applied sciences

MDPI

Article

Evaluation of Energy Saving and Emission Reduction Effects for Electricity Retailers in China Based on Fuzzy Combination Weighting Method

Si Li [1,2,*], Dongxiao Niu [1,2,3] and Luofei Wu [1,2]

1 School of Economics and Management, North China Electric Power University, Changping, Beijing 102206, China; ndx@ncepu.edu.cn (D.N.); wuluofei@ncepu.edu.cn (L.W.)
2 Beijing Key Laboratory of New Energy and Low-Carbon Development (North China Electric Power University), Changping, Beijing 102206, China
3 China Energy Economics Management Research Center, Changping, Beijing 102206, China
* Correspondence: lis@ncepu.edu.cn; Tel.: +86-010-6177-3472

Received: 26 July 2018; Accepted: 4 September 2018; Published: 5 September 2018

check for updates

Featured Application: The application of this research aims to provide an effective indicator system and evaluation method of energy saving and emission reduction effects for current electricity retailers in China, and give the specific directions for the electric power industry to adopt energy saving and emission reduction actions.

Abstract: China's electricity market is in the environment for a round of new electric power reform, energy planning and transformation and the carbon market construction. The current market players are in urgent need of implementing their own energy saving and emission reduction actions. Relatively extensive and systematic researches on the assessment of the energy saving and emission reduction effects for the power plants, power grid companies, and technical equipment have been carried out at home and abroad. However, there are still vacancies in the researches on those for electricity retailers emerged on the sales side. Based on the carding and analysis of related policies and guidance, in this paper, relevant indicators are considered to build the evaluation indicator system of the energy saving and emission reduction effects for electricity retailers. The combination weights are gained by means of analytic hierarchy process and entropy weight method. Then, after the combined empowerment of indicators, the multi-level fuzzy comprehensive evaluation of energy saving and emission reduction effects for electricity retailers is conducted. Finally, choosing 10 electricity retailers (numbered from A to J) as evaluation objects, this model is used for obtaining the evaluation results and ranking of energy saving and emission reduction effects of electricity retailers, which provides reasonable ideas for the construction of evaluation indicator system and effective comprehensive evaluation methods of energy saving and emission reduction effects for market players in the electricity sales side. The results of example analysis show that, from a single dimension, the best electricity retailers in market transactions, technical means, integrated energy services, management system, and social responsibilities are followed by B, J, D, G, C, or I. However, from a global perspective, the sorted evaluation results are D, J, I, A, H, G, E, B, F, and C, which reflects the overall energy saving and emission reduction effects of electricity retailers through the two-level fuzzy comprehensive evaluation.

Keywords: electricity retailers; energy saving and emission reduction; analytic hierarchy process; entropy weight method; fuzzy comprehensive evaluation

1. Introduction

1.1. Research Background and Significance

The transformation and upgrading of China's energy structure requires all walks of life to take an active part in energy saving and emission reduction, in order to cope with climate changes and work together to fulfill the national commitment to energy saving and emission reduction. As one of the most important component in the energy industry, the electric power industry is also bound to be involved in the energy saving and emission reduction actions, which aims at developing the way of low-carbon electricity vigorously to have the environmental pollution cut down and improve the energy efficiency utilization. At present, with the further development of the new round of electric power reform, the electricity sale side forms a market structure with the electricity retailers as the main competitive players. To push for the energy saving and emission reduction process in the electricity sales side, it is necessary to combine the multi-party policy documents. Namely, to analyze important documents in three aspects of the electric power reform, energy planning transformation, and carbon market construction issued by government departments. The attention to these policy documents should be placed on the following two points. Firstly, the current reform reflects the necessity of setting up electricity retailers in China's electricity sales market. Secondly, all three have released the signal of new energy development in the market. To achieve green power as the long-term goal of China's electric power industry, market players should actively participate in energy saving and emission reduction at this stage. Therefore, in the research on the energy saving and emission reduction effects for current electricity retailers in China, it is possible to make a reasonable assessment by combining the policy documents closely and understanding the market development orientation, which helps to provide guidance for electricity retailers to improve the effects to enhance the competitiveness and achieve long-term development by taking timely actions.

1.2. Research Status

At this stage, domestic and foreign scholars have conducted numerous researches on the energy saving and emission reduction of the electric power industry in China. On the one hand, some researches laid particular emphasis on the power production technologies and power equipments [1–4], qualitative assessment and quantitative analysis were carried out to evaluate the impact on energy saving and emission reduction by improving and applying those technologies and equipments.

Liu [1] analyzed the effects of energy saving and emission reduction for electric systems while using high-voltage frequency conversion technology, which proved that the appliance of this technology can help power plants to achieve a high-level energy saving. Jiang et al. [2] conducted the assessment of the effects of central heating supplied by large coal-fired power unit and then put forward relative measures to improve the energy efficiency. Lu et al. [3] researched on the effects after the application of advanced equipments in the fields of power transmission and transformation. The use of switching equipment to achieve energy saving and emission reduction was put forward. Luo and Ya [4] proposed to realize the saving and emission reduction in the electric power industry through resource optimization configuration technology and implemented corresponding actions at the strategic level.

On the other hand, most researches focused on the use of different comprehensive evaluation methods to assess the energy saving and emission reduction effects for the power plants [5–14] and power grid companies [15–18].

Xu and Zeng [5] established an evaluation indicator system of energy saving and emission reduction technologies form the resource and energy consumption, pollutant discharge, economic benefits, and technical performance. Next, the interval-value comprehensive method was selected to assess the effects. Chen [6] selected evaluation indicators according to the subsystems of energy saving and consumption reduction, pollutant discharge reduction, energy saving, and emission reduction relations of thermal power companies, then conducted the assessment. Cao et al. [7]

built an indicator system mainly reflected the actual production status of thermal power plants and evaluated the energy saving and emission reduction effects through grey correlation analysis method. Wang and Xie [8] chose the technical indicators of biomass power generation to finish the assessment. Li et al. [9] designed an evaluation indicator system for thermal power companies from two perspectives of energy saving and pollutant reduction. The effects were assessed based on entropy-weighted extentic method. Jia et al. [10] adopted the way that combined factor analysis and DEA (data envelopment analysis) to analyze the energy saving and emission reduction effects of power generation enterprises. During the process of evaluating energy saving and emission reduction performance of power generation companies, Zhang [11] established the indicator system from six dimensions, including energy resource utilization, pollutant discharge, and efficiency improvement, etc. It also put forward the evaluation model based on network-level analysis method and improved gray clustering decision-making. The evaluation indicator system that is proposed by Bo et al. [12] includes aspects, such as coal saving, electricity saving, water saving, and pollutant discharge, which could evaluate the status of emissions reduction of coal-fired power plant more comprehensively. Cao et al. [13] utilized the indicators of consumption and emissions to have an integrated evaluation for power plants, which was carried out by means of entropy weight based on fuzzy matter element model. Ding et al. [14] studied on the benefits of energy saving and emission reduction sides for domestic small hydropower ecological protection projects through econometric models. Zhou [15] put forward projection pursuit based on AHP (analytic hierarchy process) to construct an assessment model. Coal-fired electricity replacement, grid losses, and pollutant emissions were considered for regional power grids. Zeng et al. [16] analyzed the effects of power grid enterprises from three angles, followed by the generation side, supply side, and demand side, which reflects the dedication of energy saving and emission reduction under different perspectives. Liu [17] researched on the contribution to energy saving and emission reduction not only form power grid enterprises, but upstream companies and downstream users. To evaluate the potential of energy saving and emission reduction for the regional power grid, Wu et al. constructed three types of indicators, including power flow, power supply structure, and technology economy [18].

From the above research status, we can know that the quantitative indicators of energy consumption, wastewater discharge, and exhaust pollutant emissions are often determined to establish the indicator system of the energy saving and emission reduction effects in most previous studies. However, the indicator system established only based on these aspects is the lack of timely interpretation of new policies. The selection of evaluation indicators needs to be further combined with qualitative indicators that are closely related to policies. The evaluation indicator system of the energy saving and emission reduction effects still needs to be improved. These qualitative indicators refer to the difficulty of obtaining accurate data, or need to be considered form several aspects together as a whole, which still reflect the energy saving and emission reduction effects of companies in many ways. For example, the responsiveness to energy planning and market reform, the execution of participation in carbon market construction and the extent to which relevant knowledge is imparted to employees. Simultaneously, research objects of the energy saving and emission reduction effects are concentrated on power technologies or equipments, power plants, and power grid companies. In addition to the above studies, references [19–21] also explored the energy saving and emission reduction benefits brought by the improvement of coal-fired power plant boilers and steam turbines. Reference [22] analyzed the impact of the application of distributed generation and micro grid technology on the effects of power plants. Reference [23,24] studied the implementation path of energy saving and emission reduction for power generation companies and the management measures of power grid companies, respectively. While there are few studies on the evaluation in the electricity sales side. Therefore, the scope of evaluation of the energy saving and emission reduction effects needs to be further expanded.

The fuzzy comprehensive evaluation method is widely used to assess objects with ambiguity. Reference [25] constructed a model combining fuzzy evaluation with AHP. In [26], the fuzzy evaluation based on ISM-AHP (interpretative structural modelling method and analytic hierarchy process) was applied to build a multi-level hierarchical interpretation structure model for quantitative analysis. Reference [27] combined the fuzzy min-max method with the defuzzified centroid method to establish a logic system. In [28], the improved interval number was used for ANP (analytic network process). On this basis, the fuzzy comprehensive evaluation model was proposed to effectively solve the problem of information loss and data fluctuation. It can be seen that in order to improve the objectivity of this method, a certain number of researches have corrected the weights of indicators by combining different methods.

1.3. Main Research Contents

The research contents of this paper are mainly divided into six parts. In the first part, the influence of policy opinions on the energy saving and emission reduction actions on the sales side is arranged, the status of energy saving and emission reduction is analyzed, and the future development trend is prejudged from the view of China's new electric power reform, energy planning and transition, and carbon market construction, which provides guidance for the selection of evaluation indicator system of the energy saving and emission reduction effects for electricity retailers in China. In the second part, the energy saving and emission reduction effects of electricity retailers are set as the total evaluation target. Qualitative and quantitative indicators are chosen from five dimensions of market transactions, technical means, integrated energy services, management system, and social responsibilities. Then, the three-level evaluation indicator system of the energy saving and emission reduction effects for electricity retailers is constructed. In the third part, the indicator hierarchy is firstly classified and subjective weights of indicators are determined by AHP. Next, objective weights are determined based on the entropy weight method, in which the method is used for modifying the subjectivity of AHP. At last, combination weights of the evaluation indicator system are gained. In the fourth part, a fuzzy evaluation model on the basis of the combination weighting method is proposed to evaluate the energy saving and emission reduction effects for electricity retailers. In the fifth part, the example analysis proves that both the evaluation indicator system and the evaluation model based on fuzzy combination weighting method put forward in this paper can make a reasonable and scientific evaluation of the energy saving and emission reduction effects for electricity retailers in China. In the sixth part, conclusions are summarized to reflect the main innovation and the value of research in this paper.

2. Present Situation and Development Prospect Analysis of Energy Saving and Emission Reduction in China's Electric Power Industry

2.1. Overview of Relevant Policy Guidance in the Electric Power Industry

In recent years, China has been committed to accelerating the economic restructuring and development mode transformation, advocating efforts to develop green and low-carbon industries to support the economic development while achieving energy conservation and emission reduction. During this period, the government issued relevant policy documents to guide the work orientation for various industries to accelerate the pace for several times.

Since 2008, China has entered the energy transformation. In recent years, the increasingly severe energy environment situation has also made a strong call to the whole society to actively take part in energy saving and emission reduction, which helps to accelerate the process of energy transition. Due to a series of problems, such as large energy consumption, low energy conversion efficiency, and serious environmental pollution, the electric power industry has always been the focus of energy upgrading, conservation and emission reduction [29].

In 2015, China launched a new round of electric power reform. A diversified market players represented by electricity retailers was formed in the sales side market. In 2016, China issued a number of special plans on energy to accelerate the national transformation and upgrading of energy resources, including the electric power industry. In September of the same year, China officially became the 23rd performing party of the Paris Agreement. It measured whether it has implemented its commitment to address climate change through five major indicators, including carbon intensity, energy structure, forest reserves, carbon market pilot reform and support strength for developing countries. Obviously, the green and low carbon development is set as an important part of its ecological civilization construction. At the end of 2017, the construction of carbon emissions trading system on a national scale was officially launched. The development of a green and low-carbon economy was promoted through a reasonable market mechanism to control and reduce greenhouse gas emissions. Then, the Chinese Certified Emission Reduction projects (CCER) would be added to help companies to achieve the transition from high carbon emissions to low carbon development. The carding of multi-party documents that relevant to electric power reform and energy planning during the *13th Five-Year Plan* in China is shown in Figure 1. The full interpretation of these documents will help market players in the electric power industry make a respond to the latest policies in time, take concrete measures to implement energy saving and emission reduction actions and take every effort to achieve their own environmental targets.

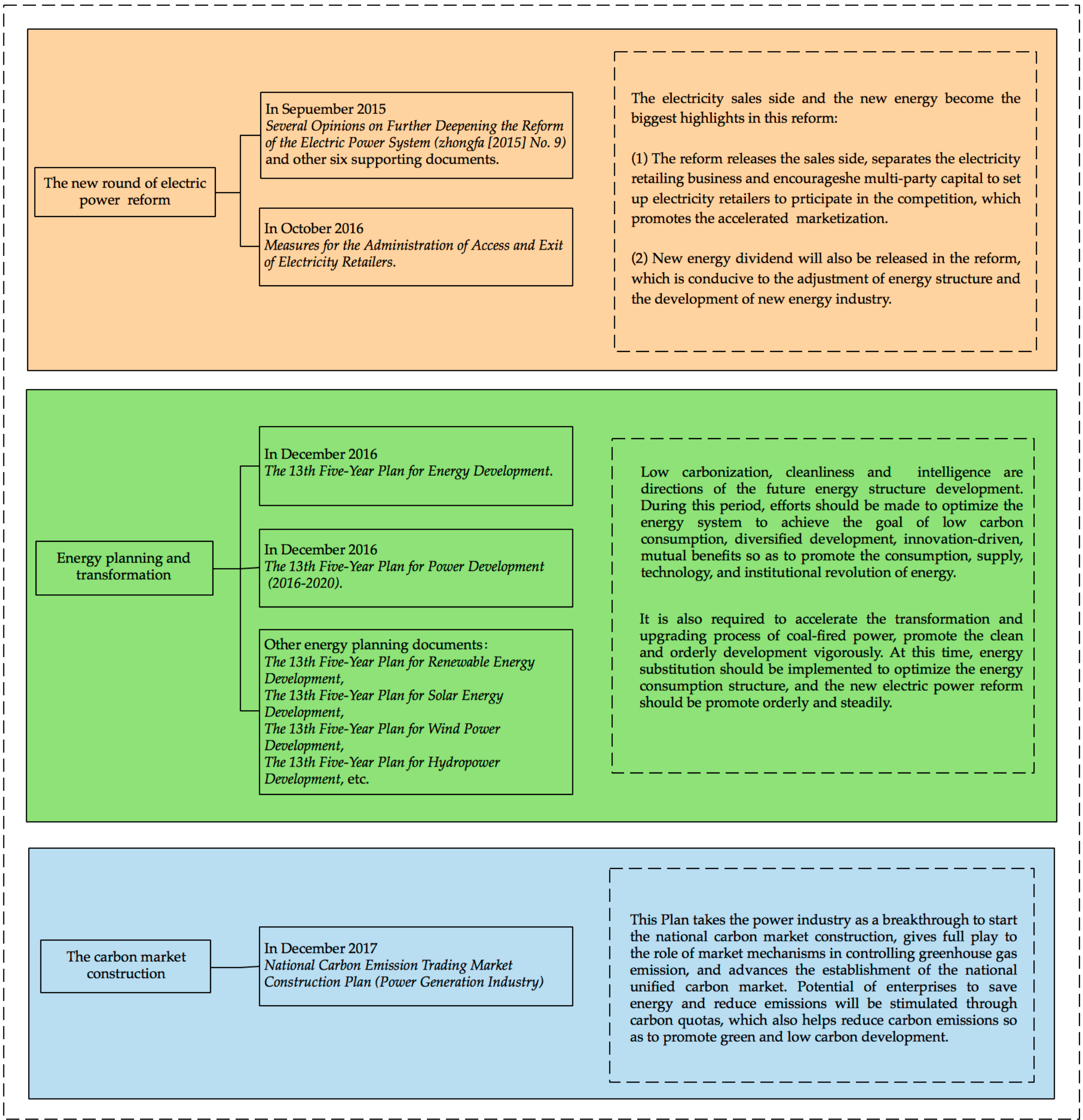

Figure 1. Policy documents on the implementation of energy saving and emission reduction actions for electric power industry in China.

2.2. Analysis on the Development Direction of Energy Saving and Emission Reduction

First of all, the new electric power reform has opened the sales side. On the one hand, the potential huge interests in the electricity sales market attracts diversified capital to form a sales company to participate in the fierce competition. By the end of 2017, the number of electricity retailers in China that have been publicized has reached more than 3200, and, as a result, a multi-competition pattern dominated by electricity retailers has been formed in the sales market. On the other hand, the release of dividends in the new energy field has also been driven by this reform. In order to satisfy the ever-increasing electricity demand in the market, electricity retailers need to carry out the value-added services other than the purchase and sale business, and build an integrated service platform to transform into integrated energy service providers. Secondly, with the gradual advancement of energy transition during the *13th Five-Year Plan* period in China, it is set to control the total energy consumption to within 5 billion tons of standard coal by 2020 and promise to achieve a 65% reduction in emissions by 2030. The goal requires that the electricity development must conform to the concept of low-carbon economy. Therefore, as a member of the main body in the sales market, electricity retailers should actively respond to the optimization and transition of energy structure, establish a low carbon energy system, implement its own energy saving and emission reduction actions and strive to build companies with leading and first-class integrated energy services. Thirdly, the beginning of the national carbon market construction has also brought new opportunities for electricity retailers. Electricity retailers can enter the carbon market to act as agents for carbon trading with huge data resources and rich market trading experience, which will support the comprehensive construction of the carbon market and effectively stimulate the energy saving and emission reduction potential for other enterprises.

With the background of the new electric power reform, energy planning and development, and the carbon market construction, it is an inevitable trend for China's electric power industry to insist the low-carbon opinions and promote energy saving and emission reduction. As an indispensable group on the road of energy saving and emission reduction, electricity retailers should take measures on market-oriented transactions in the sales side, related technology development, integrated value-added services, internal management, and social responsibilities, which improves core competitiveness and accelerates the transformation into the integrated energy service providers to help the realization of energy saving and emission reduction goal in China.

3. Selection of Evaluation Indicators of Energy Saving and Emission Reduction Effects for Electricity Retailers in China

To begin with, we consider the background of the electric power system reform, energy structure transition and optimization, and the current carbon market construction status in this paper. After that, the evaluation indicator system is proposed according to the principles of scientificalness, comprehensiveness, systematicness, feasibility, and comparability [30], in which the energy saving and emission reduction effects of electricity retailers are regarded as the overall evaluation goal. Meanwhile, five evaluation criteria are selected based on those policy documents, including market transactions, technical means, integrated energy services, management system, and social responsibilities. To further refine the five criteria, we have determined more detailed three-level indicators. Not only consider the relevant businesses that have operated by some electricity retailers, but the availability of data. Finally, the three-level evaluation indicator system is built, as displayed in the following Figure 2. Th meaning of some indicators is shown in Appendix A. The selection of evaluation indicators meets the combination of qualitative and quantitative indicators. Among them, the selection of qualitative indicators is supported by the latest policy orientation, which has a strong practical significance for electricity retailers in China.

If only one complete system is used, the evaluation can only be studied from a global perspective. Therefore, the classification of the indicator system into three levels is to conduct a multi-level evaluation of the energy saving and emission reduction effects for electricity retailers. As a result, the weight structure distribution of different levels can be obtained one by one and the importance ranking results of the next level indicators to the upper are obtained, simultaneously. On the basis of the distribution results, electricity retailers can take measures to improve the energy saving and emission reduction effect from the individual indicators and avoid useless costs.

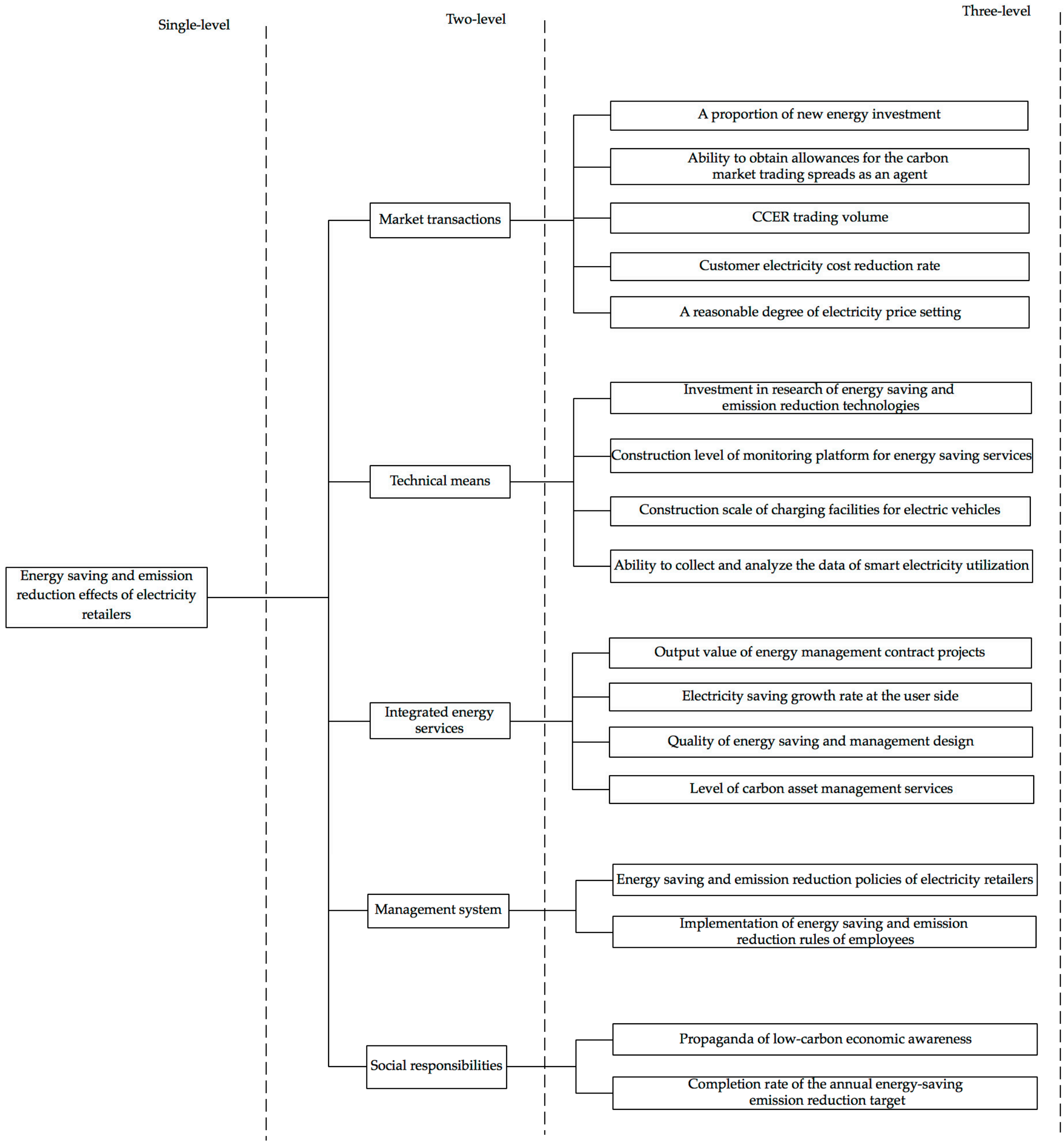

Figure 2. The three-level evaluation indicator system of the energy saving and emission reduction effects for electricity retailers in China.

4. Determination of Indicator Weights Based on Combination Weighting Method

4.1. Preprocessing of the Evaluation Indicators

We chose the Delphi method to quantify qualitative indicators. Several experts complete the scoring process according to the uniform criteria. Suppose that M is the number of experts and S_k^i is the score of the qualitative indicator k assessed by expert i. After the scores of all the experts are finished, the quantified score S_k of indicator k is given, as follows:

$$S_k = \frac{1}{M}\sum_{i=1}^{M} S_k^i \tag{1}$$

In order to eliminate the influence of units, types, and economic implications of different indicators on the evaluation results, the raw data of evaluation indicators needs to be preprocessed firstly. Suppose that x_{ij}^0 is the indicator original value. Then, the normalization of benefit type and cost type indicators is given, as follows:

$$x_{ij} = {x_{ij}}^0 / max{x_{ij}}^0 \tag{2}$$

$$x_{ij} = min{x_{ij}}^0 / {x_{ij}}^0 \tag{3}$$

where x_{ij} is the normalized value. We have the normalization matrix X^*, as follows:

$$X^* = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{21} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n1} & \cdots & x_{nm} \end{bmatrix}$$

where n is the number of evaluation indicators and m is that of evaluation schemes. $i = 1, 2, \cdots, n$, $j = 1, 2, \ldots, m$.

4.2. Analytic Hierarchy Process

Analytic hierarchy process (AHP) is often used to obtain the subjective weights of indicators. It is an evaluation method that combines quantitative and qualitative analysis with the advantage of simple calculation. In general, the overall hierarchy is divided into the target hierarchy, program hierarchy, and criterion hierarchy to make problems more rational when using AHP to make decisions [31,32]. The process of determining subjective weights through AHP is shown, as follows:

1. Divide the hierarchy of indicators

In this paper, the specific hierarchy division of the indicator system is shown in Table 1.

2. Construct the pairwise judgment matrix between hierarchies

The nine-level scale method is applied to compare the elements in pairs. The meaning of the scale a_{ij} of 1 to 9 is given in Table 2, as follows.

The judgment matrix A is defined, as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{21} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n1} & \cdots & a_{nm} \end{bmatrix}$$

3. Hierarchical single arrangement and consistency check

Hierarchical single arrangement refers to calculating the maximum eigenvalue $\lambda_{\max}$ of the single-layer judgment matrix and the corresponding eigenvector ξ. The normalized ξ is used to get the ranking weights of each indicator at the same level when compared with the importance of a certain indicator at the previous level. The formula for determining $\lambda_{\max}$ and ξ is given in Equation (4).

$$A\xi = \lambda_{\max}\xi \tag{4}$$

The procedure of consistency check for the constructed judgement matrix is shown, as follows:

(1) Calculate the consistency indicators CI

$$CI = (\lambda_{\max} - r)/(r - 1) \tag{5}$$

where r is the order of the judgment matrix.

(2) Determine the average random consistency indicator RI

After 1000 times repeated calculations through the order from 1st to 15th, the value of RI is measured in Table 3 [33].

(3) Calculate the consistency ratio CR

$$CR = CI/RI \tag{6}$$

A consistency check is the way to determine whether the consistency of judgement matrix is within a reasonable range by checking the values of CR. When $CR < 0.1$, the judgment matrix is considered to have passed the consistency check, otherwise it needs to be properly corrected.

Table 1. Hierarchy division of the evaluation indicator system of energy saving and emission reduction effects for electricity retailers in China.

<table>
<tr><th rowspan="2">Target Hierarchy</th><th rowspan="2">Program Hierarchy</th><th rowspan="2">Criterion Hierarchy</th><th colspan="2">Type of Indicators</th></tr>
<tr><th>Quantitative</th><th>Qualitative</th></tr>
<tr><td rowspan="18">Energy saving and emission reduction effects for electricity retailers U</td><td rowspan="5">Market transactions U_1</td><td>A proportion of new energy investment U_{11}</td><td>√</td><td></td></tr>
<tr><td>Ability to obtain allowances for the carbon market trading spreads as an agent U_{12}</td><td></td><td>√</td></tr>
<tr><td>CCER trading volume U_{13}</td><td>√</td><td></td></tr>
<tr><td>Customer electricity cost reduction rate U_{14}</td><td>√</td><td></td></tr>
<tr><td>A reasonable degree of electricity price setting U_{15}</td><td></td><td>√</td></tr>
<tr><td rowspan="4">Technical means U_2</td><td>Investment in research of energy saving and emission reduction technologies U_{21}</td><td>√</td><td></td></tr>
<tr><td>Construction scale of charging facilities for electric vehicles U_{22}</td><td>√</td><td></td></tr>
<tr><td>Construction level of monitoring platform for energy saving services U_{23}</td><td></td><td>√</td></tr>
<tr><td>Ability to collect and analyze the data of smart electricity utilization U_{24}</td><td></td><td>√</td></tr>
<tr><td rowspan="4">Integrated energy services U_3</td><td>Output value of energy management contract projects U_{31}</td><td>√</td><td></td></tr>
<tr><td>Electricity saving growth rate at the user side U_{32}</td><td>√</td><td></td></tr>
<tr><td>Quality of energy saving and management design U_{33}</td><td></td><td>√</td></tr>
<tr><td>Level of carbon asset management services U_{34}</td><td></td><td>√</td></tr>
<tr><td rowspan="2">Management system U_4</td><td>Energy saving and emission reduction policies of electricity retailers U_{41}</td><td></td><td>√</td></tr>
<tr><td>Implementation of energy saving and emission reduction rules of employees U_{42}</td><td></td><td>√</td></tr>
<tr><td rowspan="2">Social responsibilities U_5</td><td>Propaganda of low-carbon economic awareness U_{51}</td><td></td><td>√</td></tr>
<tr><td>Completion rate of the annual energy-saving emission reduction target U_{52}</td><td>√</td><td></td></tr>
</table>

Table 2. The 1–9 degree scale implications of analytic hierarchy process (AHP).

Scale Values	Implications of a_{ij}
1	Indicator i is as important as indicator j
3	Indicator i is slightly more important than indicator j
5	Indicator i is more important than indicator j
7	Indicator i is strongly more important than indicator j
9	Indicator i is extremely more important than indicator j
2,4,6,8	The middle value of the above two adjacent scale judgment
Reciprocal	Ratio of the importance of indicator j to indicator i

Table 3. The assignment table for RI.

r	Values of RI	r	Values of RI
1	0	9	1.46
2	0	10	1.49
3	0.52	11	1.52
4	0.89	12	1.54
5	1.12	13	1.56
6	1.24	14	1.58
7	1.36	15	1.59
8	1.41	—	—

4.3. Entropy Weight Method

Entropy weight method is a common method for calculating the objective weights of indicators. It reflects the ability of evaluation objects to provide effective information by determining the relative proximity [34,35]. Weights that are given by the subjective weighting method can be adjusted and corrected by means of entropy weight method, which improves to get the scientific and accurate evaluation results. The determination of the objective weights of indicators based on entropy weight method is shown, as follows:

1. Construct the standardized judgment matrix

   The standardized judgment matrix constituted by the pre-processed indicator data is X^*.

2. Measure the information entropy

The total number of evaluation objects is m and that of indicators is n. Then the information entropy H_i of indicator i is calculated, as follows:

$$H_i = -k\sum_{i=1}^{m} f_{ij} ln f_{ij},\ i = 1, 2, \cdots, m \tag{7}$$

$$f_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij} \tag{8}$$

$$k = \frac{1}{\ln m} \tag{9}$$

where x_{ij} is the normalized value. When $f_{ij} = 0$, there is $f_{ij} ln f_{ij} = 0$.

The objective weights of indicators are given by Equation (10).

$$w_i = \frac{1 - H_i}{\sum\limits_{i=1}^{m} (1 - H_i)} \tag{10}$$

where $0 \leq w_i \leq 1$, $\sum_{i=1}^{m} w_i = 1$.

4.4. Determination of the Combination Weight

In the practical application of AHP, it is difficult to completely reflect the actual situation of the evaluation objects only based on subjective experience, which may lead to the final evaluation results deviating from reality and have certain limitations. In reference [26], the ISM-AHP combination weighting method is applicable to systems with many variables and unclear structures, but the structural relationship formed is too complicated. In the evaluation with a small number of variables, the difficulty is increased. In reference [36], multiplication is applied to connect the subjective and objective weights, which can improve the ability to reflect information of data to a certain extent. In reference [37], integration weights of indicators are defined according to AHP and entropy weight method, as displayed in Equation (11).

$$w_i' = aw_i^1 + (1-a)w_i^2 \tag{11}$$

where w_i^1 and w_i^2 are the indicator weights that are based on AHP and the entropy weight method, respectively. The integration weights still have partial subjectivity through this method, because the assignment a is determined by expert scoring method. While in this paper, after determining the subjective weights by AHP, the information entropy H_i is introduced to eliminate the subjectivity in the evaluation process so that the information of original data can be fully utilized, and the reliability of evaluation results can be effectively improved. The combination weights of evaluation indicators are given, as shown in Equation (12).

$$w_i' = w_i^1 H_i + w_i^2(1-H_i) \tag{12}$$

where $\sum_{i=1}^{m} w_i' = 1$, w_i^1, and w_i^2 are the indicator weights that are calculated by AHP and the entropy weight method, respectively.

5. Construction of Fuzzy Comprehensive Evaluation Model

5.1. Basic Theory of Fuzzy Comprehensive Evaluation

On the basis of fuzzy mathematics, the fuzzy comprehensive evaluation assesses objects through fuzzy transformation and the principle of maximum membership degree, is widely used in management science, economic, and environmental evaluation. Fuzzy evaluation can be used to quantify qualitative indicators, which has strong systematicness and it greatly reduces the subjectivity in the evaluation process, and is suitable for the evaluation of non-deterministic problems [38–41].

5.2. Construction of Fuzzy Comprehensive Evaluation Model Based on Combination Weighting Method

1. Decide the factor set and evaluation set

Assume that N is the number of single factors belonging to the same level, $u_i(i = 1, 2, \cdots, N)$ is the evaluation factor, $U = \{u_1, u_2, \cdots, u_N\}$ is the factor set, n is the rating level, $v_j(j = 1, 2, \cdots, n)$ is the evaluation rating standard, and $V = \{v_1, v_2, \cdots, v_n\}$ is the determined evaluation set. Five levels for the evaluation of energy saving and emission reduction effects for electricity retailers are confirmed in this paper, namely, V = {Excellent, Good, Moderate, Poor, Extremely poor}. $H = \{5, 4, 3, 2, 1\}$ is the corresponding scale.

2. Construct the fuzzy relation matrix

The fuzzy relation matrix is also called the membership degree matrix, in which r_{ij} represents the relationship of the membership degree between the evaluation factor u_i and the corresponding evaluation level v_j. In this paper, the membership degree is determined by the Delphi method. When considering the construction of the indicator system and the impact of specific indicators on the energy saving and emission reduction effects of electricity retailers, experts judge these indicators to determine the membership degree. The fuzzy vector R_i formed by the evaluation factor u_i is defined in Equation (12).

$$R_i = (r_{i1}, r_{i2}, \cdots, r_{ij}, \cdots r_{Nn}),\ i = 1, 2, \cdots, N,\ j = 1, 2, \cdots, n \tag{13}$$

where $0 < r_{ij} < 1$. The fuzzy relation matrix R composed of n elements is shown in Equation (13).

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{21} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{N1} & r_{N1} & \cdots & r_{Nn} \end{bmatrix} \tag{14}$$

3. Determine the result set of fuzzy evaluation

In order to make the best of all the information of the matrix, the $M(\cdot, \oplus)$ operator is selected to determine the fuzzy judgment result set B. The calculation of fuzzy judgment is given by Equation (14).

$$B = w \circ R \tag{15}$$

where w is the combination weights of the evaluation indicators given through AHP and the entropy weight method.

4. Determine fuzzy comprehensive evaluation results

In accordance with the principle of maximum membership degree, the energy saving and emission reduction effects of electricity retailers are classified into the corresponding evaluation levels based on the fuzzy evaluation results.

In order to conduct a further assessment of the overall energy saving and emission reduction effects of electricity retailers, multi-level fuzzy evaluation should be carried out after obtaining the single-level fuzzy comprehensive evaluation results. In the light of the principle of maximum membership degree, the level of the maximum membership degree is the final evaluation level of the energy saving and emission reduction effects of the evaluated electricity retailers.

The evaluation process of energy saving and emission reduction effects for electricity retailers based on fuzzy combination weighting method constructed in this paper is as shown in Figure 3.

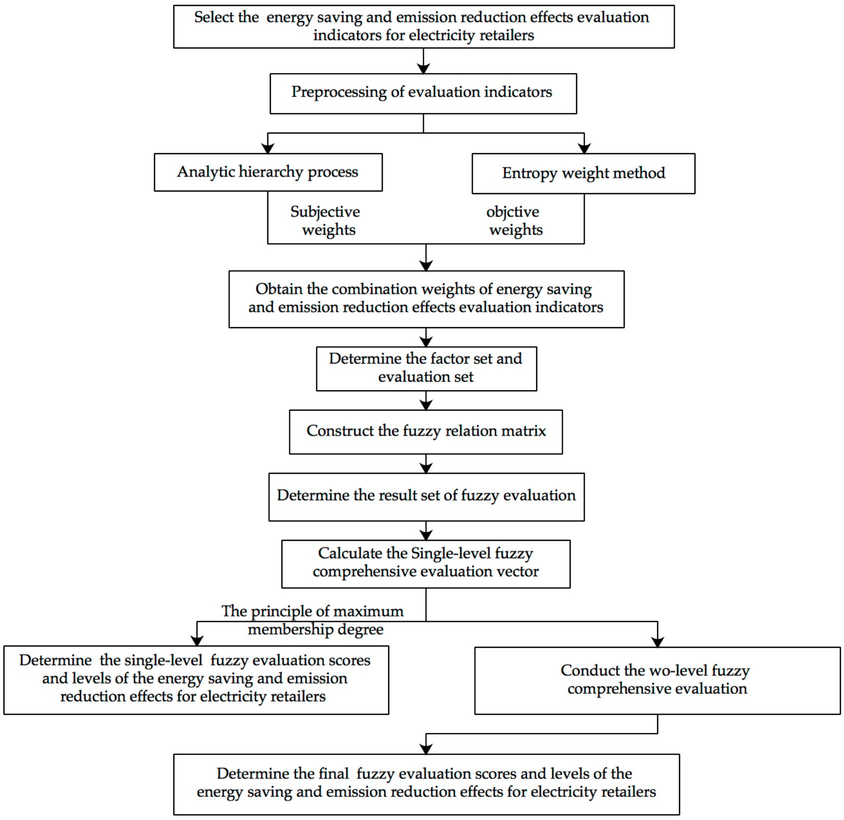

Figure 3. Evaluation process of energy saving and emission reduction effects for electricity retailers.

6. Example Analysis

In this paper, ten electricity retailers that numbered from A to J are selected as the evaluation objects. The energy saving and emission reduction effects of these five electricity retailers are evaluated based on the fuzzy combination weighting method. Firstly, qualitative indicators are qualified by experts according to Equation (1) with interval scores of [1–10] points. These experts come from some of the electricity retailers that have been carrying out relevant business activities in accordance with the policy orientation, who obviously have many years of experience in the electric power industry. They also have a deep understanding of the electric power reform, energy transformation, and carbon market construction process and they hold reasonable opinions.

Since the selected evaluation indicators are all benefit types, the raw data of all the indicators are first normalized according to Equation (2). The processed data is displayed in Table 4.

Table 4. Normalized data of energy saving and emission reduction effects evaluation indicators of electricity retailers.

Three-Level Indicators	Electricity Retailers									
	A	B	C	D	E	F	G	H	I	J
U_{11}	0.8689	0.8060	0.7355	0.9398	0.9995	0.7626	0.8507	0.8829	0.8960	1.0000
U_{12}	0.8975	0.8604	0.8157	0.9520	0.9760	0.8124	1.0000	0.9324	0.9520	0.9237
U_{13}	0.1489	0.3925	0.2684	0.6444	1.0000	0.3327	0.5553	0.7106	0.2977	0.3340
U_{14}	0.6190	0.7619	0.5524	0.9048	0.7143	0.6476	0.7810	0.7143	1.0000	0.8571
U_{15}	0.8481	0.9335	0.8404	0.9279	1.0000	0.9346	0.8038	0.9479	0.9157	0.9579
U_{21}	0.7125	0.5375	0.3656	0.8031	0.4219	0.3250	0.6906	0.8625	1.0000	0.8906
U_{22}	0.6000	0.4889	0.2889	1.0000	0.7111	0.4444	0.5333	0.4444	0.3333	0.5556
U_{23}	0.7713	0.5923	0.6477	0.8054	0.8707	0.5526	0.9134	0.8366	0.8125	1.0000
U_{24}	0.9407	0.9021	0.7352	0.8455	1.0000	0.6717	0.9545	0.7669	0.7228	0.9076

Table 4. *Cont.*

Three-Level Indicators	Electricity Retailers									
	A	B	C	D	E	F	G	H	I	J
U_{31}	0.8521	0.6549	0.2993	0.9085	1.0000	0.5880	0.4366	0.7852	0.6127	0.8627
U_{32}	0.3064	0.4641	0.2368	0.6855	1.0000	0.5685	0.3371	0.3832	0.6552	0.8382
U_{33}	0.9595	0.8639	0.8155	0.9269	0.7402	0.6862	0.8493	0.7750	0.9291	1.0000
U_{34}	0.8904	0.8800	0.7774	1.0000	0.9814	0.8403	0.9709	0.8834	0.9592	0.9825
U_{41}	0.9016	0.9147	0.9357	0.9921	0.9501	0.8635	1.0000	0.8898	0.9777	0.9606
U_{42}	0.9265	0.9027	0.9870	0.8519	0.9146	0.8249	1.0000	0.8303	0.8908	0.9243
U_{51}	0.7123	0.8630	0.7511	0.9372	1.0000	0.6644	0.7477	0.8196	0.7123	0.8345
U_{52}	0.9615	0.9707	0.9791	1.0000	0.9791	0.8678	0.9637	0.9749	0.9791	0.9791

6.1. Single-Level Fuzzy Comprehensive Evaluation

(1) Determine the subjective weights

Firstly, the subjective weights of different levels of indicators are determined based on AHP. By consulting experts' opinions, the pairwise comparison judgment matrix is constructed. Then, the maximum eigenvalues and corresponding eigenvectors are solved according to Equation (4). The weights of the evaluation indicators are obtained by normalizing the maximum eigenvectors, as displayed in Table 5.

Table 5. Subjective weights of energy saving and emission reduction evaluation indicators of electricity retailers.

Program Hierarchy	Weights of Indicators	Criterion Hierarchy	Weights of Indicators	Consistency Check
U_1	0.0939	U_{11} U_{12} U_{13} U_{14} U_{15}	0.1443 0.4309 0.3155 0.0665 0.0429	$\lambda_{max} = 5.2461$ $CI = 0.0615$ $CR = 0.0549$
U_2	0.2188	U_{21} U_{22} U_{23} U_{24}	0.5280 0.3221 0.0604 0.0895	$\lambda_{max} = 4.2496$ $CI = 0.0832$ $CR = 0.0936$
U_3	0.5800	U_{31} U_{32} U_{33} U_{34}	0.3326 0.1136 0.2572 0.2975	$\lambda_{max} = 4.1179$ $CI = 0.0393$ $CR = 0.0442$
U_4	0.0412	U_{41} U_{42}	0.2500 0.7500	$\lambda_{max} = 2$ Complete consistency
U_5	0.0661	U_{51} U_{52}	0.1429 0.8571	$\lambda_{max} = 2$ Complete consistency

It can be seen from Table 5 that weights of the criterion hierarchy indicators that are determined by AHP have passed the consistency check. In the same way, the consistency check of weights of the program hierarchy indicators are conducted. There are $\lambda_{max} = 5.3839$, $CI = 0.096$, $CR = 0.0857 < 1$, as a result, the consistency check is also passed.

(2) Determine the objective weights

The normalized judgment matrices are constructed from the normalized data, and the standardized judgment matrices are processed according to the Equations (7)–(10) by the entropy weight method. The objective weights of evaluation indicators are shown in Table 6.

Table 6. Objective weights of energy saving and emission reduction evaluation indicators of electricity retailers.

Single-Level Indicators	Two-Level Indicators	Three-Level Indicators	The Weights of Indicators
U	U_1	U_{11}	0.0105
		U_{12}	0.0050
		U_{13}	0.2814
		U_{14}	0.0320
		U_{15}	0.0044
	U_2	U_{21}	0.1329
		U_{22}	0.1300
		U_{23}	0.0339
		U_{24}	0.0179
	U_3	U_{31}	0.1072
		U_{32}	0.1993
		U_{33}	0.0140
		U_{34}	0.0064
	U_4	U_{41}	0.0023
		U_{42}	0.0042
	U_5	U_{51}	0.0171
		U_{52}	0.0014

(3) Calculate the combination weights

AHP and entropy weight method are used synthetically to determine the subjective weights and objective weights of the indicators, respectively. The combination weights of indicators are given by Equation (12) with the results, as shown in Table 7.

Table 7. Combination weights of energy saving and emission reduction effects evaluation indicators of electricity retailers.

Single-Level Indicators	Two-Level Indicators	Three-Level Indicators	Weights of Energy Saving and Emission Reduction Effects Indicators of Electricity Retailers		
			AHP	Entropy Weight Method	Combination Weights
U	U_1	U_{11}	0.1443	0.0105	0.1440
		U_{12}	0.4309	0.0050	0.4305
		U_{13}	0.3155	0.2814	0.3136
		U_{14}	0.0665	0.0320	0.0663
		U_{15}	0.0429	0.0044	0.0429
	U_2	U_{21}	0.5280	0.1329	0.5176
		U_{22}	0.3221	0.1300	0.3171
		U_{23}	0.0604	0.0339	0.0602
		U_{24}	0.0895	0.0179	0.0892
	U_3	U_{31}	0.3326	0.1072	0.3278
		U_{32}	0.1136	0.1993	0.1170
		U_{33}	0.2572	0.0140	0.2565
		U_{34}	0.2975	0.0064	0.2971
	U_4	U_{41}	0.2500	0.0023	0.2499
		U_{42}	0.7500	0.0042	0.7494
	U_5	U_{51}	0.1429	0.0171	0.1425
		U_{52}	0.8571	0.0014	0.8569

According to the distribution results of weights, we see that the importance ranking results of the two-level indicators to the energy saving and emission reduction effects of electricity retailers are followed by integrated energy services, technical means, market transactions, social responsibilities, and management system. It can be seen from the above that the level of integrated energy services has the greatest impact on the energy saving and emission reduction effects for electricity retailers among the two-level indicators, while the management system has the worst. To explore the impact of the three-level indicators on the two-level, the analysis results are as follows.

From the perspective of market transactions, the most important indicator is the ability to obtain allowances for the carbon market trading spreads as an agent, while the least important is the reasonable degree of electricity price setting. From the perspective of technical means, the most important indicator is the investment in research of energy saving and emission reduction technologies, while the least important is the construction level of monitoring platform for energy saving services. On the integrated energy services side, the most important indicator is the output value of energy management contract projects, while the least important is the construction scale of charging facilities for electric vehicles. However, the importance of the four three-level indicators included is not much different. From the view of the management system, the indicator of implementation of energy saving and emission reduction rules of employees is obviously more important than the energy saving and emission reduction policies of electricity retailers. From the perspective of social responsibilities, the indicator of completion rate of the annual energy-saving emission reduction target is obviously more important than the propaganda of low-carbon economic awareness.

The importance ranking of indicators is beneficial to the electricity retailers to take measures from a single aspect in the future, in order to achieve an effective improvement of their energy saving and emission reduction effects with relatively small investment.

(4) Obtain the results of single-level fuzzy comprehensive evaluation

The three-level indicators are scored by experts based on the evaluation set V = {Excellent, Good, Moderate, Poor, Extremely poor} and the scale $H = \{5, 4, 3, 2, 1\}$. Next, the fuzzy relation matrix $B_i (i = 1, 2, 3, 4, 5)$ corresponding to U_1, U_2, U_3, U_4, U_5 is built, respectively. The fuzzy evaluation values of single-level fuzzy comprehensive evaluation indicators are calculated by Equation (15), as shown in Table 8. And the level distribution is shown in Figure 4.

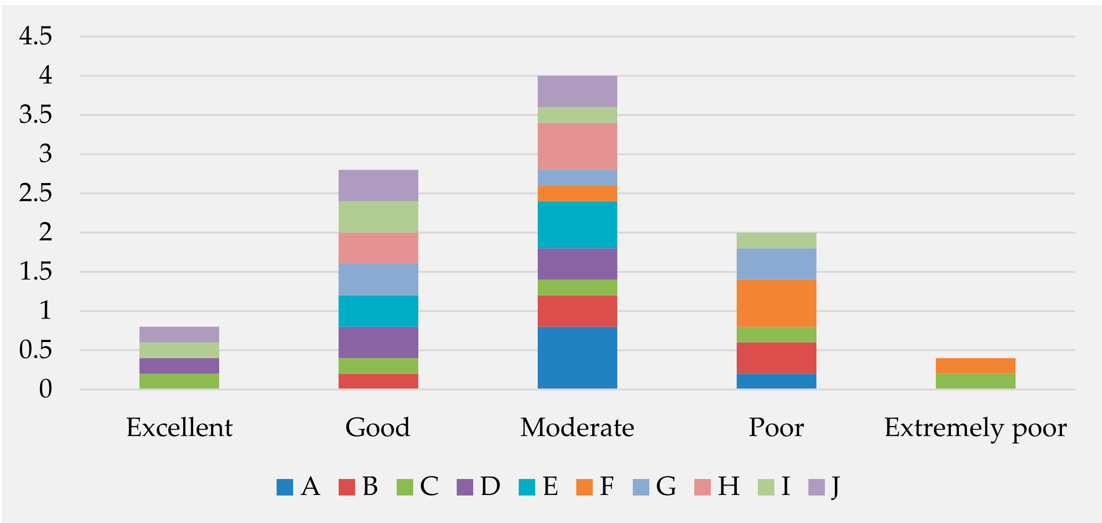

Figure 4. Level distribution of the single-level fuzzy evaluation.

Table 8. Single-level fuzzy comprehensive evaluation results.

Electricity Retailers	Fuzzy Evaluation Value				
	B_1	B_2	B_3	B_4	B_5
A	0.0288	0	0	0	0.1714
	0.2298	0.2839	0.162	0.4496	0.1999
	0.2555	0.5726	0.6117	0.4997	0.5996
	0.2817	0.1276	0.2013	0.05	0.0285
	0.2014	0	0.0234	0	0
B	0	0	0	0	0.1714
	0.1367	0	0.0234	0.1499	0.3998
	0.6589	0.1903	0.3851	0.4997	0.2284
	0.194	0.4793	0.5243	0.3497	0.1999
	0.0086	0.3145	0.0656	0	0
C	0	0	0	0.1499	0.6855
	0.0947	0	0	0.5496	0.1999
	0.3647	0.1109	0.1107	0.2498	0.0855
	0.3128	0.3191	0.4678	0.05	0.0285
	0.2251	0.5512	0.4198	0	0
D	0.1995	0.1268	0.1484	0	0.3713
	0.4542	0.2938	0.4588	0.1999	0.3713
	0.3436	0.3824	0.3399	0.5996	0.2569
	0	0.1633	0.0513	0.1999	0
	0	0.0178	0	0	0
E	0.335	0.1625	0.1358	0	0.3998
	0.457	0.25	0.1484	0.2998	0.5996
	0.1788	0.261	0.4495	0.5996	0
	0.0265	0.1035	0.2133	0.1	0
	0	0.207	0.0513	0	0
F	0	0	0	0	0
	0.0172	0.0634	0.0468	0.1499	0
	0.1384	0.2081	0.2546	0.5496	0.057
	0.3611	0.4337	0.5207	0.2998	0.5711
	0.4807	0.2788	0.1763	0	0.3713
G	0.1722	0	0.0594	0.05	0
	0.4425	0.2923	0.2296	0.7495	0
	0.3113	0.4615	0.2367	0.1999	0.057
	0.0713	0.2304	0.276	0	0.5711
	0	0	0.1967	0	0.3713
H	0.0288	0	0	0	0.1714
	0.4858	0.386	0	0.1499	0.714
	0.4562	0.4749	0.5497	0.5496	0.114
	0.0265	0.1232	0.4487	0.2998	0
	0	0	0	0	0
I	0.1391	0.3106	0	0	0.6855
	0.4413	0.207	0.4105	0.05	0.1999
	0.166	0.1174	0.2744	0.5996	0.0855
	0.1882	0.3491	0.248	0.3497	0.0285
	0.0627	0	0.0656	0	0
J	0.0288	0	0.0747	0	0.5141
	0.3019	0.6926	0.3429	0.1999	0.3998
	0.2669	0.2023	0.3902	0.5996	0.057
	0.1488	0.0535	0.1905	0.1999	0.0285
	0.2509	0.0357	0	0	0

One can observe that the single-level fuzzy comprehensive evaluation can analyze the energy saving and emission reduction effects for the five electricity retailers in the aspects of market transactions, technical means, integrated energy services, management system and social responsibilities. On the basis of the principle of maximum membership degree, the evaluation levels of energy saving and emission reduction effects for electricity retailer A to J from a single dimension are shown in Table 9.

Table 9. Level of energy saving and emission reduction effects for electricity retailers from a single dimension.

Electricity Retailers	U_1	U_2	U_3	U_4	U_5
A	Poor	Moderate	Moderate	Moderate	Moderate
B	Moderate	Poor	Poor	Moderate	Good
C	Moderate	Extremely poor	Poor	Good	Excellent
D	Good	Moderate	Good	Moderate	Excellent
E	Good	Moderate	Moderate	Moderate	Good
F	Extremely poor	Poor	Poor	Moderate	Poor
G	Good	Moderate	Poor	Good	Poor
H	Good	Moderate	Moderate	Moderate	Good
I	Good	Poor	Good	Moderate	Excellent
J	Good	Good	Moderate	Moderate	Excellent

6.2. Two-Level Fuzzy Comprehensive Evaluation

The fuzzy relation matrices R of the two-level indicators are constructed based on B_1, B_2, B_3, B_4, B_5 that are determined in the single-level evaluation. Then set {100, 80, 60, 40, 0} as the evaluation scores corresponding to V = {Excellent, Good, Moderate, Poor, Extremely poor}. Table 10 shows the final scores of the overall energy saving and emission reduction effects of electricity retailers, which are obtained through the quantization of evaluation levels.

Table 10. Two-level fuzzy comprehensive evaluation results.

Electricity Retailers	Fuzzy Comprehensive Evaluation Vectors	Maximum Membership Degree	Fuzzy Evaluation Levels	Comprehensive Evaluation Scores	Sorted Resuls
A	(0.0140, 0.2094, 0.5643, 0.1751, 0.0325)	0.5643	Moderate	59.014	4
B	(0.0113, 0.0590, 0.3626, 0.4548, 0.1077)	0.4548	Poor	45.798	8
C	(0.0515, 0.0447, 0.1387, 0.3745, 0.3852)	0.3852	Extremely poor	32.028	10
D	(0.1571, 0.4058, 0.3548, 0.0737, 0.0039)	0.4058	Good	72.41	1
E	(0.1722, 0.2357, 0.3593, 0.1530, 0.0750)	0.3593	Moderate	46.534	7
F	(0, 0.4880, 0.2326, 0.4809, 0.2329)	0.4809	Poor	37.096	9
G	(0.0527, 0.2696, 0.2795, 0.2549, 0.1386)	0.2795	Moderate	53.804	6
H	(0.0140, 0.1834, 0.4958, 0.3020,0)	0.4958	Moderate	57.9	5
I	(0.1263, 0.3401, 0.2308, 0.2542, 0.0439)	0.3401	Good	63.854	3
J	(0.0800, 0.4134, 0.3241, 0.1463, 0.0314)	0.4134	Good	66.37	2

It can be seen form the above, the final fuzzy evaluation levels of the ten electricity retailers' energy saving and emission reduction effects that are determined by the principle of maximum membership degree are followed by Moderate, Poor, Extremely poor, Good, Moderate, Poor, Moderate, Moderate, Good, and Good. The comprehensive evaluation scores of the ten electricity retailers are obtained by quantifying evaluation levels. As shown in Figures 5 and 6, among them, the comprehensive evaluation score of electricity retailers D is 72.41, which has the best energy saving and emission reduction effects. Combined with the results of single-level fuzzy evaluation, the company D needs to continue to strengthen actions in market transactions and integrated energy services to improve its energy saving and emission reduction effects. Electricity retailers C has the worst energy saving and emission reduction effects with the scores of 32.028. The company C has fulfilled social responsibilities better to promote the energy saving and emission reduction. However, from a holistic perspective, the main reason for the poor performance of energy saving and emission reduction effects of electricity retailer C may be that there are great problems in the two aspects of technical means and integrated energy services, and there is still room for improvement in market transactions and management system.

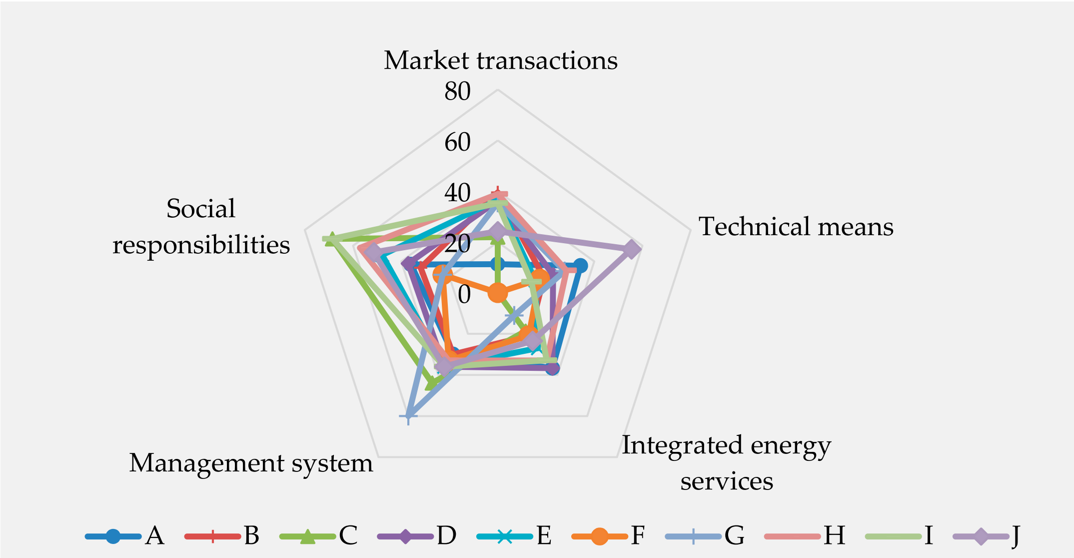

Figure 5. Radar chart of energy saving and emission reduction effects of the five electricity retailers.

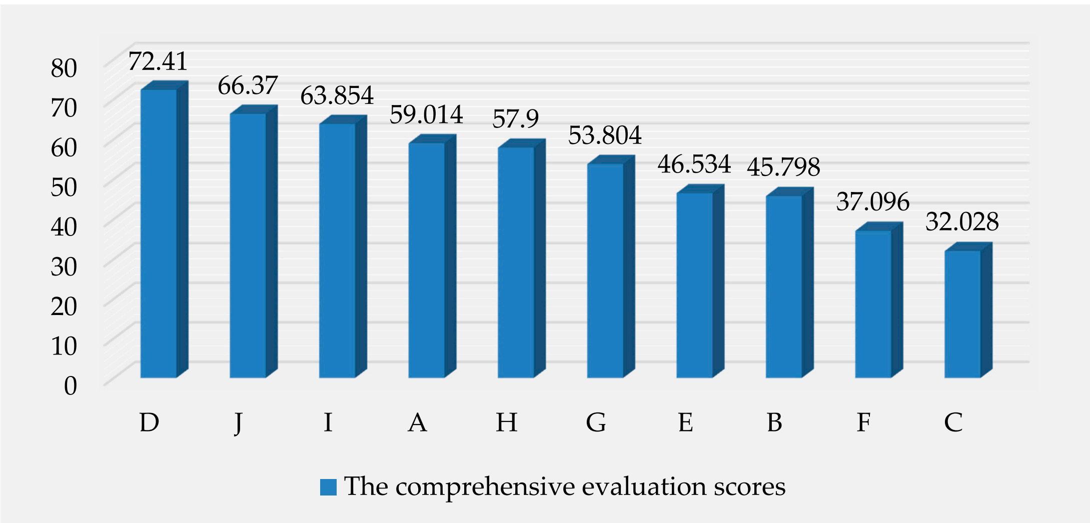

Figure 6. Evaluation scores of energy saving and emission reduction effects of the 5 electricity retailers.

7. Conclusions

In this paper, firstly, we discuss the research vacancy at home and abroad on the evaluation of energy saving and emission reduction effects in China's electricity industry. On the basis, electricity retailers emerged on the sales market are treated as the research objects. Then, key indicators are screened to construct the corresponding evaluation indicator system by interpreting the multi-party policy documents that are related to the electric power reform, energy transformation, and carbon market construction. Secondly, AHP and entropy weight method are grouped together to obtain the modified weights of indicators and the model is established based on fuzzy comprehensive evaluation theory. Thirdly, the multi-level fuzzy comprehensive evaluation of energy saving and emission reduction effects for electricity retailers is conducted in accordance with the principle of maximum membership degree, a total number of five levels are reserved for the effects, including Excellent, Good, Moderate, Poor, and Extremely poor. Through the single-level fuzzy comprehensive evaluation, the energy saving, and emission reduction effects for electricity retailers in five aspects of market transactions, technical means, integrated energy services, management system, and social responsibilities are obtained. Through the two-level fuzzy comprehensive evaluation, the overall evaluation level is determined. Then, the energy saving and emission reduction effects for electricity retailers is sorted by quantifying the evaluation levels. The results of example analysis show that the method applied to the evaluation of energy saving and emission reduction effects for electricity retailers in China can fit the characteristics of the evaluation indicators with a good performance. At the same time, it can also draw a reasonable evaluation result.

The main research findings of this paper are as follows:

(1) Choose the emerged electricity retailers as evaluation objects and take the qualitative factors of policies into consideration in the process of constructing the indicator system. Therefore, the indicator system that is proposed in this paper can better reflect the specific impact of the new electric power reform, energy planning and transformation, and the carbon market construction on China's current energy saving and emission reduction actions in the electricity sales side. In a word, it enlarges the research scope for market players in China's electricity sales side on the evaluation of energy saving and emission reduction effects and it improves the totality of the existing evaluation indicator system in the electric power industry.
(2) Apply the fuzzy combination weighting method into the evaluation of energy saving and emission reduction effects for electricity retailers. The weights of indicators given by combining AHP and entropy weight method are more comprehensive, accurate, and scientific. Moreover, qualitative indicators can be reasonably quantified through the multi-level fuzzy comprehensive evaluation, which helps to provide a valid method for electricity retailers that are actively involved in the current electricity sales market in China to assess the effects. Therefore, it gives the reference point for electricity retailers in China to realize the sustainable development in the sales side effectively by means of taking timely and appropriate actions on energy saving and emission reduction, implementing the concept of low carbon electricity to improve their core competitiveness.

We will focus our future research on the following points:

(1) With the continuous improvement of China's electric power reform, energy planning and transformation, and the carbon market construction, timely interpretation of policy documents will be conducted so as to analyze the implications and impacts on energy saving and emission reduction actions of electricity retailers. Furthermore, the selection of indicators will be carried out around the latest market environment, and the existing evaluation indicator system will be improved and revised.
(2) In the future research, according to the actual operation status of electricity retailers and the availability of data, we will consider converting some qualitative indicators into quantitative ones. To improve the reliability of evaluation results, the quantification process based on the expert scoring method will be replaced by actual data.
(3) Based on the data distribution of indicators, we will study the corresponding membership function in the middle and later time of the sales market development. Then, the fuzzy evaluation value will be calculated by means of the explicit membership function and a more scientific and practical evaluation method will be realized.

Author Contributions: S.L., D.N. and L.W. were involved in the model constructing; S.L. and L.W. collected the data; S.L. and D.N. conducted the empiricial research and analyzed the data; S.L. wrote the paper; L.W. completed the typesetting and proofread.

Funding: The research is funded by [the Fundamental Research Funds for the Central Universities] grant number [2018ZD14] and [the 111 Project] grant number [B18021].

Acknowledgments: 1. The paper is supported by "the Fundamental Research Funds for the Central Universities (2018ZD14)". 2. The paper is supported by the 111 Project (B18021).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Here are explanations for some indicators:

(1) Ability to obtain allowances for the carbon market trading spreads as an agent

It refers that electricity retailers manage the carbon allowances reasonably for the power generation companies, steel and other emission control companies and help them to obtain the market quota trading spreads on the basis of fulfilling the performance. It requires experts to evaluate from several aspects, including the improvement of market awareness of the carbon market trading by acting as an agent for control emission companies, the rationality of management methods, the effectiveness of the agent in obtaining carbon emission data, etc.

(2) CCER

CCER (Chinese Certified Emission Reduction) means a voluntary emission reduction of greenhouse gas certification, derived from projects such as photovoltaic power generation, wind power and biomass power generation, etc., which are used to offset the carbon emissions of emission control companies. The CCER trading volume is usually measured in tons.

(3) A reasonable degree of electricity price setting

It also requires experts to evaluate from several aspects, including whether the price set by electricity retailers meets the needs of various users, the rationality level of guiding users to save electricity, whether the price adopts the form of diversified packages, etc.

(4) Construction scale of charging facilities for electric vehicles

It belongs to the category of energy saving, emission reduction and demand response services in integrated energy services. The electricity retailers actively participate in the investment and construction of electric vehicle charging facilities. The number of facilities operated in the target market by electricity retailers is selected as a measure.

(5) Construction level of monitoring platform for energy saving services

The construction of monitoring platform includes graphics control workstation, energy control center, energy efficiency management center, real-time data servers, relational data servers, and total control units, which requires experts to evaluate from several aspects.

(6) Ability to collect and analyze the data of smart electricity utilization

The ability depends not only on one aspect. For example, whether electricity retailers have developed a relatively complete intelligent power management system based on the Internet of Things environment, whether it can fully utilize the big data to analyze customer needs and use the results to design quality services, etc. Obviously, it requires experts to evaluate from several aspects.

(7) Energy management contract projects

It is a business operation mode in which the electricity retailers provide a set of energy saving services by signing contracts with customers and then recover investment and profits from the benefits obtained by customers after the energy saving renovation. The output value is usually measured in 10,000 yuan.

(8) Quality of energy saving and management design

The energy saving management design can cover many fields such as industry, construction, lighting, power grid, power plant and so on. The quality of design includes the energy saving technology provided by electricity retailers, the degree of integration and utilization of existing resources, the effectiveness of energy conservation, etc., which requires experts to evaluate from several aspects.

(9) Level of carbon asset management services

Carbon asset management services include carbon verification and carbon asset development. The electricity retailers assist the emission control companies in completing the greenhouse gas emission verification and develop carbon assets based on the actual gap or surplus. The assessment includes the quality of writing carbon emissions reports, the timeliness of verification work, the ability to use carbon financial instruments to achieve asset appreciation, etc., which also needs to be evaluated by experts from multiple aspects.

References

1. Liu, J.R. Analysis of Energy Saving and Emission Reduction Effects of High Voltage Frequency Conversion Technology under the Characteristics of Electric Power Production. *China Venture Cap.* **2013**, *12*, 83. [CrossRef]
2. Jiang, P.; Chen, B.; Qi, L. Analysis of Energy Saving and Emission Reduction Effect of Central Heating Supplied by Large Coal-Fired Power Unit. *Guangxi Electr. Power* **2017**, *40*, 22–24. [CrossRef]
3. Lu, M.X.; Ji, H.H.; Mo, Y.T.; Wang, Z.X. Ways to Realize Energy Saving and Emission Reduction of Power Equipment, Especially Switchgear. *Electrotech. Electr.* **2014**, *34*, 60–61. [CrossRef]
4. Luo, Y.H.; Ya, H.Q. Research and Application of Power Saving and Emission Reduction and Resource Optimization Allocation Technology. *China High Technol. Enterp.* **2013**, *31*, 70–72. [CrossRef]
5. Xu, N.Z.; Zeng, W.H. A Comprehensive Method Based on Interval-Value for Evaluation of Energy-Saving and Emission-Reducing. *Environ. Sci. Technol.* **2014**, *32*, 187–192. [CrossRef]
6. Cheng, Y.X. Research on the Effect Evaluation of Energy-Saving and Emission Reduction in Thermal Power Enterprises. Master's Thesis, North China Electric Power University, Beijing, China, 2013.
7. Cao, L.H.; Xu, J.J.; Li, Y. Evaluation on Performance of Energy-Saving and Emission Reduction in Thermal Power Plants Based on Grey Relation Method. *Environ. Eng.* **2014**, *32*, 140–143. [CrossRef]
8. Wang, H.X.; Xie, C. Analysis on Energy-Saving Emissions Effect of Biomass Power Generation. *Eng. Technol.* **2015**, *7*, 218.
9. Li, J.Y.; Zhang, H.; Cheng, Y.X. Study on Evaluation of Energy Saving and Emission Reduction Effect in Thermal Power Enterprises Based on Entropy-Weighted Extentic Model. *Heilongjiang Electr. Power* **2013**, *35*, 478–482. [CrossRef]
10. Jia, Z.Y.; Wei, Z.C. The Effect Analysis and Empirical Research of Power Enterprises in Energy Conservation. *Sci. Technol. Manag. Res.* **2014**, *34*, 229–234. [CrossRef]
11. Zhang, L. Comprehensive Evaluation of Energy Saving and Emission Reduction Performance of Thermal Power Enterprises Based on Complex System Theory. Master's Thesis, North China Electric Power University, Beijing, China, 2015.
12. Bai, J.H.; Wei, J.P.; Liu, J.X.; Xu, F.L.; Wang, H.S. Fuzzy Comprehensive Evaluation for Energy Saving and Emission Reduction of Coal-Fired Units Based on Subjective-Objective Weighting Method. *Power Equip.* **2018**, *32*, 90–93. [CrossRef]

13. Cao, L.H.; Cui, W.T.; Xu, J.J.; Li, Y. Application of Entropy-Weight-Based Fuzzy-Matter Model Element in Comprehensive Evaluation of Energy Saving and Emission Reduction in Power Plants. *Therm. Power Gener.* **2015**, *43*, 54–57. [CrossRef]
14. Ding, Y.F.; Tang, D.S.; Wang, T. Benefit Evaluation on Energy Saving and Emission Reduction of National Small Hydropower Ecological Protection Project. *Energy Procedia* **2011**, *5*, 540–544. [CrossRef]
15. Zhou, H.R. Evaluation Model and Method for Energy Saving and Emission Reduction of Regional Power Grid. *Electr. Age* **2015**, *35*, 54–57.
16. Zeng, M.; Xu, Z.Z.; Liu, X.L.; Liu, Q.Y. Power Grid Enterprise Energy Conservation and Emission Reduction Effect Analysis Model and Application—Based on Improved TOPSIS Method. *Technoeconomics Manag. Res.* **2012**, *34*, 12–16. [CrossRef]
17. Liu, Q.Y. The Study on Comprehensive Evaluation about Energy-Saving and Emission Reduction Contribution Effect of Power Grid Enterprise. Master's Thesis, North China Electric Power University, Beijing, China, 2012.
18. Wu, Y.W.; Chen, R.; Lou, S.H.; Chen, W. Fuzzy Comprehension Evaluation of Potential Energy Saving and Emission Reduction on Regional Power Grid Using Entropy Weight. *J. Huazhong Univ. Sci. Technol. Nat. Sci.* **2010**, *10*, 115–118. [CrossRef]
19. Sun, J.D.; Wang, X.D. Technology of Energy Saving and Emission Reducing in Boiler of Coal-Fired Power Plant. *Electr. Power* **2010**, *43*, 55–57. [CrossRef]
20. Wang, Y. Research on Energy Saving and Consumption Reduction Method of Steam Turbine in Coal-Fired Power Plant. *Sci. Technol. Vis.* **2015**, *34*. [CrossRef]
21. Li, S.K. Discussion on Energy Saving and Emission Reduction of Thermal Power System in Thermal Power Plant. *Low Carbon World* **2013**, *20*, 137–138.
22. Xue, S.; Wang, Z.J.; Zeng, M. Energy Saving and Emission Reduction Assessment Model for Distributed Generation and Microgrid Technology. *Huadong Electr. Power* **2013**, *41*, 694–698.
23. Song, X.H. Energy-Conservation Route of Power Generation Industry Based on Low Carbon Economy. Master's Thesis, North China Electric Power University, Beijing, China, 2012.
24. Tian, X.; Yang, S.Z.; Guo, B. Research on Energy Saving and Emission Reduction Measures for Provincial Power Grid Enterprises. *Technol. Outlook* **2015**, *3*, 68–73. [CrossRef]
25. Liang, Z.H.; Yang, K.; Sun, Y.W.; Yuan, J.H.; Zhang, H.W.; Zhang, Z.Z. Decision Support for Choice Optimal Power Generation Projects: Fuzzy Comprehensive Evaluation Model Based on the Electricity Market. *Energy Policy* **2006**, *34*, 3359–3364. [CrossRef]
26. Zhang, S.; Shi, X.Z.; Gu, D.S.; Huang, G.H. Analysis and Evaluation of Safety Management Capability in Mine Based on ISM and AHP and Fuzzy Evaluation Method. *J. Cent. South Univ.* **2011**, *42*, 2406–2416.
27. Karavas, C.; Arvanitis, K.; Papadakis, G. A Game Theory Approach to Multi-Agent Decentralized Energy Management of Autonomous Polygeneration Microgrids. *Energies* **2017**, *10*, 1756. [CrossRef]
28. Wang, M.; Niu, D.X. Research on Project Post-Evaluation of Wind Power Based on Improved ANP and Fuzzy Comprehensive Evaluation Model of Trapezoid Subordinate Function Improved by Interval Number. *Renew. Energy* **2019**, *132*, 255–265. [CrossRef]
29. Li, B. Current Status and Improvement of Energy Saving and Emission Reduction in Power Industry. *Low Carbon World* **2017**, *7*, 109–110. [CrossRef]
30. Peng, Z.L.; Zhang, A.P.; Wang, S.F.; Bai, Y. Designing Principles and Constructing Processes of the Comprehensive Evaluation Indicator System. *Sci. Res. Manag.* **2017**, *38*, 209–215. [CrossRef]
31. Li, Z.M.; Zhang, J.H.; Chen, M.J. Fuzzy Comprehensive Evaluation of Enterprise's Oderly Power Utility Based on Analytic Hierarchy Process. *Power Syst. Prot. Control* **2013**, *41*, 136–141. [CrossRef]
32. Bai, L.; Wang, H.; Shi, C.; Du, Q.; Li, Y. Assessment of SIP Buildings for Sustainable Development in Rural China Using AHP-Grey Correlation Analysis. *Int. J. Environ. Res. Public Health* **2017**, *14*, 1292. [CrossRef] [PubMed]
33. Deng, X.; Li, J.M.; Zeng, H.J.; Chen, J.Y.; Zhao, J.F. Research on Computation Methods of AHP Weight Vector and Its Applications. *Math. Pract. Theory* **2012**, *42*, 93–100. [CrossRef]
34. Cheng, X.H.; Liang, Q.L.; He, J.Q. Method for Weight Decision of WSNs Performance Index Based on Entropy Weight Method. *Transducer Microsyst. Technol.* **2013**, *32*, 44–47. [CrossRef]

35. Li, C.; Yu, C. Performance Evaluation of Public Non-Profit Hospitals Using A BP Artificial Neural Network: the Case of Hubei Province in China. *Int. J. Environ. Res. Public Health* **2013**, *10*, 3619–3633. [CrossRef] [PubMed]
36. Lu, D.D.; Song, W.H.; Zhang, G.C.; Huang, N.; Liu, P. Evaluation on Vulnerability of Hazard Bearing Body in Petrochemical Enterprises Based on AHP-Entropy Weight Method. *J. Saf. Sci. Technol.* **2015**, *11*, 180–185. [CrossRef]
37. Sun, L.; Zhang, Y.X. Fuzzy Comprehensive Evaluation on Risk of Human Resource Management Outsourcing Based on Combinational Weight. *Technol. Econ.* **2012**, *31*, 77–81. [CrossRef]
38. Dong, Y.; Fu, W.X. Application of Fuzzy Comprehensive Evaluation Method in Water Quality Evaluation of the Weihe River. *Ind. Saf. Environ. Prot.* **2015**, *41*, 17–20. [CrossRef]
39. Qin, Q.; Dai, W.; Yang, Q. Security Evaluation on Ecological System of City Based on Entropy Weight and Fuzzy Synthetic Evaluation. *J. Northwest Teach. Univ. Nat. Sci.* **2014**, *50*, 110–114. [CrossRef]
40. Miao, S.J.; Wang, Z.M.; Liu, Y.Y.; Cui, S.J.; Liang, M.C. Fuzzy Evaluation Model of Mining Methods and Its Application Based on AHP. *Min. Res. Dev.* **2017**, *25*, 66–69. [CrossRef]
41. Wang, Y.; Zhang, J.; Guo, E.; Sun, Z. Fuzzy Comprehensive Evaluation-Based Disaster Risk Assessment of Desertification in Horqin Sand Land, China. *Int. J. Environ. Res. Public Health* **2015**, *12*, 1703–1705. [CrossRef] [PubMed]