Research on Regional Difference of Energy Consumption in Production Stage of Civil Building Materials based on Theil Index

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Abstract. Total quantity control is an important means to achieve the goal of building energy conservation in China, but the statistical method of energy consumption data in the production stage of civil building materials has not been established yet. This paper firstly constructs the calculation method of energy consumption in the production stage of civil building materials according to the usage amount of building materials, and then obtains the data of energy consumption in the production stage of civil building materials from 2008 to 2017 according to the statistical yearbook. Then, 30 provinces and cities in China are divided into 3 regions. According to Theil index analysis method, the regional differences of the production energy of China's civil building materials from 2008 to 2017 are calculated. According to the calculation results, China's energy consumption in the production stage of civil building materials shows an overall trend of convergence growth, but the intra-regional difference is greater than the inter-regional difference. The Theil index is the highest in the western region, but the contribution rate of the Theil index is the largest in the eastern region.

1. Introduction
In recent years, with the acceleration of Urbanization in China, the contradiction between energy and resource constraints and urban development has become increasingly prominent. Solving these two problems is of vital importance to improving people's living standard and optimizing energy structure. According to the Tsinghua university's-Report of China's Building Energy Efficiency Development(2020) shows that China's total construction area nearly 60.1 billion m² in 2008, including 47.4 billion m² of residential building, 12.8 billion m² of public building. Among them, building energy consumption accounts for about 22% of the total energy consumption of the whole society, and the energy consumption in the construction stage accounts for about 11% of the total energy consumption of the whole society. In 2018, the energy consumption of China's civil building construction is about 520 million tce [1], so the building sector has a huge potential to reduce energy consumption, and it is necessary and urgent to reduce energy consumption in the building sector.

Civil building energy consumption includes building construction energy consumption, building operation energy consumption and building demolition energy consumption. Construction energy consumption includes building material production energy consumption, building material
transportation energy consumption and building construction energy consumption \cite{2}. According to statistical data, the total energy consumption in the production phase of civil building materials accounts for more than 80% of the energy consumption in the construction phase, and 10%-15% of the full life cycle of the building \cite{5}. The energy-saving potential of the building materials production stage is huge, and studying the energy consumption of the building materials production stage is of great significance to the society as a whole to achieve energy conservation goals. However, related research on energy consumption in the production phase of building materials is scarce, and related research is still in its infancy. The calculation and statistical methods of energy consumption data have not yet been established. This article constructs a statistical method to obtain energy consumption data from 2008 to 2017, and then uses the Theil Index analysis the regional differences in energy consumption during the production phase of civil building materials among 30 provinces and cities in China.

2. Data acquisition

2.1. The statistical scope of energy consumption in the production stage of civil building materials

Energy consumption in the production stage of civil building materials refers to the total energy consumption in the production stage of building materials used in civil buildings completed this year. Theoretically, the total energy consumption can be calculated by adding up the energy consumption of a single building material in the production stage. However, there are many types of building materials used in the building system, and it is impractical to calculate the energy consumption data of all building materials. Therefore, it is necessary to filter out the main energy-consuming materials. Xiao Zhongming \cite{6} sorted out the current situation of the materials used in civil buildings, and analyzed the usage of main raw materials and the proportion of energy consumption in China’s civil buildings, and found that steel was the most important material affecting the energy consumption of civil buildings \cite{7}.

Cement-based materials (including concrete and its components, mortar, building blocks, etc., and the raw materials used include cement, sand and gravel aggregate, and mineral admixtures) ranked second in energy consumption. Cement is the most energy consuming material for civil building, so cement is listed as the first statistical object. Building ceramics and glass came third in energy consumption. According to the statistical Yearbook of China’s Construction Industry, there are 5 types of building materials, including steel, wood, cement, glass and Aluminum. Aluminum is used less in civil buildings and wood consumes less energy. Therefore, the statistical scope of energy consumption in the production stage of civil building materials is narrowed down to the energy consumption of steel, cement, plate glass and ceramics.

2.2. Establishment of calculation method for energy consumption in the production stage of civil building materials

At present, there is no direct method to calculate the energy consumption data in the production stage of civil building materials, only existing channels can be used to construct the calculation method \cite{8}.

\[
E = \sum_{i} M_i Q_i \tag{1}
\]

In Equation (1), \(E\) represents the energy consumption in the production stage of civil building materials; \(M_i\) represents the consumption of class \(i\) building materials; \(Q_i\) represents the comprehensive energy consumption per unit product of class \(i\) building materials.

According to China Energy Statistics Yearbook 2018\cite{9}, comprehensive energy consumption per unit product of steel, cement and plate glass for civil buildings can be found. Consumption of civil building materials can be expressed by the annual completed area of civil buildings and the use intensity of building materials. The calculation method is shown in Equation 2:

\[
M_i = S \times m_i \tag{2}
\]
In Equation (2), \( S \) represents the annual completed area of civil buildings (\( m^2 \)); \( m_i \) stands for the use intensity of civil building materials, cement: 102 kg/m²; steel: 49 kg/m²; Plate glass 0.1 weight case /m²; Ceramic 2.27 m² / m².

According to equations (1)(2), the results are shown in Table 1.

Table 1. Energy consumption data in the production stage of civil building materials.

| Items     | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  |
|-----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Total     | 1184.24 | 1289.72 | 1420.53 | 1627.68 | 1860.89 | 2081.88 | 2185.33 | 2160.44 | 2169.80 | 2139.12 |
| Beijing   | 28.01 | 29.84 | 32.54 | 35.27 | 46.86 | 49.59 | 50.64 | 55.34 | 59.81 | 53.99 |
| Tianjin   | 7.08 | 10.28 | 10.75 | 12.05 | 13.70 | 14.70 | 16.53 | 17.12 | 17.07 | 17.07 |
| Hebei     | 39.04 | 42.63 | 49.77 | 58.81 | 68.29 | 70.06 | 68.17 | 61.67 | 58.94 | 52.49 |
| Shanxi    | 14.01 | 13.28 | 14.58 | 14.12 | 17.60 | 20.97 | 21.57 | 19.76 | 18.17 | 18.92 |
| Neimenggu | 20.17 | 19.88 | 22.39 | 23.88 | 21.54 | 20.92 | 20.98 | 17.54 | 14.19 | 11.32 |
| Liaoning  | 37.31 | 48.31 | 65.11 | 89.00 | 91.09 | 103.61 | 86.27 | 52.60 | 34.93 | 26.77 |
| Jilin      | 20.33 | 22.52 | 22.85 | 23.19 | 32.51 | 34.10 | 40.37 | 30.13 | 28.02 | 19.30 |
| Heilongjin | 47.21 | 44.04 | 45.98 | 49.48 | 54.41 | 58.94 | 61.40 | 59.76 | 57.25 | 56.92 |
| Shanghai  | 24.64 | 24.79 | 27.81 | 26.98 | 30.08 | 32.27 | 35.06 | 34.18 | 36.45 | 40.01 |
| Jiangsu   | 243.64 | 232.31 | 254.21 | 281.55 | 318.27 | 354.96 | 394.74 | 381.48 | 380.14 | 380.14 |
| Zhejiang  | 167.65 | 181.96 | 196.02 | 223.29 | 246.33 | 278.32 | 302.09 | 311.54 | 317.71 | 307.02 |
| Anhui     | 43.44 | 46.92 | 54.29 | 62.01 | 67.73 | 76.87 | 78.04 | 79.66 | 74.57 | 75.25 |
| Fujian    | 37.05 | 37.15 | 44.24 | 54.41 | 60.14 | 69.54 | 75.09 | 80.54 | 87.70 | 80.20 |
| Jiangxi   | 29.36 | 32.11 | 33.80 | 40.89 | 53.40 | 63.04 | 67.18 | 73.50 | 76.12 | 76.97 |
| Shandong  | 82.26 | 85.15 | 96.96 | 99.12 | 113.64 | 124.05 | 126.75 | 123.80 | 123.79 | 120.36 |
| Henan     | 60.19 | 66.88 | 72.00 | 82.94 | 90.40 | 99.50 | 107.67 | 97.21 | 104.13 | 107.95 |
| Hubei     | 50.11 | 54.12 | 67.58 | 87.42 | 109.34 | 118.69 | 131.74 | 141.77 | 151.76 | 161.11 |
| Hunan     | 51.95 | 56.84 | 57.14 | 63.96 | 74.34 | 87.27 | 90.31 | 94.44 | 100.43 | 105.73 |
| Guangdong | 52.89 | 54.68 | 48.48 | 61.51 | 66.89 | 70.54 | 68.00 | 71.37 | 79.48 | 85.84 |
| Guangxi   | 18.41 | 20.43 | 23.13 | 26.29 | 28.10 | 31.98 | 37.87 | 42.35 | 43.45 | 46.11 |
| Hainan    | 2.11 | 2.39 | 3.05 | 3.31 | 4.84 | 5.30 | 4.51 | 4.26 | 3.72 | 3.21 |
| Chongqing | 37.94 | 42.75 | 46.26 | 48.42 | 63.67 | 67.41 | 70.41 | 71.62 | 74.51 | 71.99 |
| Sichuan   | 57.60 | 64.57 | 67.41 | 75.68 | 86.67 | 100.63 | 106.64 | 112.58 | 115.10 | 117.08 |
| Guizhou   | 7.26 | 7.26 | 7.68 | 8.91 | 10.56 | 14.13 | 15.54 | 17.74 | 23.05 | 26.35 |
| Yunnan    | 20.03 | 22.38 | 24.79 | 25.07 | 33.28 | 38.13 | 40.84 | 37.91 | 38.37 | 41.03 |
| Shanxi    | 17.49 | 18.23 | 21.10 | 30.56 | 30.83 | 35.81 | 38.95 | 40.10 | 37.84 | 38.70 |
| Gansu     | 10.80 | 9.56 | 11.08 | 13.50 | 18.07 | 22.54 | 22.88 | 22.42 | 21.70 | 16.63 |
| Qinghai   | 1.17 | 1.31 | 1.65 | 1.89 | 2.00 | 2.68 | 2.81 | 2.01 | 1.73 | 1.91 |
| Ningxia   | 4.30 | 5.52 | 5.90 | 7.58 | 8.72 | 11.04 | 8.32 | 6.89 | 5.70 | 4.29 |
| Xizang    | 13.02 | 14.90 | 16.32 | 19.79 | 26.51 | 32.89 | 34.47 | 29.28 | 24.74 | 20.20 |

3. Analysis of regional differences

3.1. Theil Index
Theil Index was originally used to calculate income differences between countries, but later it was widely used in the field of regional difference analysis. The biggest feature of Theil Index is that it can simultaneously calculate inter-regional differences, intra-regional differences and overall differences, so as to analyse the development imbalance of various regions more clearly. Theil index ranges from 0
to 1, and the smaller the index is, the smaller the difference between the regions is. In this paper, the required equations are adjusted according to the literature as follows [10]:

\[
T = \sum_{i=1}^{i} \left( \frac{E_i}{E} \right) \ln \left( \frac{E_i / E}{X_i / X} \right)
\]

(3)

\[
T_{wj} = \sum_{j=1}^{j} \left( \frac{E_{ij}}{E_{j}} \right) \ln \left( \frac{E_{ij} / E_{j}}{X_{ij} / X_{j}} \right)
\]

(4)

\[
T_w = \sum_{j=1}^{j} \left( \frac{E_{j}}{E} \right) T_{wi} = \sum_{j=1}^{j} \left( \sum_{i=1}^{i} \left( \frac{E_{ij}}{E_{j}} \right) \ln \left( \frac{E_{ij} / E_{j}}{X_{ij} / X_{j}} \right) \right)
\]

(5)

\[
T_b = \sum_{j=1}^{j} \left( \frac{E_{j}}{E} \right) \ln \left( \frac{E_{j} / E}{X_{j} / X} \right)
\]

(6)

In equations (3)-(6), \(i\) represents the number of provinces; \(J\) represents the number of regions (divided into Eastern, Central and Western three regions); \(T\) represents the whole Theil index; \(T_w\) and \(T_b\) respectively refer to Intra-Regional Theil index and Inter-Regional Theil index. \(T_{wi}\) refers to the Theil index for the provinces of intra-regional. \(X\) represents the total population of China.

Theil index also can be used to calculate the inter-regional and intra-regional contribution rates:

\[
W_b = T_w / T
\]

(7)

\[
W_w = T_w / T
\]

(8)

\[
W_j = \left( \frac{E_j}{E} \right) \times \left( \frac{T_w}{T} \right)
\]

(9)

\(W_b\) represents the contribution rate of inter-regional difference to the overall Theil index. \(W_w\) represents the contribution rate of intra-regional differences to the overall Theil index; \(W_j\) represents the contribution rate of Region \(J\) to the overall Theil index.

3.2. Regional difference calculation

According to the geographical distribution of China, we divide it into three regions. The Eastern region (region 1) includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Shandong, Zhejiang, Fujian, Guangdong and Hainan. The Central region (Region 2) includes Shanxi, Henan, Hubei, Hunan, Anhui, Jiangxi, Jilin and Heilongjiang provinces. The Western region (Region 3) includes Inner Mongolia, Shanxi, Sichuan, Chongqing, Guizhou, Guangxi, Yunnan, Gansu, Qinghai, Ningxia and Xinjiang [11]. The results calculated by Equation (3)-(9) are shown in Table 2.

| Items  | 2008   | 2009   | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| \(T_{w1}\) | 0.2430 | 0.2414 | 0.2480 | 0.2351 | 0.2329 | 0.2444 | 0.2811 | 0.3026 | 0.3045 | 0.3091 |
| \(T_{w2}\) | 0.0437 | 0.0356 | 0.0326 | 0.0504 | 0.0568 | 0.0563 | 0.0688 | 0.0958 | 0.1099 | 0.1328 |
| \(T_{w3}\) | 0.0672 | 0.0777 | 0.1102 | 0.0564 | 0.0754 | 0.0689 | 0.0625 | 0.0656 | 0.0719 | 0.0781 |
| \(T_w\) | 0.1642 | 0.1627 | 0.1718 | 0.1587 | 0.1604 | 0.1647 | 0.1868 | 0.2057 | 0.2106 | 0.2188 |
| \(T_b\) | 0.0097 | 0.0074 | 0.0558 | 0.0149 | 0.0094 | 0.0086 | 0.0084 | 0.0093 | 0.0080 | 0.0056 |
| \(T\) | 0.1739 | 0.1701 | 0.1718 | 0.1587 | 0.1604 | 0.1647 | 0.1868 | 0.2057 | 0.2106 | 0.2188 |
| \(W_b\) | 0.0558 | 0.0437 | 0.2276 | 0.1735 | 0.1698 | 0.1734 | 0.1952 | 0.2150 | 0.2186 | 0.2244 |
| \(W_w\) | 0.9442 | 0.9563 | 0.7547 | 0.9143 | 0.9446 | 0.9501 | 0.9570 | 0.9565 | 0.9633 | 0.9750 |
| \(W_1\) | 0.5515 | 0.5565 | 0.4404 | 0.5310 | 0.5381 | 0.5366 | 0.5372 | 0.5342 | 0.5333 | 0.5320 |
| \(W_2\) | 0.2261 | 0.2315 | 0.1823 | 0.2248 | 0.2386 | 0.2398 | 0.2443 | 0.2446 | 0.2519 | 0.2624 |
| \(W_3\) | 0.1660 | 0.1675 | 0.1316 | 0.1582 | 0.1675 | 0.1726 | 0.1750 | 0.1773 | 0.1778 | 0.1803 |
According to Table 2, the Theil index trend is plotted as shown in Figure 1 and 2.

The total Theil index of energy consumption in the production stage of China's civil building materials shows an upward trend, which is mainly caused by intra-regional differences. The contribution rate reaches 94%, while the inter-regional differences decrease year by year by only about 5%. Intra-regional differences, central and western regions (W2, W3) contribution to the overall difference is small, the eastern region (W1) differences are the important and main influence factors to regional differences, the contribution rate maintained at about 55%, and keeping stable during the 2008-2017. The contribution rate of the central and western regions is also increasing year by year, which indicates that after the implementation of policies such as the economic rise of the central and western regions of China, the economy of these two regions develops rapidly, and the Theil index changes. Therefore, it can be concluded that the overall difference of energy consumption in the production stage of civil building materials in China is mainly caused by intra-regional differences, and the intra-regional differences mainly come from the eastern region.

4. Conclusions
Based on the Statistical Yearbook of China Construction Industry, this paper constructed the calculation method of energy consumption in the production stage of civil building materials, obtained the data of energy consumption from 2008 to 2017, and analysed the regional difference of energy consumption through the Theil index, and drew the following conclusions through the analysis:

(1) Since 2014, the growth rate of energy consumption in the production stage of civil building materials has been flat, indicating that the implementation of China's policy of energy consumption reduction has achieved remarkable effects. However, due to the imbalance of regional economic development, energy consumption also varies greatly.

(2) According to the results of Theil Index, the difference in energy consumption in the production stage of China's civil building materials is mainly caused by intra-regional differences, and the inter-regional difference makes the smallest contribution. The western region has the most obvious
difference, while the eastern region contributes the most to the Theil index. This shows that with the economic development in the western region, the imbalance of development in western region becoming more obvious, leading to the largest Theil index in the western region. The eastern coastal areas, which are economically developed, contribute the most to the Theil index.

3) The direct statistical channel of energy consumption in the production stage of civil building materials has not been established, which brings great difficulties to the data acquisition. In the future, the channel should be unblocked as soon as possible to form a stable data flow of energy consumption in the production stage of civil building materials, and the development trend and energy saving potential can be analysed.

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