Research on Evaluation Model of Investment Efficiency of Power Grid Enterprise Under New Electricity Reform

Zhang Dong1,2*, Nuermaimaiti·Ruze2 Song Xiaoyan3, Xu Yu1 and Liu Qiong1

1Inner Mongolia Electric Power Research Institute, Hohhot City, Inner Mongolia, 010020, China
2School of Economics and Management, North China Electric Power University, Beijing 102206, China
3Inner Mongolia Wuhai Energy Conservation Supervision and Testing Center, Wuhai City, Inner Mongolia, 016000, China

*Corresponding author’s e-mail: zhd9240@163.com

Abstract. The three-stage DEA model was applied to study the investment efficiency of a power grid enterprise (PGE) under the reform of electricity transmission and distribution price. This research indicates that environmental variables, including GDP Per Capita and the proportion of industrial power consumption, have a significant impact on the investment efficiency of PGE. To be specific, GDP Per Capita and the proportion of industrial power consumption have a positive influence on the investment efficiencies of PGE in this research. Without environmental variables and random errors, the main reason for the low investment efficiencies of PGE was the lack of scale efficiency. In order to improve its investment efficiency, PGE should attach great significance to economies of scale and a reasonable plan of the enterprise scale.

1. Introduction
With the comprehensive and ongoing implementation of the reform of electricity transmission and distribution price (hereinafter referred to as the Reform), PGE’s way of making profits has gradually changed, and their investment thus has been affected at the meantime. After the Reform, PGE have been subjected to all-around and precautionary supervision which stresses on effective assets as its core and oversees the transmission and distribution revenue, cost, price, etc. PGE can only gain permitted revenue generated by electricity transmission and distribution, making the electricity transmission and distribution price a mechanism and become an important external policy constraint for power grid investment behaviour. Therefore, in the new round of electricity reform, PGE should concentrate on developing scientific investment structure, increasing the input-output ratio and avoiding inefficient and ineffective investment[1].

Under the mechanism of the Reform, investment effectiveness is the core criterion of the investment of PGE, and its evaluation mainly includes power supply reliability, service quality, user demand, economic benefits, social benefits, environmental benefits, etc. From the perspective of input, Literature[2] divided the investment scenarios of power grid planning into inelastic and elastic investment and studied the targeted investment strategies in PGE by adopting the full life cycle evaluation on input and output efficiency. Literature[3] analysed the influence of power grid investment posed by the Reform from aspects of power grid planning and investment decision. In line
with the Reform, the literature built a strategy system for precise power grid investment with characteristics of “Three Excellences”, i.e. excellent assets, excellent service and excellent performance. Literature[4] categorised investment funds into internal and external funds and studied the maximum investment capability of power PGE under the new electricity reform. Under the mechanism of the Reform, the investment of PGE has a profound impact on its future earnings. During the investment decision-making process, PGE were advised to prioritise the effective assets investment whose income was calculable and extractable before considering its investment efficiency. At present, most of the literatures focus on sorting out the current policies and rules in regard to the Reform and not on studying the investment efficiency of PGE. However, under the new electricity reform, this research studied investment efficiency evaluation based on the three-stage DEA model from the perspective of PGE. Literature[5] applied the three-stage DEA model to study China’s provincial PGE’ operational efficiency under the new electricity reform and taking environmental variables and random factors into account. China’s cultural industry is divided into three different geological perspectives: East, Middle and West. Literature [6] applied the three-stage DEA model to study the investment efficiency of China’s cultural industry, and the results showed that environmental factors had a significant impact on the investment efficiency of cultural industry in China.

Combined with researches of the above literatures, this paper applied the three-stage DEA model to study the investment efficiency of PGE under the mechanism of electricity transmission and distribution reform. The advantage of applying three-stage DEA model is that it can separate the management factors from external environmental factors and random errors of technical efficiency and can evaluate the comprehensive efficiency of different fields more accurately and finally obtain more reliable results. Based on the three-stage DEA model, this paper took a PGE as the research object and evaluated its investment efficiency by establishing an input-output index system that adapts to the reform of the power system.

2. Research method
Two articles [7-8], published by Fried (1999, 2002), pointed out that the traditional DEA model does not consider the influences of external environmental factors and stochastic noises on the efficiency evaluation of Decision Making Unit (DMU). Hence, a new three-stage DEA model was proposed to solve the above issues. At the first step, the BCC model is used to calculate the overall efficiency under the influences of external environmental factors and stochastic noises. At the second step, based on the first step, the advantages of the Stochastic Frontier Model (SFA) method are combined to quantify the influences of stochastic noises and external environment on efficiency estimation. The third step is employed to eliminate the influences of stochastic noises and external environment on the efficiency estimation, and only analyze the efficiency values related to the internal management level, thus, obtaining more accurate results.

2.1 The first stage: the traditional DEA model
This stage uses the initial input-output data and the input-oriented BCC model for traditional DEA analysis [9]. The specific BCC model is as follows:

\[
\min \theta - \varepsilon (e^T S^- + e^T S^+) \\
\sum_{j=1}^{n} x_j \lambda_j + S^- = \theta x_0 \\
\sum_{j=1}^{n} y_j \lambda_j - S^+ = y_s \\
\sum_{j=1}^{n} \lambda_j = 1, \lambda_j \geq 0 \\
S^+, S^- \geq 0
\]

where \(X\) and \(Y\) represent input and output vectors in this formula; \(\theta\) represents the overall efficiency value of the DMUs; \(\lambda_j (j = 1, 2, \ldots, n)\) represent weight vector for input and output of each DMUs; and \(S\) represents the slack variables.
2.2 The second stage: SFA regression analysis

**Fried** pointed out that the traditional DEA model calculation results are mainly affected by three factors, namely management efficiency, stochastic noises and external environmental factors. Therefore, it is necessary to use the SFA model to eliminate the influence of stochastic noises and external environment factors on efficiency estimation. The SFA regression model is described as follows:

\[
S_{ni} = f(Z_i; \beta_n) + v_{ni} + u_{ni}; \ i = 1,2,\cdots, I; \ n = 1,2,\cdots, N
\]  

(2)

where \(S_{ni}\) represent the slack values of the input; \(Z_i\) indicate environmental variables; \(\beta_n\) demonstrate the coefficients of the environmental variables; \(v_{ni} + u_{ni}\) means the mixed error terms; \(u_{ni}\) is management inefficiency, \(u \sim N(0, \sigma_u^2)\); \(v_{ni}\) means stochastic noises, \(v \sim N(0, \sigma_v^2)\).

For the slack variable of the i-th input, the SFA model is established as:

\[
X_{ni}^A = X_{ni} + \max \left[ f(Z_i + \beta_n) - f(Z_i + \beta_{ni}) \right] + \max(v_{ni}) - v_{ni}
\]

(3)

where \(X_{ni}\) is the original input values; \(X_{ni}^A\) is the adjusted input values; \(\max(v_{ni}) - v_{ni}\) implies the adjustment dispatching all the DMUs in the least desirable environment confronted by all DMUs; The term \(\max(f(Z_i + \beta_n) - f(Z_i + \beta_{ni}))\) adjusted DMUs to a common condition of nature called the unluckiest condition confronted by all samples. The above is to adjust all DMUs to the same environment level.

2.3 The third stage: the adjusted efficiency value

The input data adjusted at the second stage is substituted into the first stage of DEA model for calculation, and the efficiency value of the DMU which removes the influences of stochastic noises and environmental factors is obtained, which can more accurately reflect the investment efficiency level.

3. The Establishment of an Index System

After the Reform, the operational performance of PGE mainly depends on the growth of effective assets and investment efficiency, and the two are also important basis for PGE to increase the permitted income[10]. Thus, the index system on the investment efficiency for PGE established under the context of the Reform actively adapts the investment regulations but also have specific and quantified indexes as indication. Based on the diversity of investment scenarios under the new electricity reform and on the basis of the existing index system, this paper established an index system that matches with the real needs of model and research methods, which is shown as in Figure 1.
3.1 The selection of input variables
Under the new round of electricity reform, the input of PGE should meet the relevant requirements of investment supervision. The input also has to reflect the power supply capacity, sociality and environmental influence of the power grid, and maximises the comprehensive investment efficiency. With the comprehensive and ongoing implementation of the Reform, PGE will bear the risks brought by the fluctuation of the input index that can form effective assets. From the perspective of the investment structure of PGE, selecting the input variables can fully reflect the true investment level of the enterprise. This paper selected three representative indexes: wire length, fixed asset investment and personnel size. These indicators can reflect the comprehensive investment level in finance, techniques, human resources and other aspects.

3.2 The selection of output variables
Under the regulation of electricity transmission and distribution, the output of PGE mainly reflects on: power supply reliability, quality service, customer satisfaction and other aspects. This paper selected electricity sales volume per ¥10,000 fixed asset, supply reliability and voltage conformity rate as output indices. Electricity sales volume per ¥10,000 fixed asset = electricity sale volume / the original value of fixed asset of the power grid on average. This reveals the usage efficiency of the asset and the effectiveness of fixed investment management. Line loss rate refers to the ratio of the consumed and lost electricity to the total supply volume, which is the overall technical economic index that benchmarks the electricity usage management and technical management as well as the supply capacity of PGE. Supply reliability rate quantified the supply reliability of a PGE, i.e., the capacity of sustainable supply. It also suggests the supply quality of a PGE is one of the important indicators that affect customer satisfaction. Therefore, these three indices cater to the research focus of the paper.

3.3 The selection of social variables
When it comes to the selection of social variables in PGE, the industrial unique context should be considered. The investment efficiency of a PGE has been impacted by changes of numerous social variables, including the Reform and other elements such as the economic level, industrial development and city scale. These factors impose a direct impact on supply volume and sale volume, thus influencing the investment efficiency of PGE. This paper selected two indices, namely, GDP per capita and industrial electricity consumption ratio to reflect the electricity usage structure of this region, as GDP per capita represents the region’s economic level and the industrial electricity consumption ratio is how much proportion the industrial electricity consumption takes in the total electricity, an indicator of local electricity consumption structure.

3.4 Data sources and its treatment
The data studied in this paper were data published by finance departments, development departments and production departments of 9 beaches of a PGE. The environmental variables varied from each other due to different statistical criteria and incomplete statistics. Thus, the paper collected the input index of a PGE in 2016. In order to make the calculation easier and generate reliable results, the original indices of GDP per capita was log-transformed. The original statistics mainly came from China Statistical Yearbook and other public publications.

4. Empirical Analysis
The use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in table 2 should be used.

4.1 The first stage: the analysis of the overall investment efficiency
In the first stage, based on input-oriented BBC model with environmental variables, the investment efficiency score of each decision-making unit (see Table 1) was calculated by Deap2.1. The average
score of overall technical efficiencies, pure technical efficiencies and scale efficiencies were 0.0801, 0.974, and 0.819, respectively. The overall technical efficiency score is used as the benchmark to evaluate the overall investment efficiency in PGE. Under existing environment, A, C, E and I lie on the production frontier, indicating that these four branches had better production efficiencies. However, other branches which had relatively lower overall technical efficiencies awaits greater improvement in the investment allocation and management. In addition, the pure technical efficiencies outscored the scale efficiencies. It revealed that the pure technical efficiencies dominated, and the scale efficiencies subordinated. As all branches except the second one scored 1 on technical efficiency, the investment efficiency of those branches lied on the technical efficiency frontier and they were overall good. As the results in the first stage were disturbed by the external environment and random factors, they did not reflect the investment efficiencies of those branches in real terms. Thus, it is necessary to conduct the second stage for adjustment.

| DMUs | Comprehensive Operational Efficiency | Pure Technical Efficiency | Scale Efficiency |
|------|----------------------------------|-------------------------|-----------------|
|      | I      | III     | I      | III     | I      | III     |
| A    | 1      | 1       | 1      | 1       | 1      | 1       |
| B    | 0.525  | 0.526   | 0.763  | 0.761   | 0.692  | 0.687   |
| C    | 1      | 1       | 1      | 1       | 1      | 1       |
| D    | 0.519  | 0.578   | 1      | 1       | 0.578  | 0.519   |
| E    | 1      | 1       | 1      | 1       | 1      | 1       |
| F    | 0.491  | 0.497   | 1      | 1       | 0.497  | 0.491   |
| G    | 0.934  | 0.944   | 1      | 1       | 0.944  | 0.934   |
| H    | 0.739  | 0.755   | 1      | 1       | 0.755  | 0.739   |
| I    | 1      | 1       | 1      | 1       | 1      | 1       |
| Mean | 0.801  | 0.811   | 0.974  | 0.973   | 0.829  | 0.819   |

4.2 The second stage: the analysis of the environmental variables’ effect on investment efficiencies

The regression of SFA model was used in this stage where the input slack variables such as the personnel size, fixed asset investment and lengths of lines were explained variables, and two external environment factors, i.e., GDP per capita and industrial electricity consumption ratio were explanatory variables. As is shown in Table 2, Frontier 4.1 was used to build up the SFA model and calculate the regressed results, examining the effect that the two environmental factors exert on the three input slacks. Based on Table 2, log-likelihood value and LR test were all significant at 1% level, suggesting that the regressed estimators were good. Moreover, the coefficient values of two environmental variables versus three input slack variables were all significant at 1% level. That is to say, these environmental variables had significant effect on input slack variables, either positively or negatively. A positive regression coefficient represented that the increases of environmental variables brought about increases in input redundancy, and vice versa. What’s more, values of the three slack variables were all above 0.99, and all passed the significance test. Then, the social variables selected in this paper were proven to exert prominent effect on efficiency scores. Therefore, it is necessary to use SFA model to remove the managerial and random factors.

| Slacks Variable | Fixed Asset Investment | Length of Line | The amount of employees |
|-----------------|------------------------|----------------|------------------------|
|                 | Coefficient | T test   | Coefficient | T test   | Coefficient | T test   |
| Constant        | -44905.87   | -39795.85* | -738.98      | -589.26* | -2145.81   | -61.47*  |
| Per capita GDP  | 1809.44     | 295.25*   | 29.77        | 3.38*    | 86.43      | 75.42*   |
Industrial electricity weight

|            | 23969.43 | 21818.40* | 394.45 | 329.30* | 1145.73 | 37.74* |
|------------|----------|-----------|--------|---------|---------|--------|
| $\sigma^2$ | 430758280| 116652.35 | 983818.69 |
| $\gamma$  | 0.9999   | 10499196* | 0.9999  | 6356.50* | 0.9999  | 115901.36* |
| Log likelihood | -93.881 | -56.919 | -66.512 |
| LR test    | 8.498*   | 8.495*    | 8.498*  |

Note: *** Implies the 10%, 1% confidence level.

The following conclusions can be made from Table 2:

- **GDP per capita.** The coefficients of GDP per capita versus input variables were all positive, indicating that the effect of GDP per capita on input redundancy was positive and significant. The increases of GDP per capita led to increases in three input redundancies. It can be seen that the coefficient of GDP per capita versus fixed asset investment is the largest. This shows that the PGE was committed to a relatively large fixed asset investment. However, unreasonable increases in fixed asset investment is a waste of resources. Such an economic growth model will end up with low investment efficiency for the PGE.

- **Industrial electricity consumption ratio.** The coefficient of this variable versus slack variables were all positive. It indicates that slack variables will increase as this variable improve; the increase of industrial electricity consumption ratio drives the PGE enhance its input, which is detrimental to resources saving, and will reduce the PGE’s investment efficiency.

As environment differentiation and errors always exist, investment efficiencies of the PGE were varied from one place to another. Therefore, when it comes to the evaluation on the investment efficiencies of the PGE, errors and relevant external environmental factors should be adjusted, ensuring that all decision-making units are under the same external environment and at the same level of errors. Thus, an effective evaluation on investment efficiency can be guaranteed.

### 4.3 The third stage: adjusted DEA results

Having adjusted statistics without environmental and random factors, new overall efficiency scores were generated by the analysis BBC Model on Deap 2.1 in the third stage. The efficiency scores in the first stage and the third stage were tabulated in one single table (see Table 1), as it was easy to compare. From the adjusted results, A, C, E and I branches lied on the production frontier, while overall technical efficiencies in other decision-making units were higher. The average score of overall technical efficiency increased 10% from 0.801 to 0.811. Since the pure technical efficiency of decision-making unit B improved 1%, the average score of pure technical efficiency increased 1%. However, there was a declining tendency in all scale efficiency scores, that is to say, the average of scale efficiency reduced 11% from 0.829 to 0.739. Seen in Figure 2, without environmental variables and errors, the pure technical efficiencies and overall technical efficiencies in all branches witnessed an increase while the scale efficiencies a decrease. Therefore, the external and random factors were the causes of lower investment efficiencies for a part of branches, while the reduction of scale efficiencies was attributed to inefficient management.

### 5. Conclusions

The paper studied the investment efficiencies of 9 branches of a PGE through three-stage DEA model analysis, among which, the regression of SFA model without environmental variables and random errors was conducted to analyse the investment efficiencies in the second stage. The main conclusions are as follows:

- Through the application of three-stage DEA model, it is concluded that relevant environmental factors and random errors exerted an impact on the results. Thus, to achieve an accurate evaluation on investment efficiencies, noises of environmental variables and random errors must be cleared out.
As shown in Table 1, the adjusted pure technical efficiency was averaged at 0.973, and the adjusted scale efficiency 0.819, lower than 15.4%. It means that the lower scale efficiency was the main reason why PGE cannot improve its investment efficiency. Therefore, the scale efficiency should be improved, and production activities should be arranged properly.

According to the SFA regression of the two environmental variables, the results revealed that their effects on input slack variables were significant. Both GDP per capita and industrial electricity consumption ratio had positive effects on investment efficiencies of the PGE.

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