Chapter 2
China's Provincial Energy Efficiency of Construction Industry in 2005–2010: An Empirical Study Based on the DEA Model

You-zhi Zhang and Hong-chun Gu

Abstract In China's construction industry there exist high consumption and low energy efficiency, and improvement of energy efficiency has an important significance for the sustainable development of construction industry. According to the framework of total factor energy efficiency, a DEA model was developed to study China's provincial energy efficiency of construction industry during 2005–2010. The results have shown that, during this period, the average energy utilization efficiency of China's construction industry has increased to a certain extent, but technology progress only has limited impact on the improvement of construction energy efficiency; there are significant differences in regional energy efficiency, generally the construction energy efficiency in eastern coastal areas is relatively higher, while inefficient utilization of energy in construction industry has been observed in central-western regions. Finally, the impacts of industrial structure, energy consumption structure, enterprises strength and technology level on the provincial construction energy efficiency have been studied.

Keywords DEA • DEA effectiveness • Energy efficiency • Technology innovation • Energy-saving

Energy is an important factor to promote and constrain economic development, improving energy efficiency has been accepted as national consensus. According to statistics, construction industry has become an important pillar industry of China's economy, the value added of construction industry reached 6.7 % in 2010; on the other hand, despite energy consumption of construction industry accounted for only 1.5 % of the total energy consumption, the total energy consumption of construction industry has increased year by year, has increased from 25.36 million tons of

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standard coal in 2005–47.88 million tons of standard coal in 2010. Therefore, continuous improvement of energy efficiency in the construction industry has an important impact on economic growth.

In 1978, Charnes and Cooper created Data Envelopment Analysis (DEA), as a non-parametric estimation methods, which was suitable to evaluate relative production efficiency of multiple Decision-Making Units (DMU) [1]. DEA model has been widely used to study energy efficiency, eco-efficiency, innovation and sustainable development capacity [2–6].

Although the DEA model also was used, some improvement was made in this paper: in existing literatures the energy efficiency of the iron and steel, mining and other heavy industrial sectors was usually discussed, energy efficiency of construction industry became theme in this paper; existing studies focused on national or regional energy efficiency, while provincial energy efficiency of construction industry will be comparatively studied; the cross-sectional data was widely used in existing research, the panel data will be used to analyze temporal characteristics of energy efficiency among inter-provincial construction industries.

The main content of this paper is divided into three parts: First, a brief introduction of DEA models and research methods; Then, empirical research on energy efficiency of China's inter-provincial construction industry by using DEA model; finally, after discussion of empirical results, some recommendations to energy-saving are made.

2.1 Research Method

2.1.1 The DEA Model

There are many different kinds of DEA models, and C^2R and BC^2 are most commonly used. In C^2R model relative efficiency of a DMU is calculated under the condition of constant returns to scale (CRS). While in BC^2 model it is assumed that DMU is under the condition of variable returns to scale (VRS), and the convexity assumption $\left(\sum_{j=1}^{n} \lambda_j = 1\right)$ will be added to C^2R model, thus technical efficiency is decomposed into pure technical efficiency and scale efficiency. Although it is suitable for C^2R model to measure comprehensive efficiency of a DMU, it is unable to discern technical inefficiency or scale inefficiency when a DMU is DEA inefficient.

When measuring production efficiency of a DMU, the DEA model can be divided up into input-oriented and output-oriented categories. For the input-oriented model input realizes minimization under the condition of output unchanged; while in output-oriented model output achieves maximization under the condition of input unchanged. Taking into account that energy-saving is the basic principle of energy use, and also to control inputs is more practical than to control output. Therefore, in this paper the BC^2 input-oriented model is used to identify pure technical efficiency and scale efficiency of energy in construction industry.

Where very province is treated as a DMU, the DMU uses input ${x_{mj}}^t$ to achieve output${y_{sj}}^t$, thus given input the linear programming equation is shown as following:

$$\min \theta$$
$$s.t. \sum_{j=1}^{n} x_{mj}^{t}\lambda_j \le \theta x_0,\ \sum_{j=1}^{n} y_{sj}^{t}\lambda_j \ge y_0,\ \sum_{j=1}^{n} \lambda_j = 1; \quad \text{where, } \lambda_j \ge 0,\ j = 1, 2, \ldots n. \tag{2.1}$$

According to Eq. (2.1), pure technical efficiency (*Pte*) can be calculated, and technology efficiency (*Te*) can be also solved when removing the convexity assumption.

2.1.2 Malquist *Productivity Index*

According to Caves' ideas (1982), *Malquist* productivity index is a useful tool for analyzing the total factor energy efficiency of construction industry. By using *Malquist* index, interregional technical progress changes (*Techch*) can be examined, but also the technical efficiency change (*Effch*) can be decomposed into pure technical efficiency change (*Pech*) and scale efficiency change (*Sech*), thus total factor energy efficiency (*Tfpch*) can be solved.

Assuming that (x_t, y_t) and (x_{t+1}, y_{t+1}) is respectively the relationship of input-output for period t and t+1, thus the change in input-output relationship from (x_t, y_t) to (x_{t+1}, y_{t+1}) is the productivity change, which may be resulted from the changes in technology level or in technical efficiency. Supposing that $D_t(x_t, y_t)$ and $D_{t+1}\left(x_{t+1}, y_{t+1}\right)$ is separately the distance function of a DMU on given period t technical reference, thus *Malquist* productivity index is shown as following:

$$M_t\left(x_t, y_t, x_{t+1}, y_{t+1}\right) = \left[\frac{D_t\left(x_{t+1}, y_{t+1}\right)}{D_t\left(x_t, y_t\right)} \times \frac{D_{t+1}\left(x_{t+1}, y_{t+1}\right)}{D_{t+1}\left(x_t, y_t\right)}\right]^{1/2} = Pech \times Sech \times Techch \tag{2.2}$$

If $M_t\left(x_t, y_t, x_{t+1}, y_{t+1}\right) > 1$, it means that the total factor productivity raises; *Techch* represents technology boundary change from period t to $t + 1$, if *Techch*>1 which indicates that there is technical progress; *Effch* refers to relative technical efficiency change from period t to $t + 1$, when *Effch*>1 indicating improvement of relative technical efficiency; *Pech* is the pure technical efficiency change, if *Pech*>1 indicates that the DMU has improved its management efficiency; *Sech* is the changes in scale efficiency, when *Sech*>1 it means that the DUN is approaching to the optimal production scale.

2.1.3 The Analysis Data

According to analytical framework of the total factor energy efficiency, the value-added of construction industry is treated as output factor in the DEA model, and then energy, capital and labor are treated as input factors. Finally there is some explanation of these data as following:

1. **Output factor**. The value added of provincial construction industry is the output variable in DEA model, which would be conversed to 2005 fixed price by using the GDP deflator.
2. **Capital stock**. Usually capital stock is estimated by using perpetual inventory method [7], where the fixed assets investment of provincial construction industry is used to replace the capital stock, which also would be translated into 2005 unchanged price.
3. **Labor input**. The average number of employees of provincial construction enterprises is used to calculate labor input index.
4. **Energy input**. Construction industry will consume coal, oil, natural gas and hydropower, which would be converted into standard coal with reference coefficient of standard coal.

Because there is no complete data of Tibet, Hong Kong, Macao and Taiwan regions, study object will be energy efficiency of construction industry in 30 provinces mainland China, and study period is 2005–2010 considering of the availability and quality of the data. The original data all come from China Statistical Yearbook, China Energy Statistical Yearbook and China Construction Industry Statistical Yearbook in 2006–2011.

2.2 Empirical Study of Provincial Energy Efficiency of Construction Industry

2.2.1 The Analysis of Total Factor Energy Efficiency of Construction Industry

Firstly, the software DEAP 2.1 will be used to estimate 2005–2010 energy efficiency of provincial construction industry under the condition of constant returns. According to the estimated results, some findings can be found as following:

1. The total factor energy efficiency of provincial construction industry was averagely 0.6–0.7, which meant that as a whole the energy utilization in China's construction industry still stood on a low level without meeting DEA efficiency. It is worth noting that during this period the energy efficiency of construction industry experienced a U-type process (first decreased and then increased), but overall the energy efficiency undergone a downward trend.

2. There was significant regional difference in the total factor energy efficiency of provincial construction industry, China could be divided into high grade, middle grade and low grade according to energy efficiency level. Generally the energy efficiency of construction industry was highest in eastern coastal areas, while the energy efficiency of construction industry is relatively lower in the western-middle regions. Specifically, the energy efficiency of construction industry in some provinces reached to DEA efficiency, which was Beijing, Heilongjiang, Shanghai and Zhejiang, the energy efficiency of Ningxia, Jiangsu and Liaoning was also more than 0.9 approaching to DEA efficiency, these seven provinces were regions with highest energy efficiency. On the other hand, those provinces with lower energy efficiency mostly concentrated in the western-central regions, and the construction energy efficiency in Shanxi, Shandong, Hubei, Gansu and Hainan was less than 0.5 during most of 2005–2010, which were regions with lowest energy efficiency.

2.2.2 *Total Factor Energy Efficiency of Construction Industry Based on* Malquist *Index*

Malquist model was solved by using software DEAP2.1, and total factor energy efficiency would be respectively decomposed by time and region, as shown in Tables 2.1 and 2.2.

Some results could be found from the decomposition of construction energy efficiency by time and region (Tables 2.1 and 2.2):

1. Total factor energy efficiency of provincial construction industry arrived to 1.042 averagely, indicating that energy efficiency experienced a upward trend generally. However the progress in energy efficiency was undergoing a downward trend, declining from 1.068 in 2006 to 1.016 in 2010, which meant that it was difficult to continuously maintain energy efficiency.
2. During the same period, the average of technical efficiency in construction industry was 0.977, despite of high-speed growth of 9.4 % in 2009, while it still experienced a downward trend. The decomposition of technical efficiency indicated a falling trend in pure technical and scale efficiency, and they all experienced a change process (first decline, and then rise, again down).
3. Thus, during this period, the improvement in energy efficiency of China's construction industry mainly came from technology progress; except that the average of technological progress index was only 0.95 in 2009, during most time the technology progress was greater than one, which indicated a widespread technology progress in energy efficiency was reached during the period of 2005–2010, as shown in Table 2.1.
4. According to the decomposition of total factor construction energy efficiency by region (Table 2.2), except of Fujian, Jiangxi, Guangdong and Shanxi, the construction energy efficiency raised on varying degree, where Guangxi

Table 2.1 The decomposition of total factor construction energy efficiency in 2005–2010 (by time)

Year	2006	2007	2008	2009	2010	Average
Technical efficiency	0.966	0.923	0.933	1.094	0.98	0.977
Technology progress	1.106	1.185	1.069	0.952	1.037	1.067
Pure technical efficiency	0.978	0.959	0.956	1.074	0.989	0.993
Scale efficiency	0.988	0.963	0.973	1.018	0.991	0.986
Total factor energy efficiency	1.068	1.094	0.995	1.039	1.016	1.042

Table 2.2 The decomposition of total factor construction energy efficiency in 2005–2010 (by region)

Region	Technical efficiency	Technology progress	Pure technical efficiency	Scale efficiency	Total factor energy efficiency
Beijing	1	1.095	1	1	1.095
Tianjin	0.927	1.121	0.923	1.004	1.039
Hebei	0.999	1.068	0.999	1	1.067
Shanxi	0.984	1.076	0.982	1.004	1.059
Neimenggu	0.952	1.119	0.946	1.004	1.063
Liaoning	0.977	1.058	0.994	0.983	1.034
Jilin	1.021	1.107	1.045	0.977	1.131
Heilongjiang	1	1.022	1	1	1.022
Shanghai	1	1.066	1	1	1.066
Jiangsu	1.014	1.039	1	1.014	1.054
Zhejiang	1	1.031	1	1	1.031
Anhui	0.989	1.041	0.991	0.998	1.031
Fujian	0.902	1.045	0.903	0.999	0.942
Jiangxi	0.937	1.016	0.938	0.999	0.952
Shandong	0.952	1.132	1.062	0.895	1.073
Henan	0.978	1.042	0.976	1.002	1.019
Hubei	0.943	1.063	0.942	1.001	1.003
Hunan	0.975	1.043	0.974	1.001	1.017
Guangdong	0.923	1.045	1.034	0.892	0.965
Guangxi	1.085	1.055	1.062	1.022	1.145
Hainan	0.948	1.088	1	0.948	1.031
Chongqing	0.994	1.065	0.996	0.998	1.058
Sichuan	0.995	1.023	0.994	1.001	1.015
Guizhoou	0.995	1.077	1.003	0.991	1.071
Yunan	0.983	1.041	1.009	0.974	1.023
Shanxi	0.919	1.073	0.929	0.989	0.986
Gansu	1.012	1.065	1.038	0.975	1.078
Qinhai	0.982	1.096	1.016	0.966	1.076
Ningxia	1	1.071	1	1	1.071
Xinjiang	0.944	1.138	0.978	0.966	1.074
Average	0.977	1.067	0.993	0.986	1.042

experienced the highest growth rate of 14.5 %. It could be found that the improvement in construction energy efficiency mainly came from technological progress, all provinces had technical progress in construction industry, and highest speed of technological progress in Xinjiang reached 13.8 %.

However, the enhancement in technical efficiency only was observed in eight provinces, accordingly technical efficiency declined in 22 provinces, thus low technical efficiency would become a main constraint of improvement in construction energy efficiency.

2.3 Impact Factors of Construction Energy Efficiency

Energy efficiency may be affected by many factors, such as industrial structure, energy consumption structure, and etc. where the impact of industrial structure, energy consumption structure, the technical level of construction enterprises and enterprise strength on the construction industry energy efficiency would be briefly analyzed in this paper.

Where, the proportion of service sector, the ratio of industrial to service sectors will be used for estimating industrial structure; the consumption proportion of the coal, oil and electricity to would be used to measure the energy consumption structure of regional construction industry; the rate of technical equipment would be used to reflect the technical level of regional construction enterprises; and finally the proportion of special-class and first-class construction enterprises would be used to reflect the corporate strength of regional construction companies.

To simplify the discussion, we only calculated *Pearson* correlation coefficient between construction energy efficiency and its influencing factors in 2010, by which the indirect impact of these four factors on the construction energy efficiency would be studied, as shown in Table 2.3.

According to Table 2.3, we can reach the following conclusions:

1. Industrial structure have an important impact on construction industry energy efficiency, the correlation coefficient of service sector reached 0.378, while the correlation coefficient of the ratio of industrial to service sector arrived to −0.226. It indicates that service sector with lower energy consumption has a positive role in improving energy efficiency; correspondingly industrial sector with high energy consumption would be harmful to improving energy efficiency.
2. Also the energy consumption structure have a significance on construction energy efficiency. Where, the more the primary energy consumption ratio of coal, petroleum products consumption, the lower the energy efficiency; oppositely, as a secondary energy increase in electricity consumption will have an active part in improving construction industry energy, whose correlation coefficient reaches 0.450.

Table 2.3 *Pearson* correlation coefficient of construction energy efficiency and relevant factors

Factor	Indicator	Correlation coefficient
Industrial structure	The proportion of service sector	0.378
	The ratio of industrial to service sector	−0.226
Energy consumption structure	The consumption ratio of coal	−0.137
	The consumption ratio of petroleum	−0.179
	The consumption ratio of electricity	0.450
Technology level	The rate of technical equipment	0.138
Enterprise strength	The proportion of special-class and first-class enterprise	0.197

3. The technology level has a positive impact on the improvement in construction industry energy efficiency, and the correlation coefficient arrives to 0.138. It is consistent with usual anticipation, higher rate of technical equipment means higher technical level; thus more modern construction machinery and equipment are used, less labor input but more high productivity, accordingly more conducive to improvement in energy efficiency.
4. Qualification grade is an important indicator to measure the strength of construction enterprises, the higher qualification grade, the greater financial strength, technical level and personnel quality. Consistent with usual expectations, the stronger the enterprise strength the higher energy efficiency of construction industry, and the correlation coefficient reaches 0.197.

2.4 Conclusion

By the analytical framework of total factor energy efficiency, a DEA model was designed study China's provincial energy efficiency of construction industry during 2005–2010. The results have shown that, during this period, the average energy utilization efficiency of China's construction industry has increased to a certain extent, but technology innovation only has limited impact on the improvement of construction energy efficiency; there are significant differences in construction energy efficiency among regions, generally the construction energy efficiency in eastern coastal areas is relatively higher, while inefficient utilization of energy in construction industry has been observed in central-western regions. Finally, industrial structure, energy consumption structure, enterprise strength and technology level have important impacts on the provincial construction energy efficiency, thus adjustment of industrial structure and energy consumption structure, enhancement of enterprise strength and technology level would have significance on the energy efficiency in provincial construction industry.

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