

# Strategies and Countermeasures for Ensuring Energy Security in China

Huang Weihe<sup>1</sup>, Han Jingkuan<sup>1</sup>, Wang Yusheng<sup>1</sup>, Shen Juexin<sup>1</sup>, Cheng Lei<sup>2</sup>

1. PetroChina Planning & Engineering Institute, Beijing 100083, China

2. CCTEG Coal Industry Planning Institute, Beijing 100120, China

**Abstract:** Energy security is important for the security of a country. Affected by global geopolitics and the COVID-19 pandemic, China is currently facing severe challenges in terms of energy security. Reducing the scale of oil and gas imports via comprehensive and efficient utilization of domestic energy and ensuring energy security require additional research for promoting sustainable high-quality development in China. In this study, the evolution of energy security is reviewed, and the energy security strategies of typical countries are summarized. Next, energy security in China is defined in terms of five dimensions: sustainable development, guaranteed supply, scientific support, economic affordability, and guaranteed systems. Further, the state of energy security in China is studied, and corresponding strategies are proposed. We propose the idea of China attempting to stabilize the production of traditional forms of energy, ensuring the supply of imported oil and gas, promoting renewable energy consumption to complement the current energy mix, encouraging cooperative innovation in energy science and technology, and improving the nation's energy-development mechanism. Finally, we suggest several policies to ensure China's energy security, including a top-level plan, integrated development of gas and renewable energies, scientific innovation of renewable energies, and international cooperation.

**Keywords:** energy revolution; energy security; security assurance; energy economy; situation analysis

## 1 Introduction

As a significant part of a national security system, energy security is a major concern globally [1]. Researchers have conducted studies on energy security, including core issues, an energy security evaluation index system, energy security strategies, energy security under climate change, and other related topics. Although China has become the world's largest primary energy consumer, its domestic energy production is insufficient to meet the consumer demand. The limited growth of China's domestic fossil energy production is the central problem of the nation's energy security and the main factor leading to the decrease in its annual energy self-sufficiency rate. Because of its limited resources, China is highly dependent on foreign energy sources, among which crude oil amounts to 72.5% of its external dependence in 2019. Given the complex global geopolitical circumstances and the spread of COVID-19, China is facing serious energy security challenges.

Meanwhile, China's energy industry is facing pressure to achieve better environmental protection and climate control, and the total demand will remain high despite China's economic development having entered a new normal and the demand for energy resources having slowed down. It is estimated that China's total energy consumption of standard coal will peak at approximately 5.9 billion tons by 2040. A domestic energy resource evaluation in China indicates that, with the exception of natural gas, coal and oil productions have reached or

---

**Received date:** November 17, 2020; **Revised date:** December 16, 2020

**Corresponding author:** Wang Yusheng, senior engineer of PetroChina Planning & Engineering Institute. Major research field is power and energy system strategy. E-mail: wangyusheng@petrochina.com.cn

**Funding program:** CAE Advisory Project "Promoting the Revolution of Energy Production and Consumption (2035)—Energy Revolution Promotes Economic and Social Development and Ecological Environment Protection" (2018-ZD-11)

**Chinese version:** Strategic Study of CAE 2021, 23(1): 112–117

**Cited item:** Huang Weihe et al. Strategies and Countermeasures for Ensuring Energy Security in China. *Strategic Study of CAE*, <https://doi.org/10.15302/J-SSCAE-2021.01.017>

approached their peak. Moreover, although wind and solar are rich resources of energy, their large-scale development will considerably challenge the real-time power balance of the power grid because of a lack of resource endowment, technology costs, and other factors, and they will be insufficient to meet the main short-term energy goals. A method of controlling and reducing the scale of oil and gas imports and ensuring energy security through the comprehensive and efficient utilization of domestic energy resources remains a major problem for achieving high-quality sustainable development in China.

Under the macro background of China's economic development, which is entering a new stage, this study fully considers the general trend of the gradual strengthening of environmental protection and climate governance, defining China's energy security from multiple dimensions and raising strategic measures and policy suggestions to ensure such security.

## 2 Evolution of energy security

### 2.1 Evolution of energy security and common national strategies

The concept of energy security is constantly being enriched and improved with changes in development needs. During the 1970s, with the fourth Middle East War triggering an oil crisis, the major oil-consuming countries around the world established the International Energy Agency (IEA) and first defined the concept of national energy security. Based on the Cold War era, the IEA's definition of energy security emphasized stability of the supply and price of crude oil. Energy security research also focused on the stability of the energy supply and energy price, but with a single energy variety and dimension [2]. Since the 1980s, the idea of energy security has gradually developed toward supply stability, economy, energy diversity, and safety, newly containing the dimensions of environmental security and economic security. During the 21st century, energy security is expanding to a broader range of social, economic, environmental, climate-related, and consumer security concerns covering multiple dimensions of energy availability, affordability, sustainability, energy governance, and international cooperation, among others [3]. Different countries have different resource endowments and economic and environmental needs, and their energy security strategies and measures also have different emphases. Therefore, research on defining energy security should be conducted on an actual development basis, combining the requirements of economic and social developments and the environmental capacity.

The United States was the first country in the world to formulate an energy security strategy, which mainly consists of four aspects: saving energy, improving the mechanism, providing flexible government financing, and maximizing the use of renewable energy [3]. On January 24, 2017, President Trump signed an executive order labeled "Energy Independence." In addition, in March 2017, the U.S. government launched the *U.S. Priority Energy Plan*, which is committed to reducing energy costs and maximizing the use of domestic energy resources, particularly traditional fossil fuels. The core aim of U.S. energy security is clearly to realize a self-supply of energy and lower the nation's dependence on external energy sources.

Germany's energy security strategy is set on a foundation of renewable energy, supported by improvements in energy efficiency. On September 28, 2010, the German Federal Ministry of Economy and Technology published its *Energy Plan* as a long-term strategy specifying that its energy strategic goals are the development of renewable resources to achieve core and economic rationality, supply security, and environmental friendliness by 2050.

Most of Japan's oil and gas supply depends on imports, and thus its government attaches significant importance to cooperation with oil and gas producing countries and its own reserves. The long-term goal of Japan's energy strategy is to transform its energy by building a clean, low-carbon, efficient, and intelligent new energy supply system through various channels, resulting in sustainable development.

### 2.2 China's energy security under conditions of the energy revolution

The world today is undergoing major changes, reflecting profound adjustments in the world economy, science and technology, culture, security, and politics. China's domestic development environment is also undergoing lasting changes. For fairer, more sustainable, and safer development, the government is promoting the formation of a new development pattern for which the domestic economic cycle is playing a leading role while promoting a dual domestic-international economic cycle [4]. Because energy is the source of power for economic development, there are five aspects (four types of revolution and one type of cooperation) that should primarily be involved in China's energy security, which are in accord with the new strategic requirements of the energy revolution, i.e., revolutions in the consumption, supply, technology, and mechanism, and international cooperation.

### 2.2.1 Sustainable development

Energy production and utilization have increased the emissions of carbon dioxide and pollutants, which cause global warming, climate change, and air pollution. Previous methods of generating extensive economic growth have created serious environmental problems and increased social governance costs. Thus, energy security must be closely aligned with environmental and sustainable development issues. On the one hand, China should strive to fulfill its obligations for its carbon dioxide emissions to peak by 2030 and become carbon-neutral by 2060. On the other hand, China should ensure that people can enjoy their rights in terms of energy development and meet their growing needs for a better life. Per GDP carbon emissions, energy consumption, and per-capita carbon emissions must be considered, given the carbon-emission reduction target.

### 2.2.2 Guaranteed supply

Energy supply security aims to improve the availability of energy, establish a system of diversified energy sources, ensure multi-source energy import channels and reliable energy transportation methods, form a better replacement and coordinated development mechanism between traditional and new energy, guarantee the full and continuous supply of energy to the greatest extent possible, reduce the terminal risk of the energy supply, and ensure the development of economic activities [5]. The central influencing factors are the degree of resource security, energy import channels, and energy strategic emergency reserves.

### 2.2.3 Supported technologies

Science and technology are the fundamental driving forces for improving energy efficiency and the energy structure and to reduce energy and environmental conflicts. Science and technology security mainly refer to the scientific and technological support capabilities required to formulate and implement a national energy security strategy. They involve various stages of energy production, transportation, and consumption, including the ability to promote and apply energy-saving and mature technologies of different energy varieties, the research and development of short-board technologies, and the ability to reserve and cooperate using high-end technologies. They also involve such aspects as the corresponding standards system and energy information collection and application capabilities.

### 2.2.4 Affordability in the economy

Economic affordability is mainly based on a practical consideration of the coordinated development of China's economy and energy. In China's energy transformation and upgrade process, energy production and costs will inevitably change with adjustments to the energy structure, which will affect economic development and the living standards of people. The impact of the energy industry and energy prices on the national economy, the impact of energy imports on international trade, and the percentage of per-capita energy consumption in income are important indicators used to measure China's energy economic security.

### 2.2.5 System stability

The energy system mechanism is a momentous content and system guarantee of energy security. In the context of the energy revolution and energy transition, the energy system mainly covers an energy hierarchical management, supervision, and incentive mechanism; an energy market and price reform mechanism; energy-related laws and regulations; and a new global energy governance system.

## 3 Analysis of energy security situation facing China

### 3.1 Sustainable security

In 2019, China's total energy production included 3.97 billion tons of standard coal, of which coal accounted for 69.2%, and coal accounted for 57.7% of the total consumption of 4.86 billion tons of standard coal. At present, China's total energy production, total consumption, coal production, and installed thermal power capacity rank first worldwide. Although the nation's energy utilization efficiency continues to improve and its energy structure continues to be optimized, China still faces greater environmental and climate governance pressures. China has become the world's largest energy producer and consumer, and coal has long accounted for more than 60% of its energy consumption. Although China's current energy intensity, carbon emissions per unit of GDP, and energy consumption levels are much higher than those of other developed countries such as the U.S., Japan, and European countries, its per-capita carbon emissions and energy consumption levels are much lower. Nevertheless, there is much room for improvement. Given the environmental capacity constraints and global climate change

requirements for low-carbon energy development, China should make major adjustments in the direction of its energy use and consumption structure in the future.

### **3.2 Supply security: Uneven distribution of fossil energy resource endowments, highly concentrated import channel, and weak emergency reserve system**

China's energy resources and production are clustered in the western region of China, whereas its energy consumption is concentrated in the more developed eastern coastal areas [6]. The current domestic fossil energy resource evaluation shows that, although coal and oil production are approaching or reaching their peaks, there is room for growth in natural gas production. The limited growth space for domestic fossil energy production is the principal issue for China, and is also the main reason why the self-sufficiency rate of primary energy has decreased in recent years.

In 2019, China's foreign dependence on crude oil exceeded 70%, and its natural gas dependence was close to 45%. China's oil and gas imports are highly dependent on high-risk countries and regions, with a high proportion of maritime channels, specifically through the Strait of Malacca.

Compared with developed countries such as the U.S., Japan, and European nations, China has fewer strategic oil and gas reserves and emergency reserve facilities, resulting in its poor ability to adjust to fluctuations in the international oil and gas market on the one hand, and a greater impact on the safe and efficient operation of its pipeline network on the other.

### **3.3 Technological security**

After years of exploration, development, and accumulation, China's energy industry has developed certain technical advantages in the field of engineering science and technology. Some of these advantages have become or will become the best in the world [7]. Nevertheless, the current overall technological level of China's energy industry falls short of meeting the requirements for energy structure transformation and upgrade, and there is a gap in its engineering technology capabilities compared to those of other developed countries. A variety of needs remain for independent research, the development of core technologies, and the introduction and absorption of external technologies. Most technologies such as geophysical prospecting and equipment, mining equipment and manufacturing, materials, assembly, sealing, mechanical processing, automation, and coal quality improvement processing technologies remain poorly developed. In the oil and gas field, technologies for deep ocean water, shale oil and gas, and tight oil and natural gas hydrates are weak; furthermore, the technical developments of oil and gas in low-temperature environments, as well as large-scale liquefied natural gas (LNG), still needs to be improved. In the power field, the manufacturing capacity of key components of high-end power equipment is relatively weak, and offshore wind power systems, intelligent distributed power supplies, and micro-power grid application technology need to be refined. In addition, high-efficiency and low-cost energy storage and multi-energy complementary technologies will be a bottleneck for energy development in the near future. In a free-trade environment, the formation of a global industrial division in the labor system and industrial chain through the exchange of existing and comparative advantages can solve such problems; however, the multilateral free-trade system is experiencing unprecedented challenges owing to geopolitics. The improvement of China's energy industry will become challenging and risky if China relies on the global industrial chain and the introduction of foreign technology. Therefore, China must strengthen its domestic research and development of core technologies and products, eliminate its high dependence on imported products and technologies, and enhance the ability of technology to support the energy industry.

### **3.4 Economic security**

China's energy resources consist of coal, oil, natural gas, electricity, and renewable energy, which are mature energy categories, forming a relatively complete energy system. Historical and future forecast data all indicate that growth in the energy industry will remain above 10% and 5% in the secondary industry and GDP.

In the long term, the energy trade has had a significant impact on China's international trade. Oil and natural gas imports are the largest energy trade in China, which is a net energy importer. The autoregressive model based on historical data on the total trade volume of goods released by the General Administration of Customs of China, together with the long-term forecast results of China's energy trade in the *World Energy Outlook* issued by the IEA in 2018, forecast China's long-term trade in goods and energy. They conclude that China's energy imports currently offset the nation's goods trade surplus, but the energy trade deficit is likely to shift to a surplus by 2025.

In contrast to developed countries such as the United States, the United Kingdom, Germany, and Japan, China's current GDP per capita and its comprehensive energy prices are relatively low. In the future, the affordability of energy prices will trend upward as China's economy develops and GDP per capita continuously increases. In addition, China's high degree of dependence on foreign oil and gas and the normalization of COVID-19 will also have enormous impacts on China's energy security.

## 4 China's energy security strategy

### 4.1 Strategic goals

We aim to build a new-era energy security system that features sustainable development, a reliable supply, support from science and technology, affordability in the economy, and system stability. This system should depend on China's energy resources, follow the economic law of energy supply-and-demand development, take energy supply-side structural reform as the main aspect, and focus on improving the quality and efficiency of energy utilization.

China should realize the safe, clean, and efficient use of energy, thus ensuring sustainable economic and high-quality social development. In the implementation of the nation's energy security strategy, maintaining a stable production in the traditional energy industry is a basic guarantee. In addition, ensuring the safety of imported oil and gas resources is an important method, and accelerating the development and utilization of renewable energy and strengthening energy-saving and emission-reduction technologies to improve energy efficiency are important for building China's energy governance system in the new era.

In the first stage, from 2020 to 2035, the establishment of a clean, low-carbon, safe, and efficient energy system will initially be planned, enabling China to realize its socialist modernization. Moreover, a diversified energy supply system can take shape, the ability to resist risks will increase, and the primary energy self-sufficiency rate will remain above 80%.

In the second stage, from 2035 to 2050, China will comprehensively improve the quality of a clean, low-carbon, safe, and efficient energy system. A diversified supply system will show strong stability and better meet consumer demand. The proportion of renewable energy, such as wind and solar, in China's primary energy structure will significantly increase, the ecological environment will be fundamentally enhanced, the primary energy self-sufficiency rate will gradually surpass 95%, and energy independence will be realized while considering international cooperation.

### 4.2 China's energy security strategies

#### 4.2.1 Stabilize traditional energy production

Given the dual effects of demand-side adjustments and supply-side structural reforms, China's total coal consumption will reach a peak. China has abundant coal resources, but it is necessary to apply measures such as production capacity planning, large-scale mine production capacity increases, and the construction of smart mines to stabilize the scale of domestic coal production and meet the basic needs of domestic coal consumption. At the same time, it is necessary to keep China's coal imports and their sources stable, primarily to meet the demand of its coastal areas.

By increasing the exploration and development of oil from marine sources and in Xinjiang province, and by examining unconventional sources of oil; increasing scientific and technological research on deep onshore, deep-water, and unconventional oil and gas resources to expand proven reserves in new areas; boosting the recovery rate and reducing the shrinkage of old oil fields; and strengthening and transforming its technical reserves, China will strive to achieve a long-term stable production of annual domestic oil production and control its degree of foreign dependence to within 70% of total oil consumption. In addition, China will deepen its cooperation with foreign countries to compensate for the operating pressure on domestic oil and gas companies caused by their inefficient production capacity.

Driven by the dual effects of air pollution prevention and control, and the transition to clean, low-carbon energy, demand for natural gas will continuously grow. To maintain the steady growth of natural gas production, China shall increase its exploration efforts in major gas-bearing basins both on the continent and in the ocean. It will also highly value both conventional and unconventional gas and increase its technical research and transformation of tight gas, shale gas, and natural gas hydrate. Moreover, it will adopt natural gas as a strategic and growing business endeavor and effectively increase its proportion of overseas natural gas assets, construct an integrated value chain

of LNG, and conduct the exploration and development of natural gas, along with its sales and utilization, to steadily expand the production of overseas natural gas rights and interests.

#### 4.2.2 Ensure the safety of imported oil and gas supply

China's crude oil imports are highly dependent on high-risk countries and regions, and the proportion of its imports through marine transport is high, among which Malacca and the Strait of Hormuz are major channels. From the perspective of long-term development, because China's acquisition of resources from around the world is uncertain, the necessity of planning new routes is urgent. It is recommended that the nation open new marine and land channels to realize the diversified importation of oil and gas resources from Central Asia, Russia, West Asia, the Middle East, Africa, Australia, South America, North America, and other regions and diversify such import routes.

There are additional strategies to ensure the security of China's oil and gas supply, for instance, facilitating the construction of crude oil storage facilities, enhancing the ability to resist fluctuations in the international crude oil market, decreasing the impact on China's national economy when import channels are restricted, establishing and improving natural gas peak shaving and emergency response systems, taking advantage of the national oil and gas pipeline network company, and improving the efficiency of oil and gas resource allocation.

#### 4.2.3 Implement multi-energy complementarity and increase the proportion of renewable energy consumption

Accelerating the comprehensive utilization of renewable energy is the key task in solving China's energy security in the future, and it is also the most realistic way for China to reduce its dependence on external energy. Under the aim of protecting the ecological environment, the development of hydropower stations and pumped storage power stations in southwestern regions such as the Dadu River and the upper reaches of the Lancang River shall be accelerated, the development of nuclear power in coastal areas shall be stimulated, and the intensification of the installed nuclear power capacity shall be advocated, all of which will have immense value in practice. Efforts will also be made to strengthen the local development of wind and solar resources in the central, eastern, and southern regions of China, improve the conversion efficiency of photovoltaic power generation and the single-unit capacity of wind power to reduce power generation costs, strengthen the flexible transformation and construction of the power system, and improve the power system's ability to absorb new energy, promoting the development of energy storage technology, reducing energy storage costs, and increasing the proportion of renewable energy consumption.

#### 4.2.4 Improve the level of energy technology and accelerate cooperation in energy technology innovation

China shall continue to increase the promotion and application of mature technologies such as industrial energy conservation and building energy conservation. China shall strengthen the research and development of new energy production and the implementation of energy-saving technologies, improve its energy efficiency, and enhance its energy production and utilization. Simultaneously, China shall conduct technical research on key technologies and equipment.

China shall increase its investment in innovation, connect its energy industry with advanced technologies such as artificial intelligence and big data, and optimize its energy development and utilization methods to create a new production capacity through technological innovation. Meanwhile, China shall conform to future energy transformation and development trends and devote resources to the exploration of and cooperation in polar oil and gas, natural gas hydrates, and other energy sources. It will also contribute to the cooperation in and the utilization of large-scale, high-efficiency, low-cost renewable energy and energy storage, as well as promote cooperation in the integrated local energy system and an intelligent energy grid based on the large-scale utilization of renewable energy. Moreover, it will appeal for cooperation in the development of inferior resources and recycling resources, suggest cooperation of energy and resource development and ecological environmental protection, and encourage cooperation in energy and resource high-end equipment manufacturing.

#### 4.2.5 Improve the energy development system and mechanism

The energy revolution can only succeed in a market-oriented environment. Related measures include advancing China's energy market reform, improving the degree of openness of the energy market, promoting energy price reforms, further promoting the construction of a market mechanism that is conducive to the development of new energy, improving the long-term stability of its systems and mechanism for the development of renewable energies, building institutional mechanisms for the energy industry based on Chinese characteristics, and establishing a risk-response mechanism to effectively resolve and reduce the impact of unpredictable events on national energy

security.

## 5 Countermeasures and suggestions

### 5.1 Conducting top-level energy security design and overall planning and formulating independent energy-development strategies and policies

Energy security involves national, economic, environmental, regional, and cooperative security, as well as industries besides minerals, materials, mechanics, optics, and information. The Chinese government is recommended to conduct top-level design and overall planning for national energy security and refine the development path and corresponding guarantee policy measures to improve China's energy self-sufficiency rate at various stages according to national medium- and long-term energy plans and the implementation steps realizing energy independence.

### 5.2 Accelerating the integration of natural gas and renewable energy to promote energy transformation and upgrades

The development of renewable energy, including wind and solar energy, is an effective way to reduce China's economic dependence on international oil and gas and to achieve energy transformation and upgrades, and is a significant way to improve China's future energy self-sufficiency rate. The promotion of renewable energy development and utilization technologies and industries should be the main points of China's long-term energy security strategy, in addition to the *Renewable Resources Law* implemented in 2006, which should be revised in light of the energy security requirements of the new era, the state of energy supply and demand, and advanced foreign experience.

Natural gas power achieves a good peak-shaving performance and is currently the most realistic way to promote the large-scale development and utilization of wind and solar resources. It is suggested that in western and northern China, where wind resources are concentrated, power grids, natural gas production, and importation pipeline layouts should be combined, and onshore multi-energy complementary integrated energy bases should be built, transmitting the power to the central and eastern regions through ultrahigh voltage power grids. In the eastern coastal areas where wind resources are concentrated, the layout of power grids and imported LNG receiving stations should be combined and the construction of a coastal multi-energy and complementary integrated energy base should be coordinated to immediately realize the development and utilization of resources.

### 5.3 Establishing an interdisciplinary, cross-field, collaborative, and efficient energy technology innovation research and development system

Disruptive new energy technologies are important starting points for improving China's energy utilization efficiency and optimizing the energy consumption structure. They are also the most effective way to increase the proportion of renewable energy consumption and ensure the safety of China's energy supply. China should establish a national key scientific and technological research and development program. It should also focus on shortcomings and key technologies such as wind energy and precise solar forecasting, big data energy analysis, smart and gas grids, large-scale energy storage technology, offshore wind power technology, and other technologies to take advantage of China's system and establish a cross-discipline, cross-field, collaborative, and efficient scientific technological research and innovation system mechanism. The nation should also build a government–industry–university–research collaborative innovation support platform to conduct joint research.

### 5.4 Deepening energy cooperation with foreign countries to build a new energy governance system

China's government shall establish a joint mechanism to ensure energy, diplomacy, fiscal policy and taxation, foreign trade, finance, and other areas, as well as continue to consolidate and strengthen its overseas energy cooperation, particularly with countries along adopting the Belt and Road initiative, and its energy base construction. It should also promote energy trade and import diversification and expand cooperation with Northeast Asia, Central Asia–Russia, West Asia, and Southeast Asia. It must also strengthen its energy trade and technical cooperation with other countries, deepen its multilateral and bilateral international energy cooperation mechanisms, and build a green, low-carbon global energy governance system and a safe and efficient energy security system. Finally, China should promote the openness and fairness of the international energy market and maintain the safety of energy transportation channels.

## References

- [1] Lu S L. Research on world energy issues and China's energy security [D]. Beijing: Party School of the Central Committee of C.P.C, 2011. Chinese.
- [2] Cheng L. China's energy security challenges and analysis of coal security role [J]. Coal Economy Research, 2019, 39 (4): 10–14. Chinese.
- [3] Shin J, Shin W S, Lee C Y. An energy security management model using quality function deployment and system dynamics [J]. Energy Policy, 2013, 54(3): 72–86.
- [4] Cheng L. Analysis of China energy security and policy recommendations in the new era [J]. Energy of China, 2018, 40(2): 10–15. Chinese.
- [5] Xinhuanet. General Secretary Xi Jinping speech at a symposium of experts in the economic and social fields [EB/OL]. (2020-08-24) [2020-10-26]. [http://www.xinhuanet.com/politics/leaders/2020-08/24/c\\_1126407772.htm](http://www.xinhuanet.com/politics/leaders/2020-08/24/c_1126407772.htm). Chinese.
- [6] Huang W H, Han J K, Wang Y S, et al. The Belt and Road energy cooperation and strategic research on the construction of the western energy corridor [M]. Beijing: Science Press, 2019. Chinese.
- [7] Wang Y S. Discussion on engineering science and technology supporting oil and gas cooperation in the Belt and Road [J]. Petroleum Planning and Design, 2020, 31(3): 10–12. Chinese.