Regional Disparities and Transformation of Energy Consumption in China Based on a Hybrid Input-Output Analysis

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Abstract: Different regions in China have different energy consumption characteristics and changing trends. This paper focuses on analyzing trends in energy consumption changes along the timeline for 30 regions in China. Using the Hybrid Input-Output Model, this paper decomposes energy consumption in 30 regions in 2007, 2012 and 2016 into energy embedded of final consumption expenditure, gross capital formation, inflow and outflow. We use these four dimensions as coordinates to draw a regional radar map. According to the changing characteristics of the radar map, 30 regions are divided into three groups. By analyzing the reasons for the changes in three regions, we draw the following conclusions. For regions where energy consumption is mainly inflow, the economically developed regions have to form a low energy consumption environment while achieving economic growth. The economically underdeveloped regions need to carry out energy conservation and emission reduction as well as ensuring the level of economic development. For some outflow regions with moderately economic development, it is necessary to balance the economic development and energy consumption control according to regional characteristics. For resource-rich regions which are in the process of transformation from agriculture to industrialization, they have to maintain the rapid development speed and strengthen their infrastructure with less energy consumption of buildings.

Keywords: regional energy consumption; Hybrid Input-Output Analysis; RAS method; energy structure decomposition

1. Introduction

In the “new normal” status of China’s economy, the growth rate of energy consumption is slowing down, and problems of development quality and efficiency are prominent [1]. Meanwhile, problems such as unbalanced and uncoordinated energy development demand prompt solutions in China [2–6]. The unbalanced development is mainly reflected in the consumption structure of energy production, such as the normalization of excess coal production in China. By 2018, coal’s share of total energy consumption was 59%, while the proportion of non-fossil energy in the energy consumption structure was significantly lower than that of developed countries. Also, the imbalance between energy supply and demand is an important issue. Regions with high energy endowments and abundant resources have low demand while the demand of major energy-consuming regions slows down, which, to some extent, leads to the intensification of the contradiction between regions supplying and receiving energy and the imbalance of the relationship between energy supply and demand. With the different foundations of economic development in different regions, regional disparities of energy development patterns exist. The driving force, restricting factor, and influence of regional energy consumption have changed accordingly. In some regions, for example, the main driver of energy consumption has
changed from import and export to industrial (as in Shanxi). Strict environmental policies in regions such as Beijing, Tianjin, and Shanghai have shown effectiveness in controlling energy consumption and carbon emissions. The experience of these effective energy reform strategies is worth studying further.

Thus, it is necessary to find out the changing rules of energy consumption in different regions and formulate corresponding policies to guide energy consumption. There are different ways to divide the research area. For example, Zhang et al. took the Beijing-Tianjin-Hebei region as an example to explore the correlation between economic development and energy consumption [7]. Lin and Zhang used the original international-level regions divided by the indicators of economic development—the east, middle and west [8]. To demonstrate the relevant studies in detail, Table A1 (in Appendix A) compares the articles of different regional division methods from the perspectives of types of the survey region, description method, research methods, main conclusions, and contributions.

According to the previous demonstration in Table A1, some studies of changes of energy demand start from a single region while the others study multiple regions. In multi-region research, the division of regions is mainly in economic or administrative senses. Some studies made custom grouping criteria based on the energy related indicators or comprehensive characteristics of energy and economy. The methods to describe the changes are various, mainly including economic indicators, energy indicators and social indicators. Some studies used decomposition analysis method with the hybrid input-output matrix to build further indicators to represent the specific dimensions. Therefore, we found that it would play a supplementary role for the current research on region partition methods if the regions are divided with comprehensive consideration of administration, economic development level and energy related indicators when studying the multi-region, using the indicators of comprehensive. To achieve the different division objectives, various methodologies are adopted based on the available data and sources. To find the knowledge gap, the contributions of each piece of research are sorted out and we found that the current literature focused more on the contrast in space than the comparison in space. Thus, it is innovative to present a dynamic comparison along the timeline for research on the changes of energy consumption. In addition to exploring the economic reasons, it is of practical significance to explore the policy direction behind the change of energy demand and analyze the effect of energy policy accordingly.

Thus, in this paper, we specifically attempt to answer three questions: (1) How to demonstrate the changes of energy consumption in the sense of comprehensive consideration of administration, economic development level and energy related indicators? (2) What are the underlying reasons behind the changes of energy consumption? (3) Which policies can we stick with in the next stage of development?

To solve the above research questions, this manuscript is expected to deconstruct the main changing trend of China’s regional energy consumption. Hence, this paper chooses China’s 30 regions (except Tibet, Taiwan, Hong Kong, Macau) as the study target to obtain overall understanding and extend specific policy discussion from the view of variation trends of energy consumption. To better demonstrate the changing rules of energy consumption in various regions, comparative analysis along the timeline is conducted among survey regions. The energy consumption changing map is thus obtained to describe the characteristic variations within different regions in terms of different expenditure channels. By inducing the characteristics, the regional division standards are concluded to explore the underlying reasons of changing rules, considering the relevant policies at the time. Through the analysis of the policy effect, we can put forward valuable suggestions.

2. Literature Review of Methodology

As for studying the regional energy consumption changes, there are many articles using various models to specifically present the regional energy consumption disparities. In order to better display the applicability of the methodologies, various related research methods need to be compared. Table A2 (in Appendix A) lists the main methods commonly used for studying energy consumption and compares their advantages, disadvantages and application scope.
According Table A2, we can find that although the decomposition analysis is relatively easy to conduct, the residual problems and implicit influence factors are hard to completely consider. Moreover, when the decomposition approach is used at the same time as the input-output approach, there is a general rule that the Structural Decomposition Analysis (SDA) method is used to study the driving factors of change, while the Input-Output Analysis method is used to analyze from a demand perspective [9–11]. In these studies, the variables are generally explained by rebuilding variables, which requires the equation expression of the relationship mechanism between variables in combination with the input-output table.

The empirical analysis method is not suitable for multi-tiered analysis and research the inter-regional influences. The Input-Output Analysis Model is complex but can show the economic interactions among sectors clearly. Thus, in order to achieve our research objectives of studying the changing rules of embedded energy expenditures within different regions, the Input-Output Method is the most suitable. Similar to research on the drivers of economic development, when we study the drivers of energy consumption change, we can choose to start from the energy demand side, and make an in-depth analysis of the problems from the perspectives of energy embedded in the consumption (consisting of household and government consumption), capital formation and import and export, which can be demonstrated in the input-output table. Therefore, we adjust the input-output table by replacing the monetary value with energy value, which is computed by the standard coal equivalent and regional energy balance tables. Thus, we can finish preprocessing the data and form the variables to be studied from the final demand level so that the structural analysis of variables is not needed afterwards.

To achieve the goal of dynamic analysis, we have to collect energy related data along timeline. Based on the available public data and information, we construct the hybrid input-output table with the updated data in 2007, 2012, and 2016. We can not only explore the characteristics of the accomplished fact of these years, but also deconstruct and analyze the reasons corresponding to China’s Five-Year Plan strategy to summarize the changing rules.

To sum up, in this paper, we include China’s 30 regions except for Tibet, Taiwan, Hong Kong and Macau in the research scope. Input-Output Analysis is suitable for calculating direct and indirect impacts in the comprehensive accounting framework. Thus, a Hybrid Input-Output Method is adopted to decompose the regional energy consumption into embedded energy in final consumption expenditure, gross capital formation, inflow and outflow. In order to reflect the decisive role of policies in energy consumption change, we combed and analyzed policies during the 11th Five-Year Plan period and the 12th Five-Year Plan period. In designing the research period, considering the availability of data, the latest available data of 2007, 2012, and 2016 are used as the research nodes to analyze the regional embedded energy changes within 10 years. The period of the eleventh and twelfth Five-Year Plans overlaps with the research period of this paper. Based on the analysis and discussion, we try to verify the impact of energy-relevant policies on energy development in the current period and speculate on the impact of these policies on energy consumption in the future.

The framework of the article is generally described as follows:

Section 3 uses the Hybrid Input-Output Analysis model to process the data, and the four indicators are decomposed then, including per capita embedded energy of final consumption, capital formation, inflow, and outflow. The data source is also explained.

Section 4 draws the radar map of 30 regions according to the indicators obtained in the second part. Based on the changing trend of each indicator shown in the Radar Map, 30 regions are divided into three categories. This part analyzes in detail the reasons for the changes in these three groups in 2007, 2012, and 2016, taking the regional economic development into account.

Section 5 summarizes the results of the changing trend of the three groups based on the third part and puts forward some suggestions for the implementation of related policies in the future.
3. Modeling and Data

3.1. Modeling

In order to better understand regional energy consumption, we analyze regional energy consumption in the form of energy embedded in final consumption expenditure, gross capital formation and net outflow. We adopt the Hybrid Input-Output Model to decompose energy consumption.

Because the regional input-output table cannot directly provide statistical data, we first need to complete the hybrid input-output table of 2016 by estimation. We use the Biproportional Scaling Method (also known as RAS-iterative method) to calculate the intermediate flow data of 2016 based on the data of 2012. Based on reasonable assumptions, we calculate the final energy demand data for 2016 using the constant proportion principle. Taking interregional energy trade into consideration, we reduce the net outflow data to inflow and outflow. Thus, we distinguish how energy consumption supports residential life, urbanization and industrialization as well as interregional trade. The specific data operation steps are as follows.

3.1.1. To Analyze the Intermediate Flow

According to the method described in Li, et al.’s work [12], the 42 sectors in the original input-output table are combined into 10 sectors (shown in the Table A3 in the Appendix A). The currency flow of energy-related sectors in the input-output table is replaced by physical data in the form of caloric value in the Energy Balance Tables. Because the given data of different physical units cannot be added together, it is necessary to preprocess the energy balance tables with different coefficients in order to match the department classification in the input-output table.

Firstly, we multiply them with energy equivalent coefficients. Then, the units of different energy sources in the energy balance tables are transformed into ton of standard coal equivalent (tce). Finally, the energy flows in energy balance tables are accumulated to match the sector classification of the input-output tables.

In Table 1, \( Z^E_{ij} \) and \( Z^N_{ij} \) represent the direct energy input and direct monetary input value of sector i to sector j. \( X^E_i \) and \( X^N_i \) represent the sum of direct input value from sector i to the 10 sectors. \( X_i \) represents the total direct input value from the ten sectors to sector j. X represents the total intermediate flow of 10 sectors. The variables in Table 1 meet the following equations:

\[
\sum_{j=1}^{10} Z^E_{ij} = X^E_i \\
\sum_{j=1}^{10} Z^N_{ij} = X^N_i
\]

Table 1. Intermediate flows of hybrid input-output table.
The regional input-output tables and energy balance tables of 2007 and 2012 are available from China’s Statistical Yearbooks, from which we can obtain data of monetary flows and energy flows for Table 1. In order to estimate the intermediate flows in 2016, an iteration method is adopted.

First, we assume that the proportion of total intermediate demand ($X_{i,t}$) in gross output ($GO_{i,t}$) is unchanged in 2012 and 2016 (shown in Equation (3)).

$$\frac{X_{i,2012}}{GO_{i,2012}} = \frac{X_{i,P}^{2016}}{GO_{i,2016}}$$

In Equation (3), $X_{i,t}$ and $GO_{i,t}$ are the total intermediate demand and gross output of sector $i$ in year $t$. We use $X_{i,P}^{2016}$ to represent the predicted total intermediate output. Thus, the total intermediate demand of each sector in 2016 can be preliminarily estimated.

We can obtain the accurate data of total final demand ($FD_{i,2016}$) in 30 regions from the China Statistical Yearbook 2016. Thus, we define the actual total intermediate demand ($X_{i,R}^{2016}$) as shown in Equation (4).

$$X_{i,R}^{2016} = GO_{i,2016} - FD_{i,2016}$$

In Equation (4), $FD_{i,2016}$ is the total energy flow value from sector $i$ for final consumption expenditure, gross capital formation and net outflow in 2016; $GO_{i,2016}$ is the total energy output of sector $i$ in 2016.

The error coefficient (EC) represents the ratio of the predicted total intermediate demand to the actual total intermediate demand (as shown in Equation (5)).

$$EC_1 = \frac{X_{i,R}^{2016}}{X_{i,P}^{2016}}$$

The $EC_1$ here means the first error coefficient attained by the predicted total intermediate output and the actual total intermediate demand.

Finally, the predicted results are multiplied by $EC_1$ to get an adjusted value. With the above steps, we get estimated intermediate demand for regional input-output tables of 2016.

For intermediate input flows, we can get all the sectors’ total intermediate input in 2016 according to Equation (6).

$$X_{j}^{R} = GI_{j} - S_{j}$$

$GI_{j}$ represents Gross Input which is approximately equivalent to the gross output ($GO_{j}$) (as shown in Equation (7)). $S_{j}$ represents the input of all the value items added to sectors $j$, including depreciation of fixed assets, remuneration of workers, net production tax and operating surplus. $S_{j}$ can be obtained based on the assumption that the ratio of added value of all the sectors to gross output remains unchanged in 2012 and 2016 (as shown in Equation (8)).

$$\text{while } i = j, \ GI_{j} = GO_{i}$$

$$\frac{S_{j,2012}}{GI_{j,2012}} = \frac{S_{j,2016}}{GI_{j,2016}}$$

$S_{j,2012}$ and $S_{j,2016}$ represent the Value added of sector $j$ in 2012 and 2016, respectively. $GI_{j,2012}$ and $GI_{j,2016}$ represent the gross input of sector $j$ in 2012 and 2016, respectively.

Based on Equations (9) and (10), the error coefficient ($EC_2$) can be attained as the ratio of the predicted total intermediate input ($X_{j,P}^{2016}$) to the actual total intermediate input ($X_{j,R}^{2016}$).

$$\sum_{i=1}^{10} X_{i} = \sum_{j=1}^{10} X_{j}$$
Finally, the predicted results are multiplied by the error coefficient, which gives a more accurate value of all the sectors' total intermediate input.

Moreover, due to the errors existed between the real value and estimated value, we use the RAS method to reduce them. After clarifying the achieving process of the intermediate flow data of all the sectors in 2016, we make the specific iterative process as follows:

1. We calculate the proportional coefficient of input-output structure of each sector ($\mu_{ij}$) in the base year (2012) (as shown in Equation (11)).

   \[
   \mu_{ij} = \frac{Z_{ij,2012}}{G_{Oj,2012}}
   \]  

Then, we multiply $\mu_{ij}$ by the gross input of sector $j$ in 2016. Thereupon, we get the initial Intermediate flow in 2016 (as shown in Equation (12)).

   \[
   Z_{ij,2016,(1)} = \mu_{ij,2012} \times G_{Ij,2016}
   \]  

The corner (1) here refers to the value adjusted in the first iteration. Meanwhile, we can get $X_{i,2016,(1)}$ by adding $Z_{ij,2016,(1)}$ in rows.

2. We can get the initial row ratio ($\beta_1$) in Equation (13).

   \[
   \beta_1 = \frac{X_{i,2016}}{X_{i,2016,(0)}}
   \]  

In Equation (13), $X_{i,2016,(0)}$ represents the row sum of the initial Intermediate flow ($Z_{ij,2016,(0)}$).

3. We multiply $Z_{ij,2016,(1)}$ by $\beta_1$ to get the new intermediate flow $Z_{ij,2016,(2)}$ and the row ratio changes to $\beta_2$ (as shown in Equation (14)).

   \[
   \beta_2 = \frac{X_{i,2016}}{X_{i,2016,(2)}}
   \]  

4. We multiply the adjusted $Z_{ij,2016,(2)}$ by $\beta_2$ to get the new intermediate flow $Z_{ij,2016,(3)}$ and the row ratio changes to $\beta_3$.

\[ \cdots \cdots \]

Repeat the steps of 2–4 until $\beta_n$ is 1.

At this point, the intermediate input (demand) of ten sectors in each region is obtained.

In conclusion, in Table 1, sectors 1 to 4 are energy sectors, and the energy supply flows are expressed in tons of standard coal equivalent (tce). The remaining six are the energy consumption sectors expressed in US dollars based on PPP (purchasing power parity). The total intermediate demand was calculated based on the unchanging assumptions and RAS iteration.

In addition, for final use, we cannot accurately estimate the consumption data except fixed capital formation of each sector in each region, because of the lack of relevant data of subsectors. Therefore, we only focused on analyzing capital formation in 2016. The calculation method is as follows:

\[
\frac{FA_{2012}}{TF_{2012}} = \frac{FA_{2016}}{TF_{2016}}
\]  

In Equation (15), $FA_{2012}$ and $FA_{2016}$ represent the Fixed Assets Investment of various sectors in 2012 and 2016; $TF_{2012}$ and $TF_{2016}$ represent the Total Fixed Capital Formation of the sectors in 2012.
3.1.2. To Analyze the Final Demand

Using the same sector combination method of Section 3.1.1, the intermediate flow, final demand, and flow-out and flow-in values are summed up respectively to match the category of sectors. The final demand is discussed from the perspective of terminal use, consisted of consumption, capital formation and net exports. To study the energy flow in more detail, we discuss net exports separately as inflow and outflow channels. As shown in Table 2, consumption means the terminal energy consumption of a sector, including household and governmental energy consumption. Capital formation means the total capital formation of a sector over a period of time. Outflow means the direct output from a sector to other nations and regions. Inflow means the direct input from other nations and regions.

Table 2. Final demand of hybrid input-output table.

| Input  | Output | Intermediate Demand | Final Demand | Inflow | Gross Output |
|--------|--------|---------------------|--------------|--------|--------------|
| Energy Sectors | 1 | ... | Z_E | FC_E | FF_E | FO_E | FI_E | GO_E |
| 4 | ... | Z_E | FC_N | FF_N | FO_N | FI_N | GO_N |
| Non-energy Sectors | 5 | ... | Z_N | FC_N | FF_N | FO_N | FI_N | GO_N |
| 10 | ... | Z_N | FC_N | FF_N | FO_N | FI_N | GO_N |

Among them, FC_E and FC_N represent the direct energy consumption and direct monetary consumption from sector i to the final consumption sector, including residential and governmental consumption expenditure. FF_E and FF_N represent the direct energy capital formation and direct monetary capital formation from sector i to the capital formation sector, including the total fixed capital formation and the increase in inventory. FO_E and FO_N represent the direct energy output and direct monetary output from sector i to other nations and regions. FI_E and FI_N represent the direct energy input and direct monetary input from other nations and regions to sector i. GO_E and GO_N represent gross output of energy sector i and non-energy sector i.

From the Table 2, the following balance relationship in Equation (16) can be obtained:

\[ \sum_{j=1}^{10} Z_{ij} + FC_i + FF_i + FO_i - FI_i = GO_i \]  

(16)

Because of the lack of available gross output data in 2016, we assume that the monetary flow is equal to the output value multiplied with current year’s price. The data of the first and second sectors are obtained according to the amount of energy available locally in the energy balance table. Among them, the coal mining and processing industry in the first sector adopts raw coal data as product output. The price is selected from the annual records of the National Bureau of Statistics. We set 2012 as the base year, so that the price in 2016 is calculated by using price of 2012 multiplying with annual increase percentage. According to Equation (17), the total output of the first and second sectors in 2016 was calculated. Among them, the sector gross output in 2012 was selected from the input-output table of 2012.

\[ \frac{FX_{2012}}{GO_{2012}} = \frac{FX_{2016}}{GO_{2016}} \]  

(17)

In Equation (17), FX_{2012} and FX_{2016} represent sector output value in 2012 and 2016. The calculation of FC (consumption), FF (capital formation), FO (output), and FI (input) follows the same way. GO_{2012} and GO_{2016} represent the sector gross output in 2012 and 2016.

The output data of the third and fourth sectors are selected from the annual provincial data of the National Bureau of Statistics, and the prices are from the price index of the National Bureau of Statistics. Then, the production is multiplied with current year’s price to get the output. In the same
way with Sector 1 and 2, we calculated the total output of other sectors for 2016. The data of Beijing and Hainan in the third sector are missing in the National Bureau of Statistics, so the data are selected from the Energy Balance Table.

Then, it comes to the total output of the non-energy sectors. As for the other sectors except sixth sector, we use Equation (18) to calculate the total output of all sectors in 2016.

\[
\frac{S_{j,2012}}{GO_{j,2012}} = \frac{S_{j,2016}}{GO_{j,2016}}
\]  
(18)

In Equation (18), \(S_{j,2012}\) and \(S_{j,2016}\) represent the added value of sector j in 2012 and 2016. \(GO_{j,2012}\) and \(GO_{j,2012}\) represent the total output of sector j in 2012 and 2016.

In the calculation of the fifth sector, the added value data of water conservancy is not counted in most regions. So we assume that the ratio of added value of water conservancy to the added value of primary production remains unchanged (Equation (19)).

\[
\frac{SW_{2012}}{SP_{2012}} = \frac{SW_{2016}}{SP_{2016}}
\]  
(19)

In Equation (19), \(SW_{2012}\) and \(SW_{2016}\) represent the added value of water conservancy in 2012 and 2016. \(SP_{2012}\) and \(SP_{2016}\) represent the added value of primary production in 2012 and 2016.

The output data in the sixth sector are selected from the annual data of different provinces. The calculation method of total output is consistent with that of the third and fourth sectors. The remaining added value data of all the sectors is taken from the Provincial Statistical Yearbook.

3.2. Data Processing

After achieving the data of hybrid energy input-output tables, we concentrated on the primary energy consumption based on the data processing method used in Li, et al.’s work [13].

Thus, we got the following vectors as four indicators of embedded energy:

\[
XC = \begin{bmatrix} XCE_1 & \ldots & XCE_4 & XCN_5 & \ldots & XCN_{10} \end{bmatrix}^T
\]  
(20)

\[
XF = \begin{bmatrix} XFE_1 & \ldots & XFE_4 & XFN_5 & \ldots & XFN_{10} \end{bmatrix}^T
\]  
(21)

\[
XO = \begin{bmatrix} XO_1^E & \ldots & XO_4^E & XO_5^N & \ldots & XO_{10}^N \end{bmatrix}^T
\]  
(22)

\[
XI = \begin{bmatrix} XI_1^E & \ldots & XI_4^E & XI_5^N & \ldots & XI_{10}^N \end{bmatrix}^T
\]  
(23)

In Equations (20)–(23), vector \(XC\) represents the total of energy or non-energy products consumed for final consumption expenditures (both direct and indirect). Likewise, vector \(XF\) represents that for gross capital formation. Vector \(XO\) and vector \(XI\) corresponds to outflow and inflow, respectively. In this way, the regional energy consumption is decomposed.

4. Analysis of the Decomposition Results

Based on the hybrid input-output tables established in the second section, we explore the use of primary energy (final demand) in 30 regions of China. The primary energy consumption is analyzed from four dimensions: per capita embedded energy of final consumption, per capita embedded energy of capital formation, per capita embedded energy of inflow, and per capita embedded energy of outflow. Then, we will discuss these four indicators and classify the regions according to their characteristics.

For categorizing the energy consumption changing characteristics of 30 regions, we use a radar map for analysis. Taking the above four dimensions as coordinates, the decomposed embedded energy
indicators of 2007, 2012 and 2016 are illustrated as Radar Maps by region. Taking Zhejiang for example (Figure 1), of the vertical direction, the top half is the final consumption expenditure per capita, and the bottom half is the outflow per capita. Horizontally, the left axis is inflow per capita and the right axis is gross capital formation per capita. The orange, blue and green quadrilaterals represent the four indicators in 2007, 2012 and 2016 respectively.

Figure 1. Four indicators changes of Zhejiang in 2007, 2012 and 2016 of group 1.

Intuitively, we can see Zhejiang has a significantly large inflow in 2007. By comparing the indicators in different years, we found that the four indicators showed an obvious narrowing trend from 2007 to 2012, and slight increase of final consumption expenditure from 2012 to 2016. We found similar trends in some of the 30 regions. Meanwhile, some regions have different changing characteristics. Hence, we divide the 30 regions into the following three groups according to the overall changing trend in the radar map:

(1) Group 1: the energy used in the regions mainly depends on inflows: the embedded energy indicators first decreased and then slightly changed;
(2) Group 2: the energy used in the regions mainly depends on outflows: the embedded energy indicators first decreased and then slightly changed;
(3) Group 3: the energy used in the regions mainly depends on outflows: the embedded energy indicators changed from horizontal to a vertical extension.

4.1. Analysis of Group 1: Regions with Indicators First Shrink Sharply and Then Change Slightly

Group 1 includes Beijing, Shanghai, Tianjin, Jiangsu, Zhejiang, Fujian, Shandong, Chongqing, Jilin, Anhui, Guangxi, and Yunnan. With the similar changing characteristics of the four indicators in Figure 1, these regions’ inflow per capita is significantly higher than other indicators. We define them as the energy inflow regions. As shown in Figure A1 (in Appendix A), the four indicators of Group 1 regions first shrink sharply from 2007 to 2012 and then changed slightly from 2012 to 2016.

The following significant changes are worth exploring for these regions. In 2007, these regions generally had a sharp angle on the left of the radar map, indicating relatively large per capita embedded energy of inflow in 2007. From 2007 to 2012, the indicators of most regions generally dropped sharply. Among them, the reduction of per capita embedded energy inflow is the most significant. Tianjin and Shandong experienced dropping indicators of final energy consumption per capita and total capital formation. From 2012 to 2016, the overall change was small. It is partly because the data of 2016 are extrapolated from the data of 2012, and partly because 2016 is the beginning of the 13th Five-Year Plan.
Therefore, it makes sense that we ascribe the performance in 2016 to the coherence of policy from the 12th Five-Year Plan to the 13th Five-Year Plan.

There is a large gap in the economic development level among the 12 regions of Group 1. Thus, the 12 regions are divided into two categories for further analysis. The first category is the economically developed regions, including Beijing, Shanghai, Tianjin, Jiangsu, Zhejiang, Fujian, Shandong, Chongqing, and Jilin. The regional GDP per capita in 2016 was greater than the average level of Mainland China, which was more than $8000. The second category is economically underdeveloped regions, including Anhui, Guangxi, and Yunnan. These regions had a low level of GDP per capita in 2016, which was below $6000.

4.1.1. Developed Regions with Indicators First Fell Sharply and Then Changed Slightly

The seven developed regions have strong geographical advantages. They locate along the east and south coasts, which have provided a great boost for the international and interregional trade of these regions. The large ports in the seven regions generally have many excellent deep-water harbors capable of berthing 10,000-ton ships, complete and advanced container transport services, 100 million-ton loading and unloading terminals, and other facilities, with throughput reaching the world’s first level. The developed land transports in these regions connect closely to river transport. The complete transport network forms the basis of a great deal of import and export.

Furthermore, these regions are mainly home to the earliest open coastal cities. Therefore, policy support and resource gathering have accelerated the economic development of these regions and widened the gap with other regions. A favorable external environment is a hotbed for rapid industrialization and urbanization. These developed regions’ GDP per capita reached more than 8000 US dollars in 2016. The more developed economic conditions usually make relatively higher energy consumption. It is clearly reflected in 2007 that these regions have a sharper angle on the inflow indicator than other undeveloped and developing regions. That is because these regions are not rich in natural resources, and ranges of energy resources need to be imported to maintain their high energy demand, such as natural gas, petroleum, and coal. Secondly, these regions generally vigorously develop an export-oriented economy and set up product export enterprises. The inland products can also go global through these regions. Finally, these developed regions usually have the advantage of introducing advanced technology. Due to the difference in technical level, some products can only be roughly processed in the inland. Then it needs to make precision processing in the coastal developed regions to increase value-added in domestic sales or exports. Therefore, these regions have higher energy embedded of inflows and lower outflows. By 2012, the per capita embedded energy of inflows decreased sharply while the final consumption expenditures are relatively higher than other indicators. Taking Shanghai as a typical example, there are two reasons to explain the changes. On the one hand, the population density of Shanghai is higher than that of other regions, which makes the energy intensity (energy consumption per capita) lower. On the other hand, Shanghai has strict control over the low-carbon economy, energy conservation, and emission reduction. The government has restricted investment in high-polluting and energy-consuming enterprises and focused on expanding capital-intensive and knowledge-intensive industries. Thus, the agglomeration effect of talents and scientific and technological achievements has been enhanced, and the technological innovation capability has been enhanced. The development of high-tech industries has been promoted and the production efficiency has been improved, which resulted in a decrease in the growth rate of primary energy investment. The phenomenon intensified in 2016. In addition, Shanghai, Beijing, and Chongqing, etc. show an increase in inflow mainly because of an initiative called “Made in China 2025”. To keep pace with the new round of global technological revolution and industrial transformation, China stresses the upgrade of the manufacturing industry. Some energy-intensive enterprises were established, including new energy vehicles, nuclear or renewable energy power equipment, and so on. This has led to increased inflows and consumption of energy embedded products in these regions.
Shandong and Jilin had many key national construction projects due to the area stimulus strategies before 2007. These regions are the country’s old industrial base of steel, diesel, paper, cigarette, and electronic industries before the 1990s. The economic strength and citizens’ living standards have long been ahead of most of the country. However, in the stage of the rapid development of the capital market over the period of the 11th and 12th Five-Year Plans, it was difficult for the old industries in these regions to find a suitable development path in the process of modernization transformation with a slow economic development pace. By 2016 the capital formation in these regions had plummeted. These regions, on a traditional heavy industry basis, have incomparable advantages to develop the embedded energy industry for forcing China’s manufacturing power. Moreover, energy conservation and emission reduction policy posed in the 11th Five-Year Plans was also significant reasons for the change from 2007 to 2012. Beijing, Jiangsu, Tianjin, Shanghai, Chongqing, Jilin, Zhejiang, and Fujian provinces are among the first batch (July 2010) and second batch (November 2012) of low-carbon pilot provinces and cities. To increase the efficiency of economic growth and decouple fossil energy consumption, these regions have proposed relatively strict carbon intensity reduction targets in the period of the 12th Five-Year Plan. These regions have generally undergone the adjustment of industrial structure and energy structure in the industrial field. This promotes energy conservation and emission reduction, reducing energy consumption. After seeing the long-term effects of energy conservation and emission reduction, it has become a consensus to win the protracted war for energy conservation and emission reduction. In 2016, a series of favorable industrial support policies enabled the rapid development of high-tech industries, advanced manufacturing, and modern service industries in these regions. This has given further impetus to the development of high-efficiency industries. The embedded energy use has dropped to a fairly low level, though the change is not noticeable because of the small cardinality.

4.1.2. Undeveloped Regions with Indicators First Fell Sharply and Then Changed Slightly

Guangxi and Yunnan locate in the southwest of China, which is rich in natural resources and diverse in resource types. However, from 2007 to 2016, the national proportion of primary industries in both regions was higher than the national proportion of total output value. It means that the primary industry is in the early stages of development from agriculture and industrialization. To develop industry, it is necessary to import lots of energy-intensive products, which add to high embedded energy in terms of per capita inflow. Similar to Beijing, Tianjin, and other regions in Section 4.1.1, some cities in Guangxi and Yunnan are also pilot low-carbon cities, so energy consumption also decreased significantly from 2007 to 2012. In terms of energy structure, these regions have gradually reduced the proportion of the use of traditional fossil energy, and vigorously developed non-fossil energy such as hydro and biomass energy. Anhui province also showed a sharp decline in the per capita inflow of embedded energy in 2012. Anhui connects inland and coastal provinces, so there is a basic balance between inflow and outflow embedded energy.

In addition, Anhui showed a continuous decrease in the energy embedded of the final consumption expenditure and gross capital formation in 2012. Because during the period of the 11th and 12th Five-Year Plans (2006–2015), Anhui province upgraded traditional industries through further technological innovation and promotion. But the agriculture foundation of Anhui is relatively weak, and the industrialization level is backward. Although Anhui locates in east China, it belongs to central China in regional economic planning. The orientation of double standard makes its planning policy and development direction more obscure. Anhui has a good agricultural foundation, but its industrial development is restricted by the siphoning effect of the large city clusters in the Yangtze River Delta.

4.2. Analysis on Group 2: Energy Outflow Regions with Indicators First Shrunk Sharply and Then Changed Slightly

Group 2 includes eight regions: Henan, Jiangxi, Hunan, Hubei, Sichuan, Hainan, Xinjiang, and Guangdong. As shown in Figure A2 (in Appendix A), this group of regions is characterized by
indicators first shrink sharply and then changed slightly, which is the same trend as that of the first group. But in terms of the energy consumption structure, these regions differ from Group 1 with the energy flow direction. The prevalence of these regions in 2007 had a relatively prominent angle on the embedded energy index of per capita outflow, but the Angle was not as sharp as that of Group 1 on the inflow direction. In 2012, the indicators of various regions generally dropped sharply. Among them, the reduction of embedded energy per capita outflow is the most significant, especially in Guangdong. From 2012 to 2016, the overall change was not significant except for Hubei. The same reason as Group 1 is that the data of 2016 is calculated based on the data of 2012. On the other hand, policy consistency is also not negligible.

These regions mainly located in western, southern, and central China. Generally, they have low economic development level with relatively poor energy resources. Ranking the 30 provinces in terms of GDP per capita in 2016, we can find that these regions are concentrated in the lower middle except Guangdong and Hubei. As the two provinces with the best economic performance in this group, we first analyze the reasons for the obvious changes in Guangdong and Hubei.

The most obvious change in Hubei is the further expansion of capital formation in 2016. Hubei’s economy ranks 11 among the provinces in China according to the per capita GDP of 2016. To vigorously develop the economy and drive the development of the surrounding regions, Hubei has introduced a lot of industrial enterprises, especially information technology industries. For example, Jingzhou, one of the major developed cities of Hubei, was approved as the demonstration zone for undertaking the industrial transfer in 2012, becoming the fifth state-level demonstration zone for undertaking industrial transfer. For example, the total industrial output value above the scale of industrial transfer undertaken by Jingzhou alone to 2016 is about 164 billion US dollars. The electronic industry transferred from other regions (e.g., Shenzhen) is the foundation of the Hubei information technology industry to take off in recent years. The information technology industry is characterized by high technology integration and high-power consumption. This is one reason for the rapid growth of capital formation energy consumption in Hubei in 2016.

The most significant change worth explaining in Guangdong is the sharp decrease in outflow from 2007 to 2012. Among Group 2, Guangdong has a higher economic level and is classified as a developed region. But Guangdong’s development path is very different from that of Beijing and Shanghai. As the largest import and export province in China, Guangdong plays the role of overseas trade for the southwest and inland regions. However, due to the large-scale impact of the European debt crisis in 2012, Guangdong’s imports and exports overall showed a downward trend. During this period, Guangdong faced a severe foreign trade situation, which was no less than the financial crisis in 2008. To improve the situation, Guangdong adjusted its export structure, expanded emerging markets, and promoted the transformation of processing enterprises to stabilize export growth. In 2016, Guangdong’s import and export turned better, of which the trade value accounted for China’s total trade value ratio is greater than one-quarter. In addition, Guangdong has always been a key area of information technology development in China. Its advanced technology and economic advantages attract people from all over the country to work there, and more labor force drives energy consumption growth.

In addition, regulations on energy conservation were promulgated in 2006. These required energy-using units and individuals to replace inefficient equipment with highly efficient and energy-saving equipment. Also, there are restrictions on moving away from industries that consume too much energy or produce too much pollution. During the 11th Five-Year Plan period, Guangdong intensified its efforts on saving energy and reducing energy consumption. By “upgrading and transforming” and “transferring and eliminating” a number of energy-consuming enterprises, the elasticity coefficient of energy consumption reduced significantly, from 1.22 in 2005 to 0.28 in 2012, and then rebounded slightly. Thus, the per capita energy embedded of the outflow of Guangdong is correspondingly decreased.
For the other regions, the rapid growth of the secondary industry in these regions is the main reason for the decline of the four indicators from 2007 to 2012. Secondary industry supports the economic development of the region. These regions are committed to promoting rapid industrialization and urbanization to improve energy efficiency. During the 12th Five-Year Plan period, these regions implemented many corresponding policies, such as improving and upgrading the industrial structure and adjusting the direction and focusing of energy distribution. The policies boost the proportion of high value-added and low energy-intensive products and stimulate to adopt new energy-saving production techniques. Therefore, with the decrease of embedded energy in capital formation per capita, inflow and outflow also decreased.

4.3. Analysis of Group 3: Energy Inflow Regions with Indicators Changed from Horizontal to Vertical Extension

Group 3 includes Hebei, Heilongjiang, Liaoning, Shaanxi, Gansu, Ningxia, Qinghai, Inner Mongolia, Shanxi, and Guizhou. The indicator changing characteristics of these regions are different from the other groups. As shown in Figure A3 (in Appendix A), regions in Group 3 generally have relatively high value in the per capita embedded energy of inflows in 2007 and outflows in 2012. This shift in energy consumption structure was reinforced in 2016. Graphically, this means that the radar map for each region of Group 3 has changed from a horizontal flat quadrilateral to a vertical thin quadrilateral. From 2007 to 2012, the radar map’s sharp angle at the inflow indicator is obtuse, with a sharp angle at the outflow. This trend also strengthened in 2016. In addition, the per capita outflow embedded energy in 2016 is generally higher than the level in 2007.

In order to analyze the reasons for the changes, we explain them from the perspectives of geographical conditions, economic development level (GDP), and regional regulations. Firstly, from the perspective of geographical conditions, all the regions except Guizhou locate in the north of China. These regions are generally rich in natural resources and mineral resources, which is suitable for the development of primary and secondary industries. According to the comparison of the growth of the output value of the three industries during the study period, it is found that these regions are generally in the process of developing from agriculture to industrialization, with a low degree of modernization and generally lower level of economic development than the national average. As shown in Figure 2, Shaanxi, Liaoning, Ningxia, Qinghai, and Heilongjiang provinces are at the developing level in terms of per capita GDP in 2016 ($6000–8000). Shanxi, Guizhou, and Gansu are economically underdeveloped regions (GDP per capita less than $5500 in 2016). That is because, in the past 30 years, China has transformed its economy into an export-oriented one. Manufacturing, information electronics, and other industries are growing much faster than heavy industry. To develop a high-end manufacturing industry in the region, it is necessary to have a good foundation for industrial upgrading, which requires the region to have low-cost and high-efficiency industrial clusters. However, these regions have a relatively poor industry investment environment compared with other surrounding regions. So these regions have not yet extricated themselves from the transformation of industrial restructuring, which has slowed down the pace of economic development. Inner Mongolia is an exception, with a per capita GDP of us $10,849 in 2016, mainly due to the relatively developed coal industry and real estate.

According to the regional Statistical Yearbook from 2007 to 2016, the transportation and storage industries in Guizhou, Liaoning, Inner Mongolia, Shanxi, and Ningxia grew rapidly during the decade. This shows that the scale of commodity circulation increases fast. In addition, the tertiary industry of transportation and storage in these regions accounts for a relatively high proportion, and the commodity circulation in these regions is at a relatively large scale compared with that in other provinces. This leads to higher embedded energies of input and outflow. However, the government puts forward the requirements of optimizing industry and product structure in the 11th and 12th Five-Year Plans. This means that the industrial structure adjustment and enterprise efficiency promotion contribute to the energy embedded in the production should be efficient. Liaoning, for example, has adopted
technological innovation and asset restructuring to transform traditional advantageous industries. It adjusts the backward production capacity structure and makes the newly built industrial capacity more energy-efficient. Technological progress leads to improved energy efficiency, which reduces the amount of embedded energy. Meanwhile more high-value-added industrial parks bring higher output value. As a result, the embedded energy of capital formation per capita in Liaoning decreased. On the other hand, affected by the national economic restructuring, the heavy industries need to reduce the proportion of low-profit and high-pollution factories and products to provide space for energy-efficient production. Hence, reducing stocks of energy-intensive products in these regions leads to an increase in embedded energy per capita outflow.

Since 2012, the construction industry in Shaanxi, Gansu, Guizhou, Ningxia, Qinghai, Shanxi, and Heilongjiang has increased significantly. This reflects the increasing scale of infrastructure construction for industrialization and urbanization in northern China, which is active and promotes economic development. The proportion of the construction output value in the secondary industry of
Inner Mongolia and Liaoning is relatively low, indicating that the activity degree of industrialization and urbanization construction is relatively low and the industrial scale is not large. However, the rapid growth of construction in Inner Mongolia also indicates the fast development of industrialization and urbanization in this region. Construction energy consumption is one of the “three main energy consumption items”, which is equal to that of industry and transportation. In particular, the energy consumption of buildings shows a sharp upward trend with the continuous increase in the total amount of buildings and the improvement of living comfort. Therefore, as the proportion of the construction industry in the secondary industry in these regions continues to increase, per capita energy consumption remains high. This is particularly evident in Figure A3 of Heilongjiang, where per capita consumption expenditure rose roughly threefold from 2007 to 2016. It’s worth mentioning the emerging industry has become a new investment hotspot in the Group 3 regions by 2016. Industrial chain integration and cluster transfer have become a tendency. To improve the regional industry development foundation, these regions tend to undertake the transfer of high-tech industries, especially knowledge-intensive or capital-intensive industries rather than resource-intensive industries. These measurements also reduce the per capita energy embedded of inflows and gross capital formation.

However, in Shanxi, as an exception, the changes in per capita embedded energy indicators of outflow is particularly prominent in Figure A3. Shanxi’s primary industry grew rapidly from 2007 to 2008 and began to decline after 2009. In order to develop the economy, Shanxi vigorously developed tertiary industry. Since 2015, the tertiary industry in Shanxi has accounted for more than 50%. Meanwhile, Shanxi has reduced the share of secondary industry from about 55% in 2012 to less than 40% in 2016. Shanxi’s energy consumption structure changed from coal-dominant in 2012 to “coal and non-coal going hand in hand” in 2016. Shanxi adjusts the industrial structure, achieves industrial transformation, and begins to move forward from industrialization to modernization. The outflow of Inner Mongolia in Group 3 was relatively persistently high from 2007 to 2016, by contrast with other regions. Inner Mongolia, as a large coal power base, is also one of China’s five national comprehensive energy bases. By the end of 2016, Inner Mongolia had installed 25.56 million kW of wind power, ranking first in China, and 6.36 million kW of photovoltaic power. The cumulative installed capacity of wind power and photovoltaic power reached 31.92 million kW. In 2016, the Inner Mongolia autonomous region transferred 135.7 billion kilowatt-hours to the outside world, ranking first among all regions in China. During the period of the 12th Five-Year Plan, China built a north-south coal transport corridor with strategic significance from the western to central parts of Inner Mongolia. In 2016, Inner Mongolia accounted for one-fourth of the 3.36 billion tons of raw coal produced in China. The coal industry chain of Inner Mongolia has been continuously extended. In addition to the single coal mining and transportation, the strategy of transporting coal-to-oil and coal-to-natural gas to the outside world keeps its embedded energy of outflow high.

In summary, Table 3 summarizes the grouping analysis as follows:

Thus, we can conclude some policies deserved to continue in the next stage of development. The energy conservation and emission reduction are effective in dealing with the high energy embedded in the inflow and capital formation from the enterprise level. By vigorously developing the secondary industry through policy support, the energy embedded in the per capita outflow can be decreased. Policy promotion of industrial restructuring and industrial upgrading can effectively increase the energy embedded in the per capita outflow.
Table 3. Comparison of characteristics of three groups.

| Group | The Main Characteristics | The Dominant Underlying Reasons | Typical Regions |
|-------|--------------------------|---------------------------------|-----------------|
| Group 1: the energy used in the regions mainly depends on inflows: the embedded energy indicators first decreased and then slightly changed; | Regions of Group 1 shift from energy inflow regions into balanced development regions. | The change is basically affected by the level of economic development and regional energy conservation and emission reduction targets. | Shanghai, Shandong and Yunnan. |
| Group 2: the energy used in the regions mainly depends on outflows: the embedded energy indicators first decreased and then slightly changed; | The main trend of these regions is that embedded energy of per capita outflow decreases significantly. | The dominant reason for the change is the growth of the secondary industry and adjustment of import and export structure. | Hubei and Guangdong. |
| Group 3: the energy used in the regions mainly depends on outflows: the embedded energy indicators changed from horizontal to a vertical extension. | The outflow regions are mainly characterized by the obvious increase in energy embedded in per capita outflow. | The adjustment of the industrial structure brings about the adjustment of energy consumption structure, which influences the status of energy exporters of the regions of Group 3. | Shanxi and Inner Mongolia. |

5. Conclusions and Suggestions

By comparing the changes in the primary energy consumption structure in 30 regions of China in 2007, 2012, and 2016, this paper decomposed it into energy embedded of final consumption expenditure, capital formation, outflow, and inflow. In order to achieve the interpretability and representativeness of outcome, we then use the per capita value to analyze the four indicators. According to the change trend consistency of indicators in different regions, we divided 30 regions into three categories. The results are as follows:

(1) The first group is characterized by energy inflow regions with indicators first shrunk sharply and then changed slightly. This group consists of 12 regions, including Beijing, Shanghai, Tianjin, Jiangsu, Zhejiang, Fujian, Shandong, Chongqing, Jilin, Anhui, Guangxi, and Yunnan. The former seven regions are developed regions with significant energy saving and emission reduction effects. The middle three regions have a heavy industry base and their economy is based on energy-intensive industries. They lost the orientation of development, which resulted in a worse economic situation and large energy consumption. The last three regions are old industrial bases for crude energy conservation and emission reduction but have yet to find a way to balance with economic development.

(2) Corresponding to the first group, the second group is characterized by energy outflow regions with indicators first shrunk sharply and then changed slightly. This group is made up of 8 regions, including Henan, Jiangxi, Hunan, Hubei, Sichuan, Hainan, Xinjiang, and Guangdong. All in all, the rapid growth of the secondary industry in these regions is one of the main reasons for the decline of four indicators.

(3) The third group is characterized by energy consumption structure changing greatly, including 10 regions mainly in the north of China. In these regions with good resource endowments, the angle of inflows in 2007 changed to the sharp angle in the outflows in 2012, and the angle got sharper in 2016. When energy efficiency is improved, and urbanization and industrialization are advanced, the energy consumption structure changed and improved.

Based on these changes, we made the following suggestions for different regions:

(1) For regions where energy consumption is mainly inflow, the economically developed regions have to form the environment of low energy consumption while achieving economic growth, such as Beijing, Shanghai, Tianjin, Jiangsu, Zhejiang, and Fujian. At present, these regions have formed a relatively mature industrial structure and energy consumption structure. On the one hand, practical and effective policy measures should be adopted to reduce energy consumption. For example, we should actively introduce new and high-tech talents, make great efforts to incubate
new industries, attach importance to the reality of higher education, train special talents, strive to
develop energy-efficient industries, and realize energy conservation and emission reduction
through technological innovation. On the other hand, emission reduction and low-carbon life
should be brought into the social atmosphere from the spiritual level. For example, the public
awareness of energy conservation and emission reduction should be enhanced, so does corporate
social responsibility. The economically underdeveloped regions need to carry out energy
conservation and emission reduction actions and ensure the level of economic development
stables, such as Shandong, Chongqing, Jilin, Anhui, Guangxi, and Yunnan. A suitable derivative
industry should be established on the basis of the old industrial base. Traditional energy-intensive
industries need to improve the efficiency of resource utilization. Among them, raising the level of
science and technology is the most suitable way.

(2) For some outflow regions of which economic development is at a moderate level, it is required
to balance the relationship between economic development and energy consumption control.
For governments, future development plans need to consider energy conservation and emissions
reduction. The government should implement preferential policies to introduce new industries
and energy-efficient industries to build a sound industrial base. In addition, some regions are
rich in tourism resources, so we can increase the development of tourism resources and develop
the tertiary industry, such as Hainan, Xinjiang and Guangdong, and so on.

(3) The remaining regions are in the process of transformation from agriculture to industrialization
and are in the period of rapid development, such as Shaanxi, Qinghai, Ningxia, Shanxi,
Heilongjiang, and Liaoning. In the coming period, these regions should strengthen their
infrastructure construction while controlling the energy consumption of buildings. On the one
hand, new buildings need to control energy consumption; on the other hand, most building
energy-saving measures can be completed on the existing buildings. In the process of developing
industrialization, industries should be developed according to local conditions. These regions
need to undertake the transfer of high-tech industries, promote the agglomeration of advanced
industries, establish high energy efficiency industrial parks, and form the agglomeration effect,
so as to promote economic development.

The deficiency of this paper lies in that the input and output data in 2016 deduced by the RAS
method rely too much on data of 2007 and 2012. During this period our country’s economic growth
rate tends to slow gradually, so, compared with the actual results, the estimation may be too large.
We hope to optimize it in future research, so as to obtain more accurate input-output data.

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Appendix A
Table A1. Research on description method of changes in energy consumption involving regional differences.

| Types of the Survey Region | Data Description Methods | Research Methods | Main Conclusions | Contributions |
|----------------------------|--------------------------|------------------|------------------|--------------|
| Single provincial region: Guangdong Province of China [14]. | Period of data: 2004–2014; The factors involved in the logarithmic mean Divisia index (LMDI) method: Population, gross domestic product (GDP), Value added, Energy consumption, Fuel consumption, and Primary energy quantity conversion factor. | The logarithmic mean Divisia index (LMDI) decomposition method; the input-output method | The growth of GDP per capita and population are the dominant factors driving energy consumption growth, while the improvement of electricity supply efficiency is the main factor inhibiting energy consumption growth. | It analyzed the primary energy consumption growth and the influencing factors of regions with complex energy supply and conversion systems, with a new method to derive primary energy quantity conversion factors (RPQEC). |
| Single national region: Australia [15]. | Period of data: between 2004–05 and 2014–15. The driving factors of changes in energy consumption: the technological effect, the energy intensity effect, the level effect of Final demand, the mix effect of Final demand, and the distribution effect of Final demand. | The environmentally-extended input-output (EEIO) analysis and the structural decomposition analysis (SDA) | This paper analyzed the direct and embodied energy consumption from the perspective of different industrial sectors and final demand by the EEO method and explore the drivers by SDA method [8]. | This paper found that the transport sector and the exports sector take charge of the major direct net energy consumption, while the manufacturing sector is a key industrial sector, and small changes in its inputs and final demand can greatly reduce energy consumption. |
| Single national region: Singapore. | Period of data: 2000–2010 | The input-output (I-O) analysis and the structural decomposition analysis (SDA) | Exports were the main reason for carbon emissions growth. In addition, a quarter of carbon emissions come from households, which is proportional to income. | It gains insight into the impact of mitigation measures adopted by urban states that are disadvantaged by alternative energy sources and have limited mitigation options. |
| Multi-region in administrative sense: 30 regions in China (except Taiwan, Hong Kong, Tibet and Macao) [16]. | Period of data: 2001–2015; Three typical indicators: carbon intensity (CI), per capita carbon emissions (PC) and total carbon emissions (TC). LMDI model data: the effects of energy structure (ES), energy intensity (EI), economic output (EO) and population size (P) on TC. | Log mean Divisia index (LMDI) | (1) There is a strong decoupling relation between GDP and CI in most China; and China’s carbon emissions (PC, TC) have plenty of scope for complete decoupling; (2) EO and EI are the main inhibiting and motivating factors respectively for carbon emission reduction; (3) ES on increasing PC and TC varies between positive and negative. | It started the study of decoupling relationship between economic growth and carbon emissions among all provinces in China, with three typical carbon indicators (carbon intensity, per capita carbon emissions and total carbon emissions) and the emission impact factors. |
| Multi-region in administrative sense: 30 individual Chinese provinces [3]. | Period of data: 1978–2014; The energy consumption per capita measures overall environmental pressure, the explanatory variables include GDP per capita and its squared and cubic terms, and the ratio of secondary industry value-added to GDP. | The autoregressive distributed lag (ARDL) modeling | The correlation degree between energy consumption (per capita) and GDP (per capita) varies by region, in most areas the relationship is linear; but the relationship of some regions is "inverted U" or "inverted N", which means the peak energy consumption per capita exists in these provinces. The secondary industry is significant in per capita energy consumption. | This paper examined the environmental Kuznets Curve (EKC) relationship for energy consumption for the 30 individual Chinese provinces, taking accounts for the provincial heterogeneity. It used a long sample period data to reflect the entire dynamics of energy consumption situations and economic development after the reform and opening-up. |
| Multi-region in administrative sense: 29 regions [17]. | Period of data: 2001–2012; Research angles: urbanization degree, energy consumption indicators, trade openness degree, and GDP per capita. | Empirical analysis model: a panel data set model, system generalized methods of moments (GMM-sys) estimation methods | Urbanization and capital are the main driving forces of China’s economic growth. The relationship between urbanization and economic growth is “U-shaped”. Heavy industry has a significant negative impact on the economy. International trade affects the economy in many ways. | This paper used a dynamic framework, with indicators of population size, geography and so on, to study the effects of urbanization, energy consumption, trade opening, and especially heavy industry on economic growth. |
Table A1. Cont.

| Types of the Survey Region | Data Description Methods | Research Methods | Main Conclusions | Contributions |
|---------------------------|--------------------------|------------------|------------------|--------------|
| Multi-region in administrative sense: 29 Chinese provinces \[18\]. | Period of data: 1995–2010; Indicators: population, per capita income, industrial structure, energy-efficient production technologies, inter-fuel substitution, economic and human geography. | Index Decomposition Analysis (IDA) | The study analyzed the driving forces behind a country’s changing energy consumption from the perspective of the spatial dimension. | It reflects the impact of economic and human geography changes and provides valuable insights and richer information about the spatial changes of other influencing factors than traditional national-level analysis. |
| Multi-region in economic sense: Silk Road Economic Belt (including 9 provinces in China section) \[19\]. | Period of data: 2005–2015; Main indicators: energy bio capacity (EBC), energy ecological pressure index (EET), economic contribution coefficient (ECC), Energy ecological support coefficient (EEESC). | The energy ecological footprint (EEF) fairness evaluation model with main coefficient | The EEF of the target provinces is increasing and the northwest regions grow faster than the southwest regions. But there is little change in EBC, and the difference in energy ecological pressure is gradually increasing. | This study focused on the fairness between the regional EEF and economic growth. It laid a groundwork for understanding reducing regional energy ecological pressure differences and regional energy cooperation. |
| Multi-region in economic sense: the three major economic circles: Yangtze-River-Delta, Pearl-River-Delta and Jing-Jin-Ji \[1\]. | This study adopts renewable energy data from other’s journals. | Multi-regional input-output (MRIO) model | Demand-driven embodied energy reflects the real energy consumption patterns of developed regions or megacities. | This study examined the energy consumption patterns of China’s three major economic circles and analyzed the inter-regional energy spillover effects in the domestic trade networks. |
| Multi-region in economic sense: division based on the four economic sectors proposed in the 11th Five-Year Plan: eastern, western, central and northeast parts (30 regions) \[2\]. | Period of data: 1995–2015; Three decomposition targets: the activity effect (the increased energy demand due to the economic activities), the structural effect (the influence of China’s regional industrial transfer), and the Intensity effect (the influence of regional energy consumption efficiency). | A complete decomposition model | The economic aggregation increase mainly explains the rise of China’s total energy consumption. China’s economic activities show the characteristics of transferring between the eastern, the central and western regions, along with the total energy consumption growth. China’s energy efficiency has improved consistently. | This study used decomposition analysis model to explain the changes of total energy consumption, considering the regional structure adjustment, and then gave policy suggestions. |
| Multi-region in the sense of energy related parameters: the top 10 Wind Energy producing States of the US \[20\]. | Period of data: 2017; Economic impact: direct costs of building a new wind energy farm, labor costs, material and service costs, etc. | Multi-region input-output (US-MRIO) model | This study explored the impact of wind energy farms installation on regional and sectoral spill-over effects in ten US states, considering the local and multi-regional economic disruptions. | This study provided the related analysis of the new jobs created and increase of energy-related products in each region in the final demand and value-added. |
| Multi-region in the sense of energy related parameters: various countries in the world \[21\]. | Period of data: 2012; Perspective from final demand: EBC (energy use embedded in its imports of consumer products). | A total-consumption-based multi-region input-output accounting method | This study considered major inter-regional net trade flows and analyzed the trade imbalances related to consumer products in major economies from the perspective of currency and energy use. | This study analyzed the energy use of the end consumers by the global supply chain with the accounting method, and it proposed to adjust trade patterns to achieve sustainable energy use. |
| Multi-region in the sense of the economic strategies: Coastal Development Strategy, Western Development Strategy, the Rise of Central China, and the Plan for Revitalizing the Northeast Region \[12\]. | Data for 2002, 2007, 2010 are from other journals: the multi-regional input-output table of 2002 is from Zhang’s team of National Information Center, and the input-output tables of 2007 and 2010 are from the paper of Liu et al. \[22\]. | Multi-regional input-output analysis model; structural decomposition analysis (SDA) | National strategy influences regional economy and carbon emission pattern. The carbon emission of the economic zone is the most notable, and the carbon flow between regions is the more active and balanced. The carbon emission structure is positively affected by the final demand. | This paper adopted a larger database, including data of 2002, 2007, 2010. It used the national economic strategy to China’s regional zoning standards, and analyzed the motivating factors of carbon emissions. |
| Multi-region in the sense of the economic and energy standard: custom grouping criteria combined with the regional economic development level and energy intensities \[13\]. | Using vectors XR, XC and XO to represent the sum of the direct and indirect energy or non-energy products consumed for final consumption on expenditure, gross capital formation and flow-out. | A hybrid energy input-output model | The economically developed areas have higher energy consumption and lower intensity, the economically underdeveloped areas have lower energy consumption and lower intensity, and the moderately developed areas have higher energy consumption and higher intensity. | It explained China’s regional differences in energy consumption in terms of embedded energy in 2007. |
Table A2. Comparison of methods used to study energy consumption.

| Methods | Advantages and Disadvantages | Application |
|---------|-------------------------------|-------------|
| **Decomposition analysis (including Structural Decomposition Analysis (SDA) and Index Decomposition Analysis (IDA).)** | SDA method: Its data used are mostly outdated because it requires national or regional complete input-output tables, which is hard to come by [23]. IDA method: Its data used are most updated because it adopts time-series data [23]. It mainly includes Laspeyres Index Methods (LIMs) and Divisia Index Methods (DIMs) and Log Mean Divisia Index (LMDI); LIM method: It is simple to understand, but there are residual items in the decomposition result. DIM method: It is hard to understand with no unexplainable residual problems [2]; LMDI method: It has better adaptability, and theoretical foundation, computational simplicity, and good decomposition results without any unexplained residuals term [12,21,22]. It is user-friendly. But it can only examine one absolute quantity factor at most (for example, economic scale), while the other implicit influence factors of energy consumption (such as industrial structure) are difficult to be fully considered. Decomposition analysis can explain the changes and impacts that occur in any variables over time or space [24]. For example, it is widely used to analyze the changes in energy consumption, energy intensity, and energy-related emissions from the view of national or sector level [2]; The IDA method mainly focuses on the researches with less driving factors for objects [25]; LMDI can study the driving factors of energy consumption of urban and rural residents in China, the driving forces of energy consumption, carbon emission, and nitrogen oxides of specific regions [9,12,15,22,26]; The LMDI method can also handle cases with zero values in the data set without leaving residuals during analysis [27]. | |
| **Empirical analysis methods:** | The traditional time series method may have some deviation and is not suitable for non-stationary series [3]. Regression methods are not well suited to the multi-tiered analysis and there are many differences from national sector levels to sectorial levels [24]. The autoregressive distributed lag (ARDL) model is more reasonable for the time series of individual provinces. However, it cannot reveal the inter-regional influences when concerning regional energy consumption issues [27,28]. The empirical test method is adopted to study nation-wide or regional energy consumption [19,24,25]. The ARDL approach can be used to handle the stationary and non-stationary time series data sets [27,28]. Advanced heterogeneous panel technologies, such as the enhanced average group (AMG), which is suitable in expressing the impact of urbanization on energy consumption [29]. | |
| **Input-output analysis method** | The input-output analysis can completely show the economic links between various departments. The source or use of a resource is clearly displayed in a complex economic network [30]. Input-output analysis method can be used to quantify and assess embedded energy consumption (including direct and indirect consumption), carbon emissions intensity, energy intensity, and the role of intermediate trade in China’s energy consumption changes in regional and interregional trade based on interactions between sectors and that with other economies [16,31–39]. It can investigate the driving factors of embedded energy emissions in a specific period [36]. Multiregional Input-output analysis is practical in mapping the energy allocation diagrams [14]. | |
Table A3. Sector combination of 42 sectors in regional input-output tables.

| Sector No. | Combined Sectors | Original Sectors |
|------------|------------------|------------------|
| 1          | Coal Mining and Processing | Mining and washing of coal |
| 2          | Petroleum and Natural Gas Extraction and Supply | Extraction of petroleum and natural gas |
|            |                   | Production and distribution of gas |
| 3          | Petroleum, Coking and Nuclear Fuel Processing | Processing of petroleum, coking, processing of nuclear fuel |
| 4          | Electricity, Heat Producing and Supply | Production and distribution of electric power and heat power |
| 5          | Agriculture, Forestry, Animal Husbandry, Fishery and Water Conservancy | Agriculture, Forestry, Animal Husbandry and Fishery |
|            |                   | Administration of water, environment, and public facilities |
| 6          | Non-energy Industry | Mining and processing of metal ores |
|            |                   | Mining and processing of nonmetal and other ores |
|            |                   | Food and tobacco processing |
|            |                   | Textile industry |
|            |                   | Manufacture of leather, fur, feather and related products |
|            |                   | Processing of timber and furniture |
|            |                   | Manufacture of paper, printing and articles for culture, education and sport activity |
|            |                   | Manufacture of chemical products |
|            |                   | Manufacture of non-metallic mineral products |
|            |                   | Smelting and processing of metals |
|            |                   | Manufacture of metal products |
|            |                   | Manufacture of general purpose machinery |
|            |                   | Manufacture of special purpose machinery |
|            |                   | Manufacture of transport equipment |
|            |                   | Manufacture of electrical machinery and equipment |
|            |                   | Manufacture of communication equipment, computers and other electronic equipment |
|            |                   | Manufacture of measuring instruments |
|            |                   | Other manufacturing |
|            |                   | Comprehensive use of waste resources |
|            |                   | Production and distribution of tap water |
| 7          | Construction      | Construction      |
| 8          | Transport, Storage and Post | Transportation, storage, and postal services |
| 9          | Wholesale, Retail Trade and Hotel, Restaurants | Wholesale and retail trades |
|            |                   | Accommodation and catering |
| 10         | Others            | Repair of metal products, machinery and equipment |
|            |                   | Information transfer, software and information technology services |
|            |                   | Finance            |
|            |                   | Real estate        |
|            |                   | Leasing and commercial services |
|            |                   | Scientific research and polytechnic services |
|            |                   | Resident, repair and other services |
|            |                   | Education           |
|            |                   | Health care and social work |
|            |                   | Culture, sports, and entertainment |
|            |                   | Public administration, social insurance, and social organizations |
Figure A1. Cont.
**Figure A1.** Changes of four indicators in 2007, 2012 and 2016 of Group 1.

**Figure A2.** Cont.
Figure A2. Changes of 4 indicators in 2007, 2012 and 2016 of Group 2.

Figure A3. Cont.
Figure A3. Changes of 4 indicators in 2007, 2012 and 2016 of Group 3.

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