Research on assessments of Water-Energy-Food security

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Abstract. This article which is based on the analysis of the W-E-F coupling relationship constructs W-E-F security assessment index system and adopts coupling method of entropy method and analytic hierarchy process to define the weights of each index. On the basis of the index system, the article makes an assessment on the security of W-E-F system. Finally, the article takes Inner Mongolia as an example to carry out empirical research on W-E-F system security assessment. This research can provide reference for water resources, energy and food management decision-making.

Keywords: Resilience perspective; W-E-F system; security assessment; Inner Mongolia.

1. Introduction
With the development and changes of social economy, climate changes and situations at home and abroad, our country's Water, W)-Energy (E)-Food (F) are facing tremendous pressure and challenges. Water is "the source of life, the essential of production, and the foundation of ecology." A large amount of water resources are consumed in the process of energy and food production; energy is needed as support during the development and use of water resources; food is also can be converted into energy through production and processing. The three in the W-E-F system have extremely complex relationships, especially in the processes of production, consumption and management among which there existing trade-offs and potential conflicts [1]. To this end, from the perspective of different scales and considering different driving factors, this paper adopts the "pressure-state-response" model and uses the method of entropy method and analytic hierarchy process to do research on the security of water, energy and food from a collaborative perspective.

2. Water-Energy-Food security evaluation index system based on PSR
The PSR model is a "pressure-state-response" model (see Figure 1), which solves the three basic issues of sustainable development: "problems that arise, why they occur, and how to deal with them". The pressure-state-response index proposed by the PSR model compares the evaluation object with the reference standard, and conducts the evaluation by judging the security trend of the system through the comparison result. The model is mainly used in the fields of sustainable development of regional environment, WEF system security research, and various resource index systems research.

In the water-energy-food system, pressure represents the factors that threaten the security of the system, and the status indicates the current security status of the system, while response means measures to improve the security of the system.

Pressure (P) refers to the index that can lead to changes in system security, including pressure caused
by social economy and population, water consumption and energy consumption as well as pressure caused by crop production and environmental pollution. The pressure index are all negative. The greater the final weight, the less the pressure on system security. State (S) refers to the actual performance of the system under the pressure of various indicators. It is a natural state without measures to intervene, including the per capita possession of various resources, usage, and pollution. The status indicators are mostly positive indicators. The greater the calculation weight, the more the pressure on the system. Response (R) refers to a series of decisions made to intervene, improve or adapt to the status caused by pressure to achieve the purpose of preventing or improving the security state of the system, such as pollution control expenditures, scientific research expenditures, medical and health expenditures. The response indicators are all positive indicators which exert the more pressure on the system if they weigh more highly.

**Figure 1** PSR model

**Table 1** Index system

| Systematization | Index system | Unit                      |
|-----------------|--------------|---------------------------|
| Water resource  | Water production | (Ten thousand tons)       |
|                 | Water resources per capita | (Tons per person)          |
|                 | Effective irrigation area of farmland | (Thousand ha)             |
|                 | Total domestic water | (Ten thousand m³)         |
|                 | Waste water discharge | (One thousand million Nm³) |
| Energy          | Total energy consumption | (Ten thousand tons of standard coal) |
|                 | Energy consumption of industries above designated size | (Ten thousand tons of standard coal) |
|                 | Total power of agricultural machinery | (Ten thousand kilowatt) |
|                 | Rural electricity consumption | (Ten thousand kilowatts per hour) |
| Food            | Total grain output | (Ten thousand tons)       |
|                 | Gross output value of primary industry | (Billion yuan)            |
|                 | Total sown area of crops | (Thousand ha)             |
|                 | Amount of fertilizer used in farmland | (Ten thousand tons)       |
| Supplementary   | Proportion of primary industry | (%)                     |
| indicators      | Proportion of secondary industry | (%)                     |
|                 | Proportion of tertiary industry | (%)                     |
|                 | GDP | (Billion yuan)            |
|                 | Urbanization rate | (%)                     |
|                 | Natural population growth rate | (%)                     |
|                 | Forest cover rate | (%)                     |
|                 | Waste water discharge | (Ten thousand tons)       |
|                 | Exhaust emissions | (One thousand million Nm³) |
|                 | Waste discharge | (Ten thousand tons)       |
|                 | Pollution control expenditure | (Billion yuan)           |
3. Water-energy-food security assessment based on E-AHP

The analytic hierarchy process first clarifies the relationship between indicator data, and divides the indicator system into pressure indicators, status indicators and response indicators. Afterwards, it judges the importance of comparison indicators and compares all the indicators with each other to obtain a judgment matrix. The feature vector which obtained after the normalization of the judgment matrix and the normalized calculation is exactly index weight calculated by analytic hierarchy process. The entropy weight method first calculates the proportion of the indicator in each year, and then calculates the information entropy and difference coefficient of the indicator through the formula, and finally calculates the proportion of the difference coefficient of the indicator to the total, which is the weight calculated by the entropy weight method. To ensure the accuracy of the weights, the average of the weights obtained by the two methods is taken as the final weight, and the comprehensive index of the system is obtained after multiplying the weighs and the standardized index data.

4. Empirical Research

4.1 Brief introduction to the study area

Inner Mongolia Autonomous Region is a provincial-level administrative region of the People's Republic of China. Its capital is Hohhot, which is located in the north of my country. The whole area is basically a high-profile landform area, covering plateaus, mountains, hills, plains, deserts, rivers, lakes and other landforms.

The total amount of surface water resources in Inner Mongolia is about 40.6 billion cubic meters, and the total amount of groundwater resources is about 13.9 billion cubic meters. The total water resources account for 1.92% of the national water resources. The distribution of water resources in the whole region of Inner Mongolia is very uneven, and the distribution of water resources is not compatible with population gathering areas and food production areas, resulting in a small amount of water resources per capita and effective irrigation area.

Geological researchers have discovered the world's largest rare earth mine in Baotou, the Baiyun Obo Mine, in the Inner Mongolia Autonomous Region, as well as many new mineral resources. The total amount of coal resources in the entire region is roughly estimated to be about 851.88 billion tons, including the amount of resource reserves that have been verified and the amount of resources predicted which are similar in number. The proven reserves of coal resources in the region are 41.165 billion tons, accounting for 26.24% of the country's total and it is the region with the largest reserves of resources in my country.

The crops in the Inner Mongolia Autonomous Region are divided into food crops and economic crops. Food crops include wheat and rice, and economic crops include soybeans, corn, and potatoes. In 2019, the total sown area of agricultural crops in the region was about 8.886 million hectares, of which 6.828 million hectares were sown for food crops and 2.058 million hectares were sown for cash crops. As of the end of 2019, the total power of agricultural machinery in Inner Mongolia Autonomous Region was 38.599 million kilowatts.

The Inner Mongolia Autonomous Region is distributed from east to west with the Daxinganling virgin forest area and multiple secondary forest areas, as well as multiple long-term artificial forest areas. The forest land and forest area of the entire region rank first in the country. According to preliminary statistics, in 2019, the Inner Mongolia Autonomous Region completed afforestation area of 909,000 hectares, returning farmland to forest area of 27,000 hectares, and natural forest resource protection project of 58,000 hectares. At the end of the year, the forest area of the entire region was 26.149 million hectares, with a forest coverage rate of 22.1%.

4.2 Data resources

This article conducts research and discussion on the basis of several indicator data from 2010 to 2017 in parts of Inner Mongolia.

The selection of the water system security evaluation system mainly considers the production and
consumption of water resources and the degree of recycling of water resources. It selects water production, per capita water resources, domestic water consumption, effective irrigation area of farmland, and waste water discharge. Energy security evaluation indicators are mainly selected based on the direction of energy consumption and energy utilization. Through the total energy consumption, the energy consumption level, energy consumption structure and energy growth rate can be observed. Industrial development is one of the important components of urban economic development. The level of industrial development in this area can be judged by the energy consumption of industries above designated size. The increase in energy consumption of industries above designated size means the improvement of industrial level and the development of urban economy. The total power of agricultural machinery refers to the sum of various mechanical power produced during the development of the primary industry. The total power of machinery can be used to determine the level of agricultural mechanization in a certain area. The improvement of the level of mechanization increases the efficiency of human resources, which indirectly affects the output of primary industry crops and maintains the security of the water-energy-food system.

Agriculture, forestry, animal husbandry and fishery are collectively referred to as the primary industry. The development of the primary industry directly affects the country’s food security. Unstable development of these three indicators cannot be ignored. Therefore, in order to ensure the security of food production, transportation and consumption, the development of these three indicators cannot be ignored.

4.3 Construction of W-E-F index system based on PSR
This article selects indicators from three aspects: water resources, energy, and food. Most of the indicators are obtained from statistical yearbooks, relevant statistical bulletins, etc. And some indicators are selected from existing literature research results. The final statistical results of the indicator system are as follows

Table 4.1 Index system data

| Number | Index | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| A1     | Natural population growth rate(‰) | 0.0005 | 0.0006 | 0.0006 | 0.0005 | 0.0005 | 0.0005 | 0.0005 | 0.0005 |
| A2     | Total domestic water(metric tons) | 843.00 | 2080.00 | 2112.00 | 2947.00 | 2620.00 | 2921.00 | 2571.00 | 1865.00 |
| A3     | Total energy consumption (Mega joules) | 4202.73 | 3575.47 | 3199.28 | 3473.89 | 3627.56 | 3295.73 | 3390.80 | 3514.20 |
| A4     | Energy consumption of industries (Kilowatts) | 3158.50 | 3274.80 | 3395.30 | 3522.00 | 3608.80 | 3570.60 | 3931.30 | 4135.82 |
| A5     | Rural electricity consumption(Megawatts) | 4514.00 | 4595.00 | 4628.70 | 4514.80 | 4640.50 | 4816.00 | 84710.00 | 117545.00 |
| A6     | Amount of fertilizer used in farmland(Ton) | 10.10 | 10.41 | 11.30 | 10.75 | 11.63 | 12.27 | 12.53 | 14.02 |
| A7     | Waste water discharge(Metric tons) | 2201.07 | 2199.44 | 1780.41 | 2041.00 | 2387.80 | 2956.60 | 3640.60 | 3428.26 |
| A8     | Exhaust emissions(one thousand million Nm³) | 2703.89 | 3010.40 | 4199.70 | 4059.90 | 4802.00 | 4847.30 | 4905.70 | 4658.77 |
| A9     | Waste discharge(Ten thousand tons) | 2512.50 | 3486.20 | 2114.90 | 4264.90 | 5433.90 | 5753.30 | 7301.20 | 6593.30 |
| A10    | Total power output(Ten thousand kilowatts) | 141.00 | 142.50 | 145.05 | 145.05 | 149.55 | 147.00 | 147.95 | 145.30 |
| A11    | Water production(Ten thousand tons) | 2394.00 | 2878.00 | 3015.00 | 3472.00 | 3583.00 | 3774.00 | 3735.00 | 3868.00 |
| A12    | Water resources per capita(Tons per person) | 34.29 | 38.55 | 44.49 | 57.61 | 74.30 | 72.90 | 69.50 | 78.11 |
| A13    | Total sown area of crops(Ten thousand hectares) | 380.83 | 380.23 | 383.41 | 383.21 | 397.60 | 410.84 | 437.15 | 438.10 |
| A14    | Effective irrigation area(Ten thousand hectares) | 206.71 | 208.06 | 209.13 | 242.73 | 244.30 | 244.30 | 245.92 | 245.92 |
4.4 W-E-F security assessment

(1) The weights of W-E-F security assessment based on E (entropy method) are shown in Table 5:

| Number | Index                                      | 2010    | 2011    | 2012    | 2013    | 2014    | 2015    | 2016    | 2017    |
|-------|--------------------------------------------|---------|---------|---------|---------|---------|---------|---------|---------|
| A15   | Total land area(km²)                       | 195.58  | 195.58  | 195.58  | 195.58  | 196.23  | 199.42  | 199.42  | 199.42  |
| A16   | Forest cover rate(%)                       | 0.2300  | 0.2300  | 0.2506  | 0.2530  | 0.2580  | 0.2651  | 0.2670  | 0.2672  |
| A17   | Urbanization rate(%)                       | 0.7060  | 0.7160  | 0.7190  | 0.7240  | 0.7280  | 0.7330  | 0.7350  | 0.7410  |
| A18   | Afforestation area(Thousand ha)            | 60.910  | 39.400  | 76.560  | 53.830  | 67.570  | 69.990  | 68.400  | 56.7000 |
| A19   | Green coverage area(ha)                    | 4.221   | 4.525   | 4.732   | 4.822   | 4.885   | 4.920   | 4.985   | 4.9810  |
| A20   | Number of days for air quality to reach level 2 or higher | 315.00  | 320.00  | 340.00  | 329.00  | 288.00  | 302.00  | 321.00  | 312.00  |
| A21   | Research expenditures(billion yuan)         | 2.7843  | 7.1000  | 4.7956  | 3.9883  | 2.4306  | 3.7014  | 2.8042  | 2.3874  |
| A22   | Pollution control expenditure(billion yuan)| 11.703  | 8.9997  | 13.013  | 10.106  | 11.583  | 12.309  | 15.866  | 11.1918 |
| A23   | Medical and health expenditure(billion yuan)| 214.400 | 25.400  | 21.070  | 26.033  | 25.854  | 28.294  | 28.930  | 34.1809 |
| A24   | Total power of agricultural machinery(Ten thousand kilowatts) | 256.90  | 266.90  | 278.80  | 290.85  | 302.82  | 313.09  | 215.95  | 223.200 |

4.4 W-E-F security assessment

(1) The weights of W-E-F security assessment based on E (entropy method) are shown in Table 5:

| Table 4.3 Entropy weight |
|--------------------------|
| Number                   | A1  | A2  | A3  | A4  | A5  | A6  |
| Positive or negative indicators | (-) | (-) | (-) | (-) | (-) | (-) |
| Weight                    | 0.0411 | 0.0437 | 0.0215 | 0.0298 | 0.0237 | 0.0246 |
(2) W-E-F security assessment weight based on AHP
Firstly, clarify the target layer, criterion layer and indicator layer of AHP, and number each indicator, then divide the indicators into pressure indicators, status indicators and response indicators based on their correlation and role. The index hierarchy is shown in Table 6:

**Table 4.4 Indicator hierarchy**

| target layer | criterion layer | indicator layer | number |
|--------------|-----------------|-----------------|--------|
| WEF system security assessment | Pressure(P) | Natural population growth rate(‰) | A1 |
| | | Total domestic water(Ten thousand m³) | A2 |
| | | Total energy consumption (Ten thousand tons of standard coal) | A3 |
| | | Energy consumption of industries above designed size | A4 |
| | | Rural electricity consumption(Ten thousand kilowatts per hour) | A5 |
| | | Amount of fertilizer used in farmland(Ten thousand tons) | A6 |
| | | Waste water discharge(Ten thousand tons) | A7 |
| | | Exhaust emissions(one thousand million Nm³) | A8 |
| | | Waste discharge(Ten thousand tons) | A9 |
| | Status(S) | Total grain output(Ten thousand tons) | A10 |
| | | Water production(Ten thousand tons) | A11 |
| | | Water resources per capita(Tons per person) | A12 |
| | | Total sown area of crops(Thousand ha) | A13 |
| | | Effective irrigation area(Thousand ha) | A14 |
| | | Total land area(km²) | A15 |
| | | Forest cover rate(%) | A16 |
| | | Urbanization rate(%) | A17 |
| | | Afforestation area(Thousand ha) | A18 |
| | | Green coverage area(ha) | A19 |
| | | Number of days for air quality to reach level 2 or higher(Days) | A20 |
| | Response(R) | Research expenditures(Billion yuan) | A21 |
| | | Pollution control expenditure(Billion yuan) | A22 |
| | | Medical and health expenditure(Billion yuan) | A23 |
| | | Total power of agricultural machinery(Ten thousand kilowatts) | A24 |

The WEF security assessment weight based on AHP (Analytic Hierarchy Process) is shown in Table
7:

Table 4.5 AHP weight

| Number | A1   | A2   | A3   | A4   | A5   | A6   |
|--------|------|------|------|------|------|------|
| Weight | 0.0645 | 0.0528 | 0.0163 | 0.0191 | 0.0163 | 0.0170 |
| Number | A7   | A8   | A9   | A10  | A11  | A12  |
| Weight | 0.0340 | 0.0825 | 0.0586 | 0.0339 | 0.019 | 0.0372 |
| Number | A13  | A14  | A15  | A16  | A17  | A18  |
| Weight | 0.1041 | 0.0556 | 0.1182 | 0.0441 | 0.0305 | 0.0171 |
| Number | A19  | A20  | A21  | A22  | A23  | A24  |
| Weight | 0.0191 | 0.0175 | 0.0629 | 0.0297 | 0.0186 | 0.0310 |

(3) W-E-F security assessment weight based on E-AHP

In order to eliminate the influence of other factors on the weight, the weight calculated by the two methods is finally added and divided by two to obtain the average weight as shown in Table 8.

Table 4.6 Weight determination

| Index  | A1   | A2   | A3   | A4   | A5   | A6   | A7   | A8   |
|--------|------|------|------|------|------|------|------|------|
| AHP weight | 0.0645 | 0.0528 | 0.0163 | 0.0191 | 0.0163 | 0.0170 | 0.0340 | 0.0825 |
| Entropy weight | 0.0411 | 0.0437 | 0.0215 | 0.0298 | 0.0237 | 0.0246 | 0.0335 | 0.0757 |
| Final weight | 0.0528 | 0.0483 | 0.0189 | 0.0244 | 0.0200 | 0.0208 | 0.0337 | 0.0791 |
| Index  | A9   | A10  | A11  | A12  | A13  | A14  | A15  | A16  |
| AHP weight | 0.0586 | 0.0339 | 0.0190 | 0.0372 | 0.1042 | 0.0556 | 0.1182 | 0.0441 |
| Entropy weight | 0.0444 | 0.0391 | 0.0258 | 0.0396 | 0.0844 | 0.0522 | 0.1093 | 0.0413 |
| Final weight | 0.0515 | 0.0365 | 0.0224 | 0.0384 | 0.0943 | 0.0539 | 0.1138 | 0.0427 |
| Index  | A17  | A18  | A19  | A20  | A21  | A22  | A23  | A24  |
| AHP weight | 0.0305 | 0.0171 | 0.0191 | 0.0175 | 0.0629 | 0.0297 | 0.0186 | 0.0310 |
| Entropy weight | 0.0344 | 0.0235 | 0.0284 | 0.0262 | 0.0625 | 0.0352 | 0.0257 | 0.0347 |
| Final weight | 0.0325 | 0.0203 | 0.0237 | 0.0218 | 0.0627 | 0.0325 | 0.0222 | 0.0329 |

(4) W-E-F security assessment based on E-AHP

The W-E-F system comprehensive index is obtained by multiplying the weights by the standardized data and summing them annually. The resulting comprehensive index is shown in Table 9:

Table 4.7 composite index

| Year   | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|--------|------|------|------|------|------|------|------|------|
| Composite index | 0.3390 | 0.3660 | 0.3883 | 0.3971 | 0.4124 | 0.4493 | 0.4513 | 0.4605 |

In order to more intuitively display the water-energy-food system security in Inner Mongolia, the comprehensive index is displayed in the form of icons, as shown in Figure 2:
This paper uses the comprehensive evaluation method to evaluate the security of the water resources-energy-food system in Inner Mongolia, studies the pressure in the system, the status quo of system resources and the response, and obtains the final comprehensive index. On the whole, the comprehensive index of water resources-energy-food system in Inner Mongolia continued to rise from 2010 to 2017, and the comprehensive index rose steadily from 2010 to 2012. The increase was small from 2012 to 2014, and the comprehensive index rose from 2014 to 2015 quickly, and then flattened out.

5. Main conclusions and recommendations
Inner Mongolia is a large resource province in my country and an important energy production area in my country. Coal has been used as the main energy source for a long time, and the development of renewable energy such as wind, water and solar energy is relatively low. Obtaining energy from coal has serious damage to water resources and the environment. At the same time, the lack of water resources in Inner Mongolia has brought certain resistance to energy acquisition. Therefore, in order to protect environmental security and water resources security, vigorously promote the implementation of green and clean energy. Efficient development and use, pollution control and recycling of water resources are essential.

(1) Leading green development
Promoting the development of green and low-carbon recycling industries is of vital importance to the environment and system security. In order to reduce the pressure on the social environment and the water-energy-food system caused by energy, it is necessary to accelerate the construction of a green industry system, increase the utilization of renewable energy, and increase Support for large-scale clean energy development research. At the same time, it is also necessary to solve the pollution problem in development. The pressure on the system caused by water pollution and environmental pollution cannot be underestimated. Improve water resources pollution supervision and governance through relevant policies, achieve efficient water recycling, and reduce the pressure on the system and the environment caused by pollution.

(2) Improve natural resource management and utilization efficiency
The efficiency of management and utilization of natural resources affects system security to a large extent. Ensuring the safe and stable production of food, the transformation of energy structure, and the implementation of water resources protection systems are all beneficial to protecting system security. In terms of food security, maintain the stability of food production, improve the level of food security, implement food production policies, and formulate food security protection measures based on the actual situation in Inner Mongolia. In terms of energy structure, accelerate the development and utilization of green and clean energy, and change the current situation of coal as the main source of energy in Inner Mongolia as soon as possible. In terms of water resources protection, strictly supervise and control waste
water discharge, improve waste water purification, realize the recycling of water resources, increase water resources production, and try to avoid water loss.

(3) Promote data information exchange and cross-departmental cooperation

Water resources, energy, and food are managed by multiple departments. In order to promote collaborative management, various departments should communicate more and consider the linkage factors between the three in terms of governance, and they are not encouraged to sweep their doors. In terms of academic research, diversified research is needed to gradually study the complicated relationship between the three, so as to pave the way for alleviating system pressure and maintaining the safe development of the system.

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