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Factors Affecting the Economics of Distributed Natural Gas-Combined Cooling, Heating and Power Systems in China: A Systematic Analysis Based on the Integrated Decision Making Trial and Evaluation Laboratory-Interpretative Structural Modeling (DEMATEL-ISM) Technique

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Abstract: As a clean and efficient energy, natural gas is the main driving force for China's energy transformation and the realization of green energy development. Distributed natural gas combined cooling, heating and power (DNG-CCHP) is the main utilization method of distributed natural gas with many advantages. However, the economics of China's DNG-CCHP system are poor, hindering the healthy and sustainable development of the system in China. Thus, this paper systematically analyzes the factors affecting the economics of DNG-CCHP system in China. Firstly, through the analysis of the development status and obstacles of China's DNG-CCHP system, the economic impact factor set of DNG-CCHP systems involving 34 factors is constructed. Then, the integrated DEMTTEL-ISM method is used to construct the multi-level hierarchical structure of influencing factors, the influence mechanism of the factors on the economics of DNG-CCHP system is systematically and comprehensively analyzed, and the path of improving system economics is proposed accordingly. Finally, based on the research findings and the development of China's DNG-CCHP, the coordinated development of DNG-CCHP and distributed renewable energy was discussed, and several policy suggestions are put forward to contribute to the integration of distributed natural gas and distributed renewable energy.

Keywords: DNG-CCHP system; economics; influencing factors; systematic analysis; integrated DEMATEL-ISM technique

1. Introduction

Natural gas is an efficient, low-carbon, clean and high-quality energy source. In the fields of power generation and industrial fuel, the thermal efficiency of natural gas is about 10% higher than that of coal [1]. Meanwhile, the CO_2 emissions generated by natural gas are only 59% that of coal and 72% that of oil, and natural gas does not have any dust emissions compared to coal and oil [2]. Therefore, natural gas is gradually becoming a main form of energy use in China, of which natural gas power generation (NGPG) is the major way of natural gas utilization.

NGPG is not only an important part of the power supply, but also the main driving force for China's energy transformation and development of green energy. At present, the installed capacity and power generation volume of NGPG in China are both in a low level [3], so the future development direction of China's NGPG can mainly include three major aspects. Firstly, develop natural gas peaking power stations in an orderly manner to improve energy integration, that is, promote the integration of NGPG and renewable energy power generation, which can improve the power security level of power load centers. The second is to develop natural gas-fueled combined cooling, heating and power (CCHP) projects according to local conditions which can improve environmental quality. In the economic and technological development zones and high-tech industrial parks which are the key areas of air pollution prevention and control, it should encourage the development of CCHP projects with stable heat load, and in heating areas it should moderately develop the CCHP projects with heating functions [4]. The third is to vigorously promote distributed natural gas to improve energy quality. It should accelerate the development of distributed natural gas energy and improve the comprehensive utilization efficiency of natural gas in large-scale commercial comprehensive service areas, university parks and high-tech industrial parks in large and medium-sized cities.

The economic development has gradually increased the requirements for the demand, stability, safety, efficiency and environmental standards of energy. In addition, the openness of power markets in various countries has gradually increased, and energy and power grid technologies have continued to improve, resulting that the distributed energy, which used to be a niche use of energy, gradually enters the public's field of vision, due to its higher energy efficiency [5,6]. The distributed energy system refers to the multi-linkage system that is deployed in a decentralized manner at the user's end with appropriate size and capacity to supply energy nearby, and where excess power can be supplied to the distribution network through the power equipment [7]. The original distributed energy system was mainly based on small-scale combined heating and power (CHP) systems that used natural gas as a fuel [8]. The most prominent advantage of CHP compared to the single power generation is the high efficiency of energy use. Through the utilization of waste heat, the energy utilization rate of CHP can be increased to more than 80%, which is about twice that of supercritical and ultra-supercritical thermal power units. The use of natural gas for single power generation or direct heating does not fully utilize the thermal energy of natural gas, so natural gas-fueled CHP is an effective way to make full use of natural gas. At present, the efficiency of H-level natural gas CHP system can reach more than 60%, which is about 1.3 times that of the world's most advanced coal-fired power units. Meanwhile, the energy utilization efficiency of the primary energy has been improved throughout the process, which has improved the economics of the project. With the advancement of technology and the demand for diversity of energy, distributed energy systems have gradually shifted to small-scale CCHP system and distributed renewable energy system. Among them, natural gas-fueled distributed CCHP system is the mainstream, followed by coal-, waste incineration- and bioenergy- fueled systems [9].

The distributed natural gas CCHP (DNG-CCHP) system is a new type of energy system built on or near the end user's premises, which is based on the concept of energy cascade utilization, integrating cooling, heating and power generation into a multi-energy supply system [10]. Compared with other distributed energy sources, DNG-CCHP system is relatively mature and widely used in the world and is the main direction in the development of distributed energy in China. The DNG-CCHP system can realize the cascade utilization of heat after natural gas combustion [11]. Specifically, high-grade heat is used to drive the gas turbine to generate electricity, and then the heat contained in the gas turbine exhaust is used to drive refrigeration and thermal equipment to cooling and heating. The generated cold and heat are directly supplied to the nearest place, and then produce economic benefits. The DNG-CCHP system can be operated independently or in parallel to meet the needs of users under different power load conditions [12]. Due to the no requirement for the long-distance transmission of the produced energy, and the full use of thermal energy, the comprehensive energy utilization efficiency of the DNG-CCHP system is more than 80% [13]. Moreover, the DNG-CCHP system has the functions of energy saving and emission reduction, and peak shaving and valley filling of the grid and natural gas pipeline network, which can enhance the safety of energy supply, having better economic benefits and saving social public costs [14].

Compared with centralized NGPG projects, the series of advantages of DNG-CCHP systems have been widely accepted, such as high primary energy efficiency, self-sufficiency in energy, high reliability, low environmental pollution, proximity consumption and low investment [15]. In addition, as mentioned before, the DNG-CCHP can play a double peak-filling effect on the grid and natural gas pipeline network, alleviating the peak load of power, which is conducive to enhancing the stability and safety of the power grid. In a typical DNG-CCHP system, small gas turbines, gas internal combustion engines or micro gas turbines will use high-temperature flue gas generated by natural gas combustion leading to drive generators to generate electricity. Then, waste heat flue gas is recycled through equipment such as preheating boiler or waste heat direct combustion engine to provide steam and domestic hot water for industrial enterprises throughout the year. At the same time, the building can be heated in winter and cooled by an absorption chiller in summer. Through the cascades use of energy, the overall energy efficiency and economics of the DNG-CCHP systems can be significantly improved [16].

For the above reasons, DNG-CCHP system has been broadly applied in developed countries such as the United States, Britain, Japan and the Netherlands [17]. However, in China, limited by policy guidance, technical equipment, gas supply, market management and other issues, the development DNG-CCHP systems has been relatively slow, and is still in the early stages [18]. In recent years, the Chinese government has increased its policy support for promoting the development of distributed natural gas energy. In October 2011, the China the National Development and Reform Commission (NERC), National Energy Administration (NEA), the Ministry of Finance, and the Ministry of Housing and Urban-Rural Development (MOHURD) jointly issued the Guiding Opinions on the Development of Distributed Natural Gas Energy [19], stating that distributed natural gas energy has already had the conditions for large-scale development in China, which is the first time the central government has issued guidance on distributed energy. The guide is planned to achieve an installed capacity of 50 GW by 2020, and initially realize the industrialization of distributed energy equipment. In 2014, the NERC, the NEA, and the MOHURD jointly issued the Detailed Implementation Rules for Distributed Natural Gas Energy Demonstration Projects [20], which improved the management procedures for declaring and reviewing the distributed natural gas energy demonstration projects.

However, the development of distributed natural gas energy in China is also facing multiple obstacles. Firstly, the distribution natural gas project is limited to state-driven demonstration projects and a small number of commercial projects [21], which is still far from the large-scale commercial promotion requiring building about 1000 distributed natural gas projects in 2020. Secondly, the high gas prices and difficulty in grid connection will severely affect the economics of distributed natural gas projects [22], and have become the main bottlenecks that plague the development of distributed natural gas projects. Besides, the distributed natural gas projects will face premium risks during the heating season. Since 2014, some new distributed natural gas projects have been stagnant, and many projects that have already been constructed are also out of service. Finally, the policy is difficult to implement, resulting that the support for distributed natural gas projects is not muscular enough. Although China has introduced some policies and regulations on the development of distributed natural gas projects, most of them are only principled provisions, but few supporting and subsidy policies, which is lack of implementation rules and has low operability [23].

In line with the above discussions, despite the obvious advantages of the DNG-CCHP system, in China, the development status of the DNG-CCHP system is not satisfactory, and the effect of system peaking and valley filling cannot be fully utilized, which is not conducive to improving the overall energy efficiency of China. Vigorously developing the DNG-CCHP system cannot rely solely on policy promotion, but should rely more on the power of the market, that is, the economics of the DNG-CCHP system is the decisive factor in the rapid development of the system. There are many factors affecting the economics of the DNG-CCHP system. For example, Hua et al. held that the main factors affecting the economics of the DNG-CCHP system included regional climates, energy demand, local economic conditions, local policies, etc., but they only gave a simple qualitative analysis [24]. Further, some researches into the economics of CCHP focused on measuring the economics of the DNG-CCHP system. For instance, Yuan et al. used the levelized cost of electricity (LCOE) method to measure the LCOE of DNG-CCHP in different regions. By comparing and analyzing the differences between LCOE and commercial electricity prices, the economics of DNG-CCHP in diverse regions of China were explored [25]. Hou et al. analyzed the economics of building-typed DNG-CCHP system, finding that the fiscal dilemma of building-typed DNG-CCHP system is partial and temporary, and transforming the self-generating utilization mode of building-typed DNG-CCHP system is an effective way to solve the economic dilemma [26].

In general, the related studies mainly consider the direct factors affecting the economics of CCHP, such as cost and benefits, but do not delve into the deep-seated factors that affect these direct factors [11,27–29]. In addition, the geographic location of the DNG-CCHP system, local load characteristics, technical level, electricity market and natural gas market conditions will all affect the economics of the system, indicating that researches on the economics of DNG-CCHP system via calculating the costs and benefits of a particular DNG-CCHP project has little significant value for other projects, nor can it guide the DNG-CCHP system in other regions to obtain better economics. Therefore, this paper focuses on exploring the factors affecting the economics of China's DNG-CCHP system, aiming to analyze the impact mechanism of various factors on the economics of DNG-CCHP system scientifically and systematically, which can provide reference for formulating more comprehensive policies that will help improve the economics of DNG-CCHP system in China. Specifically, this paper first analyzes the development status and obstacles of China's DNG-CCHP system, and builds a set of economic impact factors of DNG-CCHP system involving 34 factors. After that, the hierarchical structure involving all examined influencing factors are obtained via the improved interpretative structural modeling (ISM) method simplified by the decision making trial and evaluation laboratory (DEMATEL) technique, which systematically reveals the influence mechanism of each factor on the economics of DNG-CCHP system in China. Overall, the contributions of this paper include:

(1) Through the analysis of the development status and obstacles of China's DNG-CCHP system, the influencing factor set of the economics of DNG-CCHP system including 34 factors are constructed, which can provide reference for similar researches exploring the factors influencing the economics of DNG-CCHP system.
(2) The integrated DEMATEL-ISM technique is adopted to obtain the hierarchical structure of factors affecting the economics of DNG-CCHP system, and the influence mechanisms of various factors on the economics of DNG-CCHP system are examined scientifically and systematically, which can provide reference for formulating systematic and comprehensive policies that help to improve the economics of DNG-CCHP system, so as to promote the development of DNG-CCHP system in China.

The rest of this paper is organized as follows: Section 2 reports the development status and obstacles of DNG-CCHP systems in China and constructs the economic influencing factor set. Section 3 represents the methods used to obtain the hierarchical structure of influencing factors. In Section 4, the obtained hierarchical structure of influencing factors is reported and explained. Finally, Section 5 summarizes the whole paper and puts forward some targeted suggestions helping to improve the economics of DNG-CCHP system in China.

2. Constricting the Economic Affecting Factor Set of DNG-CCHP System

2.1. Development Situation and Obstacles of DNG-CCHP System

Since 2000, China's natural gas development has benefited a lot from the rapid development of the economy and society, the sharp increase in supply capacity, the continuous improvement of storage and transportation facilities, the long-term low price and the advantages of clean and environmental protection [30]. However, in the late "Twelfth Five-Year Plan" period, China's economy began to increase in a medium- and high- speed instead of the high speed in the past several decades, the economic restructuring has continued to deepen, and natural gas prices have been significantly higher, resulting that the basic factors supporting the rapid growth of natural gas demand have changed. Specifically, energy structure optimization and ecological civilization construction of the macro-policy level will replace economic and price factors as the main driving force for China's natural gas demand growth in the future [31]. There are still some uncertain factors in China's natural gas demand in the future. For instance, the external dependence of natural gas has risen rapidly and the price advantage has been significantly weakened [22,32].

China's distributed natural gas energy industry has shown a rapid increase from 2010 (Figure 1). In 1998, China built the first distributed natural gas project, and by the end of 2014, China had built 85 distributed natural gas projects. By the end of 2015, China had 288 distributed natural gas projects, including 127 completed projects, 69 projects under construction and 92 planned projects, with a total installed capacity of 11 GW, accounting for only 0.72% of the national power generation capacity, which is still a big gap compared with developed countries.

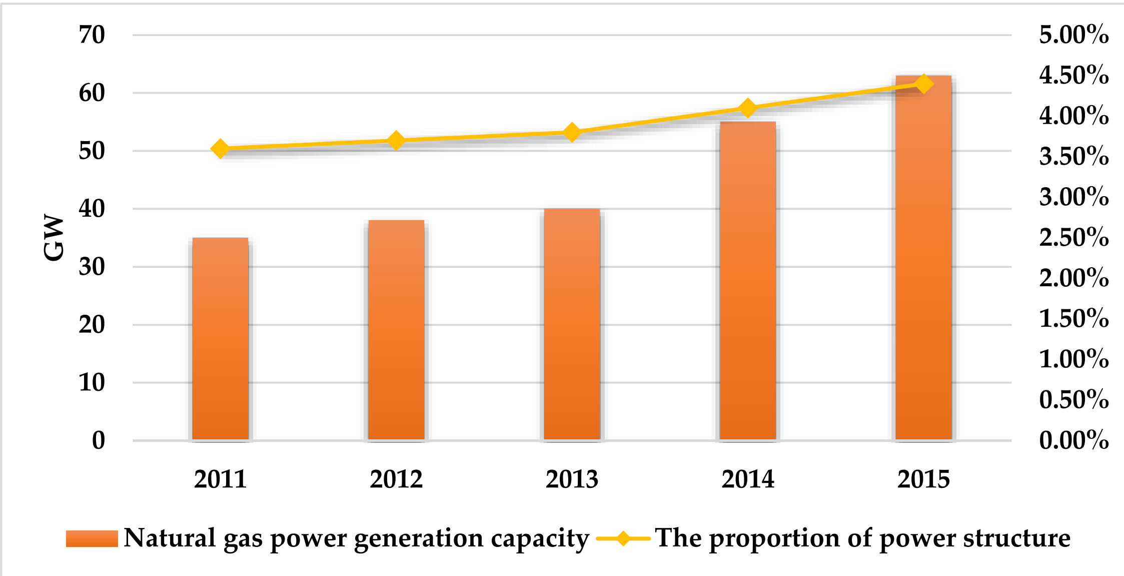

Figure 1. The installed capacity and proportion of NGPG during 2011–2015.

2015 is considered to be a turning point in China's distributed energy development [33], in which many Chinese central enterprises have begun to get involved in distributed natural gas industry, and several major energy giants have deployed natural gas distribution projects, such as China National Offshore Oil Corporation (CNOOC), China Southern Power Grid, Sinopec, China National Petroleum Corporation, China Huadian Corporation and China Guangdong Nuclear Power Group, forming a good driving effect. Meanwhile, the integrated energy supply system based on distributed natural gas is being promoted, opening up a broader space for the development of the distributed natural gas industry, and some companies have begun to explore independent energy systems with multiple energy sources. For example, in May 2016, China's Xin'ao Group's "Generalized energy and micro-grid" project, which was put into operation in Langfang, Hebei, was integrated into clean energy technologies such as distributed natural gas and solar energy, realizing safe dispatching, optimized operation and convenient trading of multiple energy sources, and fully releasing multi-dimensional values such as energy, facilities and transactions [34].

As of the end of 2015, the total project capacity of China's distributed natural gas projects was 11 GW, accounting for 16.6% of the total installed capacity of NGPG, of which the installed capacity built was 4 GW, 5 GW was under construction, and 2 GW was in the planning stage [35]. The China Electricity Council predicted that China's distributed natural gas installed capacity will reach 40 GW by 2020, which means that at least 30 GW of new distributed natural gas capacity will be needed during the 13th Five-Year Plan period, and the market growth space is still huge [36]. The reform of the oil and gas system and the downward adjustment of natural gas prices also activated China's NGPG market. Nowadays, China is promoting the oil and gas system reform, the power system reform and the combination of the Internet and smart energy, resulting that distributed natural gas will gain more room for development.

At present, China's distributed natural gas projects are improved mainly in Beijing, Shanghai, Guangdong, Tianjin, Jiangsu and Zhejiang, because these areas have developed economies and strong investment capacity, forming strong tolerance to cold, heat and electricity prices. Besides, these regions are concentrated in industry, and the heat and cold load are relatively concentrated and stable. Moreover, these regional governments have great pressure on energy conservation and emission reduction, showing high enthusiasm for developing low-carbon, recycling, and high-efficiency energy economy. Finally, they have strong financial subsidies for emerging energy conservation and environmental protection projects, resulting in strong project profitability.

Although the development of distributed energy systems represented by DNG-CCHP systems in China has received considerable attention in recent years, progress has been far below expectations. As of the end of 2015, China's only had 288 distributed natural gas projects (single unit installed capacity is less than 50 MW, and the total installed capacity is below 200 MW). The actual development level of distributed natural gas has not been able to keep up with the plan. On one hand, the DNG-CCHP project has high requirements for gas supply and economic affordability, and that is why most of DNG-CCHP projects are located in coastal and economically developed provinces, resulting that the regional development is relatively unbalanced. On the other hand, due to factors such as project economics, policy landing, difficult grid connection and land planning, market capital lacks the enthusiasm of participating in DNG-CCHP, making the policy-level promotion projects be more than the market self-issued ones [33]. In general, some specific factors that hinder the development of DNG-CCHP projects can be summarized as follows:

(1) Difficulties in grid connection. The power generation of distributed energy systems is self-use priority, and the self-sufficient power is purchased by the power grid. In 2014, the NEA issued a document stipulating that the distributed photovoltaic project using the roof of the building can be operated in the mode of using the self-generated power and the rest being on-grid, or the mode of all generated electric power being on-grid [37]. The two modes of operation of distributed energy all need to be involved in the power grid, but the difficulties in grid connection have become one of the main reasons for hindering the development of distributed energy projects. Large-scale distributed power grid integration will have impacts on grid frequency, voltage, power flow distribution, power quality and reliability. With the development of grid technology and the increase of intervention standards, the negative impacts of distributed energy on the grid will gradually decrease.
(2) The subsidy is lagging behind. The problem with DNG-CCHP projects lies in the lag in subsidy policy formulation. The NDRC has already set a subsidy standard for distributed photovoltaic power generation in 2013 [38], but the government has not yet issued a clear distributed natural gas subsidy policy. In addition, there is no unified standard for the on-grid price of NGPG, and the electricity price of DNG-CCHP projects needs to be separately formulated for the actual situation of the project. Finally, due to the uncertainties in the reform of natural gas prices, coupled with the large price fluctuations in the competitive energy such as oil and coal, the lack of subsidies and pricing policies has made investors' project returns unclear, which adds difficulty to the development of DNG-CCHP projects.
(3) Poor economics. The economics of distributed energy projects are the crucial factor that constrains their development [22,39]. For DNG-CCHP projects, core equipment such as gas turbines and

gas internal combustion engines still need to be imported, whose price is high. The supporting refrigeration and heating equipment also requires a large amount of capital investment, but the income from cooling and heating is limited. The operation costs of DNG-CCHP projects are mainly affected by gas prices, electricity prices, heating prices and cooling prices. According to statistics, the fuel cost of natural gas accounts for 70–80% of the total cost [40], and the higher gas price will obviously restrict the economics of DNG-CCHP projects. In the case of dual-fuel systems common to industrial users, price changes in alternative fuels can also change user preferences. Fuel costs account for more than 85% of total steam costs [41], resulting that the high gas prices make steam prices of DNG-CCHP system uncompetitive because the price of steam in DNG-CCHP systems is about three times that of coal-fired boilers. Besides, the relationship between gas prices and electricity prices has a significant impact on the economics of DNG-CCHP projects. Specifically, the gas-to-electric price ratio (the ratio of natural gas price to electricity price) can be used to describe the operation of DNG-CCHP projects, that is, the smaller the gas-to-electric ratio, indicating the lower the natural gas price and the higher the electricity price, the better the economics of DNG-CCHP projects [42].

(4) The business model is immature. In recent years, the contract energy management mode has become one of the main development modes of distributed energy. However, the application maturity of China's contract energy management mode is not high at present, and there may be problems in many links, mainly because the division of responsibility of individual stakeholders is not clear, contract execution is not in place, and the flows of current and cash are not clear enough. The ability of the owner to abide by the agreement and settle the electricity bill on time has also become an uncertain factor in the project. Affected by the economic downturn, some owners may not be able to pay electricity bills on time, which makes the interests of developers of DNG-CCHP projects unable to be guaranteed. Therefore, some developers even want to settle with the creditworthy grid companies, and change the power station to a full-on-grid mode, which has to face the risks of subsidy arrears.

(5) High financing costs. As mentioned above, the early stage investment of DNG-CCHP projects is very large and subject to the pressure of high gas prices [22]. The gas price is higher than the on-grid electricity price, and the competitiveness of cooling and heating prices is not strong. Potential risks and uncertainties make it difficult for DNG-CCHP projects to pass financial review by financial institutions. China's state-owned enterprises can obtain loans more easily and with lower interests, but for private enterprises that are the mainstay of distributed energy, loans are extremely difficult. Due to the late start, the business mode of DNG-CCHP projects is not yet mature, and financial institutions are quite cautious in lending to these projects. Before considering loans to the project, some banks called on the government to introduce a security mechanism to prevent loans from becoming bad debts. Besides, some banks have issued internal documents to restrict or prohibit loans to distributed energy projects. Domestic financial institutions lack the necessary understanding of DNG-CCHP projects, resulting in a single form of financing and high financing costs.

(6) Project coordination is difficult and there is no overall planning. DNG-CCHP projects typically have more stakeholders than large centralized NGPG projects. DNG-CCHP system uses natural gas to produce various forms of energy (electric power, cooling and heating), and the relationship between gas suppliers and various energy users is also complicated, so the interests of all parties are difficult to coordinate, resulting that the project progress is slow.

2.2. Factor Set Influencing the Economics of DNG-CCHP System

As mentioned above, relying on government policies to promote the development of CCHP is infeasible. An effective method is to use the market means to mobilize capital enthusiasm, so that market capital can participate more in DNG-CCHP projects, thereby promoting the development of DNG-CCHP projects. Therefore, improving the economics of DNG-CCHP system is an important measure to make full use of market capital. There are many factors affecting the economics of DNG-CCHP system, of which there are factors that directly affect the economic, such as costs and benefits, as well as factors that indirectly affect the economic, such as technical conditions, alternative energy prices and policies. According to the above analysis on the development status and obstacles of DNG-CCHP system and some previous research results [24–29,33,39], this section summarizes the factors affecting the economics of DNG-CCHP and lists them in Table 1, namely, the influencing factor set of the economics of DNG-CCHP system.

Table 1. Factors influencing the economics of DNG-CCHP systems.

Symbol	Factor	Meaning
S_1	The DNG-CCHP system scale	Large-scale DNG-CCHP system located in hotels, office buildings, shopping malls and residential areas have long operation time and large installed capacity.
S_2	Regions and climate	Regions and climate will affect the cooling and heating consumption and the transmission distance of gas and electricity, which can affect the economics of DNG-CCHP system.
S_3	Terminal load type	Different terminal load types have different time distribution of load, affecting the load rate of DNG-CCHP system.
S_4	Annual operating time of the DNG-CCHP system	The annual operating time is an important factor affecting the economics of the system which determines the service life and depreciation rate of the equipment, thus affecting the investment payback period.
S_5	Load rate	High load rate can maximize the power efficiency of the system, thereby increases the economics.
S_6	Integrated optimization and flexible designs	The designs can ensure that the system can meet the large changes in cooling, heating and power loads and energy prices, thus realizing real-time optimal operation under changing conditions.
S_7	Combined with renewable energy	The DNG-CCHP system and renewable energy system should have complementarity and synergy.
S_8	Direct supply of electricity	Direct supply of electricity in the region is one of the major economic benefits of DNG-CCHP system, and it is difficult for large DNG-CCHP to develop if there is no legal support and guarantee for direct supply of electricity.
S_9	Tax incentives	DNG-CCHP system realizes the comprehensive utilization of resources, which is in line with China's policy of reducing and exempting taxes.
S_{10}	Long-distance natural gas pipeline construction	The construction of long-distance natural gas pipeline is important supporting the rapid transfer of China's natural gas from the western resource-rich areas to the coastal efficient market, which guarantees the gas supply of DNG-CCHP system.
S_{11}	LNG supply	Since most of China's DNG-CCHP systems are concentrated in developed coastal cities, sufficient LNG imports can reduce natural gas pipeline transportation costs, thereby improving the overall economics of the system.
S_{12}	The degree of natural gas market diversification	At present, China's upstream natural gas supply is still dominated by the three major companies: CNPC, SINOPIC and CNOOC, which is not conducive to full competition in the gas market.
S_{13}	Natural gas pricing mechanism	The natural gas pricing mechanism directly affects the future trend of natural gas prices in China. Among the natural gas prices of various countries, the gas price for power generation is much lower than that of civilian use.
S_{14}	External dependence of natural gas supply	China's current natural gas supply is mainly from foreign imports, which has resulted that the natural gas prices in China are too high.
S_{15}	Unconventional gas development	Unconventional natural gas such as coalbed methane and shale gas is a kind of important energy, and its development can decrease the price of conventional natural gas.
S_{16}	On-grid price of DNG-CCHP	Electricity price is an important factor affecting the economics of the system. China's current electricity price is determined based on different user types, and the gap is nearly 66%.
S_{17}	Grid-connected technology	The current power grid is constructed based on the current being delivered from the centralized power plant to the customer premises, but the current of distributed energy systems is bidirectional, requiring grid companies make large adjustments in the grid-connected technology.

Table 1. *Cont.*

Symbol	Factor	Meaning
S_{18}	Alternative energy prices	In recent years, natural gas price has increased significantly, oil and coal prices have fallen sharply, making natural gas completely uncompetitive in industries such as power generation.
S_{19}	Gas and electricity price ratio	The gas and electricity price ratio refers to the ratio of gas price to electricity price, which directly affects the economics of DNG-CCHP system.
S_{20}	Fixed investment costs of the DNG-CCHP system	The fixed investment costs of DNG-CCHP system is mainly the equipment acquisition costs, which are closely related to specific project and come from the early stage of the project.
S_{21}	Financial costs	The financial costs incurred on the DNG-CCHP system are mainly loan interest, whose value depends on the proportion of loans to total investment and the interest rate.
S_{22}	Fuel costs	The DNG-CCHP system requires a certain amount of fuel bills per year, the largest of which is the cost of natural gas.
S_{23}	Operation and maintenance costs	Operation and maintenance costs include maintenance personnel fees and equipment troubleshooting fees, which is throughout the life of the equipment.
S_{24}	Installed capacity of the DNG-CCHP system	The installed capacity of DNG-CCHP system will have a certain impact on the on-grid price and on-grid electric power volume.
S_{25}	Cold and heat consumption	For units of different capacities, the cost of each capacity unit shows a downward trend when the cold and heat consumption increases.
S_{26}	Cooling and heating time	As the cooling and heating time increases, the cost of units of different capacities will also decrease to some extent, that is, the system has good economics in areas with high cold and heat demand.
S_{27}	On-grid electric power volume	The high on-grid electric power volume will decrease the average power generation costs of DNG-CCHP system.
S_{28}	Income from sale of electricity	The income from sale of electricity is an important revenue source of DNG-CCHP system.
S_{29}	Cooling and heating prices	The price of cooling and heating of DNG-CCHP generally only covers maintenance and water costs, saving the investment cost of facilities and thus improving the economics.
S_{30}	Power outage loss	The grid-connected power generation of DNG-CCHP system can improve the reliability of power supply on the user side, and reduce the loss of power outages, which increases the economics.
S_{31}	Carbon trading income	With the gradual liberalization of the carbon trading market, the reduced carbon emissions due to the user-side installation of distributed power generation can carry out certain carbon trading, and the annual incomes from user-side carbon trading can be expressed by the product of carbon trading price and reduced carbon emissions.
S_{32}	Subsidy income	In order to encourage users to install distributed power generation systems to promote clean energy generation, China have implemented certain subsidies for installing distributed power generation systems on the user side.
S_{33}	Environmental protection policy	Natural gas is an efficient, low-carbon, clean and high-quality energy sources, and the implementation of environmental protection policies will greatly promote the development of DNG-CCHP systems and improve the economics of these systems.
S_{34}	The mastery of the core technologies of the DNG-CCHP system	The core technology of China's DNG-CCHP still relies on imports, and the high import prices and maintenance and maintenance costs are one of the important reasons for the low economics of China's DNG-CCHP systems.

3. Systematic Analysis Model Based on DEMATEL and ISM

The economics of DNG-CCHP system is affected by many factors, and the intrinsic relationships usually exist among the factors, which constitutes a complex system. Therefore, it should analyze the influence mechanism of various factors on the economics of CCHP system from the structural perspective, so as to explore new paths to improve the economics of DNG-CCHP system. In general, the existing structural research methods mainly include structural analysis methods such as analytic hierarchy process (AHP) [43] and interpretative structural modeling (ISM) [44], management analysis tools such as the Balanced Scorecard [45], Delphi [46], efficacy-efficiency-effectiveness (3E) theory [47] and the Fault Tree Analysis (FTA) [48], mathematical analysis tools such as Grey Theory [49], attribute reduction methods [50] and clustering and factor analysis [51], and systems science methods such as the soft system methodology (SSM) [52].

Compared with other methods, ISM can not only facilitate the understanding of factors, but also analyze the influence relationship between various factors, finding the logical structure of factors interdependent and dependent, which can make the complex factor system structured and layered [44]. The ISM method makes up for the insufficiency of the above-mentioned methods to effectively analyze the intrinsic influence mechanism between structural factors, and meets the requirements of relevance, hierarchy and complexity of DNG-CCHP economic influencing factors, having the advantages of scientificity, integrity and operability. Since the ISM method requires a large number of complex matrix operations to obtain the reachable matrix, in order to reduce the computational complexity, the DEMATEL approach [53] is introduced into the ISM method in this paper. This section will introduce the DEMATEL and ISM first, and then gives the principle and steps of using integrated DEMATEL-ISM technique to analyze the influencing factors of DNG-CCHP systems' economics.

3.1. DEMATEL Technique

The DEMATEL method is a method proposed by American scholars to analyze system factors using graph theory and matrix theory [53]. Through the logical relationship between various factors in the system, a direct relation matrix is constructed to calculate the degree of influence of each factor on other factors and the degree of each factor being influenced. Based on this, the type of the factor (cause factor or result factor) is obtained, and the structure diagram of the whole system can be adjusted according to the threshold value, so that the system structure is more reasonable. The specific steps of the DEMATEL method are as follows [53,54]:

Step 1: Determine the influencing factors of the system, named $S = \{S_1, S_2, \ldots, S_n\}$;

Step 2: Investigate the mutual influence relationship between different factors, and set the corresponding to determine the direct relation matrix X via expert scoring method:

$$X = \begin{bmatrix} 0 & x_{12} & \cdots & x_{1n} \\ x_{21} & 0 & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & 0 \end{bmatrix} \quad (1)$$

where $x_{ij}(i = 1, 2, \ldots, n; j = 1, 2, \ldots, n; i \neq j)$ means the direct influence degree of factor S_i on S_j, and $x_{ij} = 0$ when $i = j$;

Step 3: Normalized direct relation matrix X and obtain the normalized matrix G $(G = [g_{ij}]_{n\times n})$:

$$G = \frac{1}{\underset{1\le i\le n}{max} \sum_{j=1}^{n} x_{ij}} X \quad (2)$$

It can be inferred that $0 \le g_{ij} \le 1$ and $\underset{1\le i\le n}{\max} \sum\limits_{j=1}^{n} g_{ij} = 1$;

Step 4: Calculate the comprehensive relation matrix T $(T = [t_{ij}]_{n\times n})$ according to the following equation:

$$T = G(I - G)^{-1} \quad (3)$$

where I is the unit matrix;

Step 5: Calculate the influencing degree and influenced degree of each factor. Specifically, the influencing degree of the corresponding factor can be obtained via adding the elements in the matrix T by rows, and the influenced degree of the factor can be calculated by adding the elements in the matrix T by columns. For example, the influencing degree and influenced degree of factor S_i are calculated as follows:

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

$$e_i = \sum_{j=1}^{n} t_{ji}, (i = 1, \ldots, n) \tag{5}$$

where f_i is the influencing degree reflecting the total influence of factor S_i on other factors, and e_i is the influenced degree reflecting the total influence of other factors on factor S_i;

Step 6: Calculate the center degree and cause degree of each factor. The center degree can be obtained by adding the influence and influenced degree of the factor, and the cause degree can be obtained by subtracting the influenced degree from the influence degree, that is:

$$m_i = f_i + e_i, (i = 1, \ldots, n) \tag{6}$$

$$n_i = f_i - e_i, (i = 1, \ldots, n) \tag{7}$$

where m_i is the center degree of factor S_i revealing the status and role of S_i in the whole system, and n_i is the cause degree of factor S_i reflecting the type of S_i;

Step 7: Based on the center and cause degrees of the factors, mark each factor in the Cartesian coordinate system, so as to analyze the importance of each factor and make suggestions for the actual system.

3.2. ISM Method

The interpretative structural modeling (ISM) was developed in the United States in 1973 by Warfield [55], initially as an analytical method for exploring problems related to complex socio-economic systems, and has become an important structural modeling technique and a relatively effective system analysis tool [44,56]. The main feature of ISM is the decomposition of complex systems into several subsystem elements by means of accumulated practical experience and knowledge, and to find out the interrelationship between the various elements to form structural graph and matrix. Through the corresponding matrix transformation and calculus, the fuzzy and complicated system can be clarified and simplified, and the simplified structural relationship can be constructed into a multi-level hierarchical structural model, which is convenient for system analysis. Its advantage lies in its ability to centrally express how the subsystems are relate to each other, not the quantity relationship, and has a strong interpretative function. When an organization encounters a complex system problem, there are a large number of factors in the system having direct or indirect relationships. These factors complicate the system structure, making it hard to clearly express the structural relationship of these factors in the system. ISM is a method that can identify the system structure, solve complex system problems that contain a large number of factors, and can establish a hierarchical relationship diagram between factors by identifying variables. The workflow of ISM can be divided into the judgment decision stage and the calculation processing stage, which can be represented by Figure 2.

The steps of ISM are [44,56]:

Step 1: Present the problem under study and determine the influencing factors of the problem, named $S = \{S_1, S_2, \ldots, S_n\}$;

Step 2: Determine the relationship between the influencing factors and construct an adjacency matrix $A = [a_{ij}]$, of which:

$$a_{ij} = \begin{cases} 0, S_i\overline{R}S_j \\ 1, S_iRS_j \end{cases} \tag{8}$$

where R means S_i has influence on S_j, and $\overline{R}$ represents S_i has no influence on S_j;

Step 3: Calculate the reachability matrix reflecting the direct and indirect relations of the factors in the system. The reachability matrix can be calculated from the adjacency matrix A using Boolean algebraic algorithm, that is:

$$(A+I) \neq (A+I)^2 \neq (A+I)^3 \neq \cdots\cdots \neq (A+I)^m = (A+I)^{m+1} = K(m \leq n-1) \quad (9)$$

where I is the unit matrix and n is the order of the matrix A. When $(A+I)^m = (A+I)^{m+1}$, $K = (A+I)^{m+1}$ is called the reachability matrix. When $k_{ij} = 1$, it reveals that S_i has influence on S_j, and if $k_{ij} = 0$, it means that S_i has no influence on S_j;

Step 4: Divide the reachability matrix and draw a hierarchical structure diagram. Firstly, determine the reachable set R_i, the antecedent set A_i and the collective set C_i of each factor by the following equations:

$$R_i = \{S_j | S_j \in S, k_{ij} = 1\} \quad (10)$$

$$A_i = \{S_j | S_j \in Y, k_{ji} = 1\} \quad (11)$$

$$C_i = R_i \cap A_i \quad (12)$$

Then, for any factor S_i, if $C_i = R_i$, it can be inferred that S_i is the top-level factor. At this time, the i-th row and column can be deleted, and a new reachability matrix is obtained.

Step 5: Repeat step 4 until all factors are deleted, and a hierarchical structure from top to bottom can be established according to the order in which the factors are deleted.

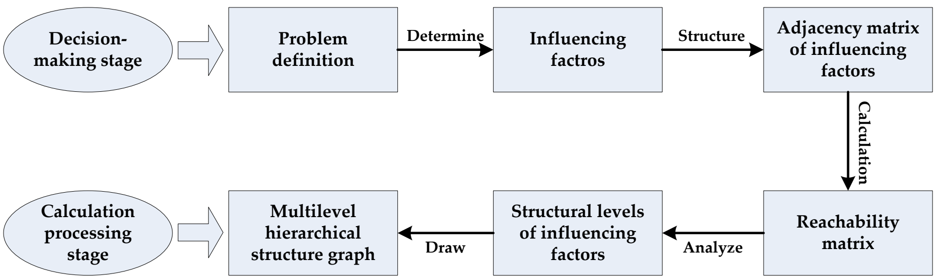

Figure 2. The workflow of the ISM method.

3.3. Ideas and Steps of the Integrated Technique

Both DEMATEL and ISM are system structure modeling methods that use matrix and graph theory to analyze system factors based on the direct pairwise relationship between system factors. DEMATEL focuses on the analysis of the relative importance of system factors and the division of cause factors and result factors, while ISM focuses on the establishment of systematic hierarchical structure that reflects the interaction of system factors [54,56]. Based on the commonality of the two methods, the integration of DEMATEL and ISM can achieve the simplification of the calculation of ISM and obtain the relative importance, natures and interactions of the system factors. The commonalities between DEMATEL and ISM method is reflected in [57]: the non-zero elements in the total relation matrix of DEMATEL and the reachability matrix of ISM represent the mutual influence relationship between the factors, while the zero elements represent the non-existing relationship between the factors. Since the total relation matrix of DEMATEL contains more information than the reachability matrix of ISM, the total relation matrix can be calculated by DEMATEL method to replace the reachability matrix. In this paper, the integrated DEMATEL-ISM technique is employed to construct the systematic hierarchical structure reflecting the affecting mechanism of the factors affecting the economics of DNG-CCHP system, and the steps are reported as below [57,58]:

Step 1: Determine the affecting factors of the economics of DNG-CCHP system, that is, $S = \{S_1, S_2, \ldots, S_n\}$;

Step 2: Calculate the comprehensive relation matrix using DEMATEL approach, according to the Steps 1–4 of DEMATEL section;

Step 3: Calculate the total relation matrix $H = [h_{ij}]$ using the following equation:

$$H = T + I \tag{13}$$

where T is the comprehensive matrix obtained by DEMATEL approach;

Step 4: Determine the reachability matrix $K = [k_{ij}]$ according to the obtained total relation matrix:

$$k_{ij} = \begin{cases} 0, \ h_{ij} < \lambda \\ 1, \ h_{ij} \geq \lambda \end{cases} \tag{14}$$

where λ is the threshold value of reachability matrix. By setting the threshold value, it is possible to eliminate the relationship with less influence, thereby simplifying the system structure and facilitating the subsequent division of the systematic interpretative structural levels of the factors. In general, for systems with fewer factors, there is no need to simplify the system structure, so the value of λ can be 0. For more complex systems, the value of λ can be set according to the needs of decision makers and the experience of relevant experts, which can simplify the system [59].

Step 5: Determine the systematic hierarchical structure based on the obtained reachability matrix, following the Steps 4–5 of ISM section.

4. Results and Interpretations

4.1. Determining the Comprehensive Relation Matrix

In this section, the factors affecting the economics of DNG-CCHP systems are analyzed using integrated DMTATEL-ISM technique, aiming to explore the influence mechanism of each factor on the economics of DNG-CCHP system. Firstly, the direct relation matrix $X = [x_{ij}]$ of DEMATEL is obtained according to the judgment of 20 experts from research institutes, grid enterprises, government regulatory agency and engineering construction units, as shown in Table 2.

In Table 2, the value of element x_{ij} determined by the experts is ranged from 0 to 5, of which $x_{ij} = 0$ indicates factor S_i has no influence on factor S_j, and $x_{ij} = 5$ reveals factor S_i has strong influence on factor S_j. When $i = j$, $x_{ii} = x_{jj} = 0$, and when $i \neq j$, the value of x_{ij} is obtained by [60]:

$$x_{ij} = \begin{cases} 0, & no\ experts\ supports\ that\ S_i\ can\ affect\ S; \\ 1, & 1\%–19\%\ of\ experts\ supports\ that\ S_i\ can\ affect\ S_j \\ 2, & 20\%–39\%\ of\ experts\ supports\ that\ S_i\ can\ affect\ S_j \\ 3, & 40\%–59\%\ of\ experts\ supports\ that\ S_i\ can\ affect\ S_j \\ 4, & 60\%–79\%\ of\ experts\ supports\ thatS\ can\ affect\ S_j \\ 5, & over\ 80\%\ of\ experts\ supports\ that\ S_i\ can\ affect\ S_j \end{cases} \tag{15}$$

According to Equation (2), the normalized matrix G can be obtained, and subsequently, the comprehensive relation matrix T is calculated via Equation (3), as reported in Table 3.

4.2. Determining the Reachability Matrix

The comprehensive relation matrix T determined by DEMATEL only reflects the mutual influence relationships and degrees of different factors, while does not consider the influence of factors on itself. Therefore, it is necessary to calculate the overall influence relationship between the various factors of the system, that is, the total relation matrix H, according to Equation (13). Hereafter, the reachability matrix K can be obtained via the total relation matrix and the threshold value λ. In this section, according to the actual operation status of China's DNG-CCHP system and experts' experience, the threshold value is set to be $\lambda = 0.05$. The obtained reachability matrix is listed in Table 4.

Table 2. The direct relation matrix of DEMATEL.

	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_{17}	S_{18}	S_{19}	S_{20}	S_{21}	S_{22}	S_{23}	S_{24}	S_{25}	S_{26}	S_{27}	S_{28}	S_{29}	S_{30}	S_{31}	S_{32}	S_{33}	S_{34}
S_1	0	0	0	4	0	3	2	3	2	0	0	0	1	0	0	0	1	0	0	5	4	4	5	5	0	0	3	3	0	3	3	4	0	0
S_2	3	0	3	2	4	0	2	1	2	2	0	0	3	0	0	0	0	0	0	3	0	3	2	3	4	4	3	2	4	0	0	0	3	0
S_3	3	0	0	3	4	3	4	5	2	2	1	0	3	0	0	2	1	0	0	3	2	3	4	2	5	5	4	4	2	3	3	4	2	2
S_4	2	0	0	0	4	3	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	4	5	3	0	0	4	4	0	5	3	3	0	0
S_5	4	0	0	5	0	4	3	3	0	2	2	0	0	0	1	2	0	0	0	0	0	3	2	4	3	3	5	3	0	3	0	3	0	0
S_6	4	0	0	3	3	0	5	3	0	2	2	0	0	0	0	0	4	1	0	5	4	2	5	4	0	0	3	0	0	5	0	0	0	3
S_7	3	0	2	4	3	3	0	2	4	3	2	0	0	0	0	3	2	0	0	4	2	3	4	3	2	1	3	2	0	3	4	4	0	0
S_8	2	0	0	3	3	3	2	0	0	2	2	0	0	0	0	0	0	4	0	2	1	3	3	3	3	3	4	4	0	4	0	0	0	0
S_9	3	0	0	2	0	0	5	4	0	3	3	0	3	3	2	4	2	4	3	3	2	2	0	3	0	0	3	3	0	2	0	0	2	2
S_{10}	4	0	2	3	0	3	3	4	0	0	3	2	0	5	4	0	3	4	3	4	2	3	0	5	0	0	0	0	3	4	0	0	0	0
S_{11}	3	0	0	3	0	3	4	4	0	3	0	2	0	4	4	0	2	4	3	3	2	4	3	5	0	0	0	0	3	3	0	0	0	0
S_{12}	0	0	0	0	0	0	2	3	0	4	4	0	5	4	5	5	5	4	4	3	3	4	3	3	0	0	4	4	4	0	4	3	0	4
S_{13}	3	0	0	0	0	0	3	3	0	3	3	4	0	2	2	5	1	3	5	0	0	5	3	3	2	2	3	4	4	0	0	0	0	0
S_{14}	3	0	0	2	0	3	3	4	1	5	5	4	3	0	5	3	2	3	4	3	2	3	3	4	3	3	0	0	0	0	0	0	0	0
S_{15}	3	0	0	2	0	4	3	3	0	4	4	0	0	5	0	0	0	4	3	0	0	4	0	3	0	0	0	2	3	0	0	0	0	0
S_{16}	4	0	0	3	0	0	3	4	0	3	3	3	0	3	3	0	0	4	5	0	0	0	0	4	0	0	4	5	4	3	0	0	0	0
S_{17}	3	0	0	3	3	4	5	5	0	3	3	0	0	0	0	3	0	3	3	3	3	0	0	5	0	0	5	3	0	4	0	0	0	0
S_{18}	3	0	0	3	0	0	4	4	0	3	3	0	3	3	3	3	0	0	4	0	0	4	0	3	4	4	3	3	4	0	0	0	0	0
S_{19}	4	0	0	3	0	0	5	4	0	4	4	0	0	2	3	3	0	0	0	0	0	5	0	4	3	3	0	4	4	0	0	0	0	0
S_{20}	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	4	0	0	0	0	0	0	0	0	0	0	0
S_{21}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{22}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{23}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{24}	0	0	0	3	0	4	4	4	3	0	0	0	0	0	0	3	4	0	3	5	3	5	5	0	0	0	5	4	0	3	5	5	0	0
S_{25}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	0	0	5	3	3	0	0	0	0	0	0
S_{26}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	0	5	0	3	3	0	0	0	0	0	0
S_{27}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	5	3	3	0	5	0	3	5	5	0	0
S_{28}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0
S_{29}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	4	3	4	3	3	0	0	0	0	0	0
S_{30}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{31}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{32}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{33}	4	0	0	3	0	3	5	3	3	3	3	3	4	1	2	3	0	4	3	0	0	3	0	4	4	4	4	3	3	2	4	4	0	4
S_{34}	3	0	0	2	0	5	5	4	0	3	3	0	0	0	5	0	5	2	0	5	5	3	5	3	3	3	2	3	4	5	4	4	0	0

Table 3. The comprehensive relation matrix of DEMATEL.

	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_{17}	S_{18}	S_{19}	S_{20}	S_{21}	S_{22}	S_{23}	S_{24}	S_{25}	S_{26}	S_{27}	S_{28}	S_{29}	S_{30}	S_{31}	S_{32}	S_{33}	S_{34}
S_1	0.01	0.00	0.00	0.06	0.01	0.05	0.04	0.05	0.03	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.02	0.01	0.01	0.07	0.06	0.06	0.08	0.07	0.01	0.01	0.05	0.05	0.00	0.05	0.05	0.06	0.00	0.00
S_2	0.05	0.00	0.04	0.04	0.05	0.02	0.05	0.03	0.03	0.04	0.01	0.01	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.01	0.07	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.02	0.02	0.02	0.04	0.00
S_3	0.06	0.00	0.00	0.06	0.06	0.06	0.08	0.08	0.03	0.04	0.03	0.01	0.04	0.01	0.01	0.04	0.03	0.02	0.01	0.06	0.04	0.08	0.09	0.06	0.08	0.08	0.08	0.08	0.03	0.07	0.06	0.07	0.02	0.03
S_4	0.03	0.00	0.00	0.01	0.05	0.05	0.05	0.05	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.06	0.08	0.05	0.01	0.01	0.06	0.06	0.00	0.07	0.05	0.05	0.00	0.00
S_5	0.06	0.00	0.00	0.08	0.01	0.06	0.06	0.05	0.01	0.03	0.03	0.00	0.00	0.01	0.02	0.03	0.01	0.01	0.01	0.02	0.01	0.07	0.06	0.07	0.05	0.04	0.08	0.06	0.01	0.06	0.02	0.05	0.00	0.00
S_6	0.06	0.00	0.00	0.06	0.05	0.02	0.09	0.06	0.01	0.04	0.04	0.00	0.00	0.01	0.01	0.01	0.06	0.02	0.01	0.08	0.07	0.05	0.09	0.08	0.01	0.01	0.06	0.03	0.01	0.09	0.02	0.02	0.00	0.04
S_7	0.06	0.00	0.03	0.07	0.05	0.05	0.03	0.05	0.05	0.05	0.04	0.00	0.00	0.01	0.01	0.05	0.03	0.01	0.01	0.07	0.04	0.06	0.08	0.07	0.03	0.02	0.06	0.05	0.01	0.06	0.06	0.07	0.00	0.00
S_8	0.04	0.00	0.00	0.05	0.04	0.05	0.04	0.02	0.01	0.03	0.03	0.00	0.00	0.01	0.01	0.01	0.01	0.05	0.01	0.04	0.02	0.06	0.06	0.06	0.05	0.05	0.07	0.07	0.01	0.07	0.01	0.02	0.00	0.00
S_9	0.07	0.00	0.00	0.05	0.01	0.03	0.10	0.08	0.01	0.06	0.06	0.01	0.04	0.05	0.04	0.07	0.04	0.07	0.06	0.06	0.04	0.07	0.04	0.08	0.02	0.02	0.07	0.07	0.02	0.05	0.02	0.02	0.02	0.03
S_{10}	0.07	0.00	0.03	0.07	0.01	0.06	0.07	0.08	0.01	0.03	0.06	0.03	0.01	0.07	0.06	0.02	0.05	0.07	0.06	0.08	0.05	0.08	0.04	0.10	0.02	0.02	0.03	0.03	0.05	0.08	0.02	0.02	0.00	0.00
S_{11}	0.06	0.00	0.00	0.06	0.01	0.06	0.08	0.08	0.01	0.06	0.02	0.03	0.01	0.06	0.06	0.02	0.04	0.07	0.05	0.06	0.04	0.08	0.07	0.10	0.02	0.02	0.03	0.03	0.05	0.06	0.02	0.02	0.00	0.00
S_{12}	0.04	0.00	0.00	0.03	0.01	0.03	0.07	0.08	0.01	0.08	0.08	0.01	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.06	0.06	0.09	0.07	0.09	0.02	0.02	0.08	0.09	0.07	0.03	0.07	0.06	0.00	0.05
S_{13}	0.06	0.00	0.00	0.03	0.01	0.02	0.07	0.07	0.01	0.06	0.06	0.05	0.01	0.04	0.04	0.07	0.03	0.06	0.08	0.02	0.02	0.10	0.07	0.08	0.04	0.04	0.06	0.08	0.06	0.02	0.02	0.02	0.00	0.00
S_{14}	0.07	0.00	0.00	0.06	0.01	0.06	0.08	0.09	0.02	0.09	0.09	0.06	0.04	0.02	0.08	0.06	0.04	0.06	0.07	0.07	0.05	0.09	0.08	0.09	0.05	0.05	0.04	0.04	0.02	0.03	0.02	0.02	0.00	0.01
S_{15}	0.06	0.00	0.00	0.05	0.01	0.07	0.06	0.06	0.01	0.07	0.07	0.01	0.01	0.07	0.02	0.01	0.01	0.06	0.05	0.03	0.02	0.08	0.03	0.07	0.02	0.01	0.02	0.05	0.05	0.02	0.01	0.02	0.00	0.00
S_{16}	0.07	0.00	0.00	0.06	0.01	0.02	0.07	0.08	0.01	0.06	0.06	0.04	0.01	0.05	0.05	0.02	0.01	0.07	0.08	0.02	0.02	0.04	0.03	0.09	0.02	0.02	0.07	0.09	0.06	0.06	0.02	0.02	0.00	0.00
S_{17}	0.06	0.00	0.00	0.06	0.05	0.07	0.09	0.09	0.01	0.05	0.05	0.00	0.00	0.01	0.01	0.05	0.01	0.05	0.05	0.06	0.05	0.04	0.04	0.10	0.02	0.02	0.09	0.07	0.01	0.08	0.02	0.02	0.00	0.00
S_{18}	0.06	0.00	0.00	0.06	0.01	0.02	0.07	0.08	0.01	0.06	0.05	0.01	0.04	0.05	0.05	0.05	0.01	0.02	0.06	0.02	0.01	0.09	0.04	0.07	0.07	0.07	0.06	0.07	0.06	0.03	0.02	0.02	0.00	0.00
S_{19}	0.07	0.00	0.00	0.06	0.01	0.02	0.08	0.07	0.01	0.06	0.06	0.01	0.00	0.04	0.05	0.04	0.01	0.02	0.02	0.02	0.02	0.09	0.03	0.08	0.05	0.05	0.03	0.07	0.06	0.02	0.02	0.02	0.00	0.00
S_{20}	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{21}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{22}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{23}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{24}	0.02	0.00	0.00	0.05	0.01	0.06	0.07	0.07	0.04	0.01	0.01	0.00	0.00	0.01	0.01	0.05	0.05	0.01	0.04	0.07	0.05	0.08	0.08	0.03	0.01	0.01	0.08	0.07	0.01	0.06	0.07	0.07	0.00	0.00
S_{25}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.00	0.06	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00
S_{26}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.06	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00
S_{27}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.06	0.04	0.04	0.01	0.07	0.00	0.04	0.06	0.06	0.00	0.00
S_{28}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00
S_{29}	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.00	0.00	0.02	0.01	0.05	0.04	0.05	0.04	0.05	0.00	0.01	0.01	0.01	0.00	0.00
S_{30}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{31}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{32}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_{33}	0.08	0.00	0.00	0.07	0.01	0.06	0.10	0.08	0.05	0.06	0.06	0.04	0.06	0.03	0.05	0.06	0.02	0.07	0.06	0.03	0.03	0.09	0.05	0.10	0.07	0.07	0.09	0.08	0.06	0.06	0.07	0.08	0.00	0.05
S_{34}	0.06	0.00	0.00	0.05	0.01	0.08	0.09	0.08	0.01	0.05	0.05	0.00	0.00	0.01	0.07	0.01	0.07	0.04	0.02	0.08	0.08	0.07	0.10	0.07	0.05	0.05	0.05	0.07	0.06	0.09	0.06	0.07	0.00	0.00

Table 4. The reachability matrix of ISM.

	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_{17}	S_{18}	S_{19}	S_{20}	S_{21}	S_{22}	S_{23}	S_{24}	S_{25}	S_{26}	S_{27}	S_{28}	S_{29}	S_{30}	S_{31}	S_{32}	S_{33}	S_{34}
S_1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	1	1	0	1	0	1	0	0
S_2	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	1	0	0	0	0	0
S_3	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	1	1	1	0	0
S_4	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	1	0	1	0	0
S_5	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	1	0	1	0	0
S_6	1	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0	0	1	0	0	1	0	0	0	0
S_7	1	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0	1	1	0	1	1	1	0	0
S_8	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	0	1	1	0	1	0	0	0	0
S_9	1	0	0	1	0	0	1	1	1	1	1	0	0	1	0	1	0	1	1	1	0	1	0	1	0	0	1	1	0	1	0	0	0	0
S_{10}	1	0	0	1	0	1	1	1	0	1	1	0	0	1	1	0	1	1	1	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0
S_{11}	1	0	0	1	0	1	1	1	0	1	1	0	0	1	1	0	0	1	1	1	0	1	1	1	0	0	0	0	0	1	0	0	0	0
S_{12}	0	0	0	0	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	0	0
S_{13}	1	0	0	0	0	0	1	1	0	1	1	1	1	0	0	1	0	1	1	0	0	1	1	1	0	0	1	1	1	0	0	0	0	0
S_{14}	1	0	0	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0
S_{15}	1	0	0	0	0	1	1	1	0	1	1	0	0	1	1	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
S_{16}	1	0	0	1	0	0	1	1	0	1	1	0	0	1	1	1	0	1	1	0	0	0	0	1	0	0	1	1	1	1	0	0	0	0
S_{17}	1	0	0	1	0	1	1	1	0	1	1	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	1	1	0	1	0	0	0	0
S_{18}	1	0	0	1	0	0	1	1	0	1	1	0	0	0	0	0	0	1	1	0	0	1	0	1	1	1	1	1	1	0	0	0	0	0
S_{19}	1	0	0	1	0	0	1	1	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	1	1	0	0	0	0	0
S_{20}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
S_{21}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{22}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
S_{23}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S_{24}	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0	0	1	1	0	1	1	1	0	0
S_{25}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0
S_{26}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0
S_{27}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	0	1	1	0	0
S_{28}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
S_{29}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0
S_{30}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
S_{31}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
S_{32}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
S_{33}	1	0	0	1	0	1	1	1	0	1	1	0	1	0	0	1	0	1	1	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1
S_{34}	1	0	0	1	0	1	1	1	0	1	1	0	0	0	1	0	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1

4.3. Division of the Structural Levels of Factors

On the basis of the obtained reachability matrix, the structural levels of all factors can be divided following the Steps 4–5 of ISM section. Specifically, based on Table 4, the initial reachable set R_i, antecedent set A_i and collective set C_i of each factor can be obtained, as represented in Table 5. From Table 5, it can be seen that the formula $R_i = C_i$ is supported for factors S_{21}, S_{22}, S_{23}, S_{28}, S_{30}, S_{31} and S_{32}, revealing that these factors are located in the first level, that is, the top of the hierarchical structure.

Table 5. Reachable set, antecedent set and collective set of each factor in the first round.

Factor	R_i	A_i	C_i
S_1	1, 4, 20–24, 27, 28, 30, 32	1–3, 5–7, 9–11	1
S_2	1, 2, 5, 20, 22–29	2	2
S_3	1, 3–8, 20, 22–28, 30–32	3	3
S_4	4, 5, 22–24, 27, 28, 30, 32	1, 3–11, 14, 16–19, 24, 33, 34	4, 5, 24
S_5	1, 4–8, 22–24, 27, 28, 30, 32	2–5	4, 5
S_6	1, 4, 6–8, 17, 20–24, 27, 28, 30	3, 5–7, 10, 11, 14, 15, 17, 24, 33, 34	6, 7, 17, 24
S_7	1, 4, 6, 7, 9, 20, 22–24, 27, 28, 30, 32	3, 5–7, 9-19, 24, 33, 34	6, 7, 9, 24
S_8	1, 8, 18, 22–24, 27, 28, 30	3, 5, 6, 8–19, 24, 33, 34	8, 18, 24
S_9	1, 4, 9–11, 14, 16, 18–20, 22, 24, 27, 28, 30	7, 9	7, 9
S_{10}	1, 4, 6–8, 10, 11, 14, 15, 17–20, 22, 24, 30	9–19, 33, 34	10, 11, 14, 15, 17–19
S_{11}	1, 4, 6–8, 10, 11, 14, 15, 18–20, 22–24, 30	9–19, 33, 34	10, 11, 14, 15, 18, 19
S_{12}	7, 8, 10–24, 27–29, 31, 32	12–14	12–14
S_{13}	1, 7, 8, 10-13, 16, 18, 19, 22-24, 27-29	12, 13, 33	12, 13
S_{14}	1, 4, 6–8, 10–12, 14–16, 18–20, 22–26	9–12, 14–16	10–12, 14–16
S_{15}	1, 6–8, 10, 11, 14, 15, 18, 19, 22, 24	10–12, 14–16, 34	10, 11, 14, 15
S_{16}	1, 4, 7, 8, 10, 11, 14-16, 18, 19, 24, 27–30	9, 12–14, 16, 33	14, 16
S_{17}	1, 4, 6–8, 10, 11, 17, 20, 21,24, 27, 28, 30	6, 10, 12, 17, 24, 34	6, 10, 17, 24
S_{18}	1, 4, 7, 8, 10, 11, 18, 19, 22, 24–29	8–16, 18, 33	8, 10, 11, 18
S_{19}	1, 4, 7, 8, 10, 11, 19, 22, 24, 28, 29	9–16, 18, 19, 33	10, 11, 19
S_{20}	20, 21, 23	1–3, 6, 7, 9–12, 14, 17, 20, 24, 34	20
S_{21}	21	1, 6, 12, 17, 20, 21, 24, 34	21
S_{22}	22	1–15, 18, 19, 22, 24–27, 33, 34	22
S_{23}	23	1–8, 11–14, 20, 23–27, 34	23
S_{24}	4, 6–8, 17, 20–24, 27, 28, 30, 32	1–19, 24, 27, 29, 33, 34	4, 6–8, 17, 24
S_{25}	22, 23, 25, 26	2, 3, 14, 18, 25, 26, 33, 34	25, 26
S_{26}	22, 23, 25, 26	2, 3, 14, 18, 25, 26, 29, 33	25, 26
S_{27}	22–24, 27, 28, 31, 32	1–9, 12, 13, 16–18, 24, 27, 33, 34	24, 27
S_{28}	28	1–5, 7–9, 12, 13, 16–19, 24, 27, 28, 33, 34	28
S_{29}	24, 26, 29	2, 12, 13, 16, 18, 19, 29, 33, 34	29
S_{30}	30	1, 3–11, 16, 17, 24, 30, 33, 34	30
S_{31}	31	3, 7, 12, 24, 27, 31–34	31
S_{32}	32	1, 3–5, 7, 12, 24, 27, 32–34	32
S_{33}	1, 4, 6–8, 10, 11, 13, 16, 18, 19, 22, 24-34	33	33
S_{34}	1, 4, 6–8, 10, 11, 15, 17, 20–25, 27–32, 34	33, 34	34

Subsequently, we delete these seven factors from Table 5 and repeat the Step 4 of ISM section, and the reachable sets, antecedent sets and collective sets of the rest factors can be obtained, as shown in Table 6. It can be seen from Table 6 that factors S_{20}, S_{25}, S_{26} and S_{27} hold the equation $R_i = C_i$, indicating that these 4 factors are located in the second level of the hierarchical structure.

Similarly, we delete these 4 factors from Table 6 and repeat the Step 4 of ISM section, so as to get the reachable sets, antecedent sets and collective sets of the rest factors, which can obtain the third level of the hierarchical structure. Repeat the above step until all factors are deleted, so that the structural levels of all factors are determined, as listed in Table 7.

Table 6. Reachable set, antecedent set and collective set of each factor in the second round.

Factor	R_i	A_i	C_i
S_1	1, 4, 20, 24, 27	1–3, 5–7, 9–11	1
S_2	1, 2, 5, 20, 24–27, 29	2	2
S_3	1, 3–8, 20, 24–27	3	3
S_4	4, 5, 24, 27	1, 3–11, 14, 16–19, 24, 33, 34	4, 5, 24
S_5	1, 4–8, 24, 27	2-5	4, 5
S_6	1, 4, 6–8, 17, 20, 24, 27	3, 5–7, 10, 11, 14, 15, 17, 24, 33, 34	6, 7, 17, 24
S_7	1, 4, 6, 7, 9, 20, 22, 24, 27	3, 5-7, 9–19, 24, 33, 34	6, 7, 9, 24
S_8	1, 8, 18, 24, 27	3, 5, 6, 8–19, 24, 33, 34	8, 18, 24
S_9	1, 4, 9–11, 14, 16, 18–20, 24, 27	7, 9	7, 9
S_{10}	1, 4, 6–8, 10, 11, 14, 15, 17–20, 24	9–19, 33, 34	10, 11, 14, 15, 17–19
S_{11}	1, 4, 6–8, 10, 11, 14, 15, 18–20, 24	9–19, 33, 34	10, 11, 14, 15, 18, 19
S_{12}	7, 8, 10–20, 24, 27, 29	12–14	12–14
S_{13}	1, 7, 8, 10–13, 16, 18, 19, 24, 27, 29	12, 13, 33	12, 13
S_{14}	1, 4, 6–8, 10–12, 14–16, 18–20, 24–26	9-12, 14–16	10–12, 14–16
S_{15}	1, 6–8, 10, 11, 14, 15, 18, 19, 24	10–12, 14–16, 34	10, 11, 14, 15
S_{16}	1, 4, 7, 8, 10, 11, 14–16, 18, 19, 24, 27, 29	9, 12–14, 16, 33	14, 16
S_{17}	1, 4, 6–8, 10, 11, 17, 20, 24, 27	6, 10, 12, 17, 24, 34	6, 10, 17, 24
S_{18}	1, 4, 7, 8, 10, 11, 18, 19, 24–27, 29	8–16, 18, 33	8, 10, 11, 18
S_{19}	1, 4, 7, 8, 10, 11, 19, 24, 29	9–16, 18, 19, 33	10, 11, 19
S_{20}	20	1–3, 6, 7, 9–12, 14, 17, 20, 24, 34	20
S_{24}	4, 6–8, 17, 20, 24, 27	1–19, 24, 27, 29, 33, 34	4, 6–8, 17, 24
S_{25}	25, 26	2, 3, 14, 18, 25, 26, 33, 34	25, 26
S_{26}	25, 26	2, 3, 14, 18, 25, 26, 29, 33	25, 26
S_{27}	24, 27	1–9, 12, 13, 16–18, 24, 27, 33, 34	24, 27
S_{29}	24, 26, 29	2, 12, 13, 16, 18, 19, 29, 33, 34	29
S_{33}	1, 4, 6–8, 10, 11, 13, 16, 18, 19, 24–27, 29, 33, 34	33	33
S_{34}	1, 4, 6–8, 10, 11, 15, 17, 20, 24, 25, 27, 29, 34	33, 34	34

Table 7. Structural levels of all factors in the hierarchical structure.

Levels	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}
Factors	S_{21}, S_{22}, S_{23}, S_{28}, S_{30}, S_{31}, S_{32}	S_{20}, S_{25}, S_{26}, S_{27}	S_4, S_{24}	S_1, S_{29}	S_7, S_8	S_6, S_{10}, S_{11}, S_{19}	S_5, S_{17}, S_{18}	S_2, S_3, S_{14}, S_{15}	S_{16}, S_{34}	S_9, S_{12}, S_{13}	S_{33}

4.4. Hierarchical Structure Graph and Interpretation

Based on Table 7 displaying the structural levels of all factors affecting the economics of DNG-CCHP system, and Table 4 reporting the reachability matrix of all factors, the hierarchical structure graph reflecting the influencing mechanism of all factors on the economics of DNG-CCHP system is drawn in this section, as shown in Figure 3, from which it can be seen that the 34 factors affecting the economics of DNG-CCHP system are divided into 11 levels. According to Figure 3, several meaningful findings can be discovered:

(1) Factors in the first level are the costs and revenues of DNG-CCHP system, including fuel costs, operation and maintenance costs, financial costs, income from sale of electricity, carbon trading income, subsidy income and power outage loss. In the second level, there are four factors, namely, cold and heat consumption ratio, cooling and heating supply ratio, fixed investment costs of the DNG-CCHP system and on-grid electric power volume, which can affect the economics of DNG-CCHP system directly, too. Among the four factors in the second level, cold and heat consumption ratio and cooling and heating supply ratio can both affect the fuel costs and operation and maintenance costs, which is in line with the feature of DNG-CCHP system, that is, cooling and heating are the main functions, which consume a certain amount of natural gas, resulting in fuel costs and operation and maintenance costs. Fixed investment costs of the DNG-CCHP system has impacts on operation and maintenance costs and financial costs, and in actual DNG-CCHP projects, a certain proportion of fixed investment costs is considered as

operation and maintenance costs, and financial costs are related to the proportion of borrowing funds in the fixed investment cost. It is worth noting that although the factor fixed investment costs of the DNG-CCHP system also is the cost of DNG-CCHP system, it affects the economics of DNG-CCHP system by its depreciation value rather the total value, resulting that this factor is not in the first level. On-grid electric power volume affects all factors in the first level except financial costs and power outage loss, revealing that on-grid electric power volume is a key factor directly affects the economics of DNG-CCHP system. Generally speaking, factors in the first and second levels are all the direct influencing factors of the economics of DNG-CCHP system, so it can be concluded that the 11 factors in these two levels can be regarded as "direct influencing factors" of the economics of DNG-CCHP system.

(2) There are two factors in the third level, annual operating time of the DNG-CCHP system and installed capacity of the DNG-CCHP system, which are obviously significant factors influencing the on-grid electric power volume. Besides, the installed capacity of the DNG-CCHP system can affect the fixed investment costs of the DNG-CCHP system. Meanwhile, the annual operating time of the DNG-CCHP system and installed capacity of the DNG-CCHP system will influence each other, and this is because for DNG-CCHP system, the load faced is relatively stable, resulting that the annual operating time of the DNG-CCHP system and installed capacity of the DNG-CCHP system are negatively correlated. Moreover, the installed capacity of the DNG-CCHP system also has effects on subsidy income and power outage loss, and this is because large-capacity DNG-CCHP systems can get more subsidies, and have less power outage loss due to the higher reliability. In the 4th level, the DNG-CCHP system scale and cooling and heating prices are the factors affecting the economics of DNG-CCHP system, which both have impacts on the installed capacity of the DNG-CCHP system. Besides, the DNG-CCHP system scale can affect the annual operating time of the DNG-CCHP system, resulting from the fact that large-scale DNG-CCHP system is usually located in hotels, office buildings, shopping malls and residential areas with large load, resulting in long operation time. Overall, the four factors in the third and fourth levels will affect the economics of DNG-CCHP system by affecting the direct influencing factors, rather than directly affecting the economics, so these four factors can be called "surface influencing factors" of the economics of DNG-CCHP system.

(3) Firstly, there are two factors in the 5th level, named combined with renewable energy and direct supply of electricity that both have impacts on the DNG-CCHP system scale. The combination of DNG-CCHP systems and renewable energy can effectively increase the utilization of renewable energy, but it may increase the instability of the system's output, thus limiting the scale of the system. On the other hand, direct supply of electricity can ensure that the system has a sufficiently stable load, and systems with direct supply of electricity are generally large-scale systems. Secondly, in the 6th level, there are four factors, namely, integrated optimization and flexible design, long-distance natural gas pipeline construction, LNG supply and gas and electricity price ratio, and these four factors all have impacts on the factors combined with renewable energy and direct supply of electricity. Specifically, the integrated optimization and flexible design of the DNG-CCHP system will affect the combination of system and renewable energy, as well as the system's direct power supply capability, and the long-distance natural gas pipeline construction and LNG supply will affect the supply of natural gas to the system, thus affecting the ability of the system to combine with renewable energy and the to supply electricity directly. The gas and electricity price ratio refers to the ratio of the price of natural gas to electricity, and the higher the ratio, the higher the gas price relative to the electricity price, the lower the economics of the system, which is not conducive to the combination of the system and renewable energy, and it is difficult to undertake large-scale direct supply of electricity due to the poor economics of the system itself. In addition, the long-distance natural gas pipeline construction and LNG supply, which reflect the natural gas supply capacity, will affect each other, and also affect the integrated optimization and flexible design of the DNG-CCHP system and

the gas and electricity price ratio. Thirdly, in the 7th level, there are three factors affecting the economics of DNG-CCHP system, that is, load rate, grid-connected technology and alternative energy prices. Among them, load rate has effects on integrated optimization and flexible design of the DNG-CCHP system, because the systems' integrated optimization and flexible design needs to be able to meet the actual load rate changes. Grid-connected technology will affect integrated optimization and flexible design, long-distance natural gas pipeline construction and LNG supply, showing that the integrated optimization and flexible design cannot be separated from the existing grid-connected technology of distributed energy, and if the grid-connected technology of distributed energy is not mature, the DNG-CCHP system does not need to increase the supply of natural gas. The price of alternative energy will affect the supply of natural gas, as well as the price of natural gas and electricity, thus affecting the gas and electricity price ratio, and gradually affecting the economics of the DNG-CCHP system. Finally, there are four factors in the 8th level, regions and climate, terminal load type, external dependence of natural gas supply and unconventional gas development, influencing the economics of the system. Among them, regions and climate and terminal load type will affect the load rate. Both external dependence of natural gas and unconventional gas development will affect alternative energy prices, which in turn will affect natural gas supply and gas and electricity price ratio. In general, the influence of the 13factors of the 5th to the 8th levels on the economics of DNG-CCHP system is more concealed, that is, they will not directly affect the direct influencing factors of the system economics, but affect the surface influencing factors, thereby transferring their influences layer by layer, and finally show them through direct influencing factors of the top layer. Therefore, these factors can be called "shallow influencing factors" of the economics of DNG-CCHP system.

(4) Firstly, there are two factors affecting the economics of the system in the 9th level, called on-grid price of NGPG and the mastery of the core technologies of the DNG-CCHP system. The on-grid prices of NGPG in China vary a lot in different regions and voltage levels, but they are all subject to government regulation. At present, the on-grid price of NGPG in China is lower than that of natural gas, making the economics of China's NGPG very poor. The reason for the high price of natural gas in China is that it is highly dependent on foreign imports and the development of unconventional natural gas is relatively small. Therefore, the on-grid price of gas-fired power generation will have an impact on external dependence of natural gas supply and unconventional gas development. The mastery of the core technology of DNG-CCHP systems directly affects the development of unconventional natural gas, and also affects the grid-connected technology of distributed energy. In addition, the core technology will have an impact on the way cooling and heating are provided, thus affecting the price of cooling and heating. Secondly, in the 10th level, there are three factors affecting the economics of the system, that is, tax incentives, the degree of natural gas market diversification and natural gas pricing mechanism. Specifically, in order to encourage the development of distributed energy, China has given certain tax incentives to distributed energy projects to improve the economics of such projects. China's tax incentives for the DNG-CCHP system are equivalent to increasing the on-grid price of NGPG to a certain extent, and through tax incentives, it can promote the development of DNG energy, increase the demand for natural gas, and thus affect the external dependence of natural gas supply. The diversification of the natural gas market is an important factor affecting the on-grid price of NGPG. At present, China's natural gas market is in a monopoly of a few energy companies (PetroChina, Sinopec and CNOOC), and the market is not competitive. The natural gas supply for most NGPG projects comes from these companies, resulting that the price of natural gas currently used for power generation is relatively high, and the on-grid price of NGPG is also high, losing the ability to compete with traditional coal-fired power. China's natural gas pricing mechanism was reformed from 2011, but the reforms have caused natural gas prices to rise rapidly, resulting in an increase in gas-fired power. At the same time, the natural gas pricing mechanism will also have an impact on the pattern of the natural gas market. According to

different pricing mechanisms, enterprises will choose different ways to adapt to the new pricing mechanism, so that the market diversification process will be affected by good or bad. Finally, environmental protection policy is the factor influencing the economics of the system in the 11th level. With the continuous advancement of environmental protection policies, the natural gas pricing mechanism will consider the environmental benefits of natural gas, and the on-grid price of NGPG will also be increased in the form of subsidies due to the environmental benefits of NGPG. Furthermore, the implementation of environmental protection policies will also promote the research of DNG-CCHP related core technologies to promote the use of clean energy sources such as distributed natural gas. In general, the impact of the six factors on the 9-11th levels on the economics of DNG-CCHP system is more abstract. They influence the shallow influencing factors to gradually modernized the influence of factors such as policy, market, price mechanism and technology level. Hence, these factors can be called "deep influencing factors" of the economics of DNG-CCHP system.

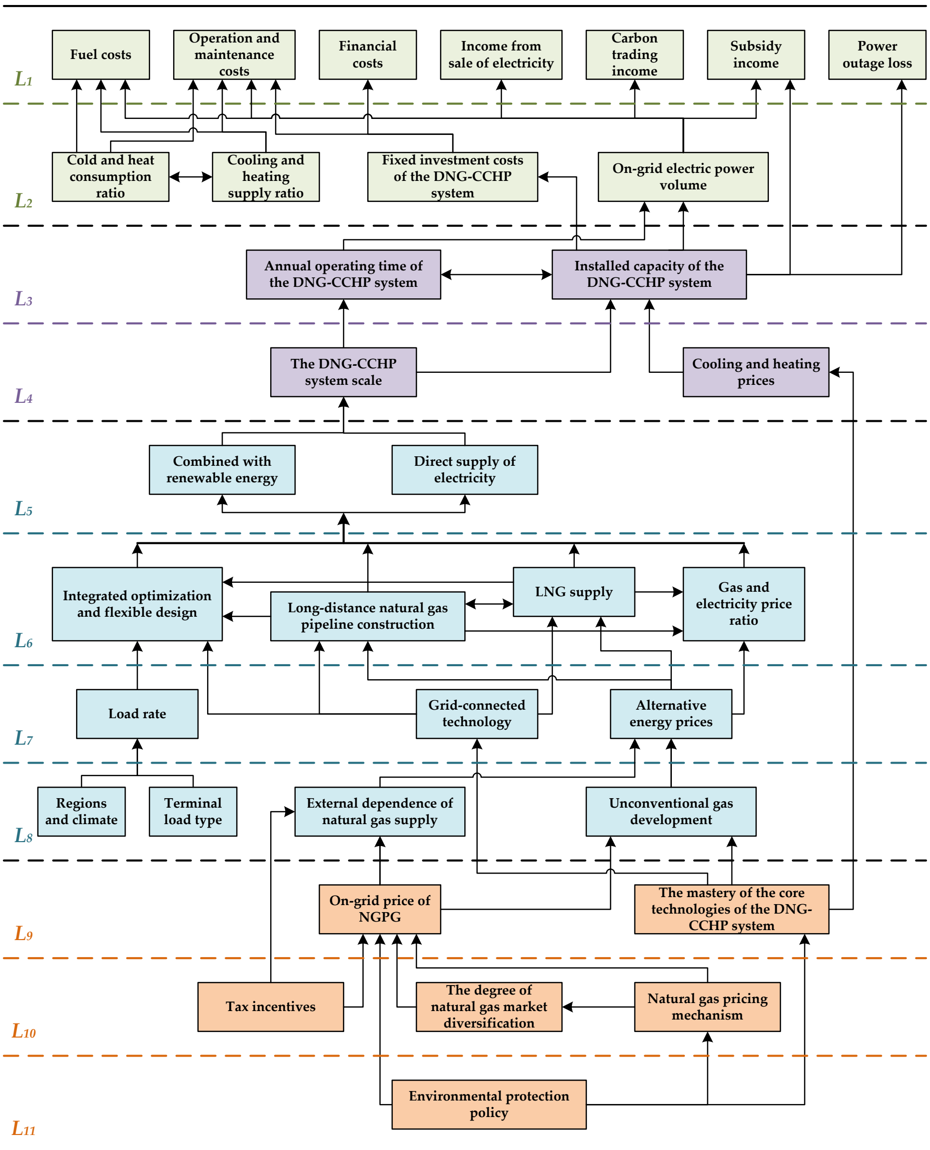

Figure 3. The hierarchical structure graph for the factors affecting the economics of DNG-CCHP systems.

Totally speaking, the 34 factors affecting the economics of DNG-CCHP system are divided into 11 levels, of which factors in the 1st and 2nd levels are regarded as direct influencing factors, those in the 3rd and 4th levels are called surface influencing factors, those in the levels 5–8 are called shallow influencing factors, and those in the levels 9–11 are called deep influencing factors. The direct factors influencing the economics of DNG-CCHP system are mainly the direct costs and revenues of the system, or the factors that affect the direct costs and revenues, and improving these factors is the most direct means to improve the economics of the system. In reality, however, there is a lack of ways to improve direct factors, but mainly by changing other factors to influence direct factors. The surface influencing factors are mainly factors that affect the direct factors, that is, they do not directly affect the economics of the system, but express their influence through direct factors. The improvement of surface influencing factors is an effective and feasible means to improve the economics of the system, but the shortcoming is that the potential for improvement is small. The influence of shallow influencing factors on system economics is more concealed, and often has little to do with the system itself, but mainly with the external factors such as fuel supply, load and the coordination with the power grid. These influencing factors are often difficult to relate to direct system costs or revenues, but rather to the systems' costs or revenues through surface factors. The improvements in these factors are more practical and achievable, and through layer-by-layer conduction, the final effects on the system economics will be more obvious. The impact of deep influencing factors on system economics is often not directly reflected in the system itself, but on other aspects that have an impact on system development, such as technology level, policy, market structure, price mechanism, etc. Improvements to these factors can fundamentally improve the external environment of the DNG-CCHP system, and help to improve the economics of the system continuously, stably, and effectively. However, the improvement of these factors involves the economic and social operation mechanism, which is more difficult. In summary, an effective and feasible way to improve the economics of DNG-CCHP system in China is to improve the surface and shallow influencing factors, while gradually and subtly improving the abysmal influencing factors. Eventually, it will fundamentally improve the economics of China's DNG-CCHP system, promote the use of clean energy represented by natural gas, and contribute to reducing environmental pollution.

5. Discussions and Conclusions

5.1. Discussion

Although DNG-CCHP systems can effectively improve energy efficiency and reduce environmental pollution, the large-scale use of natural gas also inevitably produces CO_2, thereby increasing the global greenhouse effect. In addition, natural gas is a kind of non-renewable energy, and the large use of natural gas will also accelerate the depletion of natural gas resources, thereby affecting global sustainable development. Therefore, combining DNG-CCHP system with distributed renewable energy is an important way to solve the above problems.

The synergistic development of DNG-CCHP system and distributed renewable energy has many advantages. The DNG-CCHP system can realize the step utilization of energy and carry out multiple supplies of cold, heat and electricity. Distributed renewable energy utilizes the natural resources of the user side to form a multi-energy complement with DNG-CCHP system, further improving the user's comprehensive energy utilization efficiency and reducing the system's greenhouse gas emissions. The volatility of distributed renewable energy will affect the power quality and dispatch operation of the grid, while DNG-CCHP system can utilize its peak shaving capability for flexible scheduling, suppressing the volatility of renewable energy, and making the whole system more stable for the grid. Distributed energy can also increase the security of energy supply and is especially significant for critical public infrastructure. In special cases such as extreme weather, DNG-CCHP systems can provide stable power, heat and cold, and distributed renewable energy can further decrease the system's dependence on external energy.

The applications of DNG-CCHP system and distributed renewable energy are not a competing relationship. In fact, combining DNG-CCHP system with distributed renewable energy can create synergies. The combination of distributed renewable energy and DNG-CCHP system can realize the utilization of various energy sources such as electricity, heat, refrigeration and steam. Besides, the complementarity between DNG-CCHP system and distributed renewable energy makes the project's average energy cost lower, while also hedging operational and financial risks. Finally, the coupled system of DNG-CCHP and distributed renewable energy can be compatible with advanced micro-grid and energy Internet technologies, and meet the future energy development trend of intelligent, electronic and informational. Therefore, the complementarity and synergy of DNG-CCHP system and distributed renewable energy can significantly enhance their competitiveness in the energy structure. Actually, China has enacted many policies to promote the development of distributed renewable energy, while the relevant promotion policies for DNG-CCHP development are far less than those of distributed renewable energy. In order to promote the development of DNG-CCHP and realize the integration of distributed natural gas and distributed renewable energy, it can start from the following aspects:

(1) In accordance with the direction of market-oriented reforms, it should implement new price formation mechanisms such as electricity prices, heat prices, and gas prices that are conducive to improving system efficiency. Meanwhile, China can implement the scientific price system such as peak and valley prices, seasonal prices, interruptible prices, high reliability prices, and two-part tariffs, and promote the implementation of price linkage mechanisms involving gas and electricity prices. For complementary projects involving DNG-CCHP and other forms of distributed energy, the government should coordinate the market's price discovery function and government pricing functions, accelerate the construction of the electricity and natural gas spot market, and the power auxiliary service market, and improve the marketization mechanism of ancillary services such as peak shaving, frequency modulation and standby. Before the formation of market-based prices, the implementation of electricity prices, gas prices and ancillary service price mechanisms that are conducive to the performance of various types of power supply regulation, such as a reasonable gas price-electricity price linkage mechanism, the price mechanism of gas prices and alternative energy sources, can help to ensure the economic advantages of DNG-CCHP projects.
(2) Coordinate the preparation of a special national plan for coordinated development of distributed energy. At present, distributed energy planning has not yet been incorporated into the top-level design of China's energy development. The current development of distributed energy is lack of integrated coordination mechanisms with power grid, heating, cooling and other infrastructure construction, resulting that the regional overall energy system cannot achieve optimal configuration, and repeated planning and resource waste have occurred. In order to clarify the development goals of distributed energy and coordinate the relationship between distributed energy and other energy development, it is necessary to separately formulate a nationwide distributed energy development plan. Through special planning, it can clarify the strategic significance, construction goals, development principles, management measures and implementation mechanisms of multi-functional complementarity of distributed energy like distributed natural gas, and the micro-grid intelligent energy system in China's future energy system. The competent energy departments at all levels shall clarify the regional construction goals and tasks in the energy plan, and organize energy, urban construction and other relevant departments to study and formulate comprehensive plans for regional energy supply systems for new energy-using areas such as new towns and new industrial parks. Besides, it should strengthen the connection with relevant plans for cities and land, optimize investment entities through market-based bidding, and make overall arrangements for the construction of energy supply infrastructure.
(3) Implement a proactive fiscal policy to sustain the coordinated development of distributed energy. The National Development and Reform Commission has already subsidized the standard for

distributed photovoltaic power generation in 2013, but so far the country has not yet issued a clear subsidy policy for distributed natural gas. In order to encourage more complementary and coordinated development of natural gas and renewable energy, it is necessary for the National Development and Reform Commission and the National Energy Administration to jointly issue financial support policies for distributed energy industries and projects. On one hand, in areas with developed economy and strong energy price tolerance, government can encourage the introduction of supporting policies for initial investment and operation like accelerated depreciation and tax relief. On the other hand, in the areas with underdeveloped economy, high air pollution and high carbon emissions, the provision of clean development funds through central financial subsidies can encourage the construction of DNG-CCHP projects through some business modes like Public-Private Partnership (PPP) mode and mixed ownership mode. In addition, the nationally recognized multi-energy complementary demonstration projects prioritize the total amount of thermal power installed capacity, renewable energy development scale and subsidies determined by the national energy regulations. The surplus power of the multi-energy complementary demonstration project after the local consumption can be preferentially involved in the cross-provincial power transmission and consumption, and the eligible projects can apply for the renewable electricity price additional subsidy according to the procedure. The provinces can give specific support policies to relevant projects through preliminary investment subsidies or interest subsidies, and special bonds. The power transmission and transmission costs saved by short-distance transmission due to the distributed projects can be returned to distributed power plants, which can improve their economics.

(4) Implement the public and fair access to the grid and electricity sales of distributed energy. On the basis of the Several Opinions on Further Deepening the Reform of the Power System, China will continue to deepen the reform of power transmission and distribution, open up fair access to the grid, and accelerate the market-oriented reform of the power system, allowing distributed energy to trade freely in the electricity market. China is also changing the situation that power grid enterprises integrate power transmission, power purchase, marketing, and dispatching transactions. Actually, power grid enterprises are mainly engaged in power grid investment and operation, power transmission and distribution, responsible for grid system security, ensuring fairness and non-discrimination of power grids, and fulfilling universal power service according to national regulations. It is also essential to establish a unified long-term coordination mechanism to fundamentally resolve the contradictions in the interests and prices in the on-grid process, avoiding the behavior of the power grid companies that do not comply with the laws. At the technical level, specific requirements should be established for the size and voltage level of the accessed power stations, the range of overload and voltage fluctuations, and the quality of the power. Moreover, the grid-connected technical standards should be legally defined to make the on-grid operation of the distributed generation system more operative. In terms of power generation and sales, government should fully recognize the important roles of the distributed multi-energy complementary system in the energy Internet and ensuring power security, encourage self-sufficiency, fully liberalize the nearest direct power supply, and guarantee the full acquisition of surplus power, which can mobilize the enthusiasm of market capital investing distributed power generation systems such as DNG-CCHP system, so as to promote the development of China's distributed energy.

5.2. Conclusions

As a clean energy source, natural gas is widely used to effectively reduce environmental pollution caused by coal and oil in the case of technical difficulties in the use of renewable energy. DNG-CCHP system is a widely used form of distributed utilization of natural gas, with mature technology, high energy efficiency, and user-side requirements. Besides, it can effectively promote energy conservation and emission reduction, and can play the role of cutting peaks and filling valleys, ensuring the reliability of power grid operation and enhancing the safety of energy supply. However, the economics of China's DNG-CCHP system is poor, which has become the main reason hindering the development of China's DNG-CCHP systems. There are many factors affecting the economics of the system, and each factor will affect each other, making it difficult to judge the influence mechanism of various factors on the system economics. Therefore, based on the analysis of the development status and obstacles of China's DNG-CCHP system, this paper constructed a factor set of economic influencing factors of DNG-CCHP system, and then the integrated DEMATEL-ISM method was employed to construct the identification model of the economic influencing factors of DNG-CCHP system, so as to systematically and structurally analyze the factors in the influencing factor set. Finally, the path to enhance the economics of China's DNG-CCHP system was proposed accordingly.

According to the research findings, the 34 factors affecting the economics of DNG-CCHP system constitute a hierarchical structure consisting of 11 levels with four categories, named directly influencing factors, surface influencing factors, shallow influencing factors and deep influencing factors. Among them, the direct influencing factors are mainly the costs and revenues of the system, which directly affects the economics of the system. The surface influencing factors are mainly the parameters of the system itself, which affect the economics of the system by affecting the direct influencing factors. The shallow influencing factors are mainly external factors related to the system, which indirectly affect the economics of the system by affecting the surface influencing factors. The deep influencing factors are mainly factors reflecting the development environment of the system, such as technology level, policy, market structure and pricing mechanism. These factors will affect all aspects of DNG-CCHP system development, thus affecting the economics of the system comprehensively. The improvement of direct influencing factors is the most intuitive to improve the economics of the system, but it is difficult to improve these factors because they are affected by many lower-level factors. Meanwhile, improving the deep influencing factors is continuous, stable and effective in improving the economics of the system, but the deep factors not only involve the social and economic conditions related to the system itself, but also many other aspects of social and economic development, making improvements to these factors is time consuming and labor intensive. Relatively speaking, surface and shallow influencing factors are closely related to the system itself, so the difficulty of improvement is small, and the improvement of system economics is obvious after improving these factors. According to the characteristics of different types of influencing factors, it can be concluded that in order to improve the economics of DNG-CCHP system, a feasible and effective way is to improve the surface and shallow influencing factors, and gradually improve the deep influencing factors, which can finally achieve a sustained, stable and effective improvement of the system economics.

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References

1. China Report Network. Report on the Profit Status and Investment Value of China's Natural Gas Power Generation Industry in 2018–2023. Available online: http://baogao.chinabaogao.com/dianli/295752295752.html (accessed on 15 September 2017).
2. National Development and Reform Commission. Natural Gas Development "13th Five-Year Plan". Available online: http://www.ndrc.gov.cn/fzgggz/fzgh/ghwb/gjjgh/201706/t20170607_850207.html (accessed on 7 June 2017).

3. China Industry Information Network. Analysis of Supply and Demand Situation and Future Development Trend of China's Natural Gas Industry in 2018. Available online: http://www.chyxx.com/industry/201805/643605.html (accessed on 23 May 2018).
4. Wang, J.J.; Jing, Y.Y.; Zhang, C.F.; Zhang, B. Distributed combined cooling heating and power system and its development situation in China. In Proceedings of the ASME 2008 2nd International Conference on Energy Sustainability Collocated with the Heat Transfer, Fluids Engineering, and 3rd Energy Nanotechnology Conferences, Jacksonville, FL, USA, 10–14 August 2008; pp. 699–706.
5. Huang, J.Y.; Jiang, C.W.; Xu, R. A review on distributed energy resources and MicroGrid. *Renew. Sustain. Energy Rev.* **2008**, *12*, 2472–2483.
6. Eid, C.; Codani, P.; Perez, Y.; Reneses, J. Managing electric flexibility from distributed energy resources: A review of incentives for market design. *Renew. Sustain. Energy Rev* **2016**, *64*, 237–247. [CrossRef]
7. Di Somma, M.; Yan, B.; Bianco, N.; Graditi, G.; Luh, P.B.; Mongibello, L.; Naso, V. Operation optimization of a distributed energy system considering energy costs and exergy efficiency. *Energy Convers. Manag.* **2015**, *103*, 739–751. [CrossRef]
8. Sanaye, S.; Ardali, M.R. Estimating the power and number of microturbines in small-scale combined heat and power systems. *Appl. Energy* **2009**, *86*, 895–903. [CrossRef]
9. Wang, J.J.; Mao, T.Z.; Jun, S.; Jin, H.G. Modeling and performance analysis of CCHP (combined cooling, heating and power) system based on co-firing of natural gas and biomass gasification gas. *Energy* **2015**, *93*, 801–815. [CrossRef]
10. Li, Y.J.; Xia, Y. DES/CCHP: The best utilization mode of natural gas for China's low carbon economy. *Energy Policy* **2013**, *53*, 477–483. [CrossRef]
11. Yan, B.F.; Xue, S.; Li, Y.F.; Duan, J.H.; Zeng, M. Gas-fired combined cooling, heating and power (CCHP) in Beijing: a techno-economic analysis. *Renew. Sustain. Energy Rev.* **2016**, *63*, 118–131. [CrossRef]
12. Fang, F.; Wang, Q.H.; Shi, Y. A novel optimal operational strategy for the CCHP system based on two operating modes. *IEEE Trans. Power syst.* **2012**, *27*, 1032–1041. [CrossRef]
13. Li, P.; Wang, J.; He, S.Q.; Zhou, X.Q. Calculation of energy comprehensive utilization efficiency of distributed natural-gas energy system. *Heat. Vent. Air Cond.* **2014**, *44*, 13–17.
14. Zheng, X.Y.; Wu, G.C.; Qiu, Y.W.; Zhan, X.Y.; Shah, N.; Li, N.; Zhao, Y.R. A MINLP multi-objective optimization model for operational planning of a case study CCHP system in urban China. *Appl. Energy* **2018**, *210*, 1126–1140. [CrossRef]
15. Abdollahi, G.; Meratizaman, M. Multi-objective approach in thermoenvironomic optimization of a small-scale distributed CCHP system with risk analysis. *Energy Build.* **2011**, *43*, 3144–3153. [CrossRef]
16. Han, J.; Ouyang, L.X.; Xu, Y.Z.; Zeng, R.; Kang, S.S.; Zhang, G.Q. Current status of distributed energy system in China. *Renew. Sustain. Energy Rev.* **2016**, *55*, 288–297. [CrossRef]
17. Hu, X.J.; Wang, Z.; Zhang, X.; Zhong, Y.; Gao, D. Application Research Status and Prospect of Distributed Natural Gas CCHP System. *Gas Heat* **2011**, *31*, 4–9.
18. Li, M.; Zhou, M.; Feng, Y.; Mu, H.; Ma, Q. Integrated design and optimization of natural gas distributed energy system for regional building complex. *Energy Build.* **2017**, *154*, 81–95. [CrossRef]
19. National Development and Reform Commission; National Energy Administration; The Ministry of Finance; The Ministry of Housing and Urban-Rural Development. Guiding Opinions on the Development of Distributed Natural Gas Energy. Available online: http://www.ndrc.gov.cn/zcfb/zcfbtz/201110/t20111013_438374.html (accessed on 9 October 2011).
20. National Development and Reform Commission; National Energy Administration; The Ministry of Housing and Urban-Rural Development. Detailed Implementation Rules for Distributed Natural Gas Energy Demonstration Projects. Available online: http://www.china-gas.org.cn/tzgg/2014-10-31/786.html (accessed on 31 October 2014).
21. Liu, H.S.; Zhou, S.; Peng, T.D.; Ou, X.M. Life Cycle Energy Consumption and Greenhouse Gas Emissions Analysis of Natural Gas-Based Distributed Generation Projects in China. *Energies* **2017**, *10*, 1515–1528.
22. Liu, Y.X.; Li, F.Y.; Yu, X.H. Gas Supply, Pricing Mechanism and the Economics of Power Generation in China. *Energies* **2018**, *11*, 1058. [CrossRef]
23. Wang, Z.; Xue, Q. To fully exert the important role of natural gas in building a modern energy security system in China: An understanding of China's National l3th Five-Year Plan for Natural Gas Development. *Nat. Gas Ind. B* **2017**, *4*, 270–277. [CrossRef]

24. Hua, B.; Gong, J. Techno-Economic Analysis on Combined Cold Heat and Power & Distributed System (DES/CCHP). *Nat. Gas Ind.* **2007**, *27*, 118–120.
25. Yuan, J.; Li, W.Y.; Zhang, X. Economic research on distributed gas CCHP system. *Int. Pet. Econ.* **2016**, *24*, 61–68.
26. Hou, X.; Liang, Y. Economic analysis on gas-fired building cooling heating and power system. *Heat. Vent. Air Cond.* **2016**, *46*, 24–28.
27. Sun, Z.G. Energy efficiency and economic feasibility analysis of cogeneration system driven by gas engine. *Energy Build.* **2008**, *40*, 126–130. [CrossRef]
28. Xu, D.; Qu, M. Energy, environmental, and economic evaluation of a CCHP system for a data center based on operational data. *Energy Build.* **2013**, *67*, 176–186. [CrossRef]
29. Zhang, X.F.; Liu, X.B.; Sun, X.Q.; Jiang, C.W.; Li, H.Q.; Song, Q.B.; Zeng, J.; Zhang, G.Q. Thermodynamic and economic assessment of a novel CCHP integrated system taking biomass, natural gas and geothermal energy as co-feeds. *Energy Convers. Manag.* **2018**, *172*, 105–118. [CrossRef]
30. Jia, C.Z.; Zhang, Y.F.; Zhao, X. Prospects of and challenges to natural gas industry development in China. *Nat. Gas Ind. B* **2014**, *1*, 1–13.
31. Lu, B. Gas-Fired Electric Power Has Obvious Advantages Replacing Coal-Fired Electric Power. China Energy News. Available online: http://www.cnki.net/KCMS/detail/detail.aspx?QueryID=8&CurRec=1&filename=SHCA201603070100&dbname=CCNDLAST2016&dbcode=CCND&pr=&urlid=&yx=&v=MDAwNDFNT1VLcmlmWnU1dkhpcmtVNy9JSWw4VU5pWEliN0c0SDlmTXJJOUNaT29QREJOS3VoZGhuajk4VG5qcXF4ZEVl (accessed on 7 March 2016).
32. Jia, K. China Energy Outlook 2030: Demand Growth Slows Down. China Energy News, 2016-03-07(002). Available online: http://www.cnki.net/KCMS/detail/detail.aspx?QueryID=12&CurRec=1&filename=ZYJH201604007&dbname=CJFDLAST2016&dbcode=CJFQ&pr=&urlid=&yx=&v=MTMxODRSTEtmYitWdkZ5amxXci9LUHpUQlpyRzRIOWZNcTQ5Rlk0UjhlWDFMdXhZUzdEaDFUM3FUcldNMUZyQ1U= (accessed on 7 April 2016).
33. China Industry Information Network. The Status Quo and Prospects of China's Natural Gas Distributed Energy Development in 2017. Available online: http://www.chyxx.com/industry/201611/472397.html (accessed on 29 November 2016).
34. Sohu News. Natural Gas Distributed Energy Faces Three Major Challenges. Available online: http://www.sohu.com/a/71917176_119556 (accessed on 27 April 2016).
35. Sohu News. Natural Gas Distributed Energy Development Data Summary. Available online: http://www.sohu.com/a/165091840_357198 (accessed on 16 August 2017).
36. China Industry Information Network. Forecast and Analysis of Market Size and Development Trend of China's Natural Gas Power Generation Industry in 2017. Available online: http://www.chyxx.com/industry/201708/548347.html (accessed on 8 August 2017).
37. National Energy Administration. Notice on Further Implementing Policies Related to Distributed Photovoltaic Power Generation. Available online: http://zfxxgk.nea.gov.cn/auto87/201409/t20140904_1837.htm (accessed on 2 September 2014).
38. National Development and Reform Commission. Notice on Exerting Price Leverage to Promote the Healthy Development of the Photovoltaic Industry. Available online: http://www.ndrc.gov.cn/zcfb/zcfbtz/201308/t20130830_556000.html (accessed on 26 August 2013).
39. Allan, G.; Eromenko, I.; Gilmartin, M.; Kockar, I.; McGregor, P. The economics of distributed energy generation: A literature review. *Renew. Sustain. Energy Rev.* **2015**, *42*, 543–556. [CrossRef]
40. Sohu News. The Status Quo, Problems and Development Prospects of Natural Gas Power Generation in China. Available online: https://www.sohu.com/a/220272180_814194 (accessed on 1 February 2018).
41. Xiao, W.; Sun, J.; Chen, G.; Lan, J. Analysis on Status Quo of Natural Gas Distributed Energy Development in South Five Provinces. *Guangdong Electr. Power* **2014**, *27*, 43–46.
42. Schiebahn, S.; Grube, T.; Robinius, M.; Tietze, V.; Kumar, B.; Stolten, D. Power to gas: Technological overview, systems analysis and economic assessment for a case study in Germany. *Int. J. Hydrog. Energy* **2015**, *40*, 4285–4294. [CrossRef]
43. Saaty, T.L.; Shang, J.S. An innovative orders-of-magnitude approach to AHP-based mutli-criteria decision making: Prioritizing divergent intangible humane acts. *Eur. J. Oper. Res.* **2011**, *214*, 703–715. [CrossRef]

44. Watson, R.H. Interpretive structural modeling—A useful tool for technology assessment? *Technol. Forecast. Soc. Chang.* **1978**, *11*, 165–185. [CrossRef]
45. Amado, C.A.F.; Santos, S.P.; Marques, P.M. Integrating the Data Envelopment Analysis and the Balanced Scorecard approaches for enhanced performance assessment. *Omega* **2012**, *40*, 390–403. [CrossRef]
46. Duru, O.; Bulut, E.; Yoshida, S. A fuzzy extended DELPHI method for adjustment of statistical time series prediction: An empirical study on dry bulk freight market case. *Expert Syst. Appl.* **2012**, *39*, 840–848. [CrossRef]
47. Liu, W.B.; Cheng, Z.L.; Mingers, J.; Qi, L.; Meng, W. The 3E methodology for developing performance indicators for public sector organizations. *Public Money Manag.* **2010**, *30*, 305–312. [CrossRef]
48. Xing, L.; Amari, S.V. Fault Tree Analysis. In *Handbook of Performability Engineering*; Springer: London, UK, 2008; pp. 595–620.
49. Deng, J.L. *The Basis of Grey Theory*; Press of Huazhong University of Science & Technology: Wuhan, China, 2002; pp. 1–2.
50. Polat, K.; Kırmacı, V. Determining of gas type in counter flow vortex tube using pairwise fisher score attribute reduction method. *Int. J. Refrig.* **2011**, *34*, 1372–1386. [CrossRef]
51. Bécue-Bertaut, M.; Pagès, J. Multiple factor analysis and clustering of a mixture of quantitative, categorical and frequency data. *Comput. Stat. Data Anal.* **2008**, *52*, 3255–3268. [CrossRef]
52. Rodriguez-Ulloa, R.; Paucar-Caceres, A. Soft system dynamics methodology (SSDM): Combining soft systems methodology (SSM) and system dynamics (SD). *Syst. Pract. Action Res.* **2005**, *18*, 303–334. [CrossRef]
53. Falatoonitoosi, E.; Leman, Z.; Sorooshian, S.; Salimi, M. Decision-making trial and evaluation laboratory. *Res. J. Appl. Sci. Eng. Technol.* **2013**, *5*, 3476–3480. [CrossRef]
54. Shieh, J.I.; Wu, H.H.; Huang, K.K. A DEMATEL method in identifying key success factors of hospital service quality. *Knowl. Based Syst.* **2010**, *23*, 277–282. [CrossRef]
55. Warfield, J.N. Binary matrices in system modeling. *IEEE Trans. Syst. Man Cybern.* **1973**, *5*, 441–449. [CrossRef]
56. Purohit, J.K.; Mittal, M.L.; Mittal, S.; Sharma, M.K. Interpretive structural modeling-based framework for mass customisation enablers: An Indian footwear case. *Prod. Plan. Control.* **2016**, *27*, 774–786. [CrossRef]
57. Rajabzadeh, A.; Keramatpanah, M.; Keramatpanah, A. Comparative Modeling of Supply Chain Using Interpretive Structural Modeling and DEMATEL. Organ. *Resour. Manag. Res.* **2015**, *5*, 49–71.
58. Chauhan, A.; Singh, A.; Jharkharia, S. An interpretive structural modeling (ISM) and decision-making trail and evaluation laboratory (DEMATEL) method approach for the analysis of barriers of waste recycling in India. *J. Air Waste Manag. Assoc.* **2018**, *68*, 100–110. [CrossRef] [PubMed]
59. Zhou, D.; Zhang, L. Establishing hierarchy structure in complex systems based on the integration of DEMATEL and ISM. *J. Manag. Sci. China* **2008**, *11*, 20–26.
60. Wu, B.; Xu, H.; Dai, T. Identifying Safety Factors on Express way Work Zone Based on DEMATEL and ISM. *J. Transp. Syst. Eng. Inf. Technol.* **2010**, *10*, 130–136.

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