Research on the Development Potential Evaluation of Urban Energy Internet

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Abstract. With the depletion of fossil energy and the enhancement of environmental awareness, how to develop distributed resources orderly and reasonably has become a hot issue in the construction of new generation power system. Combined with the high-speed development of Internet communication technology and information processing technology, the construction of urban energy Internet in urban areas has become one of the most important construction contents of new generation power system in the future. This paper mainly evaluates the development potentials of urban energy Internet in urban areas, and establishes the evaluation index of the development potentials of urban energy Internet. Moreover, as an example, the development potentials of urban energy Internet in Suzhou, Guangzhou, Ningbo and Qingdao are evaluated.

1. Introduction

Combined with the current high-speed development of Internet communication technology and information processing technology, American scholar Rifkin proposed the concept of energy Internet. With the urban area becoming the regional energy consumption center, the construction of urban energy Internet in urban areas has become one of the most important construction contents of new generation power system [1-3].

At present, the researches on the construction of urban energy Internet at home and abroad mainly focus on the analysis of the key technology system of urban energy Internet construction, while the researches on the evaluation of the development potential of urban energy Internet are less. Aiming at the research on the evaluation of the development potential of urban energy Internet, literature [4] analyzes the connotation and extension of the energy Internet, and constructs the index system of energy Internet development from six aspects of policy, industry, technology, innovation, construction and public ecology. Literature [5] constructs the evaluation model of the impact factors of urban energy Internet based on the interpretation structure model and AHP.

Combined with the existing research, this paper evaluates the development potential of urban energy Internet. By constructing the evaluation model for the development potential of urban energy Internet and designing the evaluation index system of the development potential of urban energy Internet, this paper quantitatively evaluates the development potential and construction capacity of urban energy Internet. What’s more, this paper distinguishes the development potential of urban energy Internet in different cities, and finds out the basic situation of urban energy Internet construction in different regions.
and cities, and thus provides theoretical guidance and reference for urban energy Internet construction and new generation power system construction.

2. Evaluation of the development potential of urban energy Internet

2.1. Construction of the evaluation index system for the development potential of urban energy Internet

This project attempts to integrate the existing research results on urban energy Internet and the development characteristics of urban energy Internet, and build an evaluation index system for the development potential of urban energy Internet, as shown in Table 1.

| Target level | Criterion level | Factor level | Index level |
|--------------|-----------------|--------------|-------------|
|              |                 | Economic development level C1 | Contribution rate of tertiary industry (%) |
|              |                 | Economic development level C1 | Added value of the tertiary industry (100 million yuan) |
|              |                 | Economic development level C1 | GDP per capita (yuan) |
|              |                 | Economic development level C1 | Total urban GDP (100 million yuan) |
|              |                 | Development of science and technology C2 | Number of patent applications per 10000 people |
|              |                 | Development of science and technology C2 | Proportion of technology development cost of scientific research institutions in GDP (%) |
|              |                 | Development of science and technology C2 | Proportion of scientific research expenditure in local financial expenditure (%) |
|              |                 | Infrastructure conditions C3 | Urban population density (person / km2) |
|              |                 | Infrastructure conditions C3 | Added value of secondary industry (100 million yuan) |
|              |                 | Infrastructure conditions C3 | Per capita telecommunication traffic (yuan) |
|              |                 | Infrastructure conditions C3 | Number of patent applications per 10000 people |
|              |                 | Infrastructure conditions C3 | Number of charging posts (10000) |
|              |                 | Infrastructure conditions C3 | Number of charging and replacing power stations |
|              |                 | Input level C4 | R&D personnel (person) |
|              |                 | Input level C4 | R&D expenditure (100 million yuan) |
|              |                 | Input level C4 | Proportion of energy conservation and environmental protection expenditure in local financial expenditure (%) |
|              |                 | Input level C4 | Number of authorized patents in the whole year |
|              |                 | Production potential C5 | Primary energy production (10000 tons of standard coal) |
|              |                 | Production potential C5 | Electric power production (100 million kwh) |
|              |                 | Energy production and consumption capacity B3 | Total urban population (10000) |
|              |                 | Energy production and consumption capacity B3 | Urban per capita disposable income (yuan) |
|              |                 | Energy production and consumption capacity B3 | Total energy consumption of urban terminal (100000 tons of standard coal) |
|              |                 | Energy production and consumption capacity B3 | Total electricity consumption of urban terminal (100 million kwh) |
|              |                 | Energy production and consumption capacity B3 | Urban new energy vehicle ownership (10000 vehicles) |
|              |                 | Energy production and consumption capacity B3 | Proportion of secondary industry (%) |
|              |                 | Energy production and consumption capacity B3 | Proportion of tertiary industry (%) |
2.2. Evaluation model of urban energy Internet development potential

2.2.1. Evaluation model based on TOPSIS value function. TOPSIS method is a sort method by approaching the ideal solution. According to the relative close degree between the evaluation objects and the ideal goal, the evaluation objects are sorted to judge the relative advantages and disadvantages. The basic idea of the method is that the scheme with the minimum distance from the positive ideal solution is the best, and vice versa [6]. TOPSIS can be used to rank multiple objects with measurability. The basic steps are as follows:

Step 1: establish the original data matrix X

\[ X = (x_{ij})_{n \times m} \]  \hspace{1cm} (1)

Step 2: use the standardized transformation formula to deal with the initial matrix dimensionless and get the normalized matrix Y.

\[
y_{ij} = \begin{cases} 
\frac{(x_{ij} - x_{ij}^{\min})}{(x_{ij}^{\max} - x_{ij}^{\min})}, & \text{x_{ij} is a positive indicator} \\
\frac{(x_{ij}^{\max} - x_{ij})}{(x_{ij}^{\max} - x_{ij}^{\min})}, & \text{x_{ij} is a negative indicator}
\end{cases}
\]  \hspace{1cm} (2)

In the formula, \( y_{ij} \) is the standardized indicator value; \( x_{ij} \) is the \( j \) indicator value of the \( i \) scheme; \( x_{ij}^{\min} \) is the minimum value of the \( j \) indicator; \( x_{ij}^{\max} \) is the maximum value of the \( j \) indicator. \( x_{ij}^{\min} \) and \( x_{ij}^{\max} \) can be obtained by searching the historical operation database, and can also be determined according to the relevant mechanism analysis.

Step 3: weight the indicators according to Index combination weighting based on entropy weight-priority relation.

Step 4: construct the weighted normalization matrix. Weighting normalized data to get weighted normalized matrix \( P \):

\[ P = (p_{ij})_{n \times m} = (\omega_p, y_{ij})_{n \times m} \]  \hspace{1cm} (3)

Step 5: generally, there is no absolute optimal solution or worst solution, so the following formula can be used to determine the positive and negative ideal solutions of the evaluation index.

\[
V^+ = \left\{ \begin{array}{c}
\begin{array}{c}
\max \limits_{1 \leq i \leq 4} p_{ij} | p_{ij} \text{ is a positive index} \\
\max \limits_{1 \leq i \leq 3} p_{ij} | p_{ij} \text{ is an inverse index}
\end{array} \\
\begin{array}{c}
\text{Optimum value p}_{ij} | p_{ij} \text{ is a dimensionless index}
\end{array}
\end{array} \right\}
\]  \hspace{1cm} (4)

\[
V^- = \left\{ \begin{array}{c}
\begin{array}{c}
\max \limits_{1 \leq i \leq 4} p_{ij} | p_{ij} \text{ is a positive index} \\
\max \limits_{1 \leq i \leq 3} p_{ij} | p_{ij} \text{ is an inverse index}
\end{array} \\
\begin{array}{c}
\text{Worst value p}_{ij} | p_{ij} \text{ is a dimensionless index}
\end{array}
\end{array} \right\}
\]  \hspace{1cm} (5)
Among them, $V^+$ is the positive ideal solution of index set, $V^-$ is the negative ideal solution of index set.

Step 6: calculate the distance scale, that is, calculate the distance from each target to the positive ideal solution and the negative ideal solution. The distance scale can be calculated by n-dimensional Euclidean distance. The distance from the target to the positive ideal solution $V^+$ is $S^+_k$, and the distance to the negative ideal solution $V^-$ is $S^-_k$:

$$S^+_k = \left[ \sum_{i=1}^{4} \sum_{j=1}^{3} (v_{ij}^+ - v_{ij})^2 \right]^{\frac{1}{2}} (k = 1, 2, \ldots, m) \tag{6}$$

$$S^-_k = \left[ \sum_{i=1}^{4} \sum_{j=1}^{3} (v_{ij}^- - v_{ij})^2 \right]^{\frac{1}{2}} (k = 1, 2, \ldots, m) \tag{7}$$

Among them, $k$ represents the $k$ scheme, and there are $m$ schemes in total.

Step 7: calculate the relative closeness. The relative closeness between the evaluation object and positive ideal solution and negative ideal solution is:

$$C_k = \frac{S^+_k}{S^+_k + S^-_k} \quad k = 1, 2, \ldots, m \tag{8}$$

Where, $0 \leq C_k \leq 1$. When $C_k = 0$, $V_i = V^-$, the target is the worst target; when $C_k = 1$, $V_i = V^+$, the target is the best target. In the actual multi-objective decision-making, the possibility of the existence of the best objective and the worst objective is very small.

Step 8: sort according to the ideal closeness $C_k$.

According to the value of $C_k$, the evaluation objectives are arranged from small to large. The higher the value of $C_k$ is, the better the target is. The maximum value of $C_k$ is the best evaluation target, which means the better the development potential.

2.2.2. Construction of relative potential model. Different cities have differences in the maximum reasonable values of various indicators, such as economic, resource, cultural and policy. In order to evaluate the development potential of urban energy Internet fairly and justly, it is necessary to establish a unified evaluation standard to ensure the comparability of the evaluation results, so that each city can be compared horizontally. Therefore, standardization is needed to obtain the relative score value of potential evaluation index, namely:

$$Q_{pi} = \frac{F_{pi}^+ - f_{\mu_i}}{F_{pi}^+} = 1 - \frac{f_{\mu_i}}{F_{pi}^+} \quad (i = 1, 2, \cdots, 7; \quad p = 1, 2, 3, 4) \tag{9}$$

Among them, $Q_{pi}$ represents the standardized score of the $i$ index in each city factor level index $F_{pi}$; $F_{pi}^+$ represents the maximum reasonable value of the $i$ index; $\frac{f_{\mu_i}}{F_{pi}^+}$ represents the corresponding score matrix value of each province [7].
3. Example analysis

3.1. Calculation of the development degree of urban energy Internet

(1) Solving normalized matrix
Use formula (9) to solve the normative decision matrix of six factor level indicators in the evaluation index system, and the solution results are shown in Table 2 to Table 4 [8-10].

| City     | Economic development level | Development of science and technology |
|----------|----------------------------|---------------------------------------|
| Suzhou   | 0.6125 0.3105 0.4955 0.5242 | 0.6252 0.4986 0.4502                  |
| Guangzhou| 0.5622 0.5480 0.5803 0.7982 | 0.6002 0.7219 0.6506                  |
| Ningbo   | 0.3025 0.1402 0.3608 0.1538 | 0.4202 0.0974 0.4806                  |
| Qingdao  | 0.4698 0.8282 0.5328 0.1105 | 0.4525 0.2761 0.4284                  |

(2) Construction of weighted norm matrix
Through the construction of the index system, the weights of the six factors corresponding to the measurement indexes are as follows:
\[ \omega_1 = (0.1854, 0.2034, 0.3002, 0.311) \]
\[ \omega_2 = (0.3024, 0.2809, 0.4167) \]
\[ \omega_3 = (0.1445, 0.2075, 0.2014, 0.1976, 0.249) \]
\[ \omega_4 = (0.2568, 0.2076, 0.1809, 0.3547) \]
\[ \omega_5 = (0.3869, 0.6131) \]
\[ \omega_6 = (0.1802, 0.1106, 0.0978, 0.1864, 0.1548, 0.1201, 0.1501) \]

(3) Calculation of the development degree of urban energy Internet
According to equations (11) to (15), calculate the relative paste progress corresponding to 6 factors respectively, so as to obtain the comprehensive score and ranking of urban energy Internet development degree of the pilot cities, as shown in Table 5:
Table 5. Comprehensive score and ranking of urban energy Internet development

| City   | Economic development level | Development of science and technology status | Infrastructure condition | Investment level | Production potential | Consumption potential | Degree of development Composite score | Ranking |
|--------|----------------------------|--------------------------------------------|--------------------------|------------------|---------------------|----------------------|--------------------------------------|---------|
| Suzhou | 0.583                      | 0.512                                      | 0.512                    | 0.392            | 0.442               | 0.512                | 2.953                                | 2       |
| Guangzhou | 0.908                    | 0.976                                      | 0.679                    | 0.976            | 0.512               | 0.803                | 4.854                                | 1       |
| Ningbo | 0.102                      | 0.191                                      | 0.122                    | 0.012            | 0.009               | 0.172                | 0.608                                | 4       |
| Qingdao | 0.481                      | 0.352                                      | 0.545                    | 0.62             | 0.048               | 0.112                | 2.158                                | 3       |

Through the above calculation and analysis, the comprehensive score and ranking of urban energy Internet development degree of four pilot cities are obtained. It can be seen from the above table that at present, the development level of urban energy Internet is consistent with the economic development trend, with higher development level in Guangzhou and Suzhou, and lower development level in Qingdao and Ningbo. It shows that the future development space of Qingdao and Ningbo urban energy Internet is large, and the development potential needs to be explored.

3.2. Calculation of development potential of urban energy Internet

First, the weight matrix W is constructed. Through the construction of index system, the weight matrix of six factors is obtained as follows:

\[
W = \begin{pmatrix}
0.6927 & 0.3073 & 0.6667 & 0.3333 & 0.2898 & 0.7102
\end{pmatrix}
\]

Secondly, extract the maximum value in the weight matrix of each factor specification, and multiply it with the weight matrix to obtain the maximum reasonable values of six factors as shown in Table 6:

Table 6. Maximum reasonable value of each factor

| Factor                        | Economic development level | Development of science and technology status | Infrastructure condition | Input level | productive potential | consumption potential |
|-------------------------------|---------------------------|--------------------------------------------|--------------------------|-------------|---------------------|-----------------------|
| Maximum reasonable value      | 0.5529                    | 0.2218                                     | 0.6446                   | 0.2995      | 0.2264              | 0.6040                |

Then, multiply the norm matrix of each factor and the weight matrix to get the score matrix of each factor, that is, the scores of six factors corresponding to each city, as shown in Table 7.

Table 7. Score matrix of each factor

| City   | Economic development level | Development of science and technology status | Infrastructure condition | Input level | productive potential | consumption potential |
|--------|----------------------------|--------------------------------------------|--------------------------|-------------|---------------------|-----------------------|
| Suzhou | 0.3483                    | 0.1658                                     | 0.1974                   | 0.1024      | 0.0294              | 0.2382                |
| Guangzhou | 0.4555                  | 0.2179                                     | 0.5628                   | 0.1499      | 0.1811              | 0.405                 |
| Ningbo | 0.1801                    | 0.1172                                     | 0.1694                   | 0.0448      | 0.0635              | 0.0893                |
| Qingdao | 0.3083                    | 0.1245                                     | 0.439                    | 0.049       | 0.0579              | 0.1035                |

Finally, according to the relative potential model, the comprehensive score and ranking of urban energy Internet development potential of pilot cities (Suzhou, Guangzhou, Ningbo, Qingdao) are obtained [11].
Table 8. Comprehensive score and ranking of energy Internet development potential of pilot cities

| City   | Economic development level | Development of science and technology status | Infrastructure condition | Investment level | Production potential | Consumption potential | Development potential Composite score | ranking |
|--------|----------------------------|---------------------------------------------|--------------------------|-----------------|---------------------|----------------------|---------------------------------------|---------|
| Suzhou | 0.4353                     | 0.3842                                      | 0.7771                   | 0.4659          | 0.9434              | 0.6263               | 3.6322                                | 3       |
| Guangzhou | 0.2513                      | 0.1713                                      | 0.3137                   | 0.179           | 0.3425              | 0.3417               | 1.5995                                | 4       |
| Ningbo | 0.7239                     | 0.5824                                      | 0.8126                   | 0.8143          | 0.8085              | 0.8805               | 4.6222                                | 1       |
| Qingdao | 0.5039                     | 0.5558                                      | 0.4708                   | 0.7884          | 0.8303              | 0.8562               | 4.0024                                | 2       |

From the above calculation and analysis results, we can see that the economic development level is not positively related to the development potential of urban energy Internet. For cities with high economic development level, the development potential of urban energy Internet is not necessarily high. Based on the score of urban energy Internet development potential, the urban energy Internet development potential of each city can be ranked as follows: Ningbo > Qingdao > Suzhou > Guangzhou.

3.3. Result discussion

The development of urban energy Internet in pilot cities of urban energy Internet is closely related to the development level of the overall economic development. Due to the imbalance of economic development between cities, there is a big gap between the development level and development potential of urban energy Internet.

(1) There is no positive correlation between the development degree of urban energy Internet and the score and ranking trend of development potential in pilot cities. As can be seen from Table 5 and Table 8, the development level of Guangzhou's urban energy Internet ranks first, while the development potential ranks the most backward among the four cities. This is because Guangzhou has a higher level of economic development, and a better overall development environment and resources. Comparatively speaking, the economic development level and urban energy Internet development level of Qingdao and Ningbo are relatively low, and the development potential needs to be further improved and explored, so there is a larger development space in the future development process.

(2) Cities with high comprehensive scores of energy Internet development potential have relatively high energy production and consumption potential. As can be seen from Table 14, cities with high comprehensive score of urban energy Internet development potential have relatively high scores of energy consumption and production potential. Therefore, for Qingdao, to promote the development of urban energy Internet and fully tap the development potential of urban energy Internet, it should start from the energy demand and supply, and promote the development of urban energy Internet through energy consumption and production. It can be seen that Qingdao's urban energy Internet has a large potential market demand and development space in the future development process. The government, enterprises and scientific research institutions should constantly improve their service capacity to better meet the potential demand, so as to promote the development of urban energy Internet.

4. Conclusion

This paper mainly evaluates the development potential of urban energy Internet. Firstly, it defines the basic concept of the development potential of urban energy Internet, and analyzes the main research contents of the development potential of urban energy Internet. Secondly, this paper analyzes the theory of influencing factors of urban energy Internet development potential from both macro and micro aspects, and then determines the influencing factors of urban energy Internet development potential. Thirdly, the evaluation index system of urban energy Internet development potential is constructed by selecting multiple indicators from 3 criteria of development potential support, development potential guarantee, energy production and consumption capacity, and 6 factors of economic development level, scientific and technological development status, infrastructure conditions, investment level, energy production potential and energy consumption potential. Finally, this paper studies the evaluation method of the urban energy Internet development potential, calculates the subjective and objective weights of each
index by entropy weight method and order relation method, weights the subjective and objective weights by mixed weight method, and determines the combined weights of each index. Based on the evaluation model of TOPSIS value function and the relative potential calculation model, the development degree and development potential of urban energy Internet in the four pilot cities are evaluated. The ranking of urban energy Internet development potential is obtained: Ningbo > Qingdao > Suzhou > Guangzhou.

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