<td>1.76</td>
</tr>
<tr>
<td>2009-2010</td>
<td>-62.22</td>
<td>-24.05</td>
<td>140.18</td>
<td>12.13</td>
</tr>
<tr>
<td>2010-2011</td>
<td>-15.8</td>
<td>62.96</td>
<td>104.01</td>
<td>129.3</td>
</tr>
<tr>
<td>2011-2012</td>
<td>-151.32</td>
<td>-132.84</td>
<td>86.69</td>
<td>-15.96</td>
</tr>
<tr>
<td>1998-2012</td>
<td>-699.07</td>
<td>-187.18</td>
<td>1740.36</td>
<td>580.84</td>
</tr>
</tbody>
</table>

3.2.1 Energy intensity effect
The energy intensity effect fluctuates and is negative as a whole, which indicates that the variation of energy intensity is helpful for reducing direct carbon emission. This phenomenon may be due to the growth of energy consumption is slower than the increase of income. It also can be explained by the improvement of energy efficiency offsetting the growth of energy consumed. And the absolute value of energy intensity effect of urban is always larger than rural, which means due to the change of energy intensity effect, urban residential direct carbon emission curtails much more than that of rural.

3.2.2 Energy structure effect
Energy structure effect is the most important factor for the variation of urban residential direct carbon emission, while it is the second most important force for rural. The energy structure effect is positive within study period, which indicates that the change of energy structure will increase residential direct carbon emission gradually. Due to the variation of energy structure, urban and rural residential direct carbon emission increase 17.40 and 5.81 million tons, respectively. The result can be explained by the tendency of residential energy consumed structure towards high-energy style. The main fuel is electricity for both urban and rural residents nowadays. According to China Statistical Yearbook, the main fuel consumed by urban residents was dominated by electricity, with share rising from 42% in 1998 to 57% in 2012. The main fuel consumed by rural residents turned from raw coal in 1998 to electricity in 2012. Meanwhile more than 80% of total electricity is generated by coal power plants in China (Wei et al., 2008), which is thought to be a high-energy consumed way [6]. Moreover, shares of gasoline and diesel oil, which are proved to have the large carbon emission indexes in Tab.1, consumed in urban and rural residents total energy consumption grew from 6.4% to 16% and 2.3% to 11% during study period, respectively. In addition, the effect of energy structure of urban emission is still bigger than that of rural based on the result of decomposition. This is because that the urban residents consume more energy with high carbon emission index than rural residents.

3.2.3 Income lever effect
Income lever effect contributes significant positive effect on the increase of emission during the
study period, with shares rising from 16% to 30% for urban residents and 8% to 33% for rural residents. It could be explained by household income increasing rapidly in China. Based on the price of 2000, urban residents’ income per capita increased nearly 5 times, from RMB5450 to RMB32838. At the same time rural residents’ income per capita rose 3.84 times, from RMB2184 to RMB10583. Accompany with the increasing of income, an upgrade of consumption is taking place. The holding for vehicles, refrigerators, air conditioners and the other appliances are rising in China, which would induce the growth of energy consumption and carbon emission. And the contribution value of income lever effect for urban residents is always larger than that of rural residents. It’s may be because there is an expanding income gap, which expanded from 2.5 times to 3.1 times during the study period, within them.

3.2.4 Population size effect

Population size effect has positive and negative effect on urban and rural emission, respectively. This is mainly source from Chinese economic transition, diminishing birth rate, accelerating urbanization and the population transfer from rural areas to urban areas. The urban population size increased 71%, while rural population decreased 24% during the study period. For population is the base of producers and consumers, the variation of population would influence carbon emission directly. Moreover, with the social development and living standard improved, energy consumed and carbon emission keep growing year by year, the change of population will induce variation of total CO$_2$ emission.

4. Conclusion and Policy Implications

In China, economic growth, improved living standard and higher rate of urbanization will induce the increasing of household energy consumption which contributes to the rising of carbon emission. To balance the economic growth with environment sustainable development, it’s vital to concern on what factors driving residential energy carbon emission.

The paper calculates the amount of direct carbon emission from urban and rural residential energy consumed during 1998 to 2012 in China. The result indicates that there is a significant gap between the two. Then the study applies LMDI to analysis the driving forces of direct carbon emission from four aspects, as energy intensity, energy structure, income lever and population size. Energy intensity contributes the most to the diminishes of residential carbon emission, while Energy structure and income lever contribute most to the increase of emission for urban and rural residential emission, respectively. Population size increases the urban residential carbon emission and decreases that of the rural.

The suggestions are made as follows:

Because of the effective of energy intensity factor, we should increase energy transfer rate and improve technology to enhance energy efficiency further.

Due to China is a scare country in oil and 60% of oil depend on the importation as well as the use of oil that has high carbon emission index increases rapidly, which would have a great pressure on Chinese environment. Thus, we should change the energy consumption structure with enhancing the share of green energy used in households’ daily energy consumption.

With living standard improved and income lever increased, residents are inevitable to consume more and more appliances, we can concern label the appliances with energy information to enhance the residents’ conscious of energy environmental protection. So that residents would reduce the consumption for high-energy appliances. At last, we should coordinate the process of urbanization to keep the population in urban and rural at a sustainable way and rationalized the household direct carbon emission.

Reference


