Research on Energy Efficiency Evaluation and Emission Reduction Strategy of Construction Industry Based on DEA and Improved FAA

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Abstract. In this paper, the DEA model and factor analysis method are used to construct the energy efficiency evaluation model and the carbon emission factor decomposition model of the construction industry, so that it could analyse the energy efficiency evaluation of the construction industry in each province of China and give the emission reduction strategy. According to the data from China's construction industry statistical yearbook from 2007 to 2015, the paper analyses the energy efficiency of the construction industry, the main influencing factors of carbon emissions, the non-effective province redundancy and the redundancy rate of energy efficiency, and propose improvement measures for energy efficiency in the construction industry in 30 provinces of China. The results show that there are only 7 provinces with effective energy efficiency in the construction industry; 6 provinces with only technically effective; among other provinces, only Jiangxi Province has increased returns to scale, and the other 16 provinces are declining in scale.

1. Introduction
The "13th Five-Year Plan" for energy conservation and emission reduction has clearly pointed out that it is necessary to strengthen energy conservation, implement advanced standards for building energy conservation, and launch pilot projects for ultra-low energy consumption and near-zero energy construction. According to national statistics, China's residential construction consumes 20% of the country's steel consumption, 17.6% of the consumption of cement, 30% of the urban built-up area is used for residential construction, and 32% of urban water consumption is consumed in the residential area. [1] Residential energy consumption accounts for about 20% of the country's total energy consumption. Improving the energy efficiency of the construction industry and reducing energy consumption play a pivotal role in achieving sustainable socio-economic development. This paper evaluates the energy efficiency of the construction industry in the past decade from the perspective of low-carbon economy, and forecasts the future development trend, which can provide theoretical guidance and practical decision-making basis for the future reform of the construction industry.

Regarding the evaluation of energy efficiency, the most widely used methods at home and abroad are DEA models. Ding Yizheng [2] used the value-impact ratio method and DEA to discuss the economic, environmental and social benefits of green buildings; Yang Yan [3] used market value method to analyze the environmental benefits of energy conservation; Zheng Lihong [4] used eQues software to study the environmental benefits of green buildings; QI Shenjun [5] used DEA model and...
factor analysis method to construct energy efficiency evaluation model for construction industry and carbon emission factor decomposition model for construction industry to study the building energy of various areas of China's construction industry and consumption of carbon emissions.

In order to analyze the impact of the construction industry on environment by means of the revelation of the output scale and economic effects of the construction industry emissions, we take the construction industry in China from 2007 to 2016 as the subject researched. On the basic of considering environmental impact factors and excluding repeated calculation in total assets mechanical equipment in the construction industry, we set up the BCC-DEA model for energy efficiency evaluation of the construction industry. In addition, in this research, lots of factors have been considered, such as scale of the construction industry, the comprehensive carbon emission intensity of energy consumption, the energy per unit of output value, the average output value of employees, and meanwhile, we adopt the FAA model to decompose the factors that influence the carbon emissions of the construction industry, combined with the “ineffective technology, ineffective scale” provinces’ input factor redundancy. We put forward the low-carbon development strategy of regional construction industry in China.

2. Energy efficiency evaluation model for construction industry based on DEA model and improved FAA

2.1. DEA model
DEA is a non-parametric method that uses linear programming to model a comprehensive analysis of multiple input and output data to evaluate the relative efficiency of decision units. The common evaluation model of DEA is CCR and BCC. Based on the CCR-DEA model, the $\sum \lambda^*_j = 1$ constraint is added to obtain a BCC-DEA model that can distinguish the pure technical validity and scale effectiveness of the technical efficiency. As shown in formula (1):

$$\begin{align*}
\min \theta \\
\sum_{j=1}^{n} \lambda_j x_j + s^- = \theta x_0 \\
\sum_{j=1}^{n} \lambda_j y_j - s^+ = y_0 \\
\sum_{j=1}^{n} \lambda_j = 1 \\
\lambda_j, s^-, s^+ \geq 0, j = 1, 2, \ldots, n
\end{align*}$$

In the formula: $\theta$ is the effective value of the decision unit DMU$_{j0}$; $x_j$ represents the input element set of DMU$_j$; $n$ represents the number of decision units; $\lambda_j$ represents the reconstruction of the input vector and output vector of the jth decision unit DMU$_{j0}$ in a valid DMU combination with respect to DMU$_{j0}$; $s^-$ is the slack variable of the input; $s^+$ is the slack variable of the output. $(1-\theta)x_0$ is the radial adjustment amount of the input element, and the redundant input amount is equal to the sum of the relaxation adjustment amount and the radial adjustment amount.

If the optimal value $\theta = 1$, and $s^- = s^+ = 0$, then the decision unit is valid for DEA; if the optimal value $\theta = 1$, but $s^+ \neq 0$ or $s^- \neq 0$, then it indicates that the decision unit is valid for weak DEA; if the optimal value $\theta < 1$, it indicates that the decision unit is non-DEA, but the larger the value of $\theta$, the higher the relative effectiveness of DEA.

The scale efficiency of the DMU can be judged by $\lambda_j$ in the BCC-DEA model: if $\sum \lambda_j^* = 1$, the DMU scale efficiency is unchanged; if $\sum \lambda_j^* < 1$, then the DMU is increasing in scale efficiency; if $\sum \lambda_j^* > 1$, the DMU is decreasing in scale efficiency. In addition, for the provinces with decreasing returns, the redundancy and redundancy rate of each input indicator can
be further calculated. The redundancy rate indicates the percentage of the redundancy of each input indicator to the total input of each indicator. The redundancy situation is to investigate the extent to which input factors can be reduced in the case of constant output; in addition, the greater the energy redundancy rate, the greater the potential for energy efficiency in the construction industry and the reduction of energy waste in the construction industry in the region.

2.2. Construction Industry Efficiency Evaluation Index Based on DEA Model

When using the DEA model, the determination of reasonable input and output indicators has a lot to do with the effectiveness and accuracy of the construction industry efficiency evaluation model. According to the research of existing scholars, based on the total factor construction industry chain, considering the characteristics of the construction industry energy consumption structure, the relationship between economic development and environmental changes, capital stocks, labor, machinery and equipment and building energy consumption are the input indicators. They are set to \( x_1, x_2, x_3 \) and \( x_4 \); the construction industry GDP and environmental impact are the output indicators, namely \( y_1, y_2 \). The indicators are selected as follows:

1. Capital stock: Existing scholars believe that the total assets of the construction industry are used as capital stocks, but the mechanical equipment is repeatedly calculated. Therefore, the difference between the total assets of the construction industry and the value of machinery and equipment is used as the capital stock.

2. Labor: Labor input should be measured by the effective labor time of employees, and the quality difference of labor should be considered. Since the relevant data is difficult to obtain, this paper selects the average number of employees in the construction industry of each province as the input of labor, that is, the number of employees at the beginning of the year and the number of employees at the end of the year plus the average.

3. Mechanical equipment: Mechanical equipment reflects the construction equipment situation and is one of the important input factors of the construction industry. This paper selects the total power of the construction machinery and equipment at the end of the year as the input of mechanical equipment.

4. Energy consumption in the construction industry: The construction industry consumes a wide variety of energy sources. Therefore, it is converted into “10,000 tons of standard coal” and aggregated to form the total energy consumption.

5. Economic output: taking the GDP of each province's construction industry as an indicator

6. Environmental impact: This paper selects the exhaust gas released from the one-time energy consumption of the construction industry as the index value and quotes the calculation method of Qi Shenjun [6] to convert the waste gas generated by energy utilization in the construction industry into CO\(_2\) emissions.

The model considers the input of decision-making units from four dimensions: capital stock, labor, machinery and energy consumption, and comprehensively considers output from both economic and environmental perspectives. The economic indicators better reflect the scale and benefits of the energy output of the construction industry. The environmental indicators reflect the environmental impact of the construction industry's economic development, which better reflects the input and output of the energy efficiency assessment of the construction industry. More comprehensive and accurate evaluation of the energy efficiency values of the provinces.

2.3. Construction carbon emission decomposition model

In order to further analyze the influencing factors of carbon emissions in various provinces, the factor decomposition method is used to decompose. Based on the results of previous studies [6-8], the two indicators of carbon emissions and total energy consumption are improved, because carbon emissions include energy consumption, the above two indicators are combined. This paper selects five factors of “carbon emissions, construction industry output value, construction industry employees, fixed assets and building area” to analyze the impact of carbon emissions in the construction industry. The decomposition model is as shown in equations (2) to (3):
\[ C_i = S_i \times \frac{C_i}{O_i} \times \frac{P_i}{P} \times \frac{A_i}{A} = S_i \times Q_{i,1} \times Q_{i,2} \times Q_{i,3} \times Q_{i,4} \]  

In the formula: \( S_i \), \( C_i \), \( O_i \), \( P_i \), \( A_i \) respectively represent the construction area, carbon emissions, construction industry output value, construction industry employees, and fixed assets of the construction industry in the first year of the province and use \( Q_{i,1} \), \( Q_{i,2} \), \( Q_{i,3} \), \( Q_{i,4} \) respectively represent the score relationship of the five factors in the above formula. Then, the carbon emission growth of a neighboring year in a certain province can be decomposed according to formula (3):

\[ C_{i,t+1} - C_{i,t} = \left( S_{i,t+1} - S_{i,t} \right) \times Q_{i,1,t} \times Q_{i,2,t} \times Q_{i,3,t} \times Q_{i,4,t} \]

\[ + S_{i,t+1} \times \left( Q_{i,1,t+1} - Q_{i,1,t} \right) \times Q_{i,2,t} \times Q_{i,3,t} \times Q_{i,4,t} \]

\[ + S_{i,t+1} \times Q_{i,1,t} \times \left( Q_{i,2,t+1} - Q_{i,2,t} \right) \times Q_{i,3,t} \times Q_{i,4,t} \]

\[ + S_{i,t+1} \times Q_{i,1,t} \times Q_{i,2,t} \times \left( Q_{i,3,t+1} - Q_{i,3,t} \right) \times Q_{i,4,t} \]

\[ + S_{i,t+1} \times Q_{i,1,t} \times Q_{i,2,t} \times Q_{i,3,t} \times \left( Q_{i,4,t+1} - Q_{i,4,t} \right) \]

\[ = \overline{C}_1 + \overline{C}_2 + \overline{C}_3 + \overline{C}_4 + \overline{C}_5 \]

In the formula, \( \overline{C}_1, \overline{C}_2, \overline{C}_3, \overline{C}_4, \overline{C}_5 \) respectively represent increase or decrease of building carbon emissions caused by changes in 5 indicators which are the building area, the carbon output of the construction industry unit, the average output value of the construction industry employees, the construction industry employees and mechanical equipment ratio and the unit construction area mechanical equipment rate.

According to the economic meaning and physical meaning of the formula indicators, for the provinces with absolute carbon emission growth, there are the following basic rules: The larger \( \overline{C}_1 \) and \( \overline{C}_3 \), the greater the contribution to the economy; \( \overline{C}_2 \) is the most important indicator for observing low carbon, It should be taken as negative, and the smaller the better, thus inhibiting the increase of carbon emissions caused by \( \overline{C}_1 \) and \( \overline{C}_3 \) growth; \( \overline{C}_4 \) and \( \overline{C}_5 \) reflects the level of industrialization of construction. The smaller D is, the better it is; the larger E is, the better due to the current construction industry employees year by year. T; for the provinces where emissions are absolutely reduced, the above five indicators are reversed.

3. Empirical analysis

3.1. Data source and processing

The data sources are China Statistical Yearbook and China Energy Statistical Yearbook from 2008 to 2017. Considering the authenticity and accessibility of the data, the data selected in this paper does not include Macau, Hong Kong and Taiwan. The capital stock data comes from the “Association of Sub-regional Construction Enterprises” of China Construction Yearbook; the initial data of the labor force comes from the “Sub-regional Construction Enterprise Employees by Registration Type” of China Statistical Yearbook; Energy Input The data comes from the regional energy balance sheet of China Energy Statistics Yearbook. It uses various energy conversion standard coal reference coefficients to convert the multiple energy sources consumed by the construction industry in each province into standard coal. The environmental output indicator data comes from the sub-regional energy balance table in the China Statistical Yearbook. It converts the multiple energy sources consumed by the construction industry in each province into CO_2 emissions. The economic output indicator data is derived from the “China's total output value of construction industry” in the China Statistical
Yearbook, and it is uniformly converted into the constant price in 2008 according to the inflation coefficient; in addition, since the data collection target of the construction area is only the building construction, according to the proportion of the output value of the building construction industry and the total output value of the construction industry, it is converted into the construction industry construction area equivalent.

After obtaining the above data, the Pearson correlation coefficient between SPSS and other indicators of construction industry assets, total mechanical power, labor, building energy consumption, economic output and environmental impact is adopted. The calculation results show that the correlation between input indicators and output indicators is very strong; the correlation between input indicators and output indicators is relatively weak, so the selected input and output indicators are ideal.

Considering that SPSS could not analyze panel data, take Beijing as an example. Due to the limited space, a bivariate analysis was performed between selected indicators. It is found that the correlation between input variables is low, and the correlation between input variables and output variables is high, so the input and output indicators selected are ideal.

Table 1 Pearson correlation coefficient

|                | Capital stock | Labor |
|----------------|---------------|-------|
| Capital stock  | Pearson Correlation | 1     |
|                | Significant (bilateral) | .434  |
|                | N              | 10    |
| Labor          | Pearson Correlation | .211  |
|                | Significant (bilateral) | .434  |
|                | N              | 10    |

|                | Labor | Equipment |
|----------------|-------|-----------|
| Labor          | Pearson Correlation | 1     |
|                | Significant (bilateral) | -.214 |
|                | N     | 10        |
| Equipment      | Pearson Correlation | .553  |
|                | Significant (bilateral) | .553  |
|                | N     | 10        |

|                | Equipment | Economic output |
|----------------|-----------|-----------------|
| Equipment      | Pearson Correlation | 1     |
|                | Significant (bilateral) | -.760 |
|                | N         | 10    |
| Economic output| Pearson Correlation | -.760 |
|                | Significant (bilateral) | .181  |
|                | N         | 10    |

3.2. Energy efficiency evaluation of construction industry in each province

The DEAP2.1 software is used to analyze the panel data of each province's construction industry. According to the CCR-DEA model and the BCC-DEA model, the comprehensive efficiency, technical efficiency and scale efficiency of 2007~2016 are calculated respectively. After, the redundancy and redundancy rate of each input index are used, in which the CO₂ emissions cannot directly obtain the data of the sub-regions. So this paper based on the calculation of the Qi the calculation results are calculated according to the proportion of the added value of the national construction industry in each region. The calculation results are shown in Table 2.
Table 2 Comprehensive energy consumption efficiency

| Province     | Comprehensive efficiency | Technical efficiency | Scale efficiency | Scale type |
|--------------|--------------------------|----------------------|-----------------|------------|
| Beijing      | 1                        | 1                    | 1               | Constant   |
| Tianjin      | 0.784                    | 0.816                | 0.961           | Decrement  |
| Hebei        | 0.766                    | 0.938                | 0.816           | Decrement  |
| Shanxi       | 0.535                    | 0.579                | 0.924           | Decrement  |
| Inner Mongolia | 0.771                   | 0.835                | 0.923           | Decrement  |
| Liaoning     | 0.907                    | 1                    | 0.907           | Decrement  |
| Jilin        | 1                        | 1                    | 1               | Constant   |
| Heilongjiang | 0.775                    | 0.881                | 0.880           | Decrement  |
| Shanghai     | 1                        | 1                    | 1               | Constant   |
| Jiangsu      | 0.882                    | 1                    | 0.882           | Decrement  |
| Zhejiang     | 1                        | 1                    | 1               | Constant   |
| Anhui        | 0.651                    | 0.702                | 0.928           | Decrement  |
| Fujian       | 0.860                    | 0.995                | 0.865           | Decrement  |
| Jiangxi      | 0.648                    | 0.688                | 0.943           | Increment  |
| Shandong     | 0.604                    | 0.716                | 0.843           | Increment  |
| Henan        | 0.580                    | 0.755                | 0.769           | Decrement  |
| Hubei        | 0.639                    | 0.698                | 0.916           | Decrement  |
| Hunan        | 0.708                    | 0.845                | 0.838           | Decrement  |
| Guangdong    | 0.873                    | 1                    | 0.873           | Decrement  |
| Guangxi      | 0.604                    | 0.677                | 0.892           | Decrement  |
| Hainan       | 1                        | 1                    | 1               | Constant   |
| Chongqing    | 1                        | 1                    | 1               | Constant   |
| Sichuan      | 0.911                    | 1                    | 0.911           | Decrement  |
| Guizhou      | 0.685                    | 0.698                | 0.916           | Decrement  |
| Yunnan       | 0.776                    | 0.811                | 0.956           | Decrement  |
| Shaanxi      | 0.597                    | 0.637                | 0.937           | Decrement  |
| Gansu        | 0.830                    | 1                    | 0.830           | Decrement  |
| Qinghai      | 1                        | 1                    | 1               | Constant   |
| Ningxia      | 0.856                    | 1                    | 0.856           | Increment  |
| Xinjiang     | 1                        | 1                    | 1               | Constant   |

It can be seen from Table 2 that the energy-efficient provinces are Beijing, Jilin, Shanghai, Zhejiang, Hainan, Chongqing, Qinghai, and Xinjiang, which constitute the frontier of China's construction industry energy efficiency; Liaoning, Jiangsu, Guangdong. The technical efficiency of the six regions of Sichuan, Gansu and Ningxia is 1, and the scale efficiency is less than 1, indicating that these regions make full use of resources, and if they want to maintain the existing output, their investment can no longer be reduced. Energy-efficient non-effective provinces in Tianjin, Hebei, Shanxi, Inner Mongolia, Heilongjiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangxi, Guizhou, Yunnan, and Shaanxi are declining in scale, indicating the existence of waste of resources, detailed redundancy conditions are shown in Table 3. In the non-effective provinces of energy efficiency, the two regions in Jiangxi and Ningxia have increased returns to scale, indicating that these two regions have large potential for increasing production and emission reduction. However, due to insufficient resource input at this stage, their output is affected, directly leading to their energy. The efficiency is low, so increasing the resource input of the two regions is an effective way to improve the energy efficiency of the construction industry.
### Table 3: Input indicator redundancy and redundancy rate for non-technical provinces

| Province        | Employee redundancy (10,000 people) | Mechanical redundancy (10,000 kW) | Energy consumption redundancy (10,000 tons) | Practitioner redundancy rate | Mechanical redundancy rate | Energy consumption redundancy rate |
|-----------------|-------------------------------------|----------------------------------|---------------------------------------------|------------------------------|----------------------------|-------------------------------|
| Tianjin         | 64276.009                           | 90.599                           | 702.594                                     | 18.45%                       | 30.92%                     | 18.44%                        |
| Hebei           | 66107.473                           | 194.48                           | 13172.636                                   | 6.18%                        | 66.38%                     | 61.71%                        |
| Shanxi          | 249976.139                          | 175.244                          | 22636.703                                   | 42.13%                       | 42.13%                     | 79.84%                        |
| Inner Mongolia  | 63486.15                            | 36.422                           | 13801.304                                   | 16.48%                       | 16.48%                     | 85.25%                        |
| Liaoning        | 0                                   | 0                                | 0                                           | 0.00%                        | 0.00%                      | 0.00%                         |
| Heilongjiang    | 56126.787                           | 43.583                           | 2435.252                                    | 11.91%                       | 11.91%                     | 26.98%                        |
| Jiangsu         | 0                                   | 0                                | 0                                           | 0.00%                        | 0.00%                      | 0.00%                         |
| Anhui           | 371477.271                          | 236.335                          | 5919.214                                    | 30.15%                       | 44.42%                     | 67.03%                        |
| Fujian          | 5228.601                            | 14.532                           | 28.361                                      | 0.53%                        | 3.44%                      | 0.53%                         |
| Jiangxi         | 323297.756                          | 62.174                           | 1434.686                                    | 52.40%                       | 31.24%                     | 31.24%                        |
| Shandong        | 766248.548                          | 461.53                           | 16533.482                                   | 28.40%                       | 36.14%                     | 57.01%                        |
| Henan           | 532176.018                          | 469.018                          | 15434.909                                   | 30.21%                       | 49.90%                     | 73.49%                        |
| Hubei           | 383360.485                          | 608.677                          | 2910.505                                    | 30.15%                       | 59.04%                     | 30.15%                        |
| Hunan           | 294562.707                          | 329.905                          | 6308.558                                    | 22.38%                       | 51.07%                     | 66.84%                        |
| Guangdong       | 0                                   | 0                                | 0                                           | 0.00%                        | 0.00%                      | 0.00%                         |
| Guangxi         | 154032.197                          | 179.577                          | 1348.286                                    | 32.31%                       | 60.46%                     | 32.31%                        |
| Sichuan         | 0                                   | 0                                | 0                                           | 0.00%                        | 0.00%                      | 0.00%                         |
| Guizhou         | 90464.781                           | 36.685                           | 7397.06                                     | 31.13%                       | 31.35%                     | 74.42%                        |
| Yunnan          | 116482.302                          | 81.758                           | 1410.46                                     | 18.85%                       | 25.23%                     | 18.85%                        |
| Shaanxi         | 208387.564                          | 210.466                          | 2683.533                                    | 38.05%                       | 49.87%                     | 36.26%                        |
| Gansu           | 0                                   | 0                                | 0                                           | 0.00%                        | 0.00%                      | 0.00%                         |
| Ningxia         | 0                                   | 0                                | 0                                           | 0.00%                        | 0.00%                      | 0.00%                         |

Under the existing output level, DEA non-technical provinces have different levels of energy input redundancy except Liaoning, Jiangsu, Guangdong, Sichuan, Gansu and Ningxia. From Table 3, it can be seen that the energy consumption redundancy rate of the provinces of Yunnan, Tianjin and Fujian is below 20%, and the energy consumption redundancy rates of the 14 provinces such as Inner Mongolia, Shanxi, and Guizhou are all above 20%. As can be seen from Table 3, the energy redundancy rate is the highest, the machinery is second, and the personnel redundancy is the smallest.

### 3.3. Decomposition of factors affecting carbon emissions

According to formulas (2)–(3), the factors affecting the carbon emissions of buildings in China are further decomposed, as shown in Table 4.
The increase in building area and the increase in per capita output are the main reasons for the increase in carbon emissions per unit of output value in the construction industry. In all provinces of the country, the decrease in carbon emissions in the two provinces. The fundamental reason is the reduction in stable number of employees in the construction industry and the amount of machinery and equipment proportion of employees and machinery in the construction industry to be too high, and maintain a building area and enhance mechanical efficiency. Zhejiang, Hainan, and Chongqing should control the mechanical ratio of existing employees. Shanghai, Jilin, and Qinghai should control the growth of new industry and increase the mechanical efficiency while maintaining the average output value and should continue to be maintained. Beijing should reduce the construction area of the construction industry are proposed from three aspects:

3.4 Regional emission reduction strategies

Through the horizontal analysis results of the DEA model and the decomposition results of the provincial factors of the FAA method, the regional emission reduction strategies of the construction industry are proposed from three aspects:

(1) For provinces with “variable scale returns”, the existing scale of investment and output effects should continue to be maintained. Beijing should reduce the construction area of the construction industry and increase the mechanical efficiency while maintaining the average output value and mechanical ratio of existing employees. Shanghai, Jilin, and Qinghai should control the growth of new building area and enhance mechanical efficiency. Zhejiang, Hainan, and Chongqing should control the proportion of employees and machinery in the construction industry to be too high, and maintain a stable number of employees in the construction industry and the amount of machinery and equipment invested. Xinjiang should take the control of construction industry personnel as the main means to improve the level of industrialization of construction and reduce unnecessary labor.

| Province    | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | Major factors contributing to increased carbon emissions | Major factors in reducing carbon emissions |
|-------------|-------|-------|-------|-------|-------|--------------------------------------------------------|------------------------------------------|
| Beijing     | -334.4 | -5.58 | 200.5 | 458.9 | -500.2 | 1, 2, 5                                                | 3, 4                                      |
| Tianjin     | 85.6   | -9.98 | 158.9 | -14.7 | -98.5  | 1, 3                                                  | 2, 4, 5                                  |
| Hebei       | 275.2  | -250.8 | 281.2 | 508.5 | -788.9 | 1, 3, 4                                                | 2, 5                                      |
| Shanxi      | 2658.2 | -1005.2 | -5623.5 | 8425.2 | -2895.5 | 1, 4                                                  | 2, 3, 5                                  |
| Inner Mongolia  | 185.3 | -18.5 | 147.8 | -148.8 | -50.8  | 1, 3                                                  | 2, 4, 5                                  |
| Liaoning    | 487.6  | -408.9 | 358.8 | -249.8 | 3.58   | 1, 3, 5                                                | 2, 4                                      |
| Jilin       | 2014.2 | -1089.8 | 1872.5 | 1102.5 | -2689.5 | 1, 3, 5                                                | 2, 4, 5                                  |
| Heilongjiang| 98.8   | -5.8  | 8.5   | 148.5 | -187.5 | 1, 3, 5                                                | 2, 4                                      |
| Shanghai    | -1523.1 | 154.5 | -458.5 | -478.5 | 8502.5 | 1, 3, 5                                                | 2, 4                                      |
| Jiangsu     | 955.2  | -58.8 | -175.5 | 141.5 | -358.9 | 1, 4                                                  | 2, 3, 5                                  |
| Zhejiang    | 120.5  | -8.52 | 48.5  | 258.9 | -258.4 | 1, 3, 4                                                | 2, 5                                      |
| Anhui       | 255.2  | -58.8 | 156.5 | 785.8 | -895.5 | 1, 3, 4                                                | 2, 5                                      |
| Fujian      | 185.2  | -85.5 | 65.5  | 185.5 | -215.5 | 1, 3, 4                                                | 2, 5                                      |
| Jiangxi     | 642.5  | -18.5 | 157.4 | -122.5 | 205.5  | 1, 3, 5                                                | 2, 4                                      |
| Shandong    | 582.5  | -205.8 | 458.8 | -168.5 | -178.6 | 1, 3                                                  | 2, 4, 5                                  |
| Henan       | 145.2  | -68.9 | 98.9  | 198.6 | -298.6 | 1, 3, 4                                                | 2, 5                                      |
| Hubei       | 142.5  | -96.3 | 168.6 | 406.9 | -568.5 | 1, 3, 4                                                | 2, 4, 5                                  |
| Hunan       | 44.5   | 6.8   | 98.6  | -58.6 | -69.5  | 1, 2, 3                                                | 4, 5                                      |
| Guangdong   | 85.5   | -25.6 | 152.6 | 572.3 | -365.3 | 1, 3, 4                                                | 2, 5                                      |
| Guanzxi     | 287.6  | -303.5 | 298.3 | -93.6 | -152.3 | 1, 3                                                  | 2, 4, 5                                  |
| Hainan      | 185.6  | -10.5 | 296.4 | -178.6 | -187.5 | 1, 3                                                  | 2, 4, 5                                  |
| Chongqing   | 158.5  | 3.2   | 148.5 | 752.3 | -985.6 | 1, 2, 3, 4                                            | 5, 2                                     |
| Sichuan     | 175.2  | -56.5 | 241.3 | 1589.2 | -2014.8 | 1, 3, 4                                                | 2, 5                                      |
| Guizhou     | 145.2  | -52.3 | 178.5 | 35.6  | -185.3 | 1, 3, 4                                                | 2, 5                                      |
| Yunnan      | 174.5  | -45.8 | 187.6 | 502.5 | -201.5 | 1, 3, 4                                                | 2, 5                                      |
| Shaanxi     | 477.5  | -201.9 | 398.6 | -789.2 | 605.2  | 1, 3, 5                                                | 2, 4                                      |
| Gansu       | 342.5  | -251.6 | 486.5 | -987.2 | 580.5  | 1, 3, 5                                                | 2, 4                                      |
| Qinghai     | 140.5  | -25.3 | 187.9 | -147.2 | 98.2   | 1, 3, 5                                                | 2, 4                                      |
| Ningxia     | 87.5   | -14.9 | 98.6  | -158.6 | 98.6   | 1, 3, 5                                                | 2, 4                                      |
| Xinjiang    | -545.8 | 523.5 | -184.2 | 158.6 | 140.6  | 1, 3                                                  | 2, 4, 5                                  |

As can be seen from Table 3, the negative contribution of Beijing, Shanghai, and Xinjiang is due to the decrease in carbon emissions in the two provinces. The fundamental reason is the reduction in carbon emissions per unit of output value in the construction industry. In all provinces of the country, the increase in building area and the increase in per capita output are the main reasons for the increase in carbon emissions, while the reduction in carbon emissions from the construction industry is the fundamental to curb carbon emissions. The level of industrialization of buildings is double-sided, which may be the cause of the increase in carbon emissions, and may be the cause of the reduction in carbon emissions.  

3.4 Regional emission reduction strategies

Through the horizontal analysis results of the DEA model and the decomposition results of the provincial factors of the FAA method, the regional emission reduction strategies of the construction industry are proposed from three aspects:

(1) For provinces with “variable scale returns”, the existing scale of investment and output effects should continue to be maintained. Beijing should reduce the construction area of the construction industry and increase the mechanical efficiency while maintaining the average output value and mechanical ratio of existing employees. Shanghai, Jilin, and Qinghai should control the growth of new building area and enhance mechanical efficiency. Zhejiang, Hainan, and Chongqing should control the proportion of employees and machinery in the construction industry to be too high, and maintain a stable number of employees in the construction industry and the amount of machinery and equipment invested. Xinjiang should take the control of construction industry personnel as the main means to improve the level of industrialization of construction and reduce unnecessary labor.
(2) For provinces with “technical effectiveness and ineffective scale”, the scale of investment of each factor should be expanded or the efficiency of existing output scale should be increased. The six provinces of Liaoning, Jiangsu, Guangdong, Sichuan, Gansu and Ningxia are all purely technically effective, indicating that these provinces make full use of the existing input resources and the investment should not be reduced. In Jiangxi and Ningxia, the scale returns are increasing, and the scale of investment of each factor can be appropriately expanded according to the existing investment ratio to improve the scale efficiency. Liaoning, Jiangsu, Guangdong, Sichuan, and Gansu have reduced their scale returns. They should improve resource utilization on the premise of existing scales. They should increase the application of low-carbon equipment, improve the level of building industrialization, and reduce the carbon emissions of construction industry units.

(3) For provinces with “ineffective technology and ineffective scale”, it is necessary to change the structure of input and output factors, improve resource allocation, and improve energy efficiency in the construction industry. As the only province with increasing returns to scale, Jiangxi can appropriately expand the scale of investment of various factors according to the existing ratio and increase the scale efficiency. The personnel redundancy rate, mechanical redundancy rate, and energy consumption redundancy rate are all high, and it is necessary to increase the investment and mechanical efficiency of low-carbon machinery to reduce the redundancy rate of employees and improve energy utilization efficiency. Tianjin, Hebei, Shanxi, Inner Mongolia, Heilongjiang, Anhui, Fujian, Shandong, Henan, Hubei, Hunan, Guangxi, Guizhou, Yunnan, and Shaanxi are all provinces with decreasing scale of returns. They should maintain the scale of the construction industry while reducing some input factors. From the results of the redundancy rate and the influencing factors affecting the carbon emissions of the construction industry, Hebei, Inner Mongolia, Shanxi, Anhui, Shandong, Henan, Hunan, Guizhou have high mechanical redundancy rate and energy consumption redundancy rate, which should be relatively large. When reducing the use of mechanical equipment, reasonable control of the ratio of employees to mechanical equipment; Hubei, Guangxi, Shaanxi, mechanical redundancy rate is the most prominent, affecting the significant reduction in the investment of mechanical equipment, of which Guangdong should reduce construction industry employees and machinery Equipment ratio, Shaanxi should appropriately increase the proportion of construction industry employees and mechanical equipment. Tianjin and Yunnan personnel investment and mechanical input need to be reduced. Energy efficiency should also be strengthened. It is necessary to change the current energy consumption structure and reduce the carbon emission coefficient of comprehensive energy.

4. Conclusion
This paper evaluates the energy efficiency of the construction industry in 30 provinces of China combined with the main factors of carbon emissions in the construction industry and the redundant resources of the provinces with ineffective scale through DEA model and improved FAA method. The construction industry emission reduction strategy provides certain decision-making basis and theoretical guidance for China’s development of low-carbon construction industry development strategy. The research shows that: 1) The seven provinces with energy efficiency in the construction industry should give priority to development, but from the perspective of carbon emission, it is necessary to reduce the use of low-carbon machinery; 2) 6 technologies that are “technically effective and ineffective” The provinces should appropriately expand the input scale of each factor or increase the energy efficiency in the existing output scale; 3) The provinces with “ineffective technology and ineffective scale” should optimize the input ratio of each factor, optimize the resource structure, and improve the energy efficiency of the construction industry. 4) The carbon emissions in Beijing, Shanghai, and Xinjiang have shown a downward trend. The fundamental reason is the reduction in carbon emissions per unit of output value in the construction industry.
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