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Review of domestic and foreign research on natural gas production, supply, storage and marketing

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Abstract

The coordinated development of the natural gas production, supply, storage, and marketing system is formed under the conditions of the continuous develop-ment of the gas industry, the gradual maturation of the natural gas market, and the gradual formation of the natural gas industry chain. As a clean and en-vi-ronmentally friendly high-quality energy, natural has important strategic sig-nificance for ensuring the security of energy supply and optimizing the energy structure. This paper provides a review of the literature on the research of the natural gas production, supply, and marketing links, summarizes the research types of existing literature, and most of the previous research covers various links of the entire natural gas industry chain. However, most of the research from the local optimization of the natural gas industry chain, such as: pipeline energy con-sumption optimization, pipeline layout, gas storage investment and benefit evalu-ation, LNG cost optimization, natural market price mechanism re-search, etc. In the future, low-carbonization and technological innovation, LNG market expan-sion, geopolitics and energy security, synergy with renewable en-ergy and policy and investment challenges are key points for research and de-velopment of natu-ral gas.

Keywords

Industry chain; Integrity; Natural gas

1. Introduction

Slow global economic recovery, China's pandemic control policy relaxation, and the mitigation of the natural gas crisis caused by the Russia-Uraine conflict have all had an impact on the trend of natural gas prices. In the first half of the year, the JKM (Ja-pan-Korean Marker, Northeast natural gas benchmark price) and TTF (Title Trans-fer Facility, Dutch Title Transfer Facility Index) fluctuated and fell, and in the second half of the year, the JKM TTF fluctuated and rebounded. The HH (Henry Hub, Henry Center Price) price maintained a low and stable level. Due to the competition be-

tween the two major demand of Europe and Asia in the LNG (Liquefied Natural Gas) market, the JKM and TTF prices have a strong correlation and their trends are basically the same The global natural gas resources are abundant, and the energy development is entering the natural gas era. The current global energy development has formed a new pattern of "four parts of the" for oil, natural gas, coal, and new energy. As a clean and environmentally friendly high-quality energy, natural gas has important strategic significance for ensuring the security of energy and optimizing the energy structure. The diversification of resources, the balance of market supply and demand, the complexity of storage and transportation facilities, and the influence of system risk and nonsystem risk of natural gas supply chain, and the transmission of technological and information resources, etc., creating a high-quality development of the natural gas production, supply, storage, sales system, in-depth research in the aspects of low-carbonization and technological innovation, LNG market expansion, geopolitics and energy security, synergy with renewable energy policy and investment challenges, etc., is the focus of natural gas industry development.

2. Domestic and foreign related research

2.1. Research on the development of natural gas industry

Scholars such as Ma Zhiguang proposed that China should analyze the supply-demand dynamics of its domestic natural gas market, forecast market development trends based on its evolutionary process, and formulate strategic measures for the natural gas industry's development in the new century (Ma & Zhu, 2003). Taking Xinjiang's natural gas industry as a case study, Lei Ting examined strategic issues in China's natural gas development, identified existing problems, and proposed countermeasures to advance the industry (Lei, 2007). Qin Yang and colleagues, analyzing the status of China's natural gas industry under the low-carbon economy paradigm, suggested addressing low utilization rates, supply-demand imbalances, and regulatory lags through technological, institutional, and governance improvements (Qin & Cao, 2011).From a sustainable development perspective, Liu Yijun et al. analyzed challenges in China's natural gas industry chain and proposed sustainability recommendations by drawing on domestic and international experiences (Liu & Cao, 2014). Xie Mao distilled developmental patterns from the U.S. natural gas industry's evolution, extracting lessons to inform China's development path (Xie, 2015). Liu Yijun's team further traced the global natural gas industry chain's transition from high to low oil price environments, examining impacts on production patterns, pricing, and prospects, while particularly assessing the opportunities and challenges for China's industry chain under sustained low oil prices (Liu & Ma, 2016).Ye Zhanghuang and colleagues predicted that China's natural gas demand growth would significantly outpace production increases, leading to widening supply-demand gaps, and proposed corresponding strategic approaches. Gao Jie's research team summarized 2019 industry developments while forecasting 2020 mar-

ket demand (Gao et al., 2020). Zhou Shuhui et al., contextualizing China's natural gas development within carbon neutrality goals, employed the LEAP (Energy-Economy-Environment) model to analyze development potential and priorities, yielding policy recommendations (Zhou et al., 2021). Wang Qiurui examined current challenges and proposed reform measures for China's natural gas industry under new circumstances (Wang, 2022).

2.2. Study on natural gas storage and peak shaving

Scholars such as Ding Guosheng, drawing on existing experiences of natural gas peak-shaving and emergency reserve systems both domestically and internationally, proposed recommendations for constructing China's natural gas peak-shaving reserve and emergency response system, and outlined the key tasks required for its establishment (Ding Guosheng, Liang Jing, Ren Yongsheng, Zhao Xiaofei, & Ran Lina, 2009). Scholars like Zhao Shuigen analyzed the natural gas reserve and emergency peak-shaving situations in several megacities at home and abroad, and offered suggestions for the construction and development of natural gas reserve and emergency peak-shaving facilities in megacities (Zhao Shuigen, Li Yue, Wang Xiaodong, & Li Qingping, 2013). Li Xuefei and colleagues, by integrating operational data from a specific project, analyzed how to establish a comprehensive urban natural gas supply guarantee system while saving on investment during the actual gas supply process (Li Xuefei & Cheng Haifeng, 2014). Zhang Jun and his team examined the issues in domestic natural gas peak-shaving and, based on the current situation of natural gas peak-shaving both domestically and internationally, proposed measures to address these issues (Zhang Jun & Lan Yujian, 2015). Zhang Yue and her research group summarized the development status of natural gas peak-shaving technologies globally, introduced the basic outlines of several peak-shaving methods, and conducted a comparative analysis among them (Zhang Yue, Wang Han, & Li Junnan, 2016). Shen Xin and fellow researchers summarized the current state of China's natural gas security and supply guarantee system, analyzed the development experiences of the United States and Europe in the natural gas sector, and summarized the insights from these experiences. They then proposed recommendations for the operational model of China's peak-shaving reserve facilities (Shen Xin, Chen Jindian, Wei Chuanbo, & Hao Yingpeng, 2017). Yao Shujun and colleagues elaborated on the current background of urban gas storage and peak-shaving in China, affirmed the importance of gas storage and peak-shaving, listed relevant policies and implementation methods, pointed out existing problems, and provided rationalization suggestions, which hold practical significance for China's gas storage and peak-shaving work (Yao Shujun, Yang Nana, & Ma Chisong, 2018). Yang Mengxin, starting from practical considerations, summarized the characteristics of economic benefit evaluation for China's gas storage facilities, constructed an economic benefit evaluation index system for China's gas storage facilities within the natural gas industry chain,

and evaluated the economic benefits of gas storage facilities within this chain using a discounted cash flow model based on Monte Carlo simulation, combined with actual cases (Yang Mengxin, 2023). Shan Baohua and his team, to address the natural gas peak-shaving demands in inland regions far from gas sources and LNG receiving terminals, utilized the "storage and transportation flexibility" characteristics of tank containers to construct an LNG tank container multimodal transport network. Aiming to minimize transportation and distribution costs as well as customer gas shortage rates, while considering the impact of different transportation modes and logistics processes on the lossless maintenance duration of tank containers, they established an LNG tank container transportation route optimization model and designed a genetic algorithm to solve it, providing references for the operational decision-making of LNG supply enterprises (Shan Baohua, Tang Limin, & Zhu Mingming, 2020). Chu Xiaohang and fellow researchers, drawing on mature gas storage and peak-shaving operational models, summarized the development path for China's gas storage facilities, offering guidance for rationalizing and improving China's gas storage and peak-shaving facilities and operational models (Chu Xiaohang, Wang Xiaoyu, & Zhang Xinyan, 2021). Wang Yongliang and his team proposed measures such as promoting electric peak-shaving gas supplementation, integrated gas-electricity development on the demand side, diversified energy use measures during the heating season, and the widespread application of combined heat and power (CHP) electric-heat separation technologies to flatten peak-valley differences. In terms of peak-shaving reserves, they clarified the gas allocation arrangements for peak-shaving between upstream and downstream parties, distinguishing between strategic reserves, peak-shaving gas volumes, and emergency gas volumes. On the demand side management front, they suggested(reasonably arranging user commissioning plans) through staggered peak management and achieving demand-side security through (moderately differentiated energy use choices). They also advocated actively implementing the scale of natural gas resources, reasonably deploying infrastructure, gradually promoting the marketization of natural gas prices, and gradually liberalizing non-resident and peak-valley gas prices (Wang Yongliang, Cao Mansheng, & Gao Yajie, 2022). Mi Lidong and his research team, centered around Sinopec's gas storage construction planning, closely integrated gas storage management, research, and production with the goal of enhancing quality and efficiency. They established a comprehensive gas storage platform centered on "production monitoring, tracking analysis, remote regulation, and auxiliary decision-making." They also set up a supporting core technology system focusing on gas reservoir geological modeling and numerical simulation research for gas storage, as well as injection-production management for gas storage. They digitally enhanced the optimization of gas storage site selection, geological research, injection-production regulation, peak-shaving optimization, and full-node management. They designed and developed a comprehensive gas storage management platform to achieve integrated

management and research covering gas storage site selection optimization, scheme design, scheme tracking, engineering construction, production operation, operational optimization, and dynamic tracking (Mi Lidong, Zeng Daqian, Liu Hua, Zhang Guangquan, & Zhang Junfa, 2023).

2.3. Research on Natural Gas Pipeline Networks

Scholars such as Ai Muyang investigated the current development status of steady-state operational optimization technologies for natural gas pipeline networks both domestically and internationally. They analyzed the characteristics and application scopes of optimization software products at home and abroad, elaborated on the solution methods for mainstream nonlinear steady-state operational optimization models for natural gas pipeline networks, and proposed several prospects targeting the constraints affecting the engineering application effectiveness of steady-state operational optimization technologies for natural gas pipeline networks (Ai Muyang et al., 2015). Gong Weilong and his team, based on the characteristics of current interconnection project construction, classified the functions of interconnected pipelines into three categories: gas supply, gas transfer, and security. They established economic evaluation models for interconnection projects under these three functions, respectively, drawing on economic evaluation methods for long-distance pipeline projects, economic benefit evaluation methods for peak-shaving gas transmission via underground gas storage facilities, and quantitative evaluation methods for safety economic benefits. Taking the Min-Yue Branch Pipeline Interconnection Project undertaken by China National Petroleum Corporation (CNPC) as an example, they conducted economic benefit indicator calculations (Gong Weilong et al., 2019). Yang Yi and his colleagues integrated the Golden Section Algorithm with the Dynamic Programming Algorithm to form an improved hybrid algorithm combining dynamic programming and the Golden Section. Using a looped pipeline network in North China as a case study, their results demonstrated that the hybrid algorithm effectively solved complex pipeline network optimization challenges, providing a reference for optimizing the steady-state operation of large-scale natural gas pipeline networks in China (Yang Yi, Diao Hongtao, Xiang Min, Sun Xiaobo, & Liu Jianjun, 2020). Liu Dingzhi and his research group established a mathematical model for optimizing natural gas pipeline throughput planning with the objective of minimizing the total cost of natural gas supply and pipeline transportation. They employed the Gurobi solver for calculations. Through quantitative analysis of resources and pipeline transportation, the model could optimize the national natural gas pipeline transportation flow directions for the next 15 to 50 years, predict local bottlenecks, analyze the timing of planned pipeline construction, enhance the efficiency of pipeline network layout planning, and provide an advanced tool for scientific decision-making in natural gas pipeline network planning (Liu Dingzhi et al., 2021). Wang Shouxi and his team, based on years of research, devel-

opment, and application practices, took the pipeline network online simulation system as the analysis object. They discussed its macroscopic and overall system architecture, hierarchy, and functional roles, explored its theories and methods, software and core technologies, as well as the core issues in system construction and implementation. Through practical application cases of the Sichuan-to-East Gas Transmission Pipeline and the long-distance submarine natural gas pipeline in the western South China Sea, they demonstrated the application process and effects of current online simulation research achievements, aiming to promote future research, development, and application of online simulation for natural gas pipeline networks (Wang Shouxi et al., 2022). He Nengjia and his colleagues constructed an optimization model for pipeline transportation capacity allocation with the objective function of maximizing the pipeline company's profits. They used the mathematical modeling system MATLAB and the genetic algorithm for optimization to determine the flow allocation and node pressures along gas transmission routes. Taking simple and complex looped natural gas pipeline networks as examples, they analyzed the impacts of different pipe diameters, pipeline residual capacities, and pipeline tariff rates on economic benefits, providing guidance for improving the transportation efficiency of pipeline operators (He Nengjia et al., 2023). Lin Min adopted the GERG-2008 equation as the equation of state, coupled the energy conservation equation with the dimensionless Helmholtz free energy and its partial derivatives, and combined it with the component transport equation to propose an adaptive flow allocation method based on actual measurement data. By constructing an augmented Kriging surrogate model to simplify the calculation process and using the NSGA-II genetic algorithm for solving, Lin employed a staggered grid for mixed gas component calculations and computed the calorific value of natural gas, providing assistance for natural gas energy metering and saving on equipment investment and metering station retrofitting costs (Lin Min, 2023).

2.4. Research on the Natural Gas Production-Supply-Storage-Sales System

Scholars such as Zhang Ningli established a dynamic programming model aimed at maximizing the profits of natural gas companies, based on the multi-stage dynamic process of natural gas purchasing and sales. They conducted a time complexity analysis to demonstrate the flexibility of the dynamic programming algorithm, providing a novel solution for optimizing the scheduling of natural gas production and sales (Zhang Ningli, Ma Yan, Zhang Xiangfen, & Xu Xiaozhong, 2014). Zhao Yanfang and her team, with the objective of maximizing the overall benefits of the natural gas industry chain, constructed a mathematical model for the production, transportation, and sales system through mathematical abstraction and simplification of system elements. They selected CPLEX software as the optimization tool to solve the model, which achieved the goal of benefit maximization by reasonably allocating

resource markets and optimizing natural gas flow directions. This significantly improved optimization efficiency and provided a basis for scientific decision-making in natural gas planning (Zhao Yanfang, Liu Dingzhi, & Zhao Jun, 2016). Yan Zhichuang and his colleagues, in the context of supply-side reform, studied the behaviors and equilibrium conditions of producers, pipeline operators, storage operators, peak-shaving operators, and marketers in the natural gas supply chain network based on the generalized Nash equilibrium theory. They explored the relationships between equilibrium prices and flows in the natural gas supply chain network and government subsidies (Yan Zhichuang & Yuan Yanhong, 2017). Guo Jiaofeng and his team proposed a Chinese plan for building a high-quality development system for natural gas production, supply, storage, and sales in China (Guo Jiaofeng, Zhao Liangying, Xu Ruiqian, & Li Jifeng, 2018). Wang Baoping, based on the national strategies of the integration of the Yangtze River Delta and the integration of natural gas production, supply, and sales, analyzed the necessity and feasibility of constructing a production, supply, storage, and sales system in the Yangtze River Delta natural gas market, and provided some construction plans and related policy suggestions (Wang Baoping, 2019). Xu Ning and his colleagues, considering constraints such as transportation modes, volumes, transport equipment, supply and demand capabilities, and station construction plans, established a mixed-integer linear programming model with the objective function of minimizing the average daily operating cost of the natural gas supply chain. Taking the annual demand task of a certain natural gas supply chain system as an example, they minimized the total construction and operating costs of the system while meeting urban natural gas demand. The optimal construction, purchasing, transportation, gas storage, and treatment plant operation plans were obtained through solving the model, and the accuracy of the model was verified, providing guidance for the construction of natural gas supply chain systems (Xu Ning et al., 2020). He Xiaodong and his team elaborated on the development status of natural gas production, supply, storage, and sales in North China, analyzed the problems faced by the system in the region, and proposed a series of development suggestions (He Xiaodong, Peng Han, He Xiaozhong, & Li Bo, 2021). Tian Shouqiang and his colleagues, taking Guizhou Province as the research base, proposed an operational scheduling mechanism for the natural gas production, supply, storage, and sales system in Guizhou based on the current status and existing problems of the system, providing a reference for the coordinated and stable development of China's natural gas production, supply, storage, and sales system (Tian Shouqiang & Zheng Wei, 2022). Yang Yi and his colleagues conducted a detailed analysis of the new situation faced by China's natural gas production, supply, storage, and sales system, reviewed the international natural gas supply and demand situation, sorted out the domestic development status, proposed suggestions for the layout of future natural gas demand potential and infrastructure, pointed out the issues that need attention in the construction of China's natural gas production,

supply, storage, and sales system, and provided relevant recommendations (Yang Yi et al., 2023).

2.5. Research on Natural Gas Market Development

Liu Xiaoli analyzed the current status and characteristics of China's natural gas market development, drew on the experiences of major developed countries such as the United States, Japan, and the United Kingdom in natural gas market development, and summarized the differences and gaps between China's natural gas market and those of developed countries. Based on the specific conditions of China's natural gas market, she proposed suggestions for its development (Liu Xiaoli, 2010). Hu Aolin analyzed the position and role of the natural gas trading market in the development of the natural gas market and, considering the current status and trends of China's natural gas market, put forward several suggestions for constructing China's natural gas trading market (Hu Aolin, 2014). Jiang Zi'ang and his colleagues, taking the Sichuan-Chongqing gas region as the research object, analyzed the development trend of China's natural gas market under the new normal and low oil price conditions from the perspective of sustainable development of the natural gas industry chain market. They further proposed coping strategies for natural gas market development during the "13th Five-Year Plan" period (Jiang Zi'ang, Wang Fuping, Duan Yanzhi, & Zhou Jian, 2016). Luan Fumao and his colleagues, based on the background of China's new normal economic development, analyzed the issues in the development of the natural gas industry. Starting from the overall perspective of China's natural gas industry, they dissected the path of market-oriented reform in the natural gas industry and proposed that China's natural gas market development needs to address monopolistic operations in production, storage, and transportation, relax market access, and introduce competition in a timely manner; establish trading centers to let the market determine prices and supply and demand; improve the legal regulatory system, establish a modern natural gas market system, and optimize resource allocation (Luan Fumao & Liu Siyu, 2018). Liu Zhongyun reviewed the development history of China's natural gas marketing, analyzed the characteristics and existing problems of natural gas marketing development, explored the situation faced by the development of the natural gas marketing system, and, from the perspective of the actual development of the existing natural gas market, proposed development ideas and measures for constructing a market-oriented natural gas marketing system under the new situation (Liu Zhongyun, 2019). Qi Aihua and her colleagues believed that the foundation for the market-oriented development of China's natural gas industry is still quite weak, with prominent regional development imbalances. They argued that it is necessary to choose a development model suitable for China's national conditions and regional characteristics; the development model should be adapted to the development stage and basic conditions, allowing multiple models to coexist (Qi Aihua & Yang Lei, 2020). Li Zhengbing and his col-

leagues used relative correlation to quantitatively describe the correlation between natural gas demand and influencing factors, employed stepwise regression to successively test the statistical significance of influencing factors, deeply excavated effective driving factors, and constructed an "optimal" stepwise regression C-D production function model to predict future trends in natural gas demand (Note: There seems to be a slight discrepancy in the name here; the original text mentions "Li Zhengbing" but the reference in parentheses is "Li Hongbing & Zhang Jijun". Assuming it's a typo and the correct reference should align with the model construction described, I've kept the focus on the model construction aspect in the translation) (Li Hongbing & Zhang Jijun, 2021).

2.6. Research on natural gas prices

Starting from the current status of China's natural gas pricing mechanism, Nie Guanghua drew on the pricing experiences of more mature foreign natural gas markets, analyzed different feasible strategies for China's natural gas pricing mechanism under future market conditions, and conducted a comparative analysis of the advantages and disadvantages of these strategies. Using the basic principles and methods of game theory as a tool, he constructed a theoretical model for the natural gas pricing mechanism, which encompassed reform ideas for the pricing mechanisms in the upstream, midstream, and downstream sectors of the future natural gas industry. He delved into the inherent mechanisms of natural gas pricing, and the quantitative model he proposed for natural gas pricing, to a certain extent, overcame the one-sidedness of previous natural gas pricing research, which primarily relied on qualitative analysis and lacked model support (Guang-hua, 2013). Wang Feng and his colleagues reviewed the reform process of China's natural gas price formation mechanism, established a mathematical economics model, and analyzed the optimal decisions of natural gas suppliers under different price formation mechanisms and the corresponding market structures. Their conclusions indicated that the reform of the natural gas price formation mechanism, shifting from the "cost-plus" pricing method to the "netback" pricing method, adapted to the new situation of diversified sources of natural gas and the networked gas pipeline system in China. This reform effectively introduced market competition and was conducive to promoting the healthy development of China's natural gas industry (Wang Feng & Liu Xin, 2014). Liu Yijun 梳理 (sorted out) the evolution path of China's natural gas price formation mechanism and inferred the future development trend of China's natural gas prices (Liu Yijun, 2015). Gao Jun and his colleagues, against the backdrop of natural gas price reforms in 2014 and 2015, analyzed the transmission effects of natural gas price reforms on the industry chain from the perspective of the natural gas industry chain's interconnections using a VAR model. They argued that natural gas prices should be linked to other energy prices and subject to moderate regulation and decentralization; that natural gas price reforms need to leverage the

cross-reinforcing effects of the energy industry; and that during the price reform process, a unified price reform should be implemented from the perspective of the production, transportation, and sales chain (Gao Jun, Wu Xintong, Shi Kai, Li Youbin, & Long Ruxiang, 2016). Li Liang and his colleagues used the EG two-step method and error correction model to study the cointegration relationship between natural gas and oil prices, as well as the impact of factors such as inventory disruptions, weather, and supply on short-term changes in natural gas prices. They believed that the influence of oil on natural gas prices was gradually weakening, and that the long-term cointegration relationship between the two was changing due to factors such as increased natural gas supply and extreme weather. Supply disruptions caused by weather factors and changes in inventory levels would affect natural gas prices, but their impact was gradually diminishing under the basic condition of oversupply (Li Liang & Xu Ling, 2018). Qiu Lingyue and his colleagues started from the current management status of domestic natural gas transmission and distribution, clarified the pricing contradictions in China's natural gas transmission and distribution, and proposed countermeasures and suggestions based on European and American experiences, including establishing a natural gas regulatory agency, eliminating redundant links in provincial pipeline transportation and gas distribution, reducing transmission and distribution price subsidies among users, and promoting the separation of pipeline transportation businesses and fair third-party access (Qiu Lingyue & Yin Jianping, 2019). Dong Bangguo and his colleagues investigated the operation methods and management experiences of natural gas prices in European and American countries before and after the reform of pipeline network operation mechanisms, deeply analyzed the current status and existing problems of China's natural gas price management, and proposed specific contents and a timetable for rebuilding the price formation mechanism for natural gas production, supply, storage, and sales. They believed that the secondary reconstruction of the price formation mechanism for natural gas production, supply, storage, and sales should be the central task of China's natural gas price reform during the "14th Five-Year Plan" period (Dong Bangguo, He Chunlei, & Zhang Yong, 2020). Li Tingdong and his colleagues, based on elaborating on the general laws of the evolution of natural gas pricing mechanisms, analyzed the main problems existing in the current natural gas pricing mechanism. Combining with the goals of China's natural gas price reform, they proposed four paths and policies to improve the natural gas pricing mechanism (Li Tingdong, He Chunlei, Dong Zhenyu, & Zhang Yong, 2021). Zhang Rui and his colleagues believed that, against the backdrop of intensifying geopolitical conflicts turning the energy crisis into a global risk, China should further promote the market-oriented reform of natural gas prices to eliminate the adverse impacts of significant fluctuations in international natural gas prices (Zhang Rui & Ma Yuan, 2023).

2.7. Research on the safety of natural gas industry chain

Scholars such as Liu Yijun quantitatively described and clearly defined the risks in the natural gas industry chain. They used statistical tools to provide a quantitative description of the industry chain risks arising from the impact of a single risk factor on nodes; a quantitative description of the industry chain risks transmitted through the interaction of risk factors between nodes; and a quantitative description of the industry chain risks resulting from unbalanced development (Liu Yijun, Wu Juan, & Qian Zheng, 2007). Sun Jiaqing and his colleagues, based on the "netback pricing method," employed system dynamics to establish a natural gas pricing mechanism model composed of a supply-demand system and a price system. They conducted analyses and evaluations from the perspectives of supply and demand, economic effects, the influence of alternative energy prices, and government regulation, and proposed several countermeasures to rationalize the natural gas pricing mechanism (Sun Jiaqing, Sun Qianwen, & Jin Zhihong, 2017a). Ji Xinying and her colleagues analyzed the risks in the downstream market of the natural gas industry chain, explored risk identification and prevention countermeasures for this market, and provided new risk response solutions for the healthy development of the downstream market of the natural gas industry chain (Ji Xinying & Zhang Donghua, 2020). Xiao Jun and his colleagues, referencing the concept of security regions in power systems, proposed a steady-state model, visualization methods, and applications for the security region of natural gas pipeline network systems (NGS-SR). They established the steady-state model of NGS-SR, which describes the safe operating range of the natural gas pipeline network system, provides abundant safety control information, and facilitates online safety analysis (Xiao Jun, Song Chenhui, Bao Zhenyu, & Li Jinyi, 2021).

2.8. Research on natural gas supply and demand relationship

Liu Yijun analyzed the causes of the "gas shortage" phenomenon, proposing that specific development stages, unique power structures, and special development trajectories are key to interpreting the "gas shortage." He also put forward suggestions for effectively preventing risks in the natural gas industry chain (Liu Yijun, 2010). Peng Yun and his colleagues, based on the objective seasonal fluctuations and imbalances in natural gas demand, took the natural gas production, sales, and operations of an oil and gas company under Sinopec as an example. They applied dynamic programming theory to the study of natural gas production, sales, and operations, establishing a multi-objective programming optimization and scheduling model for natural gas production, sales, and operations. They utilized genetic algorithms to solve the model, which, when applied to decision-making in natural gas production, sales, and operations, could enhance the balance of gas supply from gas fields, effectively coordinate the demands among various natural gas users in the market, and achieve optimal allocation of natural gas resources (Peng Yun, Cheng Jinhua, Wang Xiaolin, & Li Yue, 2012). Yang Hongwei and his colleagues, to study the

supply-demand balance in pipeline network operations, used SPS software to simulate and model a dual-gas-source, multi-user pipeline network. Based on reliability verification of existing pipeline network operating parameters, they conducted a simulation analysis of the pipeline network's supply-demand balance in conjunction with users' gas demand projections for 2025, and proposed an optimized operation plan (Yang Hongwei, Liu Fang, & Han Yinshan, 2023).

2.9. Natural gas research based on system dynamics

Based on the summarization of previous research findings, Li Junchen and his colleagues established a system dynamics model for forecasting natural gas consumption in China. They categorized natural gas consumption by industry and comprehensively considered the relevant influencing factors of natural gas consumption in each sector, enabling more effective forecasting. Based on the model's forecast results, they proposed policy recommendations for China's natural gas industry (Li Junchen, Dong Xiucheng, & Gao Jian, 2010). Shi Lijun and his colleagues, starting from the perspective of ensuring the security of natural gas supply and demand, utilized system dynamics methods to establish a forecasting model for China's natural gas supply and demand. They predicted the future trends of natural gas supply and demand in China, conducted parameter simulation experiments on natural gas consumption, and proposed policy recommendations to promote the development and utilization of natural gas resources (Shi Lijun & Zhou Hong, 2012). Wang Zhong and his colleagues constructed a system dynamics model for the exploration and development of natural gas in Sichuan using system dynamics methods. They analyzed the causal relationships and feedback mechanisms between resource taxes and other systemic factors during the exploration and development of natural gas. Through simulation, they examined the impacts and shocks of the "ad valorem taxation" reform of resource taxes on local government revenues, resource enterprise profits, and natural gas exploration and development in Sichuan. Based on the simulation results, they proposed countermeasures and suggestions for deepening the reform of resource taxes in China (Wang Zhong, Yuan Jiaqi, & Kuang Jianchao, 2014). Sun Chunling and her colleagues, based on an analysis of the causal relationships influencing project returns, constructed a system dynamics model for the returns of natural gas Public-Private Partnership (PPP) projects. Using VENSIM PLE software and taking a constructed and operational natural gas filling station in Northwest China as a case study, they conducted model validity tests, simulation modeling, and sensitivity analysis. The results indicated that the concession period, concession price, annual gas filling volume, and the private sector's expected rate of return had significant combined interactive effects on project returns. Consequently, they proposed measures combining qualitative and quantitative aspects for concession agreements (Chunling, Fei, & Mengxiao, 2016). Sun Jiaqing and his colleagues employed system dynamics methods to establish a natural gas pricing mechanism

model composed of a supply-demand system and a price system. They conducted analyses and evaluations from the perspectives of supply and demand, economic effects, the influence of alternative energy prices, and government regulation, and proposed several countermeasures to rationalize the natural gas pricing mechanism. The research results indicated that a natural gas pricing mechanism based on the "netback pricing method" could alleviate the cost pressures on upstream suppliers, reflect market supply and demand relationships, and facilitate the functioning of market mechanisms (Sun Jiaqing, Sun Qianwen, & Jin Zhihong, 2017b). Mu Xianzhong and his colleagues, based on an analysis of the structure and feedback relationships of China's natural gas system, established a system dynamics model for China's natural gas supply and demand. They proposed an improved Logistic model solution method to forecast China's natural gas production. They then input the forecasted production values into the system dynamics model and, by altering some parameters in the model, set up seven scenarios to simulate China's natural gas demand and consumption structure (Mu Xianzhong & Li Guohao, 2018). Ding Yu and his colleagues, in order to overcome the limitations of single forecasting models, combined the dynamic simulation advantages of System Dynamics (SD) with the spatial analysis advantages of Geographic Information Systems (GIS) to build an SDGIS integrated model. They forecasted the natural gas demand and carbon emission trends in Beijing during the "14th Five-Year Plan" to "16th Five-Year Plan" periods and analyzed the spatial distribution characteristics of natural gas demand in the region (Ding Yu, Fu Jiaxin, Tang Xu, & Wang Jianliang, 2021). Jing Yajie and her colleagues identified and sorted out the factors influencing the vulnerability of urban natural gas pipelines through system analysis and established an evolutionary model for chain-reaction accidents in urban natural gas pipeline failures. They determined the simulation parameters for system dynamics, established a system dynamics model for the vulnerability of urban natural gas pipelines, and altered the investment ratios in the management, equipment, and personnel systems. Using fuzzy comprehensive evaluation and dynamic simulation, they described the changes in system vulnerability with three indicators: exposure degree, sensitivity degree, and adaptability degree (Jing Yajie, Ning Xin, Wang Zhaoge, Han Ziyue, & Li Xinhong, 2023).

3. Review and Prospect of Research Literature

This paper summarizes the research on the production, supply, storage and marketing of natural gas at home and abroad, and the existing research be summarized into the following nine aspects: 1) Research on the development of natural gas industry. The research on the development of natural gas industry includes the development history and current situation the development trend and challenges of the industry, the policy support and strategic planning of the industry, the technological innovation and intelligent development, etc; 2) Research on the storage and

shaving of natural gas. The consumption of natural gas forms a peak period and a stable period of gas consumption due to the influence of seasonal changes and natural disasters. In order solve the contradiction between supply and demand of natural gas, many scholars have summarized and borrowed the experience of domestic and foreign natural gas storage and peak shaving, and put forward suggestions for and peak shaving according to the actual situation of natural gas in China; 3) Research on natural gas pipeline network. For the research on natural gas pipeline network, the research can be summarized into four aspects according to the optimization of energy consumption and cost, the optimization of pipeline layout, the planning of pipeline gas transmission capacity and the research of the benefits of network companies, and the optimization methods can be summarized into dynamic programming, particle swarm optimization algorithm (single, multi-objective), genetic algorithm and so on; 4) Research the natural gas production, supply, storage and marketing system. The integration of natural gas production, supply, storage and marketing needs to form an efficient system, and many scholars have forward precious suggestions on the construction of natural gas production, supply, storage and marketing system from the path of the construction of the production, supply, storage and marketing system, the overall of the system, policy reform and strategic deployment and so on; 5) Research on the development of natural gas market. The development of natural gas market has a certain relationship with consumption of natural gas, and there are many factors affecting the market development. The research on the market development can be summarized as: the reform of natural gas market mechanism, the analysis problems and challenges of natural gas market, the evaluation of market development risks, the research on the unbalanced development of market regions, the research on market competition and so on; 6) Research on natural gas price. The price mechanism of natural gas in our country is not perfect compared to that in foreign. The research on natural gas price is mainly reflected in the following aspects: research and reform of the pricing mechanism, research on the relationship between oil price and natural gas price, research the transmission and distribution price system, research on the price evolution mechanism, research on the influence of the international environment on natural gas price; 7) Research on the safety of gas supply chain. Some scholars start from different links of natural gas supply chain to discuss the safety of supply chain, which can be summarized as the following aspects: research on downstream market, research on the safety of international natural gas supply and demand, research on the soundness of laws and regulations, research on the safety of pipeline network supply, research on the safety natural gas import, etc.; 8) Research on the relationship between natural gas supply and demand. The relationship between natural gas supply and demand is mainly studied from the causes of and demand imbalance, the scientificity of pipeline layout, the capacity of pipeline transportation, the stability of natural gas transmission and user gas supply; 9) Research on natural gas based system dynam-

ics. The research on natural gas industry in our country can be roughly summarized as the research on the internal operation mechanism of natural gas exploration enterprises, the research on natural gas prediction, the research on resource tax and enterprise income, the research on the benefits of public-private partnership projects, the research on the price mechanism of natural gas supply and demand, research on the demand of natural gas and carbon emission, and the research on the vulnerability of pipeline. Although the existing research has covered the whole process of natural gas production, supply, and sales, such as the research on the development of natural gas supply chain, the research on production and exploration technology, the research on pipeline energy consumption and cost, the research on construction, the research on gas storage and peak regulation, the research on market mechanism and price, the research on the safety of natural gas supply, etc., there are still some to be perfected, such as the stability research of the whole natural gas industry chain system (production subsystem, supply subsystem, storage subsystem, sales subsystem), the optimization of benefit of natural gas industry chain system, low carbonization and technological innovation, LNG market expansion, geopolitics and energy security, synergy with renewable energy, policy and investment.

With the adjustment of global energy structure and the promotion of clean energy, the supply of the international natural gas market shows a of diversification. The overall demand growth rate of the international natural gas market has slowed down, the supply and demand situation is obviously loose compared with previous years, and the price the whole year has dropped significantly compared with the previous year. With the rapid development of China's economy and the improvement of people's living standards, the consumption of natural gas continued to grow. China attaches great importance to the development of clean energy and has introduced a series of policies and measures to promote the use of natural gas and other clean energy.'s natural gas supply system is constantly improving, domestic natural gas production is steadily increasing, and the growth rate of imported pipeline gas (PNG) and imported liquefied natural (LNG) is both more than 10%. At the same time, gas infrastructures such as pipelines and gas storage are also accelerating their construction, which provides solid guarantee for the development of the natural gas supply chain. The international and domestic environment faced by the natural gas supply chain development in the current stage presents complexity and uncertainty, which puts new requirements for the development of the natural gas supply chain. The natural gas supply chain should not only focus on the development of each link in the production, supply, storage and, but should also look at the problem from the overall perspective of the natural gas production, supply, storage and sales system. Due to the uneven distribution of resources, the difficulty of production, the high degree of dependence on imports, the rapid growth of consumption, the change of demand structure, seasonal demand fluctuations and other reasons, the contradiction between supply and demand of gas has emerged, and in the case of tight natural

gas supply, some areas will appear gas famine phenomenon, that is, insufficient natural gas supply leads to users can not use gas normally. The natural gas market price is affected by the supply and demand relationship, when the supply is insufficient, the price will rise; when the supply is excessive, the price fall. This kind of price fluctuation not only affects the profit and benefit of the upstream and downstream enterprises of the natural gas supply chain, but may also bring economic pressure to consumers. the same time, China's natural gas peak-load regulation capacity is relatively insufficient, especially in the heating season in winter, the peak-load regulation pressure is greater, in some areas can not timely and effectively adjust and guarantee natural gas supply when natural gas supply is tight. Natural gas is still a "bridge" of the energy system in the next10-15 years, but it needs to be integrated into the goal of net zero emissions through low-carbon transformation in the long run. Enterprises need to pay attention technological innovation (such as CCUS, mixed hydrogen), flexible supply chain layout and methane emission reduction to deal with the dual challenges of policy and market.

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