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RESEARCH ARTICLE

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Analysis and countermeasures of natural gas development in China

Abstract Natural gas has become a transitional bridge from fossil to green and clean energy worldwide. The importance of natural gas utilization in energy structure optimization and green development is no exception for China. However, the supply of China's natural gas limits the country's demand with three factors. (1) China's natural gas resource is relatively rich, but its quality is poor with deep burial depth. Therefore, the annual plateau yield of natural gas cannot be high, with an estimated value of approximately 260–270 $\times$ 10^9 m^3. (2) The demand for natural gas in China's economic development is growing rapidly. The peak demand is estimated to be approximately 550–650 $\times$ 10^9 m^3 per year or even higher. The import volume of natural gas will soon exceed that of domestic self-produced gas. (3) Natural gas is a necessity closely related to livelihood. Particularly, a shortage in natural gas supply affects social stability. Therefore, its external dependency should be under 50% and not exceed 60%. In this study, the future situation of China's natural gas is forecasted, and relevant countermeasures and suggestions are proposed in accordance with research on China's natural gas resource potential, production trend, supply-demand link, and gas supply safety factors.

Keywords natural gas, yield, consumption, external dependency, security situation

1 Introduction

China's natural gas consumption has developed rapidly at an annual rate of 15% since the launch of China's "West-East Gas Pipeline Project" for natural gas transmission in 2000 (Gu and Bai, 2019). In 2017, China's natural gas demand witnessed a 15% year-on-year increase driven by environmental protection policies such as the "Blue Sky" plan, transition from the use of coal to gas, and rapid economic development, a percentage accounting for one third of the increased global natural gas demand during the same period (State Council of the People's Republic of China, 2018). However, China's natural gas production can hardly meet the rapid growth of natural gas consumption. With an increasing import year by year, China is expected to become the world's largest natural gas importer by 2019 (International Energy Agency (IEA), 2018; International Gas Union (IGU), 2018). In 2018, the external dependency of natural gas exceeded 43%, and it will increase rapidly in the future. If no guiding measures are provided by the government, such an external dependency will soon surpass that of oil in China and become a major factor restricting national security. In view of China's natural gas resource potential, market development, and future link of supply and demand, the future supply-demand trend of China's natural gas is analyzed, and relevant suggestions on setting a reasonable safety ceiling on the external dependency of China's natural gas and addressing risks as early as possible are proposed in this study.

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2 Development status of natural gas in China

China's natural gas industry has entered a period of adjustment after decades of rapid development. The growth rate of natural gas production has slowed down in recent years. As such, a rapid growth trend of unconventional gas production has formed. At present, China's natural gas market shows three aspects of rapid growth—the consumption, import and external dependency of natural gas.

China's natural gas production has been continuously increasing from an annual yield of 7 $\times$ 10^6 m^3 in the early days after the founding of the People's Republic of China

to 148.7 × 10^9 m^3 in 2017 (Ministry of Natural Resources of the People's Republic of China, 2017) (Fig. 1). Generally, China's natural gas production has experienced four stages of development. The first stage was from 1949 to 1971. The natural gas industry underwent a slow development period, with annual yield increased from less than 10 × 10^6 to 3.7 × 10^9 m^3 in 1971. China's natural gas production took 22 years to develop from scratch. During this period, the increase in natural gas production came from the discovery of small gas fields and the development of associated gas. The second stage was from 1972 to 2003. The natural gas industry entered a period of scale growth lasting for 31 years. The yield was increased from 5 × 10^9 m^3 in 1972 to 34.1 × 10^9 m^3 in 2003, with an average annual growth rate of 6.4%. In December 1978, China strategically decided to focus on socialist modernization construction. In response to this strategy, natural gas production reached a peak of 14.5 × 10^9 m^3 in 1979. From 1980 to 1982, natural gas production declined because China markedly reduced the infrastructure investment and halved the investment budget of the gas industry. The increase in gas yield in the second stage came from the discovery of medium-sized gas fields and the development of associated gas in newly developed oil fields. The third stage (from 2004 to 2014) was a period of rapid development of the natural gas industry. This period lasted for 10 years with a yield soaring from 41 to 130.7 × 10^9 m^3 and an average annual growth rate of 12.3%. Numerous big gas fields that were discovered in Changqing, Ordos Basin, Kuqa, Sichuan Basin, Sichuan-Chongqing Gas Zone, Qinghai, and other places in China have become major contributors to the yield growth. The fourth stage has been ongoing since 2015. The natural gas industry is in a period of development adjustment. The average annual growth rate of natural gas production has been dropping to below 5%, the number of discoveries in big gas field has been decreasing, and the quality of resources has been deteriorating.

With new breakthroughs, such as reservoir formation theory and development technology, in the field of natural gas exploration, China's unconventional natural gas development and utilization have become increasingly important. The proportion of unconventional natural gas production increased rapidly from 3% in 2000 to 33% in 2017 (Fig. 2), changing the composition of China's natural gas production (Zhao et al., 2009; Zhao et al., 2012a; Zhao et al., 2012b; Zhao et al., 2013; Guo et al., 2015; Zhao et al., 2016; Jia, 2018). Particularly, the yield of tight gas, shale gas, and coalbed methane (CBM) reached 35, 9, and 4.9 × 10^9 m^3, respectively. Tight gas is by far the major contributor to unconventional gas production. Meanwhile, shale gas has a great growth potential, and CBM's growth expectation is also sound. Over time, with further innovation and development of engineering technology, unconventional gas production will soon account for half of China's total natural gas production.

Driven by key national development plans, such as the "Blue Sky" plan and urbanization, China's natural gas consumption has grown strongly. In 2000, the State Council approved the launch of China's "West-East Gas Pipeline Project" for natural gas transmission. Natural gas market consumption increased rapidly from 24.5 to 237.3 × 10^9 m^3 in 2017, with an average annual growth rate of 15% (Fig. 3). The first line of the "West-East Gas Pipeline Project" was completed and set into commercial operation in 2004, while the second line of the project was completed and set into operation in 2012, just representing the decade with the most rapid development of China's natural gas market. Affected by various factors, such as international natural gas price, international geopolitical and economic situation, and China's economic development, the growth rate of natural gas consumption slowed down from 2013, and the natural gas market entered a period of development adjustment (Yang, 2018). Year

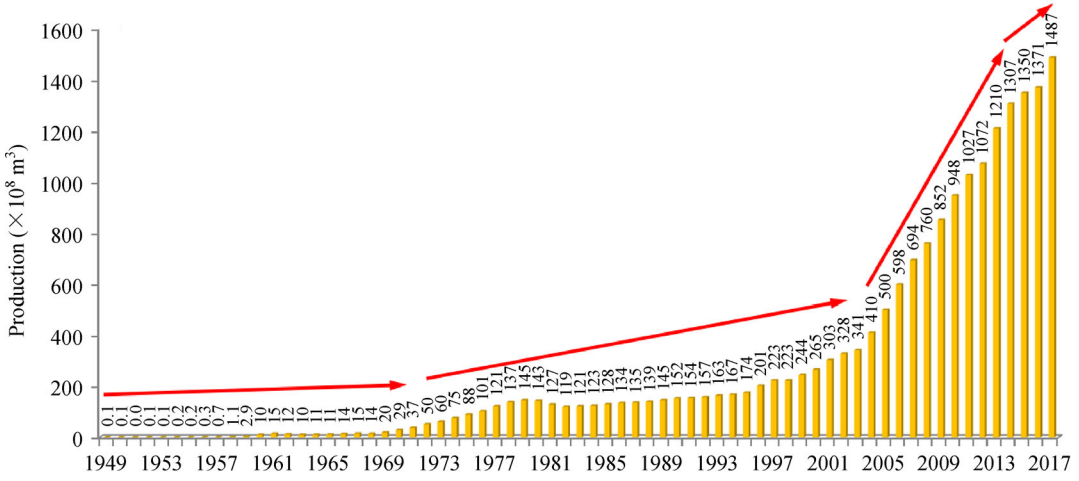

Fig. 1 Development situation of natural gas production in China (data obtained from the National Bureau of Statistics (2018)).

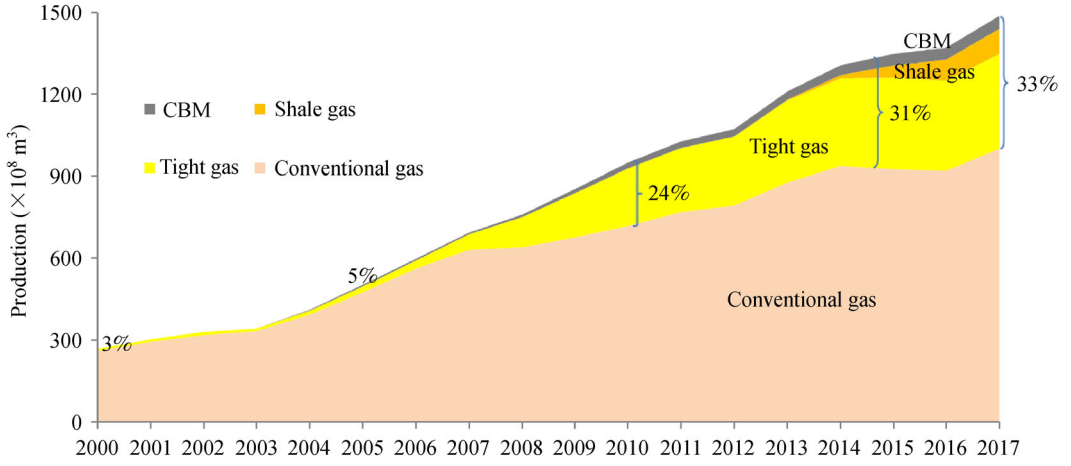

Fig. 2 Composition change of natural gas production in China (data obtained from the National Development and Reform Commission (NDRC) (2018)).

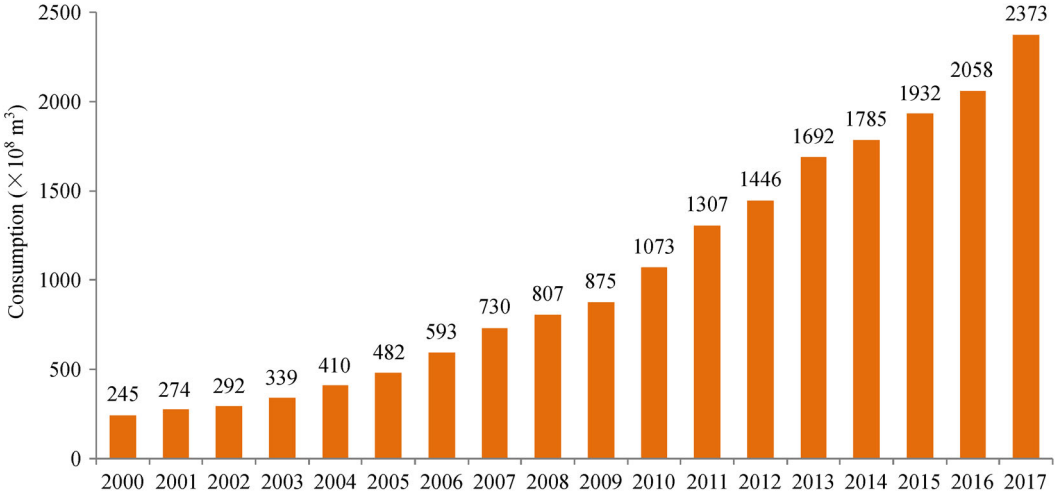

Fig. 3 Yearly natural gas consumption in China (data obtained from the NDRC (2018)).

2017 was special. Natural gas consumption witnessed an increase of 31.5 $\times$ 10^9 m^3, which increased 2.5 times year-on-year due to the adjustment of some national policies. Especially in the winter of that year, China's liquefied natural gas (LNG) trading volume and price both reached record highs (Yang and Liu, 2018), with the benchmark price reaching a maximum of 10064 yuan/ton, which is nearly 10 times that of the same period in the global natural gas market.

To meet the increasing demand for natural gas consumption, China has been importing natural gas since 2006, and the overall volume of imported natural gas has shown a rapid growth trend. In the last two years, the external dependency of natural gas has risen rapidly, reaching 39% in 2017 and over 43% in 2018. This trend will continue in the future (Fig. 4). Meanwhile, China's natural gas accounts for a relatively low proportion of primary energy consumption. In 2017, the proportion was only 6.9%, which is far below the global average of 23.9%.

3 Supply and demand situation of natural gas in China

Based on the potential of natural gas resources and their low proven degree in major gas fields, China's natural gas industry remains in a stage of rapid development, with annual proven reserves at the peak of growth. The Weng Cycle Model, which was proposed by the famous geophysicist and forecaster, Dr. Wenbo Weng, is widely

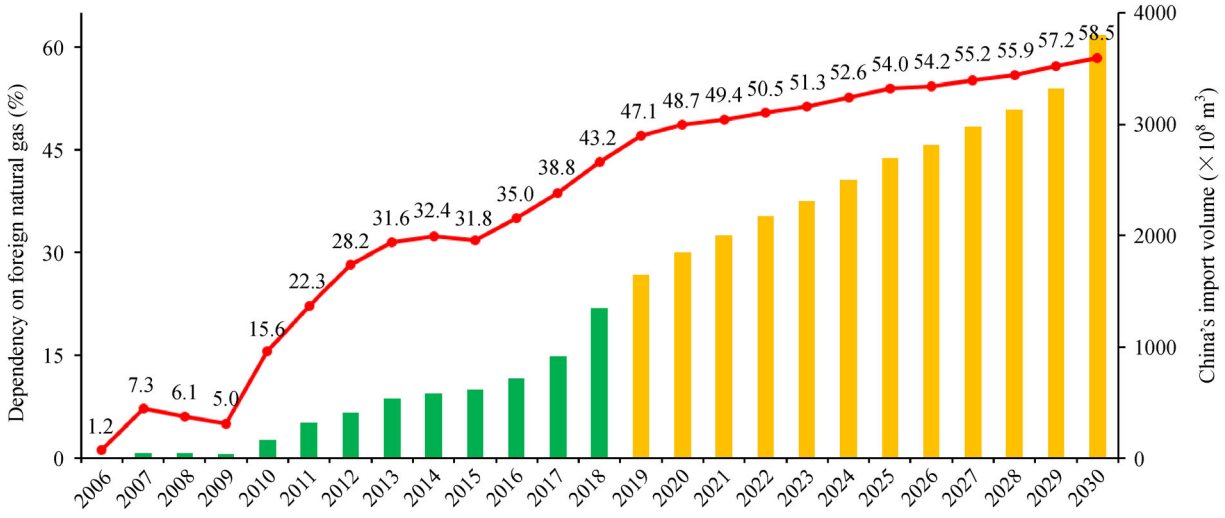

Fig. 4 The external dependency of China's natural gas (data obtained from NDRC (2018)).

used in oil and gas field production forecasts (Weng, 1984). This model considers that oil and gas field development is a complete process from prosperity to decline, and its life cycle system is irreversible. According to the forecast by the Weng Cycle Model, the annual increment scale of proven geological reserves of natural gas in China will remain in a range of 600–850 $\times$ 10^9 m^3 until 2030; thus, the peak growth of natural gas reserves in China will continue for a long time (Fig. 5).

Based on the total amount and composition of natural gas resources, the total recoverable resources of conventional and unconventional gases in China are roughly equivalent. Nonetheless, the proven rate of unconventional gas resources is low. Therefore, their growth potential would be even greater than before. The estimated proportion of unconventional gas in the developed natural gas reserves will exceed that of conventional gas by 2030. If China's natural gas production in 2015 (135 $\times$ 10^9 m^3) is taken as the base, then China's natural gas production has the chance to double by 2030 (Fig. 6). Conventional gas production will increase slightly on a stable basis, whereas unconventional gas production will develop on a large scale based on a production proportion exceeding half. With the multiplying development of China's natural gas production, the construction workload of natural gas development will also be enhanced. In addition, most developed resources are unconventional resources with relatively poor quality, therefore whether natural gas development benefits can be guaranteed is an issue worthy of attention. These two aspects are the primary limitations restricting the multiplying development of China's natural gas production.

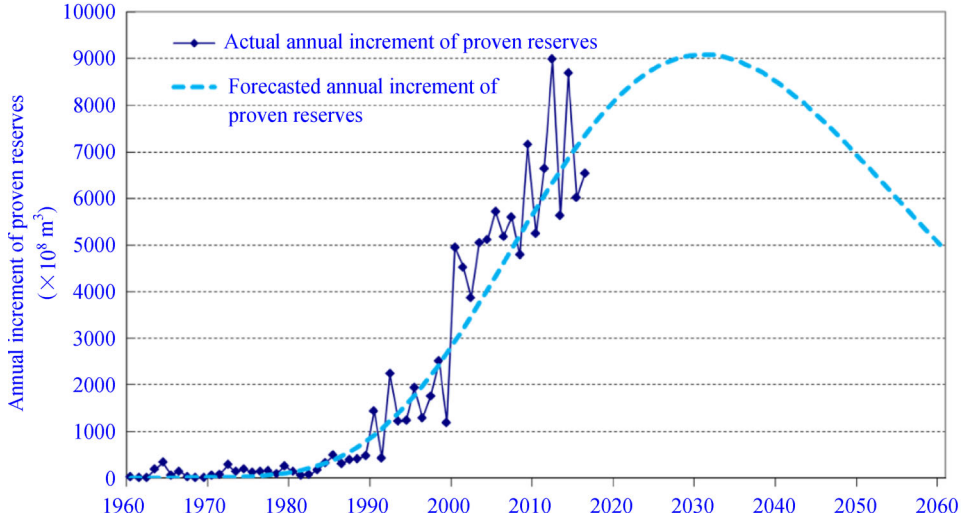

Fig. 5 Annual growth trend of proven natural gas reserves in China (The forecasted line is obtained via the Weng Cycle Model; actual data source: NDRC).

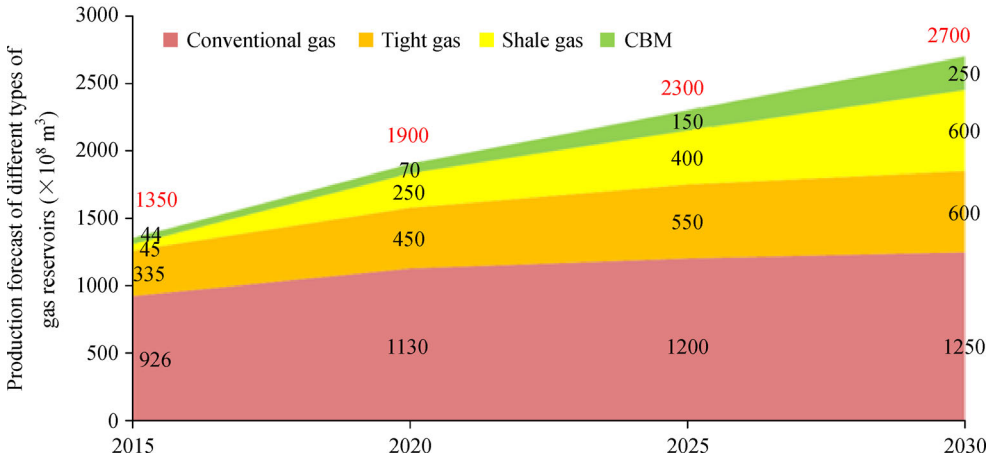

Fig. 6 Production forecast of conventional and unconventional gases in China.

With the increasing demand for natural gas in the development of national economy, especially with the implementation of the national green and low-carbon development strategy, China's natural gas consumption will continue to grow rapidly. Natural gas consumption during January–August 2018 was 180.4 $\times$ 10^9 m^3, which is an 18.2% increase over the same period of the year before. China's predicted natural gas consumption will reach 350–380 $\times$ 10^9 m^3 by 2020, whereas natural gas production in the same period will reach 190 $\times$ 10^9 m^3. Natural gas consumption will reach 600–650 $\times$ 10^9 m^3 in 2030, whereas the production will hardly exceed 260–270 $\times$ 10^9 m^3 (Fig. 7).

According to the statistics released by the National Bureau of Statistics and the Development Research Center of the State Council, China's gas consumption has grown strongly in four domains, namely, power generation, industrial fuel, urban gas, and transportation, thereby leading to the rapid growth of China's natural gas demand (Table 1) (The Oil and Gas Department of National Energy Administration et al., 2018). From 2015 to 2020, industrial gas consumption is the major body of China's natural gas consumption. With the increase in gas consumption for power generation, such a consumption will exceed the industrial gas consumption by 2022, and this trend will continue until 2030. In the future, the continuous increase in electricity consumption and the release of relevant policies will further promote the growth of natural gas demand.

4 Security situation of natural gas in China

As the gap between China's natural gas production and consumption continues to widen, the external dependency of natural gas rises rapidly with no optimistic security situation. The external dependency of natural gas refers to the dependence of natural gas consuming countries on imported natural gas. The internationally accepted method of calculation for the external dependency of natural gas is shown below:

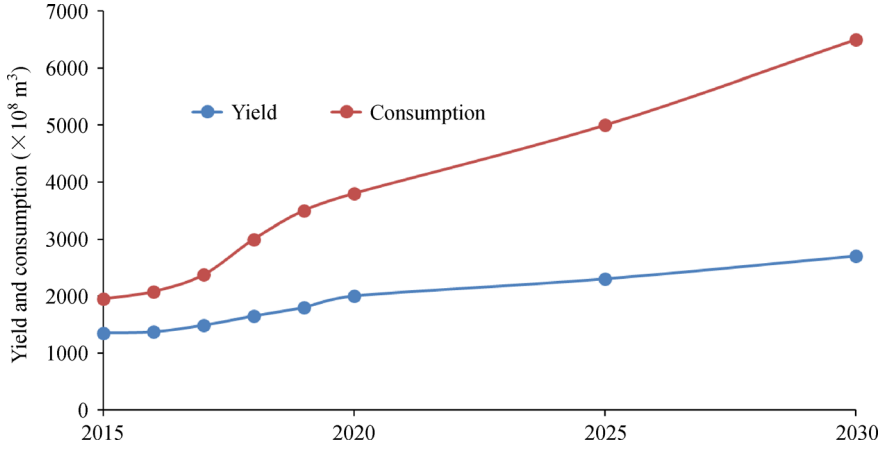

Fig. 7 Forecast of natural gas yield and consumption in China.

Table 1 Forecast of natural gas consumption in various sectors in China (unit: $\times 10^8$ m^3)

	2015	2016	2020	2025	2030
Industrial fuel	671	734	1150	1500	1800
Urban gas	411	434	750	1100	1350
Power generation	353	414	1100	1650	2000
Transportation	238	255	500	750	950

$$\begin{aligned}&\text{External dependency of natural gas}\\&=\text{Net imports of natural gas}\\&\quad/\text{Total consumption of natural gas.}\end{aligned}\tag{1}$$

According to Fig. 4, the import volume of natural gas in 2020 is estimated to be 180–190 $\times$ 10^9 m^3, and the external dependency is close to 49%. Natural gas import in 2030 is expected to exceed 350 $\times$ 10^9 m^3, and the external dependency would be in the range of 55%–59%. Natural gas is more vulnerable to external factors with more severe challenges compared with China's oil security situation, because natural gas is closely related to people's livelihood and the country. If natural gas is cut off for a day, then social problems may arise, and social stability may be affected. China's natural gas import is concentrated in gas from Central Asia and the China–Myanmar pipelines, which account for 45% of China's total gas import and 100% of the total pipeline gas import. LNG mainly comes from Australia and Qatar (accounting for nearly 55%), and its import is greatly influenced by buyer competition, mining investment and the political situation of resource countries. As a result, the stable supply of LNG in the market is at risk. Although the proportion of LNG in imported gas increases yearly, the security of transportation channels remains uncertain.

Moreover, China's natural gas reserve situation is not optimistic. China has constructed 25 gas storages, with 17.3 $\times$ 10^9 m^3 of gas in 2017, accounting for only 7.3% of the annual consumption. The United States has 419 gas storages, with a total working volume of 136.4 $\times$ 10^9 m^3 in 2016, accounting for 17.5% of the annual consumption. The geological conditions of China's basins are complex, so that the construction of gas storage reservoirs has faced great challenges in terms of scale and growth capacity. The scale and the speed both do not meet expectations. For a long time, China will not be able to meet the needs of peak shaving in terms of the location and scale of gas storages. China's gas storage capacity will reach approximately 45 $\times$ 10^9 m^3 by 2030. By then, the gas storage volume will account for approximately 8% of the consumption. The weakness of China's gas storage and peak shaving will exist for a long time. With the increase in consumption scale, the pressure on the capacity building of peak shaving and gas storage will increase.

Based on above analysis, this study suggests that the upper limit of China's external dependency of natural gas should be paid attention to in advance, and timely policy guidance should be provided. The upper limit of external dependency mentioned here mainly concerns about what factors are involved in determining the upper limit of dependency ratio and how the upper limit of dependency is determined. Regarding the factors that determine the upper limit of external dependency ratio, four factors are focused on: 1) the self-production of natural gas, which is the safest guarantee for a country; 2) the reserve of natural gas, which is an important guarantee for a country to handle unexpected gas supply incidents; 3) the domains of natural gas utilization and the amount used, and whether the amount of natural gas used in this domain can be replaced by other ways in wartime (such as coal chemical industry and underground coal-to-gas); 4) whether the replacement of natural gas consumption overlaps with the increase in oil consumption, because of the latter has serious supply security problems in China.

On the basis of above considerations, the following calculation equations are proposed to determine the upper limit of China's external dependency of natural gas, namely:

$$\begin{aligned}&\text{External dependency upper limit}\\&=(\text{Self-production}+\text{Maximum reserve})\\&\quad/\text{Total consumption},\end{aligned}\tag{2}$$

or,

$$\begin{aligned}&\text{External dependency upper limit}\\&=(\text{Total demand}-(\text{Self-production}\\&\quad+\text{Irreplaceable quantity}))/\text{Total demand}.\end{aligned}\tag{3}$$

The irreplaceable quantity mentioned here refers to the quantity of natural gas that cannot be replaced and must be ensured during wartime, including urban, chemical, transportation gases, etc. If chemical and transportation gases are replaced by petroleum or coal in wartime, the consumption of natural gas can be reduced. However, if the security situation of China's oil supply is also severe, the replacement by oil cannot fundamentally solve national security problems. Therefore, chemical and transportation gases are not included in the category of alternative consumption but considered in irreplaceable consumption. However, gases used for industrial fuel and power generation can be replaced by coal-based liquefied products and increased coal power generation, respectively, when the gas source is cut off. This part of gas consumption is considered as an alternative amount, not included in the irreplaceable amount.

Based on the prediction and analysis of China's natural gas self-production, the construction trend of gas storages, the natural gas consumption scale in various domains, and the total natural gas demand, the upper limit of China's

external dependency of natural gas is 50% and should not exceed 60%. This value is obtained on the basis of a ternary comprehensive balance of domestically produced, reserve, and demand gases. The margin is increased by 10% on the basis of safety dependency on foreign countries. In the event of major emergencies, the national system can be adopted, and short-term emergency response can be allowed by organizing unconventional production. We believe that this threshold is the key to ensure the safety of China's natural gas development. The upper limit of China's external dependency of natural gas cannot be considered in accordance with the upper limit of 65% external dependency or even higher. This threshold is determined by the close link between natural gas utilization and people's livelihood.

5 Countermeasures and suggestions

To ensure long-term safety of China's natural gas supply, we propose the following measures and suggestions:

(1) A ceiling of 50% for China's dependency on imported natural gas should be set, preferably not exceeding 60%. The country should use the ceiling of external dependency of gas to coordinate, implement, and restrict the total amount of natural gas. On this basis, the country should plan well for gas usage in related domains according to the growth scale and trend of domestic natural gas production, the scale and pace of gas storage, and the construction volume. China is a rising power. The next 10–20 years will be a critical period of development and main period of suppression by western counterparts. China should set the proportion of natural gas in the domestic primary energy consumption structure as a whole. In accordance with the natural gas consumption structure, energy security, and upper limit of domestic natural gas production, the proportion of 15% is set in this study instead of referring to the world average (23.9%) to plan the scale of natural gas consumption. This value should be based on our own capability.

(2) Technological innovation in exploration and development should be further strengthened for solid self-production capacity and the scale of China's natural gas. By strengthening exploration in new areas, China will actively expand the discovery of natural gas resources in order to increase the basis for production growth. At the same time, the pace of technological progress in key projects will be accelerated, and the potential productivity of conventional low-grade natural gas resources and unconventional natural gas reserves will be released to the maximum extent. Key researches would focus on theories and technologies for the exploration and development of deep/ultra-deep natural gas, key gas-enriched basins, natural gas reservoirs in 3D, deep water natural gas in sea areas, unconventional "artificial gas reservoirs", deep shale gas, medium-low rank CBM and on building gas reservoirs under complex geological conditions. In this manner, reliable scientific and technological support are provided to exploit the main role of low-grade natural gas resources in national natural gas production increase and stability.

(3) A nationwide interconnected natural gas storage and transportation system should be established to enhance the capacity of peak shaving and supply. According to international experience, the working volume of gas storage facilities should account for more than 15% of natural gas consumption, whereas China's working volume of gas storage facilities in 2017 was less than 10% of natural gas consumption. Therefore, we should accelerate the construction of domestic gas storage facilities and reduce the restriction of external factors. At the same time, the peak gas supply capacity will be guaranteed by strengthening the interconnection between pipe network and gas storage facilities.

(4) Natural gas import channels should be diversified to ensure a stable market supply. China's imported gas source lacks in variety. The proportion of natural gas imported from Turkmenistan and Australia is as high as 61%. The receiving capacity of LNG terminals currently in operation is close to 80×10^9 m^3 per year, and the future LNG import volume will far exceed the existing receiving capacity. Facing this series of problems, we should speed up the construction of the eastern route of the Sino–Russian natural gas pipeline and the demonstration of the western route. Furthermore, we should actively build coastal LNG terminals to expand LNG import capacity.

(5) Support for natural gas production and peak shaving policies should be strengthened to stimulate development vitality. Moreover, policy support for the utilization of unused reserves and tailings should also be strengthened. For example, lessons can be drawn from the preferential policies of China's western development strategy—the income tax rate can be reduced from 25% to 15%, and the resource tax can be reduced to 2%–3%. China should implement a differentiated tax and fee policy, increase fiscal and tax incentives for the development and utilization of deep and deepwater natural gas resources, continue and improve the subsidy policy for shale gas and CBM development, and provide financial subsidies no less than 0.2 yuan to tight gas. To cut rationally the profit distribution link among the industrial chains of natural gas production, transportation, and sales, relevant national policies should be inclined upstream to enhance the enthusiasm of natural gas exploration and development. We should promote relevant supporting policies for peak storage and shaving facilities and provide preferential policies to the main body of peak storage and shaving regulations in terms of prices and sources.

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