Analysis of factors affecting CO_2 emissions by civil buildings in China's urban areas

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Abstract

Civil buildings in urban areas are one of the main sources of CO_2 emissions. Many factors in civil buildings cause CO_2 emissions to increase in China's urban areas. Factors that have influenced CO_2 emissions from civil buildings in Chinese cities between 1997 and 2007 are studied using the Logarithmic Mean Divisia Index method. The following factors influence the increase of CO_2 emissions: urban population, per capita floor space, building structure, building energy intensity and carbon emission coefficients. The results show that, between 1997 and 2007, increase in CO_2 emissions by civil buildings in China's urban areas was largely driven by the increasing urban population and per capita floor space, which have contributed 56 and 87%, respectively, and present a trend of significant increase. The structural proportion change of areas of residential buildings and public buildings caused less of an impact of CO_2 emissions. The reduction in the intensity of energy consumption of buildings is the major factor that could deter the increase in the rate of CO_2 emissions, contributing −45%. However, this deterrence is slowing down. While maintaining the speed of urbanization of China, the key measures to suppress the increase in civil building CO_2 emissions in urban areas are to reduce the intensity of building energy consumption and to control the per capita floor space.

Keywords: civil buildings; CO_2 emissions; Influencing Factors; LMDI; China

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1 INTRODUCTION

Building carbon emissions is one of the main areas of greenhouse gas emissions in the world. At present, China is experiencing rapid urbanization and the construction boom that it brings about, and the new building area of China accounted for about half of that of the world. The operations of civil buildings in the cities (non-industrial buildings) consume ∼22–25% of China's total power generating capacity. As China's urbanization level and people's living standards continue to improve, the proportion of building energy consumption will keep rising. Jiang Yi ([1]) predicted that the total amount of the new building area constructed annually in China's towns and cities would remain at 1 billion square meters each year. By 2020, an additional 10 to 15 billion square meters of construction area for civil use will be built, leading to an increase in building energy consumption, which will exert a huge pressure on China's energy supply. The study of changes in the overall building energy, however, is more important to decide the whole energy-saving direction to be taken. In this paper, five factors, the urban population, the per capita floor area, the building structure, the intensity of building energy consumption and emission factors, are discussed to analyze the impact on the increase of carbon emissions by civil buildings in China's rapid urbanization process.

2 RESEARCH METHODS AND DATA SOURCES

2.1 Research methods

Factor decomposition is used to decompose and analyze the civil building energy consumption in urban areas. Hulten [2]

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gave a detailed description of this method. Boyd *et al.* [3, 4] proposed the multiplication and addition of the Arithmetic Mean Divisia Index, which was later standardized by Park [5]. Ang and Liu [6] proposed the Logarithmic Mean Divisia Index (LMDI). According to Ang [7] in the 1978–2003 literature reviews, LMDI is the best of all decomposition methods, as it eliminates the residual of the operating results. In this paper, LMDI is used to decompose and analyze the civil building carbon emissions in the urban areas between 1997 and 2007. The following steps show how this approach can be achieved:

Let C be the total civil building carbon emissions from civil buildings in urban areas, and the following equation can be used:

$$\begin{aligned} C &= \sum_{ij} C_{ij} = \sum_{ij} P \times \frac{S}{P} \times \frac{S_i}{S} \times \frac{E_i}{S_i} \times \frac{E_{ij}}{E_i} \times \frac{C_{ij}}{E_{ij}} \\ &= \sum_{ij} P \times A \times T_i \times I_i \times M_i \times U_{ij}, \end{aligned} \tag{1}$$

where P is the urban population; $A = S/P$ is the per capita urban floor space and S is the total urban floor space; $T_i = S_i/S$ is the ratio of different types of floor space in the total area and i is the type of buildings; $I_i = E_i/S_i$ indicates the energy consumption per unit area of different types of buildings and also means the building's energy consumption intensity and E_i is the total energy consumption by i-type buildings; $M_i = E_{ij}/E_i$ indicates the j-type energy proportion of energy consumption, C_{ij} is the carbon emissions of i-type buildings from j-type energy and C is the total carbon emissions of civil buildings. Because the energy type and proportion of buildings remain unchanged, M_i could be left out. We find that (1) can be simplified to the following:

$$\begin{aligned} C &= \sum_{i} C_{i} = \sum_{i} P \times \frac{S}{P} \times \frac{S_i}{S} \times \frac{E_i}{S_i} \times \frac{C_i}{E_i} \\ &= \sum_{i} P \times A \times T_i \times I_i \times U_i \end{aligned} \tag{2}$$

According to the LMDI approach, the total energy consumption during the initial period is C0, and the time T is CT. 'Multiplicative decomposition' and 'additive decomposition' are used to decompose the change rate of factors as follows:

$$D_{\text{tot}} = \frac{C^T}{C^0} = D_{\text{pop}} D_{\text{area}} D_{\text{str}} D_{\text{int}} D_{\text{emf}} \tag{3}$$

$$\begin{aligned} \Delta C_{\text{tot}} &= C^T - C^0 \\ &= \Delta C_{\text{pop}} + \Delta C_{\text{area}} + \Delta C_{\text{str}} + \Delta C_{\text{int}} + \Delta C_{\text{emf}} \end{aligned} \tag{4}$$

Subscripts pop, area, str, int and enf represent urban population effect, per capita floor area effect, building structure effect, building energy intensity effect and emission factor effect. The LMDI computing formulae are as follows:

$$\Delta C_{\text{pop}} = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln\left(\frac{P^T}{P^0}\right) \tag{5}$$

$$\Delta C_{\text{area}} = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln\left(\frac{A^T}{A^0}\right) \tag{6}$$

$$\Delta C_{\text{str}} = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln\left(\frac{T_i^T}{T_i^0}\right) \tag{7}$$

$$\Delta C_{\text{int}} = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln\left(\frac{I_i^T}{I_i^0}\right) \tag{8}$$

$$\Delta C_{\text{enf}} = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln\left(\frac{U_i^T}{U_i^0}\right) \tag{9}$$

It is defined such that when $a \neq b$, $L(a, b) = (a-b)/(\ln a - \ln b)$, and when $a = b$, $L(a, b) = a$.

2.2 Data sources

The data on population and the civil building areas in the cities are obtained from the China Statistical Yearbook between 1998 and 2008. The civil buildings in urban areas are divided into two categories, residential buildings and public buildings. The areas of public buildings are obtained from the year-end housing area in the cities of different regions minus the residential building areas built in the year. The existing statistics and survey results are consulted, and building energy consumption data are obtained from the 1998–2008 China Energy Statistical Yearbook. Since China's current energy statistical model depends on 'factory method' (reference [1]) for statistics and data release, no statistical system is available for building energy consumption. As a result, there are some research results with a view of CO_2 emission factors affecting single buildings, but there are very few on the influential factors of carbon emissions from civil buildings.

According to China Energy Statistical Yearbook, energy consumption by urban residential buildings refers to the total energy consumption of urban residents minus the energy consumption associated with transport that urban residents use (transport energy consumption concerns gasoline, kerosene and 95% diesel). Energy consumption by public buildings refers to tertiary industrial energy consumption minus energy consumed on transportation, storage and postal sector and concerns 95% gasoline, 50% diesel and other oils. Energy emission factors are the default value from the Intergovernmental Panel on Climate Change (IPCC) [8]. Electricity emission factor depends on the type and the sum power consumption, the date of which comes from the 1998–2008 China Energy Statistical Yearbook, and the output of plants can be used to calculate the electricity emission factor from 1997–2007 (see Figure 1). Data are shown in Table 1.

3 RESULTS AND DISCUSSION

The factors causing the increase of civil building carbon emissions in China's urban areas between 1997 and 2007 are decomposed using Equations (2) to (9). Figure 2 shows the additive composition of the urban population effect, urban per capita floor space effect, building structural effect, building energy consumption intensity effect and emission factor effect, which impact the increase of civil building energy consumption in urban areas.

3.1 Factors affecting total carbon emissions of urban civil buildings

The total carbon emissions by civil buildings in Chinese cities keep growing and increased 1.1 times over the 10 years between 1997 and 2007, with an average annual growth of 7.3%. The results based on the additive decomposition in Figure 2 show that ΔC_{pop} for urban population and ΔC_{area} for per capita floor space are the main positive factors. Before 2001, the urban population effect is the main influencing factor of increase in carbon emissions. This state changed after 2001 and per capita floor space has become the main influencing factor. We see that ΔC_{str} for building structural effect and ΔC_{enf} for emission factor effect have little impact on carbon emissions in these years, and ΔC_{int} for building energy consumption intensity is the main negative factor of carbon emissions by civil buildings. (Figure 3).

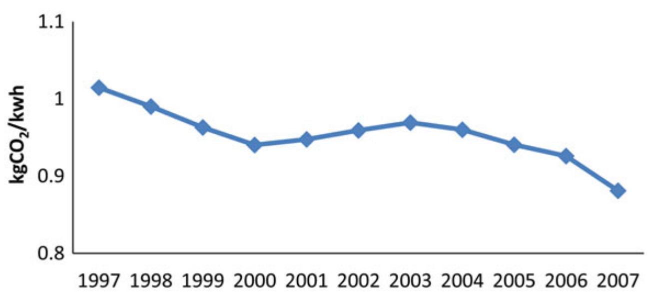

Figure 1. *The electricity emission factor of China from 1997–2007.*

3.2 Effect of urban population

Between 1997 and 2007, China's urban population grew from 390 to 590 million. The growing population is one of the major factors driving up carbon emissions by civil buildings in urban areas and contributes to the increase in building carbon emissions by adding 15.6 million t per year. The contribution in 2007 amounted to 56% of the total carbon emissions.

3.3 Effect of urban per capita floor space

The floor space of civil buildings in China's urban area increased 2.8 times to 18.6 billion square meters in 2007 from 6.55 billion square meters in 1997. The per capita floor area increased to 31.3 square meters from 16.6 square meters. Between 1997 and 2001, the per capita floor space had a smaller impact on building carbon emissions than the population growth. From 2001 onward, the impact of the per capita floor space was greater than that of the urban population growth, and this trend has been accelerating. The growth trend indicates that the per capita floor space is going to be the main factor that influences building carbon emissions in the future.

3.4 Effect of building structure

Between 1997 and 2007, the ratio of residential buildings to public buildings had little impact on building energy consumption. Between 1997 and 2001, the positive effect of proportion of building structures was relatively small. Between 2001 and 2007, the effect of the proportion of building structures became negative, owing to the increase in the proportion of residential buildings.

3.5 Effect of building energy intensity

Between 1997 and 2007, ΔC_{int} remained negative, indicating that the reduced energy intensity of buildings was the main factor that reduced carbon emissions by buildings. As can be seen from Figure 2, the intensity of building energy consumption between 1997 and 2002 declined, indicating that the intensity of building energy consumption had significantly inhibited

Table 1. *Civil building energy consumption in Chinese cities, 1997–2007 (661 cities).*

Year	Urban population (M)	Area of residential buildings (100 million m^2)	Area of public buildings(100 million m^2)	Residential building energy consumption (MTCE)	Public building energy consumption (MTCE)	Carbon emissions (Mt)
1997	394	36.2	29.3	53	37	325
1998	416	39.7	31.2	52	38	331
1999	437	41.7	31.8	53	38	327
2000	459	44.1	32.5	54	39	334
2001	481	66.5	43.6	55	40	352
2002	502	81.8	50	59	44	380
2003	524	89.1	51.8	66	51	442
2004	543	96.2	52.9	74	61	501
2005	562	107.7	56.8	79	66	563
2006	577	112.9	61.6	87	73	623
2007	594	120	66	98	79	675

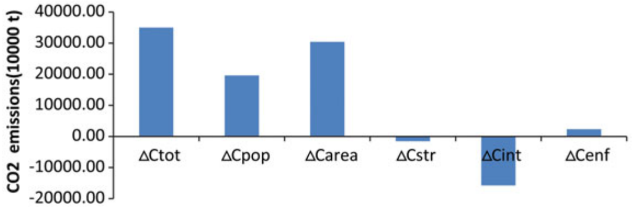

Figure 2. *Additive decomposition of civil building carbon emissions in Chinese cities in 2007.*

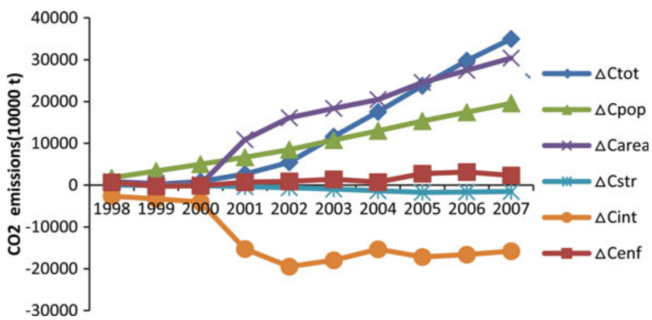

Figure 3. *Decomposition of factors affecting civil building carbon emissions in Chinese cities between 1997 and 2007.*

the increase of civil building carbon emissions in cities. Between 2002 and 2007, the intensity of building energy consumption rose, indicating the building energy consumption intensity was weakened in suppressing the growth of carbon emissions by civil buildings in urban areas.

3.6 Effect of emission factors

Between 1997 and 2007, the emission factors had little impact on building carbon emissions. Because the emission factors are the default value from IPCC 2006 and the electricity emission factor decreases every year, the total emission factor has little effect on building carbon emissions.

3.7 Future scenario predictions

According to the time series analysis method, when the urbanization rate is 70%, the population of urban areas in China will become ~0.95 billion, accounting for 70% of the total population of 1.4 billion. If the per capita floor space keeps increasing at the current rate and building structures are not changed, then building energy intensity should be kept down to below 20% of that in 2007 to effect a control on the CO_2 emissions. It will be very hard to achieve this target. As a result, controlling the per capita building area and development of green buildings are the most effective ways to control carbon emissions.

4 CONCLUSION AND RECOMMENDATIONS

In this paper, the LMDI approach is used to decompose and analyze the carbon emissions by civil buildings in China's urban areas. The results show that carbon emissions of civil buildings in China's urban areas in 2007 increased by 350 million tons over those in 1997. The increase of China's urban population and per capita floor space are the main factors affecting the increase of carbon emissions (196 million tons and 304 million tons, respectively) by civil buildings in the Chinese cities, contributing 56 and 87%, respectively. In particular, the increase in the per capita floor space is dominating the trend, while the proportion of building structures has little impact on the total carbon emissions by buildings. Meanwhile, the reduced intensity of energy consumption by buildings is the main factor that suppresses the growth of total carbon emissions, contributing -45%. It is worth noting that the effect resulting from the reduced intensity of carbon emissions is becoming weaker. By 2020, as China's level of urbanization becomes higher and the urban population and the new building area experience faster growth, there is a need to reduce the intensity of energy consumption by buildings significantly in order to have the increase of civil building carbon emissions under control. The conclusion shows that the Ministry of Housing and Urban-Rural Development should control the increase of per capita floor space and in conjunction with National Energy administration control the rate of increase in building energy intensity.

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