Potentiality Prediction of Electric Power Replacement Based on Power Market Development Strategy

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Abstract. The application of electric power replacement plays an important role in promoting the development of energy conservation and emission reduction in our country. To exploit the potentiality of regional electric power replacement, the regional GDP (gross domestic product) and energy consumption are taken as potentiality evaluation indicators. The principal component factors are extracted with PCA (principal component analysis), and the integral potentiality analysis is made to the potentiality of electric power replacement in the national various regions; a region is taken as a research object, and the potentiality of electric power replacement is defined and quantified. The analytical model for the potentiality of multi-scenario electric power replacement is developed, and prediction is made to the energy consumption with the grey prediction model. The relevant theoretical research is utilized to realize prediction analysis on the potentiality amount of multi-scenario electric power replacement.

1. Introduction
In recent years, energy crisis and environmental pollution have aroused high attention from all social members. To further promote the rapid expansion of energy conservation and emission reduction in our country, the State Grid Corporation of China timely puts forward the development strategy of electric power replacement, which is not only an important measure to increase the consumption proportion of renewable clean energy, but also a significant means to quicken energy structure adjustment of our country. Therefore, relevant theoretical research on the aspect is urgently required to be carried out on the basis of the current situation of the electric power replacement in our country. References develop a potentiality model of electric power replacement in rural areas according to their consumption characteristics, and make relevant case analysis; References develop an analytical model of energy environment emission reduction benefits of electric power replacement in Beijing according to the correlativity between energy consumption and environment emission reduction, and discuss the energy conservation, emission reduction and economic benefits of electric energy replacing fuel coal. References make analytical prediction on the future demand of main final energy in Beijing by building
grey energy demand prediction model, and conduct a research on the potentialities of electric energy replacing coal and petroleum based on the predicted result. The consumption of the energies such as GDP, coal and petroleum etc is taken as the evaluation indicator of electric power replacement potentiality in every region in the thesis. The principal component factors are extracted with PCA, and the variance contribution rate of all factors is the weight. The comprehensive evaluation indicator function is obtained through linear combination of all factors, and analysis ranking is made to the potentiality amount of electric power replacement. On the basis of the different regional promoting factors such as economic development, policy support and technical level of electric power replacement etc, diverse development scenarios of electric power replacement are constructed and prediction analysis is made to the potentiality of electric power replacement.

2. Analysis on the Potentiality of Electric Power Replacement in the National Various Regions
In general, the higher the regional energy consumption is, the larger the potential value of electric power replacement is. Moreover, the regional energy consumption is in direct proportion to its economic factors. In other words, the potential value of electric power replacement in a certain region increases with the high regional energy consumption and is in direct proportion to the regional economic factors. Therefore, the consumption of GDP, coal, petroleum and gas energies is selected as the potentiality evaluation indicator of regional electric power replacement, and integral analysis is made to the potentiality of all regions in the national various regions.

2.1. Build Potential Model
(1) Build data matrix
Assuming that there are \( n \) samples, and each sample has \( p \) variables, thereby constituting a \( n \times p \) data matrix, namely:

\[
X = \begin{pmatrix}
X_{11}, & X_{12}, & \ldots, & X_{1p} \\
X_{21}, & X_{22}, & \ldots, & X_{2p} \\
\vdots & \vdots & \ddots & \vdots \\
X_{n1}, & X_{n2}, & \ldots, & X_{np}
\end{pmatrix}
\]  

(1)

(2) Calculate correlation coefficient
The correlation coefficient \( r_{ij} \) of \( x_i, x_j \) in the original data is calculated. The specific calculation formula is as shown below:

\[
r_{ij} = \frac{\sum_{k=1}^{n}(x_{ki} - \bar{x}_i)(x_{kj} - \bar{x}_j)}{\sqrt{\sum_{k=1}^{n}(x_{ki} - \bar{x}_i)^2 \sum_{k=1}^{n}(x_{kj} - \bar{x}_j)^2}}
\]  

(2)

The correlation coefficient matrix \( R \) is obtained according to the above formula:

\[
R = \begin{pmatrix}
r_{11}, & r_{12}, & \ldots, & r_{1p} \\
r_{21}, & r_{22}, & \ldots, & r_{2p} \\
\vdots & \vdots & \ddots & \vdots \\
r_{n1}, & r_{n2}, & \ldots, & r_{np}
\end{pmatrix}
\]  

(3)

The solution to the above matrix can determine the eigen value \( \lambda_i \) of correlation coefficient matrix and corresponding eigenvector \( \mathbf{e}_i \).

(3) Determine the number of principal components
\( S_1 \) is defined as the sum of variance contribution rate of the first \( m (m \leq p) \) principal components.
\[ S_i = \frac{\sum_{k=i}^{m} \lambda_k}{\sum_{k=1}^{i} \lambda_k} \]  \hspace{1cm} (4)

The number of new variables in principal component is generally determined by calculating the contribution rate of principal component and accumulative contribution rate, and the number is determined by variance contribution rate \( S_i \geq 85\% \).

(4) Calculate principal component load
\[ l_{ij} = \sqrt{\lambda_i} e_{ij}, \quad z_1, \ldots, z_m (m \leq p) \] are new variable indicators. The variation form is as shown below:
\[
\begin{align*}
    z_1 &= l_{11} x_1 + l_{12} x_2 + \ldots + l_{1p} x_p \\
    z_2 &= l_{21} x_1 + l_{22} x_2 + \ldots + l_{2p} x_p \\
    \vdots & \\
    z_m &= l_{m1} x_1 + l_{m2} x_2 + \ldots + l_{mp} x_p
\end{align*}
\hspace{1cm} (5)

The above model is represented in matrix as follows:
\[ Z = A \ast X \hspace{1cm} (6) \]

Where \( Z = (z_1, z_2, \ldots, z_m)^T \)
\[ X = (x_1, x_2, \ldots, x_p)^T \]
\[ A = \begin{pmatrix}
    l_{11} & l_{12} & \ldots & l_{1p} \\
    l_{21} & l_{22} & \ldots & l_{2p} \\
    \vdots & \vdots & \ddots & \vdots \\
    l_{m1} & l_{m2} & \ldots & l_{mp}
\end{pmatrix} \]

A becomes coefficient matrix of principal component.

(5) Solve rotation matrix
The coordinate system turns to an angle \( \theta \) through orthogonal rotation, so that its major axis of an ellipse is in the direction of coordinate \( y_1 \), and the minor axis of an ellipse is in the direction of coordinate \( y_2 \). The rotation formula is as follows:
\[
\begin{align*}
    y_1 &= l_{11} \cos \theta + l_{12} \sin \theta \\
    y_2 &= -l_{21} \sin \theta + l_{22} \cos \theta 
\end{align*}
\hspace{1cm} (7)

U is rotation matrix of coordinates.
\[ U = \begin{pmatrix}
    \cos \theta, \sin \theta \\
    -\sin \theta, \cos \theta
\end{pmatrix} \hspace{1cm} (8) \]

(6) Calculate factor score
Function \( F \) with synthesis score is determined through the above formula:
\[ F = \frac{\omega_1 f_1 + \ldots + \omega_m f_m}{\omega_1 + \ldots + \omega_m} \hspace{1cm} (9) \]

Where:
\( f_m \) — factor function;
\( \omega_m \) — factor proportion weight
2.2. Analysis on the Potentiality of Electric Power Replacement in the National Various Regions

The PCA is used to process consumption data of energies in every region such as GDP, coal and petroleum etc, obtaining the total variance of all variables.

Table 1. Circumstance of Factors Explaining the Total Variance of Original Variables

| Components | Initial Eigen Value | Load of Rotation Quadratic Sum |
|------------|---------------------|-----------------------------|
|            | Total               | % of Variance | % of Accumulation | Total | % of Variance | % of Accumulation |
| 1          | 2.45                | 61.2          | 61.2              | 1.7   | 42.6          | 42.6              |
| 2          | 0.82                | 20.5          | 81.7              | 1.1   | 26.1          | 68.7              |
| 3          | 0.52                | 13.1          | 94.8              | 1.1   | 26.1          | 94.8              |
| 4          | 0.21                | 5.3           | 100.0             |       |               |                   |

It’s seen from the above table that the characteristic root value of the 1st factor is 2.45, and the contribution rate of its variance is 61.2%; the characteristic root value of the 2nd factor is 0.82, and the contribution rate of its variance is 20.5%; the characteristic root value of the 3rd factor is 0.52, and the contribution rate of its variance is 13.1%. The accumulated variance contribution rate of the first three factors is 94.8%≥85%. Therefore, the number of the principal components is determined 3.

Table 2. Rotation Load Matrix of Factors

| Potential Index Factors       | 1    | 2    | 3    |
|------------------------------|------|------|------|
| GDP A1                       | 0.851| 0.282| 0.277|
| Coal consumption A2          | 0.244| 0.967| 0.059|
| Petroleum consumption A3     | 0.922| 0.163| 0.191|
| Gas consumption A4           | 0.266| 0.060| 0.961|

It’s seen from the above table that GDP and petroleum consumption have higher load in the 1st factor. Two variables are mainly explained in the 1st factor, thereby obtaining factor score function:

\[ f_1 = 0.553A1 - 0.267A2 + 0.728A3 - 0.288A4 \]
\[ f_2 = -0.052A1 + 1.090A2 - 0.240A3 - 0.004A4 \]
\[ f_3 = -0.085A1 - 0.003A2 - 0.242A3 + 1.113A4 \]

Synthesis score and ranking are eventually made to the potentialities of electric power replacement in all regions.

The following conclusion can be drawn according to the analysis:

(1) The potentialities of electric power replacement in Shandong, Guangdong and Jiangsu are the largest, respectively ranked in the 1st, 2nd and 3rd places.

(2) The potentialities of electric power replacement in Hainan, Ningxia and Qinghai are the lowest and ranked in the last three places.

3. Analysis on Multi-Scenario Potentialities of Regional Electric Power Replacement

3.1. Quantum Chemical Calculation for the Potentialities of Electric Power Replacement

There is certain correlativity between the regional electric power replacement amount and power consumption. Therefore, the electric power replacement amount cannot serve as its evaluation indicators according to the increase in power consumption. Meanwhile, regional economic development, policy support of electric power replacement and the promotion role of the technical level of electric power replacement need to be considered in the potentialities of electric power replacement.
To achieve the quantum chemical calculation for the potentialities of electric power replacement, a certain year can be selected as a reference year JZ. Assuming that the consumption proportion of electric energy in final energy is the same as the reference year, and the influencing parameters of policy support, technical level and economic development etc are represented in A, B and C, respectively. Therefore, the calculation formula of the potentiality amount of electric power replacement in the \( t^{th} \) year is as shown below:

\[
F_t = \left( Y_{Dt} - \frac{Y_{D/JZ}}{Y_{Nt}} \right) \left[ (1 + A)(1 + B)(1 + C) \right]^t
\]

(10)

Where:
- \( F_t \) — the substitution amount of potentialities of electric power replacement;
- \( Y_{Dt} \) — the total power consumption amount of the \( t^{th} \) year;
- \( Y_{Nt} \) — the total energy consumption amount of the \( t^{th} \) year;

3.2. Analysis on Multi-Scenario Potentialities of Electric Power Replacement

In the process of potentiality analysis, 3 different replacement scenarios are constructed as background support of potentiality analysis of electric power replacement, based on diverse driving factors such as economic development, policy support and technical level etc. See Table 4 for the setting of the specific scenarios.

| Scenario Analysis | Specific Scenario |
|-------------------|-------------------|
| Scenario I | Relevant promotion measures are not taken for the development of regional electric power replacement. |
| Scenario II | The development of electric power replacement is impelled by issuing relevant policies of electric power replacement. |
| Scenario III | The foreign advanced electric power replacement technology is introduced to improve regional electrification level. |

Electric power industry is a pillar one in our country. When electric power supply is insufficient, it will seriously restrict economic development. When economy develops rapidly, power demand will also increase. Therefore, there is a certain correlation between economic growth and the development of electric power replacement. The basic basis for scenario analysis on the potentialities of electric power replacement can be obtained by reference to relevant theoretical research in Reference:

(1) \( (1 + C) > (1 + A)(1 + B) \)

It indicates that the execution of electric power replacement need depend on economic development, and that the relevant policies and technical level of electric power replacement have a less important effect on promoting electric power replacement.

(2) \( (1 + C) = (1 + A)(1 + B) \)

It indicates that the speed of economic development is basically consistent with the process of electric power replacement. At the moment policy support is a major factor to promote electric power replacement.

(3) \( (1 + C) < (1 + A)(1 + B) \)

It indicates that the implementation and popularization of electric power replacement doesn’t need to rely on economic development. At the moment the policy support and technical level are the key factors to affect electric power replacement.
3.3. Energy Consumption Prediction Model

Grey system theory is a theoretical method to research and solve grey system analysis, modeling and prediction, characterized by limited modeling information, convenient calculation and high accuracy etc. Therefore, it is widely applied in various prediction fields. During the analysis of regional potentialities, a grey prediction model is used for predicting the total regional energy consumption and total power consumption. The specific steps to build a model are as follows:

(1) Establish differential model equation

In consideration of \( x_1, x_2, x_3, ..., x_n \) variables, i.e.

\[
x^{(0)} = \{ x^{(0)}_1(1), x^{(0)}_1(2), ..., x^{(0)}_i(p) \}
\]

Accumulation is made to \( x^{(0)}_i \) generating accumulative sequence, i.e.

\[
x^{(1)}_i(k) = \sum_{m=1}^{k} x^{(0)}_i(m)
\]

A differential model is built according to the treated sequence. Its matrix form is:

\[
\frac{dx^1}{dt} = aX^1 + b
\]

(2) Determine equation coefficient:

The undetermined coefficients \( a \) and \( b \) in the formula can be solved with least square method. The specific steps are as follows:

\[
C = (a, b)
\]

It is analyzed from the above formula that:

\[
C = (L^T L)^{-1} L^T Y_i
\]

Where:

\[
L = \begin{pmatrix}
\frac{1}{2} (x^{(1)}_1(2) + x^{(1)}_1(1)), & \frac{1}{2} (x^{(1)}_2(2) + x^{(1)}_2(1)), & 1 \\
\frac{1}{2} (x^{(1)}_1(3) + x^{(1)}_1(2)), & \frac{1}{2} (x^{(1)}_2(3) + x^{(1)}_2(2)), & 1 \\
\vdots & \vdots & \vdots \\
\frac{1}{2} (x^{(1)}_1(m) + x^{(1)}_1(m-1)), & \frac{1}{2} (x^{(1)}_2(m) + x^{(1)}_2(m-1)), & 1
\end{pmatrix}
\]

\[
Y_i = (x^{(0)}_1(2), x^{(0)}_1(3), ..., x^{(0)}_i(m))^T
\]

(3) Solve response equation

The numerical values \( a \) and \( b \) are substituted into the above formula to obtain time response equation as follows:

\[
X^{(1)}(k+1) = \left[ X^{(1)}(1) - \frac{b}{a} \right] e^{-ak} + \frac{b}{a}
\]
3.4. Case Analysis
Hebei Province is taken as an example for potential analysis of electric power replacement, and Year 2014 is selected as a reference year. It’s seen from data analysis that the power consumption in final energy in the reference year is about 2%.

(1) Energy consumption prediction
A grey prediction method is adopted to predict the power consumption and final energy consumption of Hebei Province, thereby obtaining the following data.

**Table 4. Hebei Predicted Value of Final Energy Consumption during 2016-2020**
Unit: standard coal with millions of tons

| Year | 2016 | 2017 | 2018 | 2019 | 2020 |
|------|------|------|------|------|------|
| Predicted value of final energy consumption | 3.06 | 3.11 | 3.16 | 3.21 | 3.38 |

**Table 5. Hebei Predicted Value of Power Consumption during 2016-2020**
Unit: standard coal with ten thousand tons

| Year | 2016 | 2017 | 2018 | 2019 | 2020 |
|------|------|------|------|------|------|
| Predicted value of power consumption | 884 | 1058 | 1266 | 1515 | 1872 |

(2) Setting of Analysis Parameters of Multi-Scenario Potentialities
The rapid economic development plays an active propelling role in electric power replacement. It is seen from the analysis on *Hebei 2015 Economic Yearbook* that the economic growth of Hebei Province was 6.5% in 2014, and it kept 6.8% during 2015-2016, so the economic operation is generally steady. It is predicted that the economic growth rate of Hebei Province will be about 8% during 2016-2020; in the aspect of policy support, in Scenario I, assuming that no promoting measures are taken for the development of electric power replacement in Hebei, so its implementation depends on economic development. In Scenarios II and III, on the basis of the relevant policies of electric power replacement issued by Hebei; in technical level and Scenarios I and II, the impact of technical level of electric power replacement is not considered. In Scenario III, based on the promotion and electrification level of electric power replacement in Hebei, the influence of electric power replacement on implementing electric power replacement is increased.

According to the above theoretical basis, setting is made to the parameters of economic development, relevant policy support and technical level etc in Scenarios I, II and III. The parameters of the three aspects are represented with A, B and C, respectively. See Table 7 for more information.

**Table 6. Basic Parameters of Multi-Scenario Analysis of Electric Power Replacement**

| Setting of Scenarios | A (%) | B (%) | C (%) |
|----------------------|-------|-------|-------|
| Scenario I           | 0     | 0     | 8     |
| Scenario II          | 3.5   | 0     | 8     |
| Scenario III         | 3.5   | 4.3   | 8     |

(3) Potentiality calculation and analysis
The above predicted values of energy consumption, along with the parameters of relevant policy support, technical level and economic development etc, are substitutes into the formula, thereby obtaining the following result:
The following conclusion can be drawn according to the analysis on the potentiality amount of electric power replacement in different scenarios:

1. In Scenario I, the electric power replacement amounts of Hebei are 4.49 billion kWh, 720 million kWh, 10.47 billion kWh, 14.41 billion kWh and 19.73 billion kWh, respectively. The growth rate of the electric power replacement amount is slower;

2. In Scenario II, the electric power replacement amounts are 5.33 billion kWh, 8.55 billion kWh, 12.43 billion kWh, 17.11 billion kWh and 23.43 billion kWh, respectively. Compared with Scenario I, its growth rate is about 18.7%, indicating that electric power replacement promotes its continuous development;

3. In Scenario III, the electric power replacement amounts are 720 million kWh, 11.55 billion kWh, 16.8 billion kWh and 31.66 billion kWh, respectively. Compared with Scenario II, its growth rate is about 35.2%, indicating that the electric power replacement amount is largely raised driven by policy support and technical level of electric power replacement.

4. Conclusion and Prospect

Compared with the energies such as coal, petroleum and gas etc, electric energy is cleaner, more convenient and safer. The governments in various regions shall, according to their own geographical locations, environmental conditions, economy and energy consumption, formulate policies to support electric power replacement and guide the social members to select on their own the energy using mode of high pollution and low efficiency of electric power replacement. Meanwhile, the governments shall also constantly improve the relevant technology of electric power replacement, widely apply foreign relevant electrification technology and improve regional electrification level.

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