Analysis of direct carbon footprint of residents' consumption in Inner Mongolia Autonomous Region

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Abstract: This paper makes an in-depth study and analysis of the direct carbon footprint of residents' consumption in Inner Mongolia Autonomous Region based on the IPCC method and the decomposition model of the Logarithmic Mean Divisia Index (LMDI) from 2000 to 2016. The results show that 1) The overall consumption of urban residents and the direct carbon footprint per capita in Inner Mongolia Autonomous Region from 2000 to 2016 were much higher than that of rural residents. 2) The consumption of residents was closely related to the energy structure, and coal, heat and electricity consumption occupied the main position. 3) According to the analysis of the LMDI decomposition model, the energy structure factors contributed negatively to the direct carbon footprint of residents except 2003-2006. 4) Energy efficiency and economic development are important factors to stimulate the direct carbon footprint of residents. Finally, we provide reasonable suggestions for residents' consumption, energy saving and emission reduction.

1. Introduction
The recent situation of global warming, which is widely concerned by the international community, is not optimistic. China's work on carbon emission reduction has been mainly focused on the industrial sector, with little attention paid to the carbon footprint caused by household consumption [1]. According to statistics, the total carbon footprint of residents in 1997-2007 accounted for 52~63% [2]. However, the total carbon footprint of Inner Mongolia Autonomous Region is in the stage of sustained growth, and rapidly growing at a rate of more than 10% after the 21st century [3]. One of the main reasons is the rapid development of the secondary industry, and the improvement of residents' consumption level is also an important factor. Therefore, this paper conducts research and analysis on direct carbon footprint of residents' consumption in Inner Mongolia Autonomous Region, comprehensively analyzes the carbon footprint behavior of urban and rural residents, and puts forward reasonable suggestions on consumption, energy conservation and emission reduction.

2. Research methods

2.1 The calculation method of direct carbon footprint
The direct carbon footprint of household consumption is the carbon footprint generated by consumer energy commodities, including the carbon footprint of direct energy consumption generated by activities such as residential, travel and diet [4-6]. The types of energy consumed include primary energy: raw coal, diesel, gasoline, etc. Secondary energy: heating power and electric power. Heating power and electric power can be used as a direct source of household carbon footprint when
researched in carbon footprint [7-9].

The Carbon Emission Factor Method (IPCC) is simple and easy to use, and is measured by the total consumption of different types of energy in different industries and the carbon emission coefficient of different types of energy [10]. The calculation formula is as follows:

\[ CF^d = \sum_{i=1}^{n} M_i \times EF_i \]  

\[ (1) \]

\( CF^d \) is the direct carbon footprint of household consumption (t); \( M_i \) as the i-type fuel (t); \( EF_i \) is the carbon footprint coefficient (kg/GJ) for the i-th fuel [4].

According to the types of direct energy consumed by residents in Inner Mongolia Autonomous Region, the carbon footprint coefficient of the corresponding energy can be collected on the basis of reference carbon emission coefficient method [11], the coefficient is shown in Table 1.

Table 1. Direct Carbon Footprint coefficient of household consumption

| Energy       | Raw Coal | Coke | Liquefied Petroleum Gas | Diesel | Natural Gas | Other Coal Washing |
|--------------|----------|------|-------------------------|--------|-------------|-------------------|
| Coefficient  | 1.98     | 3.04 | 3.16                    | 3.16   | 2.18        | 0.79              |
| (kgCO₂/kg)   |          |      |                         |        |             |                   |

| Energy       | Briquette | Coke Oven Gas | Other Gas | Gasoline | Heating Power | Electric Power |
|--------------|-----------|----------------|-----------|----------|---------------|----------------|
| Coefficient  | 2.04      | 0.74           | 0.23      | 2.98     | 0.11          | 0.968          |
| (kgCO₂/kg)   |          |                |           |          |               |                 |

2.2. Analysis method of influencing factors
The Logarithmic Mean Divisia Index (LMDI) is commonly used in the analysis of influencing factors of carbon footprint. The LMDI decomposition model is the most representative carbon emission decomposition method. The decomposition method under this model is relatively stable and complete, and it does not rule out the investigation of interference items [12].

3. Measurement and analysis of direct carbon footprint residents' consumption
According to the above method, the direct carbon footprint of residents' consumption in Inner Mongolia Autonomous Region is calculated and analyzed. Energy consumption data from the Inner Mongolia Autonomous Region Statistical Yearbook [13]. The results are analyzed as follows.

3.1 Analysis of the overall results of direct carbon footprint on household consumption
As shown in figure 1, the direct carbon footprint of household consumption increased 6.86 times over 16 years. In view of the difference between urban and rural residents' direct carbon footprint in Inner Mongolia, the direct carbon footprint of urban residents' consumption is larger than that of rural residents, which is closely related to the increase of urbanization rate year by year. And urban residents consumption level is far higher than rural residents are closely related. In 2000, China implemented the "Western Development Policy ", Inner Mongolia accelerated economic development, but also brought great pressure on the environment. Overall, the direct carbon footprint of total household consumption increased from 2000 to 2004, with a significant increase from 2004 to 2006. This is related to the reform of Inner Mongolia's energy structure and the improvement of energy efficiency; 2006-2010 is the period of the 11th Five-Year Plan, with rapid economic development and an accompanying growth trend; 2012-2013 has declined sharply, which is related to the 12th Five-Year Plan, during which China emphasizes green development, Inner Mongolia strongly responds to the call of national state policy and has achieved remarkable results; After 2013, it has risen at a relatively low rate, because as the opening year for the full implementation of the spirit of the 18th National
Congress of the Party, the relevant policies require further expansion of domestic demand and efforts to build a "two-type society ".

**Figure 1** Direct Carbon Footprint of residents in Inner Mongolia

### 3.2 Analysis of the carbon footprint and energy structure of residents

The energy in Table 1 is mainly divided into five categories: coal, oil, natural gas, heat and electricity. In 2000-2012, the proportion of carbon footprint of coal consumption in Inner Mongolia Autonomous region was between 35% and 70%, accounting for the largest proportion. Coal is the most important consumer energy [13-15] in Inner Mongolia; The proportion of electricity and heat is less than that of coal, between 10% and 33%, because the amount of heat and electricity in Inner Mongolia's various energy reserves is much smaller than that of coal, and the mining and transformation of both require greater material support, so consumption has remained low for many years and has not fluctuated significantly; The carbon footprint of natural gas and oil consumption is below 9%, because natural gas as an emerging energy source was only listed as the main consumer energy in 2002, and oil production is very small. Between 2012 and 2016, the share of carbon footprint in coal consumption declined significantly, ranging from 10% to 50%, as Inner Mongolia made resource conservation and environmental protection an important prerequisite for economic and social development; The proportion of heat, electricity and oil products eventually stabilized at 33%-52%, 15%-30%, 3%-10%. This is due to the increase in other energy demand due to the decrease in coal demand; Although there is an increase in natural gas, the trend is not obvious because of the small population change.

**Figure 2** Proportion of residential energy consumption structure in Inner Mongolia

### 3.3 Analysis of urban-rural differences in the direct carbon footprint of household consumption

Inner Mongolia urban and rural dual structure phenomenon is more significant. Therefore, it is necessary to compare and analyze the urban and rural differences of per capita carbon footprint of residents, as shown in figure 3. It is known that the direct carbon footprint of per capita consumption of residents fluctuates between 1.97 and 3.21. Between 2000 and 2003, the urban-rural ratio showed a tortuous increase. The reason is that the consumption level of urban residents is much higher than that
of rural residents, and the number of urban population before 2006 is smaller than that of rural residents, so the per capita carbon footprint of urban residents is higher than that of rural residents. Urban-rural ratio fluctuations declined from 2003 to 2009 and increased from 2009 to 2012.

As a result, urban coal consumption has fluctuated and declined from 2003 to 2009, while rural coal consumption has increased, even in 2006 to 2008, compared with urban coal consumption, which was basically flat in 2009, while urban coal consumption began to be much higher than rural in 2010 [13]; In 2011, the Inner Mongolia Autonomous Region focused on environmental protection, so that the direct carbon footprint of residents' consumption began to decrease, and because urban environmental protection facilities were more perfect than rural areas, the direct carbon footprint of urban residents' consumption was much lower than that of rural areas, so that the urban-rural ratio decreased steadily from 2012 to 2016.

Figure 3 The urban-rural ratio of per capita direct carbon footprint from Inner Mongolia

4. Analysis of factors affecting the direct carbon footprint of household consumption

Based on the above results, the LMDI model is used to quantitatively analyze the effects of economic development, energy structure, energy efficiency and population factors on carbon footprint, and the relationship between carbon footprint and its influencing factors is analyzed.

Carbon footprint is closely related to energy structure, energy prices, per-capita income and other factors. Based on this, the Inner Mongolia Autonomous Region's carbon footprint Divisia index decomposition model is constructed. The specific expression is as follows:

\[ C = \sum_i C_i = \sum_i C_i \times E_i / E \times E / Y \times Y / P \times P \]  

(2)

In the formula, \( C_i \) is the carbon footprint of the \( i \)-th energy; \( E_i \) is the consumption of the \( i \)-th energy; \( E \) is the total energy consumption of residents; \( Y \) is the residents' consumption; \( P \) is the population. To clarify the impact of various factors on changes in carbon footprint:

\[ F_i = C_i / E_i, \quad S_i = E_i / E, \quad I = E / Y, \quad R = Y / P \]  

(3)

The \( F_i \) is the carbon footprint of the \( i \)-th energy source; the \( S_i \) is the proportion of the first energy source to total energy consumption; the \( I \) is the purchasing power of household income relative to energy; the \( R \) is the level of per capita consumption; and the \( P \) is the population size. Thus:

\[ C = \sum_i F_i S_i I R P \]  

(4)

By the formula (4), the change of \( C \) is related to \( F_i, S_i, I, R \) and \( P \). In order to eliminate the decomposition allowance, the LMDI algorithm proposed by Ang [16] and Choi [17] is adopted. Changes in the carbon footprint of the \( t \)-period relative to the base period are as follows:

\[ \Delta C = C^t - C^0 = \sum_i F_i^t S_i^t I^t R^t P^t - \sum_i F_i^0 S_i^0 I^0 R^0 P^0 = \Delta C_F + \Delta C_S + \Delta C_I + \Delta C_R + \Delta C_P \]  

(5)

\[ \Delta C_F = \sum_i (C_i^t - C_i^0) / \ln (C_i^t / C_i^0) \ln F_i^t / F_i^0 \]  

(6)
Among them, $t$ indicate period $t$, $0$ represents the base period, $C_t$ is the $t$ carbon footprint, $C_0$ the initial carbon footprint, $\Delta C_F$, $\Delta C_S$, $\Delta C_I$, $\Delta C_R$, $\Delta C_P$ are the contribution values of five drivers to the change of carbon footprint. Because $F_i$ is a fixed value, $\Delta C_F = 0$, Therefore, the main factors affecting the carbon footprint are $S$, $I$, $R$ and $P$. Based on formula (7)~(10), the results are shown in figure 4.

$$\Delta C_S = \sum_i (C_t^i - C_0^i) \ln (C_t^i/C_0^i) \ln S_t^i/S_0^i$$

$$\Delta C_I = \sum_i (C_t^i - C_0^i) \ln (C_t^i/C_0^i) \ln I_t^i/I_0^i$$

$$\Delta C_R = \sum_i (C_t^i - C_0^i) \ln (C_t^i/C_0^i) \ln R_t^i/R_0^i$$

$$\Delta C_P = \sum_i (C_t^i - C_0^i) \ln (C_t^i/C_0^i) \ln P_t^i/P_0^i$$

Figure 4 Trend chart of contribution value of factors to consumption carbon emission

The level of economic development has been positive. The growth rate of the carbon footprint in 2005-2013 was first slowed down and then accelerated. After 2014, the contribution value decreased significantly and increased at a slower rate. It shows that Inner Mongolia began to pay attention to the overall quality of economic development after the 11th Five-Year Plan. The energy structure is positive in the early stage and negative in the later stage. From 2000 to 2004, Inner Mongolia vigorously developed coal and other resources, from negative contribution to positive contribution; From 2005 to 2012, the contribution value gradually decreased and transformed into negative contribution. The reason is that the energy structure of Inner Mongolia is dominated by coal, and the change is small. In the past ten years, negative contributions have appeared, indicating that Inner Mongolia began to attach importance to the adjustment of energy structure. Energy efficiency is contributing positively and is basically stable except for sudden changes in 2004 and 2013. During the 10th Five-Year Plan period, increasing energy exploitation led to economic development, energy prices decreased and energy efficiency decreased, resulting in an increase in the contribution of energy efficiency. This problem was noted during the 11th Five-Year Plan, but the reduction was small and the contribution value was still positive. Population factor has a positive contribution, which indicates that with the increase of population size, the carbon footprint is increasing continuously, but its contribution is small compared with economic development.

According to the above analysis, the four factors that affect the consumption carbon footprint of Inner Mongolia residents can be divided into two categories, one is the pull factor, that is, energy efficiency, economic development and population factors, the other is the inhibition factor, that is, energy structure factor.

5. The conclusion and recommendations

5.1 Conclusions
This paper uses IPCC and LMDI to analyze and study the direct carbon footprint of residents'
consumption from 2000 to 2016 in Inner Mongolia Autonomous region. The direct carbon footprint of urban residents is higher than that of rural residents from 2000 to 2016. Energy efficiency, economic development and population size are the "three factors" driving the growth of direct carbon footprint, while energy structure is the most important factor to restrain the growth of direct carbon footprint.

5.2 Recommendations
The rapid economic development in Inner Mongolia has resulted in an increase in carbon footprint year by year. Household consumption carbon footprint is an important component of energy saving and emission reduction. The energy structure has a negative contribution to the direct carbon footprint of Inner Mongolia residents, so changing the energy use structure is particularly important to reduce the carbon footprint. Economic development is the main factor to promote the growth of direct carbon footprint of Inner Mongolia residents, so we should actively guide the residents' healthy and reasonable consumption pattern, encourage the residents to travel green, and make the Inner Mongolia Autonomous Region truly achieve green and sustainable development.

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