Exploring Critical Factors Influencing Green Development of the Power Grid Based on DEMATEL-ISM Model

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Abstract. Under the background of the Paris Agreement and Energy Revolution, the power grid, as a hub of energy supply, needs to explore the influencing factors of the green development to clear the development path. By analysing the framework of green power grid development, a three-level power grid green development indicator system including the power grid coordination upstream and downstream and the life cycle of power grid construction is constructed. The DEMATEL-ISM integration method was used to analyse the structure of the first-level indicators. Then, the results were analysed from three aspects: deep-rooted influencing factors, middle-level indirect influencing factors and surface-level direct influencing factors. The research results show that 22 influencing factors are interrelated, forming a hierarchical structure with 6 levels of influencing factors, of which 7 indicators are key factors. The study clarifies the impact of the power grid as a configuration and trading platform on the ecological environment, and provides an implementation path for the green development of the power grid to promote the coordinated of the power grid and the environment.

1. Introduction

Due to the global energy transition, sustainable development of electricity has become the common orientation of energy strategy adjustment in most countries. At present, the power industry in various countries is facing a grim situation. On the one hand, it undertakes the dual tasks of stock optimization and continuous growth [1]; on the other hand, it faces the dual pressures of environmental pollution control and climate change [2]. The power grid is the link of power transmission. How to coordinate with the ecological environment has become a key issue to achieve its green development. Therefore, we need to comprehensively consider various factors such as environmental policies, power system revolutions, and the application of new technologies. The key factors and paths to maximize the environmental benefits of the power grid itself and the coordination of upstream and downstream should be studied.

The current research on the green development of power is mainly carried out from the supply side, the grid side and the demand side. From the supply side, Dai [3] used a general equilibrium model to evaluate the economic impact and environmental benefits of large-scale renewable energy power generation in China in 2050, focusing on the impact of renewable energy on green power development. From the power grid side, Lopes, JPA [4] identified the influencing factors of the
Portuguese power system’s impact on environmental benefits, and pointed out that technological upgrading is an important factor to improve the environmental benefits of the power grid. From the demand side, Bae [5] studies factors that can increase consumers’ participation in green power pricing plans, and considers monetary and non-monetary incentives as factors that affect green pricing plans. Most of the literature only explores the green development of power from the supply side and the demand side, or the research only focuses on the impact of the power grid construction process on the ecological environment. At present, there is no comprehensive study system for the impact of the power grid on the ecological environment in the supply side, the power grid side and the demand side.

We explores critical factors influencing green development of the power grid from the supply side, the power grid side and the demand side based on DEMATEL-ISM model. The innovation of the study is that we not only evaluate the impact of the power grid construction on the environment during the life cycle, but also cooperates with the upstream and downstream to explore the role of the power grid to promote the sustainable development of energy. It is more comprehensive than existing study. On the other hand, we combined the advantages of the DEMATEL and ISM models to clarify the key factors and paths of the power grid green development, which clarified the focus of the power grid green development for the power grid enterprises.

2. The Role Framework of Green Power Grid Development
Under the influence of external ecosystems and social requirements, the effect of the power grid on the ecological environment is mainly reflected in three aspects [6-8]. First, the power grid guides the upstream to promote the green development of the power supply structure. Second, the planning, construction and operation of the power grid itself have an impact on the ecological environment. Third, the grid cooperates with the downstream to promote green development on the energy consumption side.

In summary, the green development of the power grid is to achieve the unification of economic and ecological benefits from the efficient use of energy, low waste emissions, and the rational use of natural resources. The function framework of green power grid development is shown in figure 1.

![Figure 1. The framework of the green development of the power grid.](image)

3. Influencing Factors System for Green Development of Power Grid
Studying the green development of the power grid is to solve the contradiction between the power grid, the environment and resources to achieve sustainable development. Therefore, to explore the influencing factors of the power grid, we must study the disturbance effect of the power grid system
on the ecosystem. We use the Sensitivity-Response capacity proposed by Gallopin [9] as the evaluation framework for the green development of the power grid. Then, 22 first-level indicators are summarized, as shown in Table 1.

Table 1. Influencing factors system for green development of power grid.

| First-level                          | Second-level                      | Number | Explanation                                                                                                                                 |
|-------------------------------------|-----------------------------------|--------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Energy consumption intensity        |                                   | $\alpha_1$ | The energy consumption per unit of power generation                                                                                      |
| Atmospheric pollution               |                                   | $\alpha_2$ | The emission of CO$_2$, NO$_x$, SO$_2$ and soot during power generation                                                                    |
| Water pollution                     |                                   | $\alpha_3$ | The emissions of wastewater, chemical oxygen demand and ammonia nitrogen during power generation                                           |
| Environmental governance            |                                   | $\alpha_4$ | The environmental governance measures during power generation, such as environmental protection investment, waste disposal capacity, etc. |
| Cleanliness of power generation     |                                   | $\alpha_5$ | The proportion of clean energy in local and external power supply                                                                       |
| Land resource utilization           |                                   | $\alpha_6$ | The impact of transmission lines on the land, such as the area occupied, the amount of earthwork excavated and the amount of water and soil loss. |
| Ecological diversity disturbance    |                                   | $\alpha_7$ | The impact of transmission lines on biodiversity, such as reduction rate of plant cover, extinction rate of animals and plants, animal migration rate, proximity of lines to ecologically sensitive areas, etc. |
| Landscape damage                    |                                   | $\alpha_8$ | The impact of transmission lines on the landscape, such as the area of the grid crossing the scenic spot, the devaluation of cultural value, and the coordination with the urban landscape, etc. |
| Water environment disturbance       |                                   | $\alpha_9$ | The Oil leakage and COD concentration during construction and operation of substations                                                     |
| Atmospheric disturbance             |                                   | $\alpha_{10}$ | The SF$_6$ leakage and SF$_6$ recovery rate during construction and operation of substations                                               |
| Electromagnetic interference        |                                   | $\alpha_{11}$ | The area of the electromagnetic over-range within the power grid and the strength of the electromagnetic field near the substation.          |
| Radio interference                  |                                   | $\alpha_{12}$ | The area of radio interference within the range of the power grid exceeds the standard, and the range of radio interference near the substation. |
| Solid waste discharge               |                                   | $\alpha_{13}$ | The total amount of garbage discarded by the substation and the pollutant treatment                                                        |
rate.
Discharge of hazardous waste such as transformer oil.
UHV, energy storage, microgrid and new energy flexible connection to the grid
Electricity replaces coal, oil and natural gas, and ultimately accounts for the proportion of total energy consumption
Refers to the long-distance transmission capacity and line loss rate
Refers to the intelligent substation capacity and intelligent dispatch center
The stability of power supply, which can be measured by the number of power outage hours.
The popularity of smart meters, charging piles, and electricity information collection systems.
The ratio of peak and frequency modulation capacity of energy storage on the grid side to the total capacity
The ability to reduce grid load pressure and save resources through demand-side management.

4. Influencing Factors Structure Model Based on DEMATEL-ISM
There are many factors that affect the power grid green development, and the relationship between them is complex. Therefore, we use the advantages of the DEMATEL method in distinguishing the attributes, importance and influence relationships of factors, and use the ISM to stratify each factor. Finally, the framework of power grid and ecological environment impact structure is constructed. The specific analysis process is shown in figure 2.

![Figure 2. DEMATEL-ISM model framework.](image-url)
4.1. Establish the Direct Influence Matrix [21]

The system of factors influencing the power grid green development is divided into six sub-categories with a total of 22 factors. The set of indicators is \( A = \{ \alpha_1, \alpha_2, \alpha_3 \ldots \alpha_{22} \} \). The interaction between factors is recorded as \( \beta_{ij} \), and experts including college teachers and State Grid personnel are invited to assign values to \( \beta_{ij} \) based on the interaction between factor.

The direct influence matrix is normalized, and the normalized matrix \( C \) is obtained as,
\[
C = \left( C_{ij} \right)_{22 \times 22} = \frac{1}{\max_{1 \leq i \leq 22} \sum_{j=1}^{22} \beta_{ij}} X
\]

4.2. Calculate Comprehensive Influence Matrix, the Center Degree and the Cause Degree [21]

Calculate the comprehensive influence matrix \( T \) of the index to determine the comprehensive influence of each index comparing to the highest-level factors in the index system. The formula is as follows,
\[
T = C (I - C)^{-1}
\]
where \( I \) is the identity matrix, and MATLAB is used to calculate the comprehensive influence matrix \( T \).

Use the following formula to calculate the center degree \( M_i \) and the cause degree \( N_i \) of each factors:
\[
f_i = \sum_{j=1}^{22} t_{ij}, \quad i = 1, 2, \ldots, 22
\]
\[
e_i = \sum_{j=1}^{22} t_{ji}, \quad i = 1, 2, \ldots, 22
\]
\[
M_i = f_i + e_i, \quad i = 1, 2, \ldots, 22
\]
\[
N_i = f_i - e_i, \quad i = 1, 2, \ldots, 22
\]
where \( t_{ij} \) is the comprehensive influence matrix; \( f_i \) is the influencing degree of the factor \( \alpha_i \); \( e_i \) is the influenced degree of the index \( \alpha_j \). \( M_i \) is the center degree, which is used to indicate the importance of the factors. The greater the center degree, the greater the importance of the factors; \( N_i \) is the cause degree used to indicate the role of the indicator in the system. The greater the cause degree, the greater the role of the factors.

4.3. Calculate the Total Relation Matrix and Reachability Matrix [22]

The calculation formula of the total relation matrix \( H \) is
\[
H = I + T
\]
According to the total relation matrix \( H \), the reachability matrix \( K \) is calculated as follows, where \( \lambda \) is the threshold,
\[
K_{ij} = \begin{cases} 
1, h_{ij} \geq \lambda(i, j = 1, 2, \ldots, 22) \\
0, h_{ij} < \lambda(i, j = 1, 2, \ldots, 22)
\end{cases}
\]
According to historical documents and related materials, \( \lambda = 0.08 \) is given.

4.4. Establish Multi-level Hierarchical Structure Model [22]

According to the reachability matrix \( K \), the reachability set \( R_i \) and the previous set \( S_i \) of factors can be determined:
\[
R_i = \{ \alpha_i | \alpha_i \in A, k_{ij} = 1 \} \quad (i, j = 1, 2, \ldots, 22)
\]
\[
S_i = \{ \alpha_i | \alpha_i \in A, k_{ji} = 1 \}
\]
Based on the condition of $R_i = R_i \cap S_i$, the influencing factors in the reachability matrix are cyclically layered. Six levels can be obtained: $L_1 = \{\alpha_7, \alpha_8, \alpha_{11}, \alpha_{12}, \alpha_{21}, \alpha_{22}\}$; $L_2 = \{\alpha_6, \alpha_9, \alpha_{10}\}$; $L_3 = \{\alpha_{13}, \alpha_{14}, \alpha_{16}, \alpha_{17}\}$; $L_4 = \{\alpha_2, \alpha_3, \alpha_{20}\}$; $L_5 = \{\alpha_1, \alpha_4, \alpha_{18}, \alpha_{19}\}$; $L_6 = \{\alpha_5, \alpha_{15}\}$.

5. Results

5.1. The Importance of Factors Influencing the Green Development of the Power Grid

Through the DEMATEL-ISM model, the centrality and cause of various factors are obtained, and the factors with larger centrality and cause are regarded as key factors. The key factors not only play an important role in the green development of the power grid, but also affect other factors in the system. We draw the distribution of factor importance with the centre degree as the abscissa and the reason degree as the ordinate, as shown in figure 3.

Figure 3. Causality diagram of factors influencing green development of power grid.

Energy consumption intensity ($\alpha_1$), Cleanliness of power generation ($\alpha_5$), Energy interconnection ($\alpha_{15}$), Electricity substitution ($\alpha_{16}$), Grid transmission capacity ($\alpha_{17}$), Grid intelligence level ($\alpha_{18}$) and Grid security ($\alpha_{19}$) are key factors in the system, which determine the security, intelligence, and cleanliness of power grid development. Therefore, to achieve the power grid green development, the control of these key factors should be the focus of work.

5.2. System Multi-level Hierarchical Structure Analysis

The hierarchical structure of the power grid green development is obtained by the DEMATEL-ISM method. The structure is divided into six layers, as shown in figure 4. The hierarchical structure reflects the role of various factors in the power grid green development, which can be divided into deep-rooted influencing factors, middle-level indirect influencing factors and surface-level direct influencing factors.

(1) Surface-level direct influencing factors

According to the DEMATEL-ISM, the surface-level direct influencing factors can be divided into two aspects, the level of grid service interaction and the impact of the grid on the environment.

The level of grid service and interaction is influenced by the two factors of Electricity substitution ($\alpha_{16}$) and Grid transmission capacity ($\alpha_{17}$) in the fourth layer. Therefore, on the one hand, it is necessary to improve the auxiliary service level of the grid based on a high proportion of electricity substitution and a high level of grid transmission capacity. Firstly, part of the pumped storage power station, chemical energy storage and thermal power are replaced by grid-side energy storage peak and frequency modulation. Secondly, new market entities such as renewable energy units, electricity storage facilities, electricity sales companies, and electricity users can be guided through the power grid to participate in the auxiliary service market. Finally, it is necessary to promote the friendly
interaction between the grid and users, and support the demand-side smart terminals to participate in the power grid.

The influence of the power grid on the environment is mainly affected by the factors of the fourth layer, and there is a loop relationship in the same layer. First, grid planning should consider factors such as regional endowment, load demand and spatial planning, and reasonably avoid the ecological protection red line. In the construction of the power grid, new technologies such as multi-circuit design on the same tower and oil-water separation device are used to reduce the damage to the ecological environment along the transmission line. In addition, the waste pollution should be controlled in a lower range during construction.

Figure 4. Hierarchical structure of influencing factors of the power grid green development.

(2) Middle-level indirect influencing factors
The indirect influencing factors can be divided into three routes for analysis.

(a) The first route is to consider the impact on the service of the demand-side under the premise of safe and reliable power grid, which in turn affects the grid transmission capacity and electricity substitution. First, it is necessary to promote the intelligence of the grid and accelerate the development of new technologies such as smart substations, distribution automation, and dispatch intelligence. Secondly, it is necessary to improve the safety of the power grid and form an integrated green power grid with resilience and self-healing capabilities against natural disasters and major threats. Finally, promote the development of services such as demand-side distributed energy, electric vehicle charging and replacement facilities.

(b) The second route is the impact of the supply side on the ecological environment under the influence of two factors: Energy consumption intensity (α₁) and Environmental governance (α₄), which in turn affects Electricity substitution (α₁₆). When ensuring the reliable supply of electricity, priority is given to the scheduling of renewable energy, sorted according to their energy consumption and pollutant emissions from low to high, to maximize energy saving and emission reduction. At the same time, it is necessary to control wind abandonment, light abandonment and water abandonment in the process of power generation dispatch.

(c) The third route is the effect of Solid waste discharge (α₁₃) and Hazardous waste discharge (α₁₄) in the construction of the power grid on the surface-level direct influencing factors. For solid
waste treatment, an identification-recycling-valuation-auction system can be established to implement quality control throughout the process. For hazardous waste, a dedicated storage place should be set up, and preventive measures, emergency plans, and centralized recovery mechanisms should be formulated.

(3) Deep-rooted influencing factors

According to the structure diagram, deep-rooted influencing factors include Cleanliness of power generation ($\alpha_5$) and Energy interconnection ($\alpha_{15}$). Both factors have an impact on Energy consumption intensity, Grid intelligence and Grid security. Cleanliness of power generation ($\alpha_5$) and Energy interconnection ($\alpha_{15}$) have influence on other factors in the system from two aspects of clean energy power generation and clean energy accommodation. Therefore, we can propose some measures for the green development of the power grid from the supply side and the demand side:

(a) To promote the green development of the power grid from the roots, the leading role of the power grid in the power generation process must be strengthened to increase the proportion of clean energy. The widely interconnected UHV power grid is used as the backbone grid to promote “Power-Network-Load-Storage” interaction and improve the utilization of intermittent power sources, to adapt to large-scale access to new energy such as wind power and photovoltaics.

(b) Promoting energy interconnection and clean energy consumption is another important measure to promote the green development of the grid. It is necessary to give full play to the role of the power grid in resource allocation and trading platforms. Increasing the access ratio of microgrid, energy storage and new energy can promote the optimal configuration of energy concentration and decentralization, thus promoting the deep substitution of electric energy.

6. Conclusion

The green development of the power industry has become an important way to alleviate environmental pollution and promote resource conservation. Based on the Paris Agreement, the energy revolution and other backgrounds, we have established a framework and influencing factor system for the green development of the power grid. Combining the advantages of the DEMATEL and ISM models, the DEMATEL-ISM model is established to identify the key factors for the green development of the power grid. By dividing deep-rooted influencing factors, middle-level indirect influencing factors and surface-level direct influencing factors, the path of green development of the power grid is analysed, and policy recommendations are proposed.

Through the analysis of the influencing factors of the green development of the power grid, power grid companies can clarify the focus of power grid development and achieve the coordination and unification of the power grid and the ecological environment. We have studied the key influencing factors and paths of the green development of the power grid. In the future, we will establish an index system based on important influencing factors, evaluate the green development of the power grid, and make further suggestions.

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