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Influencing Factors and Their Influencing Mechanisms on Integrated Power and Gas System Coupling

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Abstract: In order to study the deep mechanism of integrated power–gas system (IPGS) coupling, the influencing factors of IPGS coupling are investigated using the Decision Making Test and Evaluation Test–Interpretative Structural Modeling–Method-Cross-Impact Matrix Multiplication Method (DEMATEL-ISM-MACMIC). By means of a literature review and field research, on the basis of summarizing and forming an index system of IPGS coupling influence factors, this study establishes an IPGS coupling influence factor model based on the DEMATEL-ISM-MACMIC method, analyzes the attribute characteristics of each factor influencing IPGS coupling and extracts the key elements, explores the logical relationships among the factors, and finally, puts forward relevant suggestions, in order to provide theoretical and methodological support for this field of research. This study shows that the economic base, resource endowment, and economic and social development of the country are the most important factors. The study shows that the bottom-level factors, such as economic base and resource endowment; the middle-level factors, such as energy structure and market mechanism; and the surface-level factors, such as technology level and market price, are important factors influencing IPGS coupling, and the focus should be on the above factors.

Keywords: integrated power–gas systems (IPGS); influence relationships; hierarchical structure; Decision Making Test and Evaluation Test Method (DEMATEL); Interpretative Structural Modeling Method (ISM); Cross-Impact Matrix Multiplication Method (MACMIC)

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1. Introduction

The vigorous development of wind power generation, photovoltaic power generation, and other clean renewable energy sources is an essential countermeasure to address the fossil energy crisis and environmental degradation. However, renewable energy generation, like wind and photovoltaic power, is volatile, random, and intermittent in nature. The continuous expansion of its installation capacity and large-scale integration into the power grid bring new challenges to ensuring stable grid operation and safe scheduling. The problems of wind and light abandonment are particularly prominent, which significantly hinder the large-scale application of new energy generation.

Natural gas, as the cleanest fossil energy source, is often considered a "bridge" for transitioning from fossil fuels to new energy sources. With advancements in technology, its role in the energy balance is increasing. Gas turbines have fast start/stop and load regulation features, making them complementary systems with renewable energy generators that can compensate for fluctuations in output, leading to more stable power system output. Power-to-gas (P2G) can convert power system energy into natural gas, indirectly achieving large-scale and long-term storage of electrical energy, expanding the idea of renewable energy consumption. P2G can solve the problem of volatility when generating electricity from renewable energy sources, avoid carbon emissions from traditional coal-fired and other power generation methods, and provide a viable solution for the transition to a future sustainable low-carbon energy system [1]. However, P2G still has some drawbacks, such as its economic and environmental costs due to energy conversion losses, gas handling and storage, and carbon emissions [2]. Currently, the energy conversion efficiency is 33.21% for gas-fired power generation, 56.98% for combined cycle power plants, and 62.47% for P2G [3]. Gas-fired power generation and P2G enable the mutual conversion of electricity and natural gas, forming a two-way energy flow and strengthening the interaction between energy resources. This helps with the mutual integration of multi-energy systems and rapid development of the energy internet, allowing energy to cross temporal and spatial scales for high-speed conduction and collaborative optimization.

Therefore, against the backdrop of the increasing installation of renewable energy, this paper establishes an index system for IPGS coupling's influencing factors through a literature review and expert evaluation. The Decision Making Test and Evaluation Test–Interpretative Structural Modeling–Cross-Impact Matrix Multiplication Method (DEMATEL-ISM-MACMIC) is adopted to analyze the factors affecting IPGS coupling, determine the importance and causal relationships of each influencing factor, and establish a hierarchical structure model for complex system coupling. This enables the identification of the main paths affecting IPGS coupling. Finally, based on the research findings, relevant suggestions for improving IPGS coupling are proposed, with a view to providing a theoretical basis and methodological support for electric power enterprises, natural gas enterprises, and governmental departments to carry out IPGS coupling work.

2. Literature Review

Natural gas is increasingly becoming the preferred fuel for new generators in power systems due to the significant decline in natural gas prices and the clear benefits of small capital costs, high efficiency, fast response time, and low carbon emissions from gas-fired generating units [4]. Compared to traditional power systems, the new generation of energy systems with the grid as the core is closely linked to both the power and natural gas networks via gas turbines. Gas turbines are an important component that boasts fast start/stop and load regulation capabilities. They can form complementary systems with renewable energy generators to compensate for fluctuations in the outputs from these plants, resulting in more stable power output across the entire system [5]. During periods of low load or peak renewable energy output, power-to-gas (P2G) can electrolyze surplus electricity to generate hydrogen, which can then be used to make methane through a methanation reaction using water or atmospheric CO_2, which is stored in a natural gas pipeline network or storage facility. When there is a shortage of electricity, the stored natural gas is converted back into electricity or heat to supply customers [6,7]. Further, a German scholar by the name of Sterner named the method of converting power into liquids, power into chemicals, etc., "Power-to-X" [8]. The P2G synthesis of natural gas enhances the coupling relationships in Integrated Power and Gas Systems (IPGS) and promotes the stability of the energy supply in multi-energy systems.

Power and natural gas systems are closely linked, and research on IPGS coupling is receiving increasing attention [9]. The operational management of IPGS is subject to great challenges due to the uncertainty of energy loads and renewable energy generation, and the authors of [10–13] further investigates the coordinated operation of IPGS under significant uncertainties. One author examines the impact of integrated gas and electricity demand response on energy market clearing, as well as regional marginal prices [11]. The study proposes a distributed robust dispatch model to mitigate potential transmission congestion. Mirzaei proposed a novel hybrid decision theory, called the Information Gap Decision Theory (IGDT), which aims to minimize the total operating cost of wind power penetration by taking into account the uncertainties associated with power load demand and wind power output [12]. Zhang proposed a day-ahead Integrated Energy System (IES) optimal scheduling method considering P2G units and a dynamic pipe network to adapt IPGS scheduling to the anti-peak regulation of wind power generation [13].

Inadequate gas supply to the gas network can cause multiple gas units to shut down, while a safety violation in transmission lines may lead to shutdowns of multiple gas compression stations. Optimizing electric and gas systems to form an Integrated Power and Gas System (IPGS) can result in the safer and more economical operation of both systems due to their interdependence. The authors of [14–16] further investigate the reliability of IPGS under deterministic settings around the safe operation of IPGS. One author proposes a safety-constrained unit commitment model that enhances the operational reliability of IPGS in transmission lines, while mitigating the risks associated with sudden changes in real-time gas demand [14]. Zeng developed a detailed model of IPGS considering electric–gas devices and gas storage reservoirs, and evaluated the reliability of IPGS using the sequential Monte Carlo (SMC) simulation method [15]. Sawas proposed a cyber-attack-resistant joint scheduling model for P2G and gas-fired generation plants, which uses the operation of IPGS integrated systems that cannot be detected via conventional methods during cyber-attacks [16].

To further advance the integration of IPGS, the authors of [17–20] investigated the economics of IPGS in the overall market environment. Real-time pricing and subsidy mechanisms have emerged as effective options for energy system management, unlike control centers that directly control energy production or consumption. These mechanisms can effectively stimulate energy production and consumption, which aligns with IPGS's goal of overall efficiency [18]. Shu proposes an effective pricing mechanism that utilizes P2G and gas-fired units to enhance the synergies between electric and gas systems [19]. This mechanism aims to alleviate problems such as wind abandonment, network congestion, and load undersupply. Chen proposed an independent yet interrelated day-ahead operational equilibrium model for IPGS [20]. Their study found that precise information exchange between the two systems is essential for coordinated system operation.

Overall, the interactive impacts of IPGS are characterized by the interdependence and supply/demand balance of power and gas supply and consumption, and the mutual reinforcement and cross-influence of power and gas market prices and policies [21].

3. Influencing Factors of IPGS Coupling

Based on a literature analysis, this study collates, summarizes, and counts the influencing factors of Integrated Power and Gas System (IPGS) coupling by soliciting the opinions of experts and practitioners who have been engaged in related fields (electricity and natural gas fields) for many years and combining the actual situation of IPGS coupling, and finally, forms an IPGS coupling influencing factor index system containing 16 indicators in 4 dimensions (Table 1).

Table 1. Indicator system of influencing factors of power–gas system coupling.

Dimension	Influencing Factors	References
Background Factors	Economic Foundation (S1)	EC
	Resource Endowment (S2)	EC
	Energy Structure (S3)	EC
	Infrastructure (S4)	He [22]
System Factors	Gas–Electricity Property (S5)	Shu [19]; Rad [23]
	Technology Level (S6)	AlHajri [24]
	System Capability (S7)	Zeng [15]; Lv [25]
	System Function (S8)	Sawas [16]
Market Factors	Market Mechanism (S9)	Wang [18]; Shu [19]
	Supply–Demand Situation (S10)	Mirzaei [12]
	Market Competition (S11)	Red [23]
	Market Price (S12)	Shu [19]; Rad [23]
Society Factors	Policy System (S13)	Maroufmashat [26]
	Strategy Planning (S14)	Xiang [27]
	Investment Development (S15)	Odetayo [28]
	Environmental Awareness (S16)	EC

Note: EC means expert consultation.

3.1. Background Factors

Four background factors, namely, economic foundation, resource endowment, energy structure, and infrastructure, are significant factors that affect the coupling of IPGS. Economic foundation affects the construction and operational costs of IPGS. Differences in resource endowments across various regions have a considerable impact on IPGS coupling. Regions with abundant natural gas resources tend to use natural gas for power generation. The energy structure's influence on IPGS coupling is mainly reflected in system planning and development. Finally, infrastructure development level and layout affect system size and efficiency.

3.2. System Factors

Four system factors, namely, gas–electricity property, technology level, system capability, and system function, are significant factors that affect the coupling of IPGS. The gas–electricity property impacts the operation mode and optimization effect of an IPGS. The technology level's impact on IPGS coupling mainly lies in system efficiency, reliability, and safety. The system capacity can directly influence the operational status and emergency response of an IPGS. Finally, the system function determines the role and effectiveness of IPGS in meeting energy demand and providing services.

3.3. Market Factors

Four market factors, namely, market mechanism, supply–demand situation, market competition, and market price, are essential influences on the coupling of IPGS. The impact of the market mechanism on IPGS coupling is mainly reflected in aspects such as market competition and investment decisions. The supply–demand situation directly affects the operating status and supply capacity of IPGS. Market competition can affect the price formation and market share of IPGS, having an impact on the system's rate and quality of development. Market price directly affects the production costs, supply-and-demand balance, investment decisions, and sustainable development of IPGS.

3.4. Social Factors

Four societal factors, namely, policy system, strategy planning, investment development, and environmental awareness, are significant factors that influence the coupling of IPGS. The impact of the policy system on IPGS coupling is mainly reflected in policy support and management regulation. The influence of strategy planning on IPGS coupling is mainly reflected in the investment scale and market expansion. The impact of investment development on IPGS coupling is mainly reflected in the construction speed and technology level aspects. The impact of environmental awareness on IPGS coupling is mainly reflected in market demand and policy support.

4. Methodology

4.1. DEMATEL

The Decision Making Test and Evaluation Test Method (DEMATEL) is a quantitative research method used to analyze the interactions between factors in complex systems, identify the core influencing factors of the system, and simplify the system structure, and it is widely used to identify the influencing factors in various systems [29]. In this paper, DEMATEL is introduced to determine the degree of influence among the influencing factors of Integrated Power and Gas System (IPGS) coupling, and the key influencing factors among them are identified.

4.2. ISM

The Interpretative Structural Modeling Method (ISM) is a structural modeling technique, an analytical method that identifies the interrelationships between factors and establishes a hierarchical structural model of the system through logical structural matrix operations. This paper further introduces the ISM to decompose the complex system into a multilevel recursive structural form, thus facilitating the mining of the internal structure of the system [30].

4.3. MICMAC

The Impact Matrix Multiplication Method (MICMAC) is a method used to analyze the logical relationships and characteristics among factors based on the reaction paths and hierarchical cycles of the system elements. In this paper, MICMAC is combined with the DEMATEL-ISM method to classify the influencing factors into four categories of elements (spontaneous, dependent, linked, and independent), which makes the role relationship between factors clearer for understanding the substantial roles of factors in the system.

The DEMATEL-ISM-MACMIC method, which combines the three above methods, can achieve complementary advantages, both in clarifying the importance and causal nature of each factor of the system, and in deepening the understanding of the logical relationships and hierarchical structure among the factors. Currently, the DEMATEL-ISM-MICMAC method has been applied in several fields such as manufacturing [31], agriculture [32], and energy [33], and its advantages have been well demonstrated. For example, Bai used the hybrid approach of gray DEMATEL-ISM-MICMAC to determine the relationships and roles of the influencing factors in the manufacturing sector under conditions of uncertainty [31]. Using the DEMATEL-ISM-MICMAC method, Narwane discovered the interrelationships between the challenges in the sustainable development of the biofuels industry, and realized the clustering of the challenges [33]. In summary, in order to deeply, comprehensively, and quantitatively explore the role relationship and attribute characteristics of the coupling influence factors of power–gas systems, the DEMATELISM-MICMAC method can be adopted.

4.4. Analysis Steps

The analysis steps of DEMATEL-ISM-MICMAC are as follows:

Step 1: Create a direct impact matrix $O = [o_{ij}]_{n\times n}$.

A gray semantic scale was set (Table 2), and experts working in related research fields were invited to assess the functional degree between the factors. The direct influence matrix can reflect the direct influence relationships among the factors.

$$O = \frac{1}{m}\sum_{k=1}^{m} o_{ij}(k = 1, 2, \ldots, m) \tag{1}$$

Table 2. Criteria of expert evaluation.

Relation	No Impact	Weak Impact	General Impact	Strong Impact
Degree	0	1	2	3

In Equation (1), o_{ij} indicates the functional degree of factor S_i on S_j and m indicates the number of scoring experts.

Step 2: Create a normative impact matrix $N = [n_{ij}]_{n\times n}$.

The direct impact matrix O is normalized and the canonical impact matrix N is calculated.

$$N = \frac{1}{\max\limits_{1\le i\le n}\sum_{j=1}^{n} o_{ij}} O \tag{2}$$

Step 3: Create a comprehensive impact matrix $T = [t_{ij}]_{n\times n}$.

To further consider the indirect influence relationships among the factors, the combined influence matrix T is calculated, where t_{ij} indicates the degree of the combined influence of factor i on factor j. The combined influence matrix couples the direct and indirect influence relationships among the factors.

$$T = \lim_{k\to\infty}\left(N + N^2 + \cdots + N^K\right) = N(I-N)^{-1} \tag{3}$$

Step 4: Evaluate the degree of influence e_i, influenced f_i, centrality c_i, and causality r_i of each factor.

$$e_i = \sum_{j=1}^{n} t_{ij}(i = 1,2,\ldots,n) \tag{4}$$

$$f_i = \sum_{i=1}^{n} t_{ij}(j = 1,2,\ldots,n) \tag{5}$$

$$c_i = e_i + f_i \tag{6}$$

$$r_i = e_i - f_i \tag{7}$$

In the above Equations, the influence degree e_i is the strength of the combined influence of a factor on other factors and the influence degree can help determine which factors have a higher weight or importance in a system. The influenced degree f_i is the strength to which a factor is influenced by other factors and the influenced degree helps to understand which factors have a more passive position in a system. The degree of centrality c_i shows the degree of importance of factor i in the system. A positive degree of causality r_i indicates that factor i has a stronger degree of influence on other factors, and a negative degree of causality r_i indicates that factor i is more strongly influenced by other factors.

Step 5: Create a reachable matrix $R = \left[r_{ij}\right]_{n\times n}$.

The overall impact matrix $H = \left[h_{ij}\right]_{n\times n}$ is calculated, consider one's own impact on the basis of a comprehensive impact matrix.

$$H = T + I \tag{8}$$

The transformation of the integrated influence matrix to the reachable matrix is achieved by introducing a threshold λ.

$$r_{ij} = \begin{cases} 1,\ if\ h_{ij} \geq \lambda(i,j = 1,2,\ldots,n) \\ 0,\ if\ h_{ij} < \lambda(i,j = 1,2,\ldots,n) \end{cases} \tag{9}$$

Step 6: Create the hierarchy model.

Based on the reachable matrix, find the reachable set $R(S_i)$, the prior set $A(S_i)$, and the common set $C(S_i)$.

If

$$R(S_i) = C(S_i) \tag{10}$$

Then, determine factor i as the first-level factor and cross out factor i in $R\left(S_j\right)$ at the same time. Continue to determine the-second level factor via step 6 (9), and so on, and finally, obtain a hierarchical model of the factors.

Step 7: Based on the reachability matrix, evaluate the driving degree d_i and the depending degree j_i of each factor.

$$d_i = \sum_{j=1}^{n} r_{ij}(i = 1,2,\ldots,n) \tag{11}$$

$$j_i = \sum_{i=1}^{n} r_{ij}(i = 1,2,\ldots,n) \tag{12}$$

In the above equations, d_i denotes the number of factors i influencing other factors and j_i denotes the number of factors i influenced by others.

5. Results

5.1. Factors Analysis

In this study, 10 experts and scholars engaged in the fields of power system planning and operation, natural gas engineering project management, energy internet development model design, energy security strategic management, and Energy–Economy–Environment system coupling coordination were invited to assess the functional degree between the influencing factors of power–gas system coupling. A reliability test of the expert scholars' opinions in SPSS.25 software yielded a Cronbach α of 0.87, which is greater than 0.80 and has high reliability. For this purpose, the 10 valid data collected were averaged to obtain a direct impact matrix for the coupled power–gas system study $O = \left[o_{ij}\right]_{n\times n}$ (Table 3).

Table 3. Direct impact matrix O.

O	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}
S_1	0	0	1.1	2.4	0	2.1	2.2	0	2.2	2.3	2.1	2.2	2.9	2.8	2.3	0
S_2	0	0	2.9	2.2	0	2	1.9	0	2.2	2.5	2.2	2.1	2.1	2.9	2.2	0
S_3	0	0	0	2.1	0	2.2	2.1	0	0	2.1	2.6	1.9	2.8	1.3	1.9	0
S_4	0	0	0	0	0	2.7	2.8	0	0	2.5	0	2.7	0	0	1.1	0
S_5	0	0	0	2.8	0	2.3	2.1	2.8	1	1.8	0	1.9	1.1	1.2	2.1	0
S_6	0	0	0	0	0	0	2.3	0	0	0	0	0	0	0	1.2	0
S_7	0	0	0	0	0	2.5	0	0	0	0	0	0	0	0	0	0
S_8	0	0	0	2.5	0	1.9	2.1	0	0	2	0	2.1	0	0	2.7	0
S_9	0	0	0	1.2	0	2.4	2.2	0	0	2.2	2.9	2.2	0	0	1.4	0
S_{10}	0	0	0	0	0	0	0	0	0	0	0	2.4	0	0	1.2	0
S_{11}	0	0	0	0	0	3	3	0	0	2.9	0	2.9	0	0	0	0
S_{12}	0	0	0	0	0	0	0	0	0	2.6	0	0	0	0	1.3	0
S_{13}	0	0	0	2.7	0	2.1	2.1	0	0	1.9	1.1	2.7	0	0	2.6	0
S_{14}	0	0	0	2.9	0	2.2	2.3	0	2.7	1.9	2.1	1.9	2.7	0	2.1	0
S_{15}	0	0	0	0	0	2.8	2.7	0	0	2.8	0	3	0	0	0	0
S_{16}	0	0	0	2.8	0	2	2.1	0	2.3	2.2	2.3	2	2.2	2.9	2.8	0

5.2. Causality Analysis

Based on the 16 influencing factors of Integrated Power and Gas System (IPGS) coupling, the direct influence relationships among the influencing factors were determined based on the evaluation results of expert scholars. Based on the established direct influence matrix, calculations were performed according to steps 3, 4, and 5 to obtain the degree of influence, influenced, centrality, and causality of each factor (Figure 1).

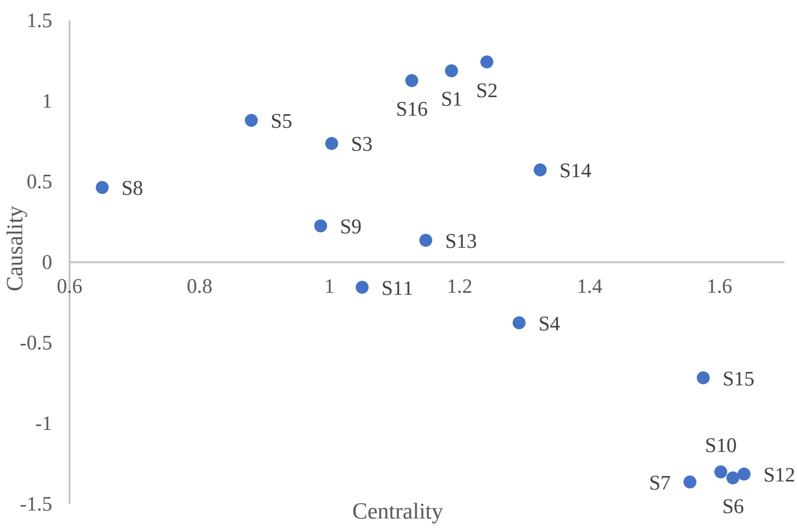

Figure 1. Centrality and causality of each influencing factor.

The Decision Making Test and Evaluation Test Method (DEMATEL) is able to identify the key influencing factors of IPGS coupling, and the results calculated from the DEMATEL-related indicators can be analyzed as follows:

(1) Centrality: The top three factors ranked by centrality are market price (S12), technology level (S6), and supply–demand situation (S10), and centrality emphasizes the importance of the influencing factors, so these three factors are important IPGS coupling influencing factors, and improving these factors is crucial to further coupling IPGS.
(2) Causality: The top-scoring factors are resource endowment (S2), economic foundation (S1), and environmental awareness (S16), indicating that these three factors tend to influence other factors, so the development and utilization of energy resources such as renewable energy and natural gas should be strengthened, the economic foundation for promoting the development of the energy industry should be firmly established, and an awareness of green and low-carbon environmental protection should be built throughout society.

It can be seen that six key factors can be identified from 16 factors using the DEMATEL method, namely, economic foundation (S1), resource endowment (S2), technology level (S6), supply–demand situation (S10), market price (S12), and environmental awareness (S16). The control of the above five key factors can facilitate the coupling of IPGS.

5.3. Hierarchy Analysis

The overall impact matrix H was established according to step 6, and a suitable λ was set to streamline the relationship between factors with a small degree of influence, thus ensuring a moderate degree of factor nodes. The traditional method for setting λ is mainly based on empirical multiple values to obtain satisfactory results (Figure 2). With the help of Figure 2, it can be found that the factor hierarchy is favored at λ = 0.08.

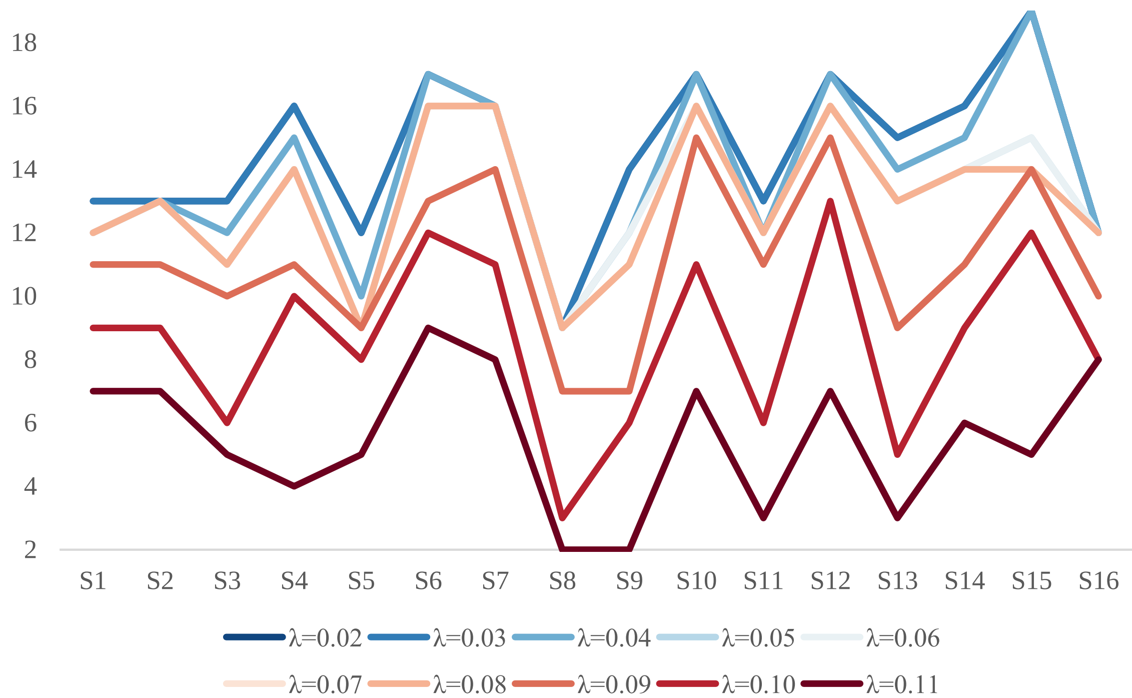

Figure 2. Node degree under different thresholds.

Based on the reachability matrix R, a hierarchical structure model of IPGS coupling influence factors was drawn by dividing each factor into levels according to step 7 (Figure 3).

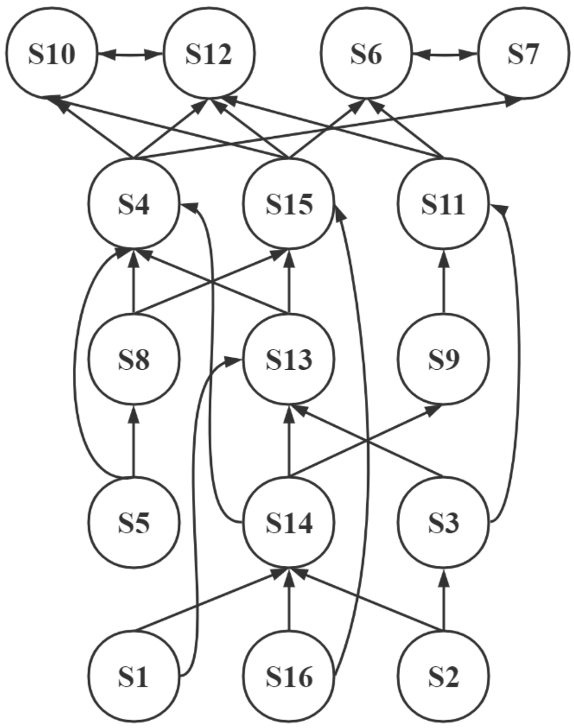

Figure 3. Hierarchical structure model.

The Interpretative Structural Modeling Method (ISM) can visualize the interaction relationship and hierarchical structure among the coupled influencing factors of IPGS, and the analysis results show the following.

(1) All the influencing factors were categorized into five levels of three orders: the basic level consisting of S1, S16, and S2; the approach level consisting of S10, S12, S6, and S7; and the transition level consisting of the remaining factors. The lower level represents the stronger influencing attributes and the upper level represents the stronger influenced attributes.
(2) The bottom-level factors are not affected by others, but do affect others, and this suggests that the bottom-level factors have a vital role in IPGS coupling. Increasing environmental awareness (S16) directly affects strategy planning (S14) and investment development (S15), and then, transmits its effects to the surface-level factors through indirect factors such as infrastructure (S4) and the market mechanism (S9), exerting a comprehensive influence on IPGS coupling. Obviously, in order to promote IPGS coupling fundamentally, it is crucial to enhance environmental awareness (S16).
(3) The middle-level factors take on the role of spreading influence and work by exerting influence on the surface-level factors. So, there is a need to harmonize the middle-level factors, especially those with a high degree of centrality (investment development (S15) and strategy planning (S14)), and those with high causality (gas–electricity property (S5) and energy structure (S3)). In most cases, the bottom-level factors are difficult or even impossible to control, such as economic foundation (S1) and resource endowment (S2), but the combined effect on IPGS coupling can be controlled by regulating controllable middle-level factors, such as strategic planning (S14).
(4) The surface-level factors do not affect the others, but are affected by them, and this suggests that the surface-level factors have a direct effect on IPGS coupling. Among the surface-level factors, technology level (S6) and system capability (S7) can provide strong support for the feasibility and efficiency of IPGS coupling at the technical level, and supply–demand situation (S10) and market price (S12) can provide strong support for the economics and sustainability of IPGS coupling at the commercial level, and both of these levels are important for IPGS coupling.

5.4. Substance Analysis

In order to make this whole study more scientific and complete, the quadrants to which each factor belongs were divided, according to step 8, into four different quadrants: spontaneous factors, dependent factors, linked factors, and independent factors (Figure 4).

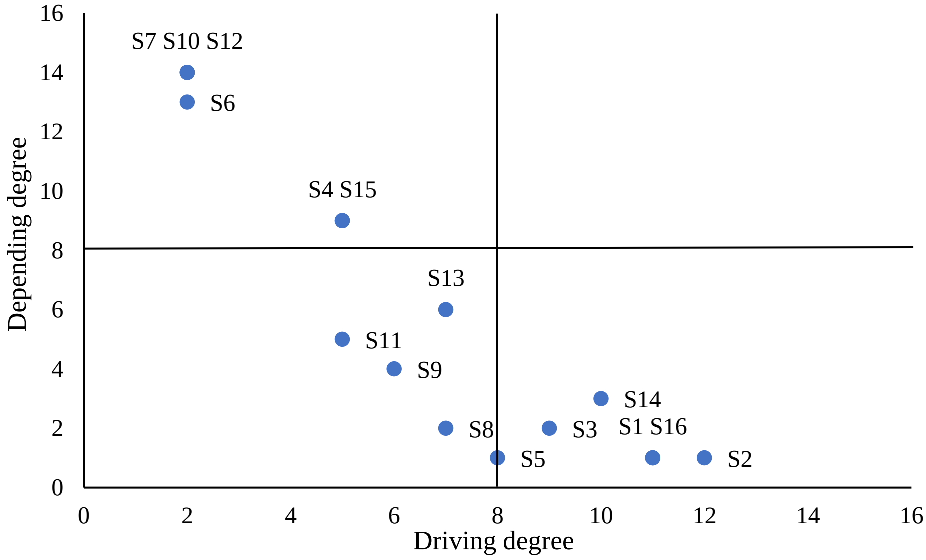

Figure 4. MICMAC analysis results.

Spontaneous factors have a weaker driving degree and depending degree. Dependent factors have a stronger depending degree and weaker driving degree. Linkage factors are stronger in both their driving and depending degrees. Independent factors have a stronger driving degree and weaker depending degree.

As can be seen from Figure 4, resource endowment (S2), energy structure (S3), strategy planning (S14), and environmental awareness (S16) are located in the fourth quadrant and belong to a more driven, less dependent set of independent factors, which are less influenced by but more influential on other factors, and are the deep core factors driving IPGS coupling.

The spontaneous factor set can be internally divided into two parts. The first part includes market mechanism (S9), market competition (S11), and policy system (S13). The dependency of these factors is higher than other factors in this limit, indicating that they are more susceptible to the influence of other factors; therefore, special attention should be paid to these deeper factors in the process of promoting IPGS coupling. The second part is system function (S8). Although the driving force and dependency of system function (S8) are lower, it has a direct impact on the infrastructure (S4) and investment development (S15) of IPGS, so it is also an important factor that cannot be ignored in IPGS coupling.

6. Suggestions

6.1. "Recognizing Self-Situation" Is the Key Foundation of IPGS Coupling

Firstly, we should study the endowment conditions and distribution characteristics of electricity and natural gas resources; understand the energy supply, energy demand structure, energy reserves and other information of different regions; determine the type, quantity, and distribution of energy resources required for Integrated Power and Gas Systems (IPGS); and coordinate the production and transmission of electricity and natural gas resources. Secondly, we should investigate the economic bases of different regions; determine the industrial structure, employment situation, financial income, and other information of different regions; determine the demand characteristics and economic affordability of IPGS service recipients; and decide on the scale and development direction of system construction according to the development situations of different regions.

6.2. "Accelerating Market Construction" Is the Primary Content of IPGS Coupling

Firstly, we should pay attention to the overall development trend of the electricity and gas industry chain; strengthen the exploration and development of electricity and gas resources; integrate resources from multiple sources, including energy, markets, technology, and talent; explore the application scenarios of electricity and natural gas conversion; and achieve a balance between supply and demand in the spatial structure. Secondly, market surveys and data analysis should be used to understand information on electricity and natural gas supply, consumption and reserves, etc., to forecast the trend of electricity and natural gas supply and demand in a timely manner and reduce the uncertainty of market prices. Finally, market-based instruments, such as competitive bidding transactions and pricing mechanisms, should be used to promote the market-based operation of electricity and natural gas to reduce the cost and improve the efficiency of the system.

6.3. "Developing Energy Composition" Is an Important Method of IPGS Coupling

Firstly, domestic and international energy markets should be combined and establish their own resource endowment to promote the upgrading and transformation of energy structure through the development of new energy sources such as solar and wind energy; reduce the dependence on traditional energy sources; and provide development conditions for IPGS coupling. Secondly, comprehensive energy planning should be developed, clean and efficient energy should be selected as the main supply source of IPGS, energy complementation and optimal allocation should be achieved, and system efficiency and competitiveness should be improved. Finally, the coupling interaction of IPGS should be recognized, the development needs of IPGS in terms of intelligence and digitalization should be considered, the construction direction and scale of IPGS should be determined, and corresponding investment plans and schedules should be made.

6.4. "Raising Environment Perception" Is an Inherent Requirement for IPGS Coupling

Firstly, the knowledge of IPGS should be popularized in society through various channels such as the media and school education, and the awareness and participation of society in environmental protection should be improved through various means, such as encouraging green technology innovation and improving environmental protection laws and regulations. Secondly, community outreach activities should be strengthened, and IPGS exhibitions or demonstration projects should be organized to show how it works, as well as its practical applications and environmental impacts, so as to give people a deeper understanding of IPGS and provide them with hands-on experience. Thirdly, partnerships should be promoted among government agencies, non-profit organizations, energy companies, and other relevant entities to enhance resource sharing, disseminate IPGS information more effectively, and work together to promote the community-wide awareness of IPGS. Fourthly, we should focus on environmental protection in the construction and operation of IPGS, and strengthen the education and management of environmental protection awareness in IPGS-related personnel in order to achieve sustainable development and maximize social benefits. Finally, a scientific environmental protection management and pollution evaluation system should be established to strengthen the environmental protection supervision and management of IPGS and conduct a comprehensive environmental impact evaluation to ensure the compliance and safety of the system.

7. Conclusions

This study combines the Decision Test and Evaluation Test–Interpretive Structural Modeling–Cross-Impact Matrix Multiplication (DEMATEL-ISM-MACMIC) Method to construct an impact factor model for the coupling of an integrated power and natural gas system (IPGS). The main conclusions drawn from this study are as follows.

Through a literature search and field research, an indicator system of influencing factors for IPGS coupling was constructed. The system includes the four dimensions of context, system, market, and society, totaling 16 factors.

With the help of scoring evaluation by experts and scholars, the degree of influence among the influencing factors of IPGS coupling was determined, and a hierarchical structure model of the influencing factors of IPGS coupling was constructed. The model includes bottom-level factors, middle-level factors, and surface-level factors. Based on the relationships between different attributes and factors, this study proposes recommendations to "recognize self-situation", "accelerate market construction", "develop energy composition", and "raise environment perception".

There are some limitations in this paper. The results of this paper are based on the opinions of 10 experts in the fields of electricity and natural gas from China. For example, the selection of factors such as "Economic Structure" and "Resource Endowment" in the IPGS coupling influencing factors index system reflects the personal thoughts of the experts, and the influence relationships between different factors reflect the academic knowledge of the experts, so the results of this paper have subjectivity that is difficult to eliminate and are not generalizable worldwide. In the future, it is possible and necessary to verify the legitimacy of these indicators in further research.

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