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Development Prioritization of Shale Gas Industry Development Strategies Using a SWOT-AHP analysis—a Case Study of China

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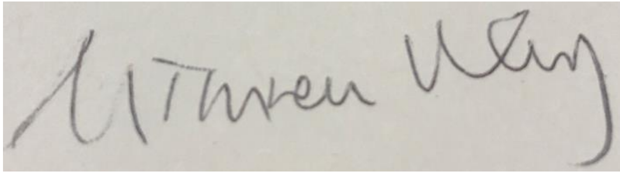
Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.



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China used to rely heavily on fossil fuels, especially coals for a long time, which renders the energy structure insufficiently balanced to support its prosperous economic development. Since 1985, China has been the world's largest coal producer and coal has dominated China's primary energy mix with a share around 70%, which pose serious threats to both human and environment (BP 2016). According to IEA (2012), China's CO2 emissions in 2008 exceeded not only the amount of the entire European continent but also the total emission of the United States, Canada, and Mexico. To mitigate environmental pollution, improve current energy system, and take the responsibility as the world's biggest developing country, the Chinese government has launched a series of projects to promote shale gas development.

With respect to sustainable development of Chinese shale gas, this research aims to assess Chinese shale gas development, prioritize potential development mode and propose strategic recommendations for its future development. To reach the aim, this research does a comprehensive analysis of Chinese shale gas development with both quantitative and qualitative methods. Apart from literature review, SWOT and AHP analysis will also be applied to assess China's shale gas development and potential development modes. This thesis first gives an over view of Chinese shale gas development by clarifying necessities and current situation. Strengths, weaknesses, opportunities and threats are then identified as a basis for AHP analysis. With priorities of development modes obtained from AHP-SWOT analysis, potential suggestions will be finally provided to promote future sustainable development of shale gas in China.

Keywords: China's Shale Gas Industry, Development Modes, AHP, SWOT

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1. Introduction

1.1 Background

Necessity of Energy Consumption Structure Optimization and Improvement and Relief of Carbon Emission Pressures

As a relatively clean fossil fuel, natural gas is regarded as a bridge in sustainable energy transition (Gao 2016). According to the predictions of IEA, global natural gas demands between 2010-2035 will increase by 50% or more than that in 2009 (GEA 2012). In such circumstances, the percentage of natural gas in global energy supply structure will reach 25% until 2035, wherein the yield of shale gas and other unconventional natural gas is about 1.6 trillion cubic meters (Yuan *et al.* 2015). At the same time, BP (2015) considers that global energy consumption amount will double than that in 1990 until 2035 and reach up to 0.18 billion crude oil amount. The main growth source is the rapid growth of natural gas consumption amount.

Natural gas has a rather low percentage in primary energy mix of China (Yuan *et al.* 2015). The amount of gas consumption in 2015 is 187.54 blillion cubic meters (bcm) and its percentage in total energy consumption is only 4.9% (National Bureau of Statistics of China (NBSC) 2016), far below than world average level (Li *et al.* 2016). In order to reduce carbon emission and realize low-carbon development, China is speeding up the adjustment of energy resource structure and planning to increase the percentage of natural gas in primary energy consumption during the "12th Five Year Plan" by 8% (Yang and Lei 2016). What is more, the Chinese government also sets a target for domestic natural gas development which aims to increase its shale in total primary energy mix by up to 10% by 2020. (Elzen *et al.* 2016) As mentioned in Plan on Shale Gas Development Plan (2016-2020), the percentage of non-foil energy consumption in primary energy consumption in 2020 will be 15% and the percentage of natural gas will be over 10% (National Energy Administration (NEA) 2016). The development of clean resource deserves great attention. Accordingly, during the period of "13th Five Year Plan", natural gas, non-fossil energy and renewable energy continue to develop at a fast speed and the percentage of clean resource is predicted to reach up to 15% by 2020(NEA 2016 and National Development and Reform Commission (NDRC) 2016) .

High Reliance of China on External Fossil Fuels and Low Guarantee of Energy Resource Security

In recent years, the import volume and external dependence of main conventional resources in China continue to increase year by year (Pi *et al.* 2015). According to the imports and exports data from General Administration of Customs, by the end of 2015, external dependence of imported oil in China was 59.6%. Besides, the external dependence degree of natural gas and coal also has prominent growth. In terms of the import amount, the import volume of coal and oil in China has a relatively large growth rate, wherein the import volume of oil is 330 millions of tons in 2015 with a growth rate of 22.9% compared to 2012(NBSC 2016) . In terms of coal, the import volume of coal in China in 2015 was 204.14 million tons, increased 48.8% compared to 2012. (NBSC 2016) The external dependence degree of coal is relatively low. When it comes to natural gas, in 2015 the total volume of import was 58.4 bcm (NBSC 2016).

As China is in the industrialization stage, fossil resource has been and remains to be the prime energy provision source of China during certain period (Yang *et al.* 2013). In conditions when domestic coal, oil, natural gas reserves and productivity do not have prominent changes, the increase of energy consumption amount will increase the external dependence degree of energy resources in China with varying degrees. While national operation is supported by resources. Excessive reliance on import will definitely generate detrimental impacts on the energy provision security and even state security.

Great Potentials of Chinese Shale Gas Development

In the past several decades, China's economy development has achieved rapid progress (Li *et al.* 2016). The growing energy demand and consumption of conventional oil and gas resources aggravate the imbalance between conventional energy supply and demand all over the world. At the same time, climate change and environmental problems have forced China to improve its energy consumption structure and greatly develop clean energy. Natural gas is a kind of clean energy resource. It is a feasible route to improve energy resource structure and decrease carbon emission by improving the share of natural gas in primary energy consumption (Yang 2016). In addition to the richness of shale gas resources in China, the success of American "Shale Gas Revolution" also has referential values for shale gas development and exploitation (Zhu and Zhao 2017). China has great potentials in shale gas resources and possesses favourable resource foundation (Zhou 2013).

Based on favourable evaluation and prediction of resource development potentials, the Chinese government has paid high attention to shale gas industry development. Energy Development Strategy Action Plan (2014-2020) mainly makes strategic planning about the exploitation and development of unconventional oil and gas resources such as shale gas and coalbed methane, which also emphasizes commercializing China's shale gas industry in a sustainable way (NDRC 2016).

1.2 Research Aim and objectives

This research aims to assess Chinese shale gas development, prioritize potential development mode and propose strategic recommendations for its future development.

To make it clear, the aim of this research is shown as these questions below:

- What is the status quo of Chinese shale gas development?
- What are the key factors affecting shale gas development in China?
- What kind of development mode is most suitable for Chinese shale gas industry?
- What are the potential strategies suitable for future shale gas development in China?

In order to approach the aim and answer questions above, there are several objectives need to be addressed:

- Clarify the necessities of shale gas industry development in China
- Assess the status quo of China's shale gas industry development by clarifying characteristics
- Identify the most influential factors related to China's shale gas industry development through quantitative evaluation
- Identify and prioritize development modes China's shale gas industry by using AHP
- Propose potential strategic suggestions with respect to the prioritized development mode

1.3 Research Approach

The first chapter provide background information of this research. The second chapter consists of literature review and a short summary. The third chapter gives an over view of Chinese shale gas development by clarifying necessities and current situation. The fourth chapter is AHP-SWOT analysis of China’s shale gas industry development. Strengths, weaknesses, opportunities an threats are identified first as a basis for AHP analysis. Then the priorities of development modes can be calculated. The last chapter provides potential suggestions with respect to results from previous chapters.

1.4 Research Method

The research will make a comprehensive analysis of Chinese shale gas development with both quantitative and qualitative methods. Theoretical and practical analyses will be applied based on the data collected from literature review and questionnaire survey to achieve objectives raised in Chapter 1.2. (See Table1.) Apart from literature review, SWOT and AHP analysis will also be applied to assess China’s shale gas development and potential development modes. In addition, a questionnaire survey will be conducted with experts from China University of Petroleum and Jinan University so as to obtain data for the AHP analysis. After identifying the key factors and making necessary comparisons between the results, the research will provide strategic recommendations for the future development.

Table 1. Table of Methods and Data Sources

Objectives	Methods	Data Sources
1.Clarify the necessities of shale gas industry development in China	Literature review	Journals and articles Government reports
2. Assess the status quo of China’s shale gas industry development	Literature review	Government reports Journals and articles
3.Identify the key factors affecting China’s shale gas industry development and evaluate their relative importance	Literature review SWOT analysis AHP	Government reports Journals and articles Questionnaire survey
4. Identify and prioritize development modes China’s shale	AHP	Questionnaire survey Results from section 3

gas industry		
5. Propose potential strategic suggestions with respect to the prioritized development mode	N/A	Results from section 2, 3, and 4

2. Literature review

At present, only the United States and Canada have realized the commercialization of shale gas development. Researches concerning the development of shale gas in China mainly focus on the environmental impacts evaluation, introduction of overseas experience, current development situation analysis (Li 2016), challenges and future prospects, etc. Due to the increasing popularity of shale gas industry development in China, there are a lot of relevant researches, in this thesis, the geological or physical analysis of Chinese shale gas are not the main focus. The results of literature review are in the following.

2.1 Foreign Experience

According to Zhou (2013) and Zhao (2015), demand growth, technical progress and policy support are three most important factors influencing China's shale gas industry, wherein technology consists in the key factor during the development of shale gas. Zhou (2013) also considers that the great success of shale gas in the US should be ascribed to diversified reasons. In summary, the development mode of the US could be summarized as labor division propelled by the market operation, technical progress propelled by labor division, output growth propelled by technical progress and energy structure optimization propelled by output growth (Wang *et al.* 2016). Throughout the comparative analysis, this thesis also raises enlightenment and suggestion for future development of shale gas industry in China.

In terms of policy, since the US takes the lead to realize the commercialization of shale gas exploitation (APERC 2015), its corresponding policy system becomes the basis reference of shale gas development and utilization for other countries. Yang thinks that preferential policy, open environment for competition, sound pipeline network infrastructure and efficient supervision system constitute the key factors in the success of American shale gas industry. Zhu assesses American energy policies and proposes that the development of unconventional oil and gas resources especially shale gas contributes a lot to the decline in energy external dependence of the US. Throughout elaborate analysis on American shale gas industry policy, Zou find out that policy incentive and long-term technical development matter a lot in the success of American "Shale Gas Revolution". In addition, China could refer to the legislation experience of the American government in terms of environment risks management, such as creating multiple communication channels for public and introducing targeted regulations for shale gas development (Liu). As for development strategies, lessons could be also be drawn from the US with regard to technology innovation and industry system development.

However, together with the progressive advancement of shale gas development and exploitation practice, even if the US has a relatively mature supervision and policy system, some scholars hold that it is not very suitable for China's present situation, in particular, the supervision system for water resource issues (Rahm). Feng points out the flaws in American shale gas development and reminds that people should calmly confront the popularity of American shale gas development. At the same time, Feng insists that the largest risks in shale gas development in China are insufficient technical innovation and fluctuating natural gas prices.

Although the successful experience in America deserves reference, China should explore a new development mode according to national conditions. Xiao Gang (2011) mentions that China started fairly late in shale gas research and fails to realize good management on gas production, transportation, and marketing. Therefore, it is not appropriate to follow American mode. Pursuant to (Pi 2010), China and America have different shale gas reserve conditions. Considering the sustainability of exploitation and development, China should have a thorough evaluation and assessment of resources potential before blindly large-scale exploitation (Zou 2013).

Meanwhile, based on the analysis of shale gas industry policies in Canada, Wang advises the Chinese government to learn from them and produce effective policies so as to achieve stable utilization and finally achieve sustainable development.

2.2 Development Conditions and Challenges

The success of American shale gas industry encourages more and more countries to accelerate the pace of unconventional oil and gas resources development. China also achieved certain progress in shale gas resources deployment with a series of pilot projects. Yang (2016) observes the development conditions of shale gas in China. Meanwhile, Chinese scholars start to focus on potential problems and challenges existing in different development stages through the whole shale gas supply chain. These challenges exist through the whole supply chain, from the upstream till the downstream.

The first concern is a monopoly of mining rights. In China, shale gas has just been derived from existing resources category since 2011, becoming the 172^{nd} independent mineral resource. Because of the geological characteristics, most shale gas reservoirs overlap other mineral resources in the same region. As indicated by the investigation by Ministry of Land and Resources, China has 180 favorable shale gas reservoirs with a total area of 1.11 million square meters, wherein 77% of them are within oil reserves regions (Pi 2015). As for the planned development regions of shale gas, most of them are overlapped with conventional oil and gas fields owned by China National Petroleum Corporation (CNPC), China Petrochemical Corporation (Sinopec), and China National Offshore Oil Corporation (CNOOC). As a result, although Chinese government encourages small companies and private capitals to participate in shale gas industry, it is hard for them to obtain mining licenses.(Wang 2016)

Secondly, there exist three major problems in the production stage, namely high exploitation costs, water resource constraints and environment risks. At present, the shale gas exploitation costs in China are much more than that of the US (Li and Jiang *et al.*2014). Even compared with domestic conventional oil and gas, the economic profits from the shale gas exploitation are much lower.

In addition, the growing output of shale gas in America inevitably lays pressures on international natural gas prices (Li and Jiang *et al.*2014).. If global natural gas price continues to decrease, profit expectations of shale gas production will be further reduced, which will discourage relevant investors, manufacturers and service providers.

Another problem is water resource constraint. Shale gas production requires a huge amount of water consumption, in particular, the hydraulic fracturing operation normally consumes 15000 tons of water per well in China (Zhang 2015). In addition, the distribution of Chinese shale gas reservoirs and water resources has a prominent regional difference. Most shale gas reservoirs are in severe shortage of water resources (NEA 2016), which further aggravates water scarcity situation in shale gas development and local uses. Furthermore, underground water pollution is the most serious environment risk confronted by shale gas production (Li and Jiang 2014).

Another concern is downstream transportation and pipeline network problem. In comparison with mature pipe network system in America, the short natural gas pipe in China could not bear great transportation pressures. Simultaneously, devoid of any effective supervision policy, the government could not guarantee the justice of entry conditions.

With regard to the supervision and management link of shale gas, there have three main management departments. Price Division and Climate Division of NDRC take charge of the formulation and execution of energy saving and emission reduction and climate change policies. Price Division of NDRC takes charge of the supervision and management of shale gas price in production and consumption links. Ministry of Land and Resources takes charge of the management and mining right of shale gas resources, distribution of exploitation right, and land utilization during circulation and shale gas development process. NEA takes charge of development plans formation and policies implementation. Ministry of Environmental Protection takes charge of the establishment of shale gas development environment supervision standards, norms and policies. Ministry of Finance and State Administration of Taxation are responsible for relevant tax and charging standards formation, such as the determination of resource tax. In general, shale gas supervision and management in China is in the sparse state. The supervision of shale gas governed by different departments lacks uniform supervision agencies. Moreover, as for the implementation of the policies and measures, various departments do not have enough coordination and communication.

2.3 Policy Research

At present, China does not have any specific laws and regulations targeted on shale gas development and utilization. However, some existing laws and regulations have binding force on shale gas exploitation and utilization. Wang has clearly observed the shale gas development and management legal system and framework in China. However, no specific terms target at shale gas development and utilization process but simply concentrate on production increase(Li and Jiang *et al.*2014).. Further improvement should be done within the existing policy system to enforce the implementation of laws and regulations. In recent years, the central government successively implements various policies to support shale gas development of shale gas by enforcing supervision of shale gas development and utilization process as well as speeding up the industrialization progress of shale gas industry.

2.4 Future Prospects and Suggestions

Li considers that China has rich and abundant shale gas resources with potent development momentum and promising prospects. Pi (2015) proposes that the Chinese government should enhance international cooperation, policy implementation and key technology R&D. Li advocates to enhance shale gas research level, increase shale gas investment and form characteristics development technology in China. Liu summarizes that the large-scale development of shale gas should refer successful experience across the world. The Chinese government could draw lessons from America, Poland, and Germany and explore proper shale gas industry development mode. Ren and Tan (2015) pays high attention to shale gas resource potentials and exploitation development conditions and compares China and America in terms of industry development process and experience. After pointing out specific problems confronted by shale gas exploitation, Jia (2105) meanwhile puts forward corresponding development suggestions. Pi (2017) analyze the features of shale gas reserves and summarize American shale gas industry development measures and technical modes. Moreover, they make an in-depth analysis on the main issues constraining Chinese shale gas development, most of which are coming from supporting policies and key technologies. Xingan (2013) uses AHP to prove that the development of shale gas industry in China encounters many influential factors and problems, including both advantageous factors such as rich resource reserves and promotion of new economic growth points and disadvantageous factors such as complicated geological conditions, insufficient capital investment and few financing channels(Li and Jiang *et al.*2014).. These factors jointly determine the future development of shale gas industry in China (Pi *et al.* 2015). However, these factors have different influential degrees. In order to promote the development of the shale gas industry in China, factors with prominent influences on China's shale gas industry should be identified to propose targeted strategies with respect to these factors (Ren *et al.* 2015).

Summary

Above all, the study on shale gas in China remains in the start-up stage. According to the research results made by domestic and foreign scholars, apart from a huge number studies on domestic geological characteristics, most scholars pay more attention to introduce American shale gas experience, analyze development status, predict future development potential and propose corresponding suggestions.

The mainstream opinion holds that among unconventional gas resources, shale gas resource is most abundant with promising development prospects, deserving high attention and focus. In addition, scholars, experts, and institutions in China has done thorough research on the latest research progress at home and abroad. It offers experiences to promote Chinese shale gas development. However, most experience that provided as policy implications or other strategies measures by scholars are mainly generated from the United States, without providing thorough discussions on why these suggestions are suitable. Therefore, this thesis attempts to adopt a SWOT-AHP analysis to provide theoretical basis before proposing potential strategic measures and the most suitable development mode for China.

3. Overview of Chinese shale gas development

3.1 Necessities

Energy shortage has become a long-term obstacle for China's rapid economic and social development (Jia *et al.* 2016). Due to the soaring energy demand from resident's consumption, industrial and agricultural production, the gap between domestic energy supply and demand is further increasing, so does the dependence on energy imports (Jia *et al.* 2016).. For keeping the national energy security and avoiding possible energy crises, it is necessary to find alternative energy sources as quickly as possible. In 2014, in the first energy conference, Xi Jinping specifically proposed the new energy strategy which set "Energy transition" as a priority in Energy Development Strategy Action Plan (2014-2020) (GOSC 2014). However, if the natural gas serves as a bridge, the transition from fossil fuels to renewables will require a long time (BP 2017). To meet the increasing demand for gas and achieve carbon reduction targets proposed in the 13th Five-Year Plan, China is now paying much attention to shale gas development (NDRC 2016).

3.1.1 Need of energy security

Energy security is of great importance to the stability of the world's economy and its sustainable development (NDRC 2016). As for China, it is urgent to build up a much cleaner and more efficient energy system so as to achieve energy security. In 2015, China's total energy consumption was 4300 million tons of standard coals, in which coals, oils and gas accounted for 64.0%, 18.1%, 5.9% respectively (NBSC 2016). However, both energy production and consumption structures were not balanced. As can be seen from the Figure 1 below, coal has dominated China's energy mix for a long period with a share of around 70% in the total energy consumption, which in the future, is still predicted to be the main primary energy (BP 2017), while natural gas and renewable energies (hydropower, nuclear power, wind power and solar energy, etc.) have only occupied a small proportion in energy mix (Jia *et al.*2016).

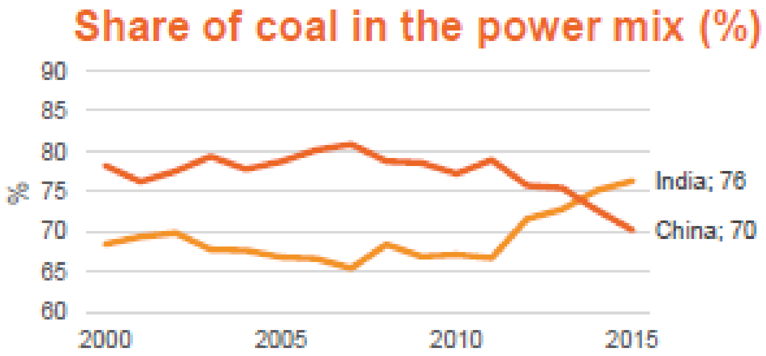


Figure 1. Share of coal in the power mix (Source: Enerdata 2016)

In fact, this coal-based energy consumption structure will be detrimental to China's sustainable development economically and environmentally. According to the 13th Five-Year Plan for Economic Development, China's economic development will catch up with that of the major developed countries, and will basically achieve the "four modernization" goals by 2050 (NEA 2016). China's GDP growth by 2020 is predicted to be the highest among major countries (NEA 2016), and meanwhile, its total energy demand is about to account for 16% to 22% of the world's total energy consumption. Development of domestic renewables as well as unconventional oil and gas resources is the key to supply the increasing energy demand for economic progress, which contributes to China's energy security with reduced external dependence. (Pi 2015)

3.1.2 Imbalance between natural gas supply and demand

Chinese conventional natural gas reservoirs are mainly distributed in middle and western areas including Chuan Yu (Sichuan and Chongqing), Shan Gan Ning (Shanxi, Gansu, and Ningxia), Xinjiang, and Qinghai, with a proven reserve of 13.01 trillion cubic meters (NEA 2016). Natural gas consumption has been growing rapidly in the past few years. As shown in the Figure 2 below, in 2000, China's gas production was 27.7 bcm)(NBSC 2016), which was not only able to supply its domestic gas consumption (24.5 bcm))(NBSC 2016) but also could be exported outside of the country, however, in 2015, its natural gas consumption (187.54 bcm))(NBSC 2016) was far more than its production (136.50bcm)(NBSC 2016). In 2015, with an annual increase rate of 14.8 % compared with 2000, China's gas consumption was 3 times the annual growth rate of its total primary energy consumption (NEA 2016). As a result of this soaring gas demand, China has become a net importer of natural gas since 2009 with 2.39 billion cubic meters imported)(NBSC 2016) and by 2015 this volume rose to 51.89

billion cubic meters(NBSC 2016), with the external dependence increasing from 2.76% in 2007 to 27.67% in 2015.

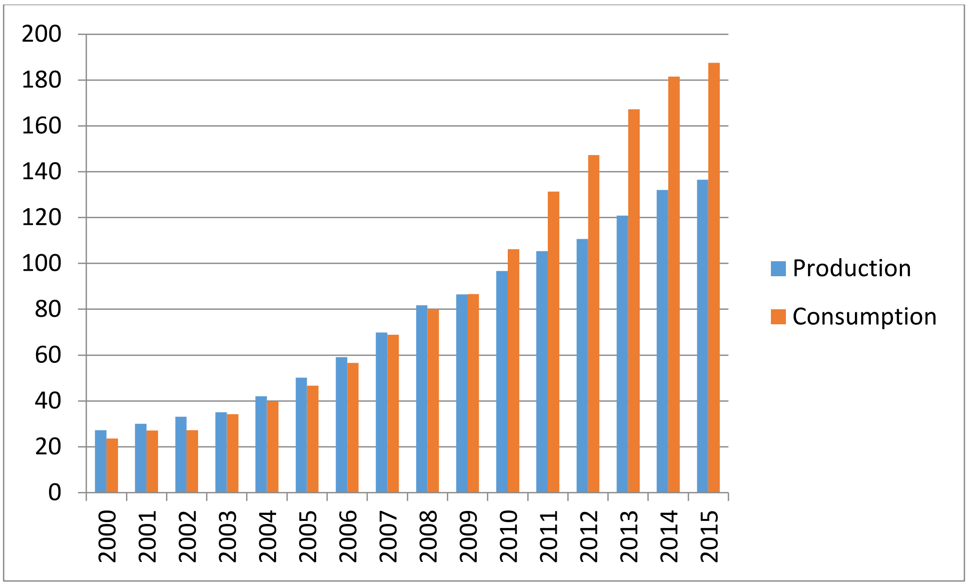


Figure2. Natural gas consumption and production between 2000 and 2015 (Data source: NBSC 2016)

Due to the continually growing demand for natural gas as well as clean energies, development and utilization of unconventional gas need to be put on the agenda as soon as possible. According to NDRC's prediction, Chinese gas demand will reach 400 billion cubic meters by 2020, while the domestic natural gas supply will be only 220 to 230 billion cubic meters, which suggests that in the next five years China will still face the imbalance between its gas supply and demand with a gap up to 180 billion cubic meters (NDRC 2016). In order to satisfy the demand for gas and if there are neither alternatives nor increased domestic gas supply, China will have no other choice but to import, with its gas import dependence rising to 44% by 2020(BP 2017). As a result, the domestic economic and social development will be further dependent on foreign energy imports, while the expanding tendency of this dependence will worsen the whole situation. Therefore, proceeding with the development of unconventional gas industry is in line with China's growing energy demand. In addition to being one of the "best solutions" to domestic gas shortage (OECD 2017), it also bridges the upcoming energy transition from fossil fuels to renewables.

Now China's domestic gas supply is a combination of conventional and unconventional gas. In 2005, its domestic gas production was 50 bcm (NDRC 2016), which increased more than twice in 2015 with a production of 135 bcm(NDRC 2016). In particular, the shale gas industry has made rapid development since the industrial breakthrough in 2011. In 2012, China made the breakthrough from "zero shale gas" with a production of 0.0025 bcm (NEA 2016). In 2015, its total production of shale gas is around 4.6 bcm (NEA 2016), up by more than 3 times compared with 2014. In addition, the daily production is predicted to be more than 20 billion cubic meters by 2040 (EIA 2016). Besides, by 2040, China's shale gas production is expected to take up 40% of the world's total production (EIA 2016), making it becomes the second largest shale gas producer (EIA 2016).

Need of sustainable economic development

In 2010, to promote the emerging strategic industries, the State Council of China issued the Decision on Accelerating the Cultivation and Development of Strategic Emerging Industries. Based on this decision, in 2011, NDRC proposed to "encourage and guide private enterprises to develop strategic emerging industries" (Yang *et al.* 2016). In addition, a series of plans on energy conservation and environmental protection have also been introduced, which requires a sustainable economic development with higher efficiency and lower carbon emissions.

In the 13th Five-Year Plan for the Control of Greenhouse Gas Emissions, China commits itself to achieve a 18% of reduction on carbon dioxide emissions per unit of GDP by 2020 compared to 2015 (GOSC 2016). To address climate change problems, it is also committed to implement other policies so as to achieve a 60% to 65% of reduction on carbon intensity by 2030 compared to 2005 (GOSC 2016). Especially in recent years, areas such as Beijing, Northern, Eastern and even Southern China are inflicted with the frequent hazy days, which also urge the application of clean energy.

Compared with other fossil fuels, natural gas is cleaner and of high quality because its combustion products are almost free of sulphur dioxide, dust and other harmful substances, and its carbon dioxide emissions are only 56% and 70% of the equivalent calorific value of coals and oils respectively (Gao 2016). If the proportion of natural gas consumption increases to 15% by 2030, the consumption of coals will reduce by about 10%, contributing to a reduction of more than 800 million tons of carbon dioxide emissions (OECD 2017).

3.2 Current development situation

Generally speaking, in China, the exploration and development of shale gas lagged much behind other countries like US and Canada (Ren *et al.* 2015), however, with strong support from government and companies, shale gas industry has made rapid progress in the past 10 years (Wang *et al.* 2014). The whole development process could be divided into three stages (see Figure 3). Before 2005, shale gas in the United States had developed a lot while in China, the industry just stayed in the research level and mainly focused on the physical and geological study by following the progress made in the United States (Gao 2016). Since 2005, China has begun to put shale gas development on the agenda. The government has contributed a lot by organizing all the relevant stakeholders to do practical research on exploration, which, however, Gao (2016) holds that Chinese shale gas industry was still staying at the lab level and was not subject to any practical test till 2009. After that, the research findings have played a significant role in the construction of pilot projects (Jia *et al.* 2016). Although these projects are mainly small exploration tests, they are still of great importance to China, because they enable it to make both theoretical and technical progress in shale gas industry (Zhang 2015).

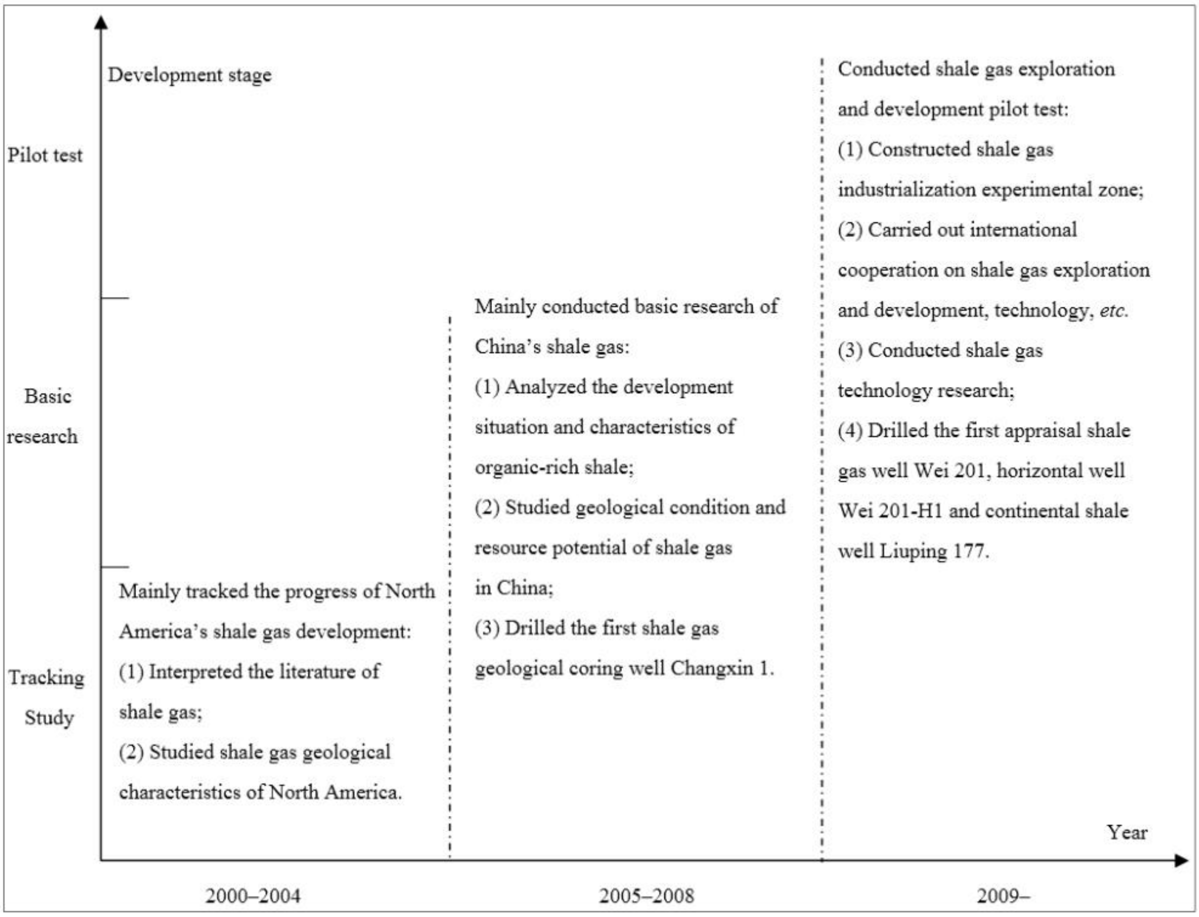


Figure 3 Stages of China's Shale Gas Industry (Source: Pi *et al*. 2015)

In general, Chinese shale gas industry is still in the early stage of development, large-scale commercialization has not yet begun (Pi *et al.* 2015). It was in 2006 that Shale gas resources exploration began. The first field investigation of Sichuan Basin which was conducted by the Petroleum Exploration Institute found huge potential in shale gas development (Xingang *et al.* 2013). In 2007, seven pilot areas were determined by the Ministry of Land and Resources to start pilot construction. Then, the national scale investigation and evaluation of shale gas resources reserves were carried out, which initially determined prospective areas of shale gas development so as to gradually solve the imbalanced distribution of shale gas resources (Gao 2016) . At the end of 2011, the Ministry of Land and Resources issued a strategic plan which set the research and evaluation of shale gas resources as a priority. Besides, the National Energy Administration, in cooperation with relevant departments, actively discussed policies to support unconventional gas exploration including shale gas. In the same year, as an important part of the "large-scale oil and gas fields development" project to accelerate shale gas technology progress and solve tough technical problems, the "research on key technologies of shale gas exploration" was launched (Pi *et al.* 2015). Till the end of 2014, China has made breakthroughs and gained important findings in Changning, Weiyuan, Jieling, Pengshui, Zhaotong, Xishui, Yanan, etc., and the total investment in shale gas industry was up to 230 billion RMB, with 780 shale gas wells (including 238 vertical wells and 345 horizontal wells) and 235 kilometers' pipelines built.

4. Analysis of China's Shale Gas Industry Development

4.1 SWOT Analysis

4.1.1 Strengths

Abundant shale gas reserves

Till 2016, China's proven conventional natural gas reserve has reached 13.01 trillion cubic meters, with 5.2 trillion cubic meters of technically recoverable reserve (NDRC 2016) . The volume of shale gas reserve is 54.41 trillion cubic meters, and the technically recoverable reserve is 25.1 trillion cubic meters. (NEA 2016)

According to a research project organized by Ministry of Land And Resources that focused on potential evaluation of shale gas reserves, most reserves are distributed in such 7 provinces as Sichuan, Xinjiang, Chongqing, Guizhou, Hubei, Hunan, and Shanxi, accounting for 68.87% of the total reserves in China (Zhang *et al.* 2012)(See Figure 4) Notably, the average shale gas reserves in Sichuan, Xinjiang, Chongqing and Guizhou are more than 10 trillion cubic meters, taking up approximately 50% of China's total proven reserves .

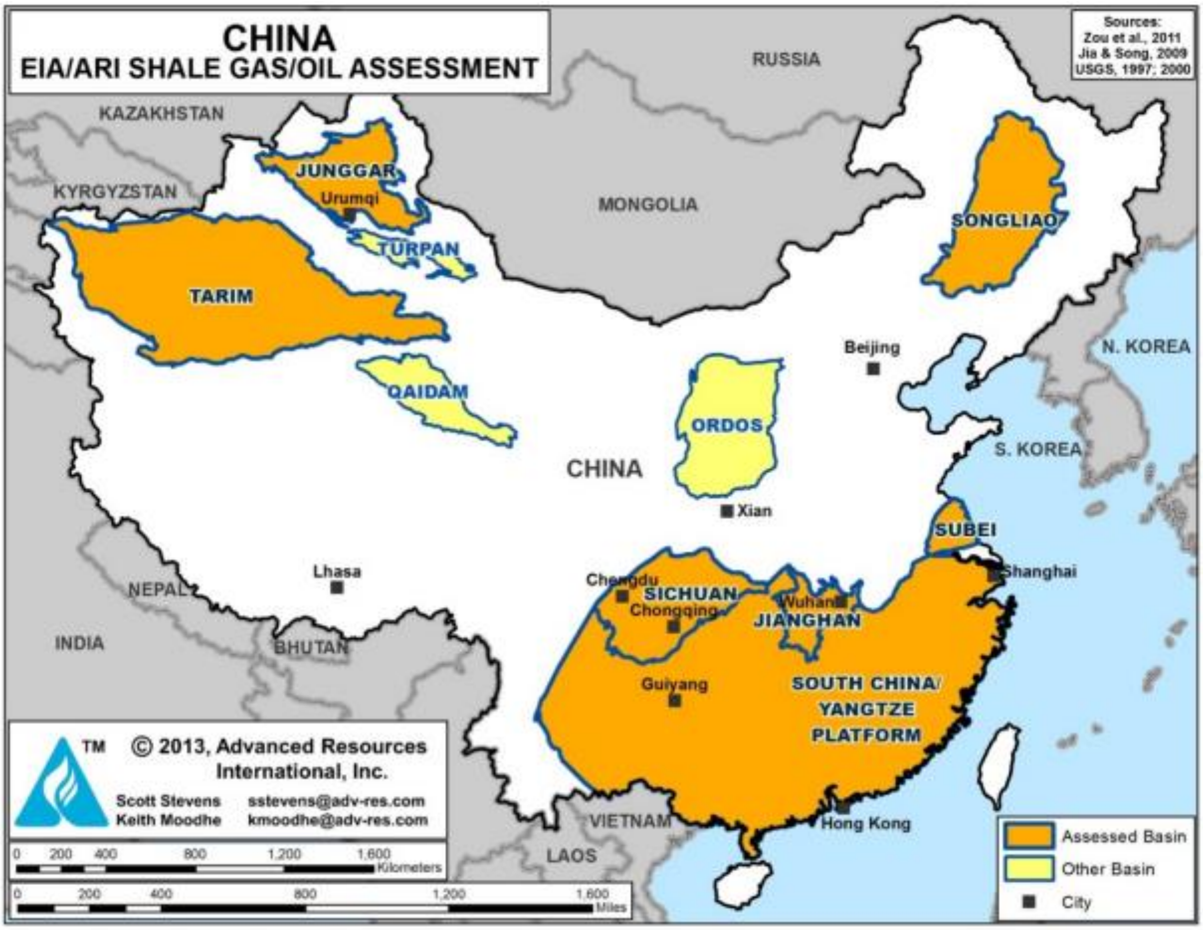


Figure 4. Distribution of China's shale gas resources reserves (Source: Zou *et al.* 2013)

Economic Profits Attraction

China's shale gas supply chain mainly consists of upstream (exploration), midstream (production), and downstream (transportation and distribution) (Chima 2011; Seydor *et al.* 2012; Gao *et al.* 2017), the major stages of which are shown in the Figure 5 below. When enterprises increase their investment in different stages, they could embrace new investment opportunities (Yang 2014). In the next decade, Chinese shale gas industry is expected to enter "golden years" with great opportunities (Jia *et al.*2016). Especially in 2015, due to the active participation of private companies, the demand for shale gas extraction equipment was more than 15 billion yuan, which was predicted to exceed 100 billion yuan by 2020 (NDRC 2106). These huge-profit opportunities could motivate relevant stakeholders to invest more in shale gas and relevant industries.

Figure 5. China's shale gas supply chain (Source: Ren *et al.* 2015)

In the exploration stage which requires mining design, drilling, etc., companies with advanced technologies and equipment can benefit first. At present, it is the state-owned oil and gas enterprises that are monopolizing shale gas development. For instance, China National Petroleum Corporation (CNPC) and China Petrochemical Corporation (Sinopec) are in charge of most of the onshore shale gases while the China National Offshore Oil Corporation (CNOOC) dominates the offshore development (Gao 2016). In fact, with exploration and production (E&P) licences granted by the Ministry of Land and Resources, these three "oil giants" can basically cover the whole shale gas industry chain (Zhang 2015). As a result, apart from these monopolists, only the companies that produce special equipment can get profits by providing drilling equipment during the exploration phase.

In the production stage, which is different from the exploration stage that requires a large amount of long-term capital investment, the equipment manufacturers in this stage in China can gain profits much faster. (Zhang 2015) In the extraction stage which always involves the hydraulic fracturing operation and demands high technical requirements, the cooperation between equipment manufacturers and oil companies is usually long-term and stable(Pi *et al.*

2015) . With up-to-date technologies and equipment supply, equipment manufacturers can always maintain their leading positions and obtain lasting benefits, which in turn can motivate them to invest more in research and development (R&D). After extraction, shale gas needs to be transported through pipelines and processing facilities, which provides opportunities for storage operators and downstream manufacturers. However, due to its under-development, China's shale gas industry has not achieved large scale production at present, therefore, the storage and transportation companies can only get profits from imported conventional gas and pipeline gas supply (Zhu and Zhao 2017). Besides, considering that those exploration areas that are situated away from gas pipelines network, the National Energy Administration recommended the use of small LNG and GNG storing devices to prevent possible waste of the gas extracted. Above all, it is obvious that, in the supply chain of shale gas industry, most profits are still gained by equipment manufacturers and oil enterprises in the short term and that for the storage and transportation operators are much backward in this chain.

Fewer Emissions

Compared with coal and oil, natural gas is much cleaner with fewer pollutants emitted (BP 2017). The coefficients of carbon dioxide emissions from coal, oil and gas are 0.702, 0.478 and 0.389 respectively (EIA 2016). Obviously, natural gas has a significantly smaller carbon emission coefficient, suggesting that it emits less carbon dioxide than coal and oil when supplying the same amount of energy. As an unconventional gas and also a clean energy, shale gas can contribute to reduction of GHG emissions and is conducive to environmental protection.

Compared with other energy sources, shale gas emits half amount of CO2 and 75% of nitrogen oxides (Wang *et al.* 2014). According to the 12th Five-Year Plan for Shale Gas Development, every year if 6.5 bcm of shale gas is produced and finally utilized to generate power instead of using coals, 14 million tons of carbon emissions, 115000 tons of sulfur dioxide, and 58000 tons of dust emissions can be reduced (NEA 2016).

Long Term Development Potential

Unlike conventional gases, shale gas resources are distributed widely with abundant shale gas contained in the reservoirs, and are able to supply relatively a long-term terms of extraction and production—which is generally 30 to 50 years, or even longer (APERC 2015), thus bringing more stable economic benefits and greater development potential. In the south of the

Yangtze River in China, from the Sinian to the Triassic, marine sediments are widely distributed and continuously developed, with a distribution area of more than 2 million km2, and the up-to-10 km thickness of black shale. Therefore, owing to the favourable geological conditions, high maturity and low rate of decline, China is able to have a long-term stable shale gas production with great economic value.

4.1.2 Weaknesses

High Investment Required

Shale gas extraction demands high capital threshold. In fact, in addition to relevant exploration and extraction experience, it is also necessary to have sufficient capital strength. In China, only the large enterprises like CNPC and Sinopec have the ability to participate in the bidding and extraction of shale gas reservoirs. For example, the required investment in 10 gas wells costs at least 300 million yuan, which may take several years to reclaim (Jia *et al.* 2016). First of all, in the exploration and drilling stage, compared with conventional gases, shale gas resources are stored deeper in the reservoirs and the technical requirements are therefore much higher, indicating that much more investment is required. In China, it usually takes about 40 million to 50 million yuan to drill a shale gas well and when needs the development is difficult, the number could even reach 70 million yuan (Ren *et al.* 2015). Besides, gas production from shale gas wells has a much higher decline rate compared with conventional gas wells (Mitchell and Casman 2011). Therefore, drilling new wells continually is necessary to keep large-scale gas production. As for gas companies, this requires a lot of investment (Hughes 2013)

Secondly, the basic production facilities required for shale gas industry cannot be shared with conventional natural gas, because most of them are located far away from conventional oil and gas wells and the densely populated areas, suggesting that additional funds and time are required for the pipe network and other basic infrastructures (Ren *et al.* 2015). Finally, in the early years, due to the limited number of wells, the output of shale gas well is not stable (Rahm 2011), but it could stabilize later. In order to maintain a stable production, enterprises have to invest more and drill more wells. Although with the expanded scale of development, the cost per well will gradually reduce, the cost of infrastructure construction, transportation and storage is still high (Pi *et al.* 2015).

Incomplete Pricing Regimes

For the shale gas industry, the industrialization and marketization are closely related to the investment environment. Despite the differences between shale gas and conventional gas, after extraction and processing, the output of shale gas is actually natural gas. Therefore, the price of natural gas determines the profits for shale gas producers, which further determine whether this development is active and effective (Pi *et al.*2015). The natural gas prices' impacts on shale gas industry have both sides. On one hand, the rise in natural gas prices will bring increased profits from gas supply and motivate producers to invest more in shale gas production. On the other hand, developing shale gas may prompt the gas market to saturate and the increased gas supply will result in a decline in gas prices, which will inhibit the enthusiasm of shale gas production.

As China's shale gas industry just started, it hasn't introduced a market-based pricing regime and the price of shale gas is still referring to conventional gas pricing mechanism. However, as for conventional gas, the pricing of which is still strictly controlled by central and local governments, the industrial and commercial gas prices are relatively high, while the civil gas prices are relatively low. Without mature market-based competition mechanisms, the existing natural gas pricing regime actually impairs shale gas development and thus hinders the industrialization process. In addition, the price fluctuation of coal, international oil and gas, and other energies will also affect the price of shale gas and bring about investment risks.

Underdeveloped Technology

Due to the high requirement of technologies in the shale gas exploration, the advancement of technology is of great importance in developing shale gas industry, Currently, China still relies heavily on imported key technologies and equipment, for example, fracture detection and evaluation, experimental analysis, precise guidance and reservoir reconstruction, capacity analysis and forecasting tools, etc. Consequently, the costs of exploration and other shale gas industry related developments are very high. In addition, although China is abundant in shale gas resources, the geological conditions of gas reservoirs are extremely complex, worsening the problems caused by underdeveloped technologies. Despite of the rich shale gas proven reserves, to locate the favourable "sweet spots" for production requires a high level of technology and equipment.

Admittedly, the technology required for shale gas extraction can be obtained through cooperation, but it still takes some time to learn. At present, the shale gas industry of American is mature, and their technologies are spread by many small oil service companies instead of being monopolized by one or several big companies. Therefore, it is possible for China to buy technologies from these small oil companies or cooperate with them on gas extraction, but the implementation of large-scale development of shale gas still relies on domestic technology improvement and innovation.

Environmental Impacts

The extraction of shale gas needs a lot of water consumption, which may result in water pollution (Vengosh *et al.* 2014; Mauter *et al.* 2014;)For instance, using hydraulic fracturing technology to extract gas, will produce a large amount of industrial wastewater(Rahm 2010). Besides, if there are cracks happening during hydraulic fracturing, the fracturing fluid will penetrate these cracks, causing groundwater pollution.

Moreover, large-scale drilling and fracturing will lead to geological disasters such as earthquakes, landslides (Wang *et al.* 2014) and air pollution (Moore *et al.* 2014). For example, volatile organic compounds will be released during the storage process. When exposed to these harmful compounds for a long time, workers and residents nearby will be harmed (Adgate *et al.* 2014; Colborn *et al.* 2011).

The emission of hydrogen sulfide is another result of exploration. This toxic substance can pose a serious threat on human’s heart and other vital organs with long-term exposure. In Sichuan Weiyuan, the concentration of hydrogen sulfide in shale gas reservoirs is up to 0.8% to 1.4%. In the north eastern region, this concentration even reaches 15%. (Gao 2016)

Additionally, certain methane will be generated during the stages of shale gas processing, piping, transportation and storage. Notably, compared with natural gas, more methane can be generated from shale gas production, which as a main greenhouse gas, will lead to climate change (Hughes 2013). This is against the goal of sustainable development.

In view of the damages on environment and human health caused by shale gas exploration, it is critical to take corresponding environmental protection measures. Otherwise, more and more opposite voices will arise, blocking the development of this industry.

4.1.3 Opportunities

Market Demand

Owing to rapid development of China's economy as well as accelerated industrialization process, there is an increasing demand for energy, particularly for natural gas. In 2015, 134.6 bcm of gas was produced in China, while the consumption was 193.0 bcm, with a supply gap of almost 60bcm (NEA 2016). According to the prediction of National energy development plan, from 2010 to 2020, natural gas demand will reach 320 ~ 370 bcm, and the share in the primary energy consumption is predicted to rise from 4.9% to 10%, while the conventional gas production will only be 160 ~ 180 bcm. Therefore, the imbalance between gas supply and demand will become more and more prominent.

Considering the growing gas demand, China has to both increase imports and accelerate the development of unconventional gas including shale gas. Through a series of strategic planning implementation, and exploitation of shale gas, China's shale gas production will accounting for 8% to 12% in total conventional gas production till 2020. By 2035, this ratio is supposed to increase to 25% and shale gas will become one of indispensable clean energy resources in China.

Policy Support

The Chinese government has been devoted to facilitating the development of shale gas, by issuing a series of supporting policies, including fiscal and taxation support policies, technology innovation support policies, and industrial development promotion policies, etc. (Pi *et al.*2015; Gao 2016; Ren *et al.* 2015).

As indicated by the 12th Five-Year Plan, China should accelerate the R&D of key technology with regard to unconventional gas resources, and improve the supporting facilities and equipment.

Based on the achievements of 12th Five-Year period, the 13th Five-Year Plan focuses on the large-scale commercial development of shale gas. According to the 13th Five-Year Plan, 20-30 more large shale gas blocks will be exploited, with the annual production capacity increasing to 150 million to 300 million cubic meters by 2020. Meanwhile, gas development and utilization subsidies policies have been introduced by the government, which shed light on a broad prospect of shale gas industry.

International Experience

As the world's first country tapping in shale gas development, the United States has formed mature exploring and managing chain of shale gas industry. Their successful experience can provide an important reference for China. The EIA officially launched the Eastern Shale Gas Program (1976-1992) in 1976, which focused on the technology development of shale gas extraction. (Pi *et al.* 2015) By the 1980s, horizontal well technology was adopted, achieving substantial technological progress. In the era of the 21st century, another key technology--hydraulic fracturing technology makes shale gas fracturing technology gradually mature. By 2015, American shale gas production reached 13.5 trillion cubic feet (OECD 2017). American shale gas' success in commercialization provides a clear direction for future development of Chinese shale gas.

Apart from technical experience, a sound policy support also contributes to American shale gas industry' success. It provides valuable experience for the fulfilment of policies and regulations related in China.

China has already started cooperation with foreign countries, on the aspect of technology, equipment, and infrastructure, greatly facilitating the expansion of Chinese sale gas market since 2007(Zhang 2013). From 2009, owing to the confirmation of a series of agreements, the US-China cooperation in shale gas development has been promoted significantly (Pi 2015). The Chinese government encourages domestic oil and gas enterprises to strengthen cooperation with international companies, in order to improve technology R&D and policy innovation of both sides.

4.1.4 Threats

Water Scarcity

In shale gas development process, the present technology such as hydraulic fracturing technology, consumes huge amount of water resources ((Wang *et al.* 2014), which might not be a serious problem in the short term. However, due to the uneven distribution of water resources and shale gas reservoirs in China, water scarcity will become a big obstacle restricting the shale gas industry' long-time development. Except Sichuan Province, shale gas reservoirs like Western and Northern China are mainly short in water resources due to the continental climate (Wang *et al.* 2014). What is worse, in recent years, the extreme weather and drought deteriorate the water scarcity. Once the large-scale shale gas production is achieved, the situation of local water shortage will be even worse. Therefore, it is essential to get enough water supplies for gas extraction and balance the local water demand for the purpose of achieving sustainable shale gas development.

Insufficient Environmental Supervision

At present, there are no specific laws or regulations regarding environmental protection for Chinese shale gas development, therefore, environmental supervision in this regard can only follow the existing rules related to environment, water and air pollution management. Ministry of Land and Resources requires participants to strengthen environmental protection in the provisions of the shale gas market entry and exit conditions, but does not establish any specific environmental regulatory standards or norms.

Besides, environmental protection departments are also not involved in the planning of shale gas development, which may lead to the lack of understanding of environmental risks and impacts during extraction (Wang *et al.* 2014). In all, the absence of appropriate environmental supervision system is not conducive to the sustainable development of China's shale gas industry.

Underdeveloped Infrastructure

The transportation of shale gas is dependent on the gas pipeline network. China's shale gas-rich areas are mainly located in the mountainous areas, which usually have poor geological conditions. Therefore, the pipelines construction in these areas is more difficult and costly.
What is more, compared with the United States, China's pipeline network and other infrastructure are far lagged behind. The added up length of built gas pipelines is only 100000 (Wang *et al.* 2014)., but the United States has reached 2 million km (Wang *et al.* 2014).). As stated before, China's shale gas infrastructure is operated by state-owned enterprises and they basically control the whole pipeline network from gas production to distribution, which allows quick and efficient gas delivery through different stages of supply chain. But, more and more small companies have been encouraged to tap into shale gas production, especially after NEA published the Regulatory Approach of Fair and Open Access to Oil and Gas Pipeline Facilities. Nevertheless, this regulatory did not have clear restriction on pipeline capacity, and with the increase of gas production from those small companies as well as large monopolies, the existing pipeline network has already been overloaded(Pi *et al.* 2015)

Monopoly on Exploitation

In the United States, shale gas investment comes from various different companies, most of which are small and medium enterprises. Owing to this diversification, the shale gas market forms an orderly competitive mechanism, which is beneficial for gas exploration and development.

As for China, at present, the rights to oil and gas exploration are mainly controlled by three major oil companies CNPC, Sinopec and CNOOC in China (Wang *et al.* 2014) This concentration hinders other investors from entering into the shale gas industry. This monopoly is harmful for the formation of market-based competition mechanism. Thus, in addition to strengthen the supervision, it is necessary to carry out large-scale commercialized revolutions in the China's shale gas industry.

4.1.5 SWOT Matrix And Development Modes

Based on the results from SWOT analysis and existing strategies proposed by Plan on Shale Gas Development Plan (2016-2020) and Energy Development Strategy Action Plan (2014-2020), 14 potential strategies are suggested in accordance with 4 development modes respectively. To prepare for AHP analysis, these potential strategies and results of SWOT analysis are presented in a complex matrix below. (See Table 2)

Table 2. Complex matrix of SWOT, development modes and potential strategies

	Strengths	**Weaknesses**
	Abundant shale gas reserves	High investment required
	Economic profits attraction	Incomplete pricing regimes
	Less Emissions	Underdeveloped Technology
	Long term development potential	Environmental Impacts
Opportunities	**S-O mode**	**W-O mode**
Market demand	Accelerating the shale gas development progress	Increasing financial subsidies
Policy support	Enhancing Policy Support	Enhancing R&D on key technologies
International experience	Increasing national investment in shale gas and relevant industry	Enhancing international cooperation and seeking more foreign investment
	Enhancing international	Conducting environmental

	cooperation and overseas experience learning	impact analysis of shale gas development
Threats	**S-T mode**	**W-T mode**
Water Scarcity	Accelerating the investigation of Shale Gas Resource Potentials in China	Attracting small and private companies to participate in shale gas industry development
Insufficient Environmental supervision	Enforcing Policy Support and Fostering Market Development Mechanism	Increasing investment in R&D innovation
Underdeveloped Infrastructure	Enhancing Environment Supervision System	
Monopoly on rights?	**Enhancing Pipe Network and Relevant Infrastructure Construction**	

4.2 SWOT-AHP Analysis

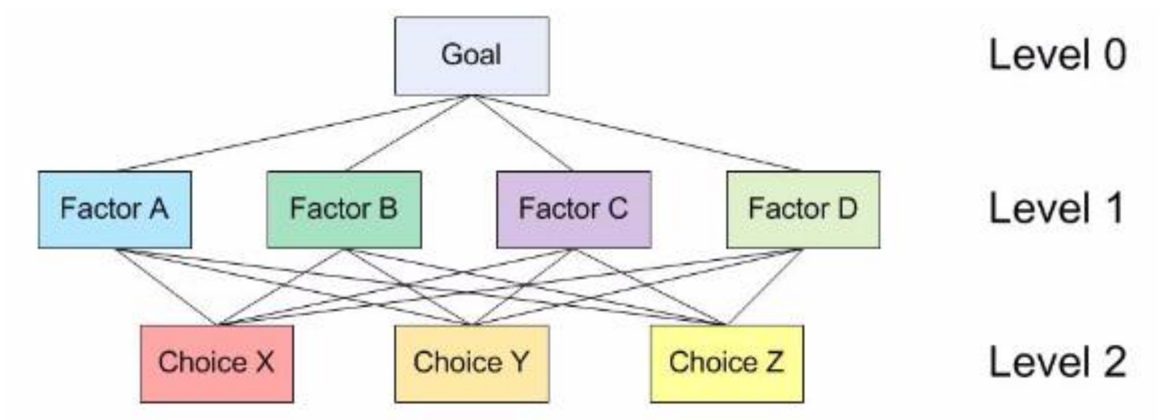
4.2.1 Introduction of AHP

According to the findings of literature review in Chapter 2, the study on Chinese shale gas development has just started up, most of which focus on introducing foreign experience and analysing several specific aspects identified from Chinese shale gas development, for instance, evaluation of development barriers(Saaty 1980), policy support and environmental impacts. There still lacks a relatively comprehensive assessment of China's shale gas industry development. This research attempts to use AHP to primarily assess development conditions of shale gas industry in China and suggest a favourable development mode with corresponding strategy recommendations.

When it comes to the assessment of industry development, although there are many methods could be adopted, such as AHP, Grey System Assessment method, DEA, Fuzzy Mathematics Comprehensive Method, Multi-objective Decision Method, and Expert Assessment Method, etc. As a tool for multi choices decision, AHP can prioritize the relative importance among all the alternative choices, considering the complex of shale gas industry development, this thesis adopts AHP to determine the most suitable development mode. Ren (2015) uses AHP to identify barriers and corresponding solutions for China's shale gas industry, which is the most relevant research with respect to this thesis study. As for combined use of AHP and SWOT, Mikko (2000) and Abdul (2013) provide similar application process for this study.

AHP was originally developed by American operational research expert Professor Satay, T.Y in the 1970s. As a method for Multi Criteria decision making, it takes complicated research problems as a big system. Through paired comparisons and analysis on multiple factors of the system, a comprehensive problem can be divided into several sub-problems, allowing independent analysis of each sub-problem. AHP has been widely used in various fields(Saracoglu 2013). By enabling decision makes to prioritize their choices and find the most suitable solutions. To make the analysis more scientific, usually, experts are invited to make objective judgment on all factors in each level and give corresponding quantitative expression of relative importance. The relative importance will be then calculated and ranked, providing basis for future decisions and solutions.

According to Satty (1980) AHP mainly consists of four steps:
The first step is to clarify the goal and key problem in hand, which refers to Level 0 in Figure 6. The second step is to build a hierarchy. Based on the first step, sub-problems will be decomposed from this main problem. Then a multi criteria level (Level 1) will be established based on in-depth analysis of these sub-problems and their corresponding influential factors (see Figure 6). Depending on the complexity of the problem, sub-criteria might also be added. The lower level (Level 2) consists of potential choices.



Figuer 6. Table of a Typical Hierarcy (Source: Abdul et al.2013)

The third step is to establish a set of pairwise comparisons matrix (Table 37). The construction of judgment matrix is the core of AHP which directly influences the results of relative importance of alternative choices under consideration. The scale of relative importances is usually represented by number 1-9(Saatty 1980) (see Table 4).

Table 3 Example of Pairwise Comparison Matrix

Criteria	A_1	…	A_j	A_n
A_1	A_{11}	…	A_{1j}	A_{2n}
…	…	…		…
A_i	A_{i1}	…	A_{ij}	A_{in}
A_n	A_{11}	…	A_{nj}	A_{nn}

Table 4 Scale of Relative Importances (according to Saaty (1980))

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

The fourth step is to weigh the priorities based on the results of comparisons. Here the characteristic roots method is adopted to calculate the weight of factors' priorities in all levels until the final priorities in the lowest level obtained. There are three sub steps described in the following.

(1) Calculation of Single Hierarchical Sequencing

As for the calculation of geometric mean value of factors in each layer in judgment matrix B, the first step is to select proper calculation method according to judgment matrix A. The root value method adopted in the thesis has the following calculation procedures.

A. Calculating the product of factors in each layer in judgment matrix A.

$$M_i = \prod_{j=1}^{4} a_{ij} \ (i=1, 2, \cdots, n)$$

B. Calculating the n root of Mi.

$$\overline{w}_i = \sqrt[n]{M_i} = (i=1, 2, \cdots, n)$$

C. Normalizing the weight of all priorities. However, the weighted value is the relative weight of factors in the judgment matrix with respect to its upper layer. For example, to get a global priority of each factor in Level 1, the weighted value of each factor in Level 2 need to be added up together.

$$\overline{w} = \left(\overline{w}_1 \quad \overline{w}_2 \quad \ldots \quad \overline{w}_n\right)^T,$$

During the pairwise comparison of factors, inconsistent judgment will inevitably appear. Consequently, it is necessary to make consistency test on the judgment matrix. Maximum eigenvalue could be calculated in line with proper vectors and further be adopted to calculate the Consistency Ratio CR:

A. Calculating the maximum eigenvalue of proper vector W, wherein $(AW)_i$ is the i^{th} weight of vector AW_i .

$$\lambda_{max} = \sum_{i=1}^{4} \frac{(AW)_i}{n w_i},$$

B. Calculating the consistency index using formula given by Prof. Satty.:

$$CI = \frac{\lambda_{max} - n}{n-1}$$

C. Finding Random Consistency Index(RI) with reference to Table 5.

Table 5. Table of Random Consistency Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

(2) Calculation of Consistency Ratio using formula

Consistency Ratio is also adopted to present the result of comparison using formula:

$$CR = \frac{CI}{RI}$$

When CR<0.1, the accuracy of weight in judgment matrix is acceptable, otherwise, the value should be recalculated after the correction of judgment matrix. When CR >0.1 , the judgment matrix does not have any consistency. In such circumstances, the judgment value should be adjusted until the pass of consistency test.

(3) Calculation of global priorities and Consistency Test

As shown above, the relative weight of all factors against the overall goal could be derived. The purpose of the AHP is to determine the importance of all alternatives with respect to the goal. The calculation of global priority is stipulated as follows:

Supposing that Level A consists of n factors: $A_{1,}$ $A_{2,}$ … A_n and their priorities within group A are $a_{1,}$ $a_{2,}$ … $a_{n,}$ while Level B consists of m factors: $B_{1,}$ $B_{2,}$ … B_m and their priorities with respect to factors in Level A are $b_{1j,}$ $b_{2j,}$ … $b_{mj,}$ and the global priority is Bn=X.

4.2.2 AHP of China’s Shale Gas Industry Development

Based on the results of chapter4.1, a SWOT matrix is established as shown in Figure 7 below. Level 0 here represents the goal of this research, which is to prioritize potential strategies to promote shale gas industry development in China. Level 1 consists of 2 levels of criteria. Four factors of SWOT (Strengths, weaknesses, opportunities and threats) are the first level criteria while S1, S2,S3, S4,W1,W2,W3,W4,O1,O2,O3,T1,T2,T3,T4 are sub criteria. The relationship between strategies, sub criteria, criteria and goal are indicated by lines.

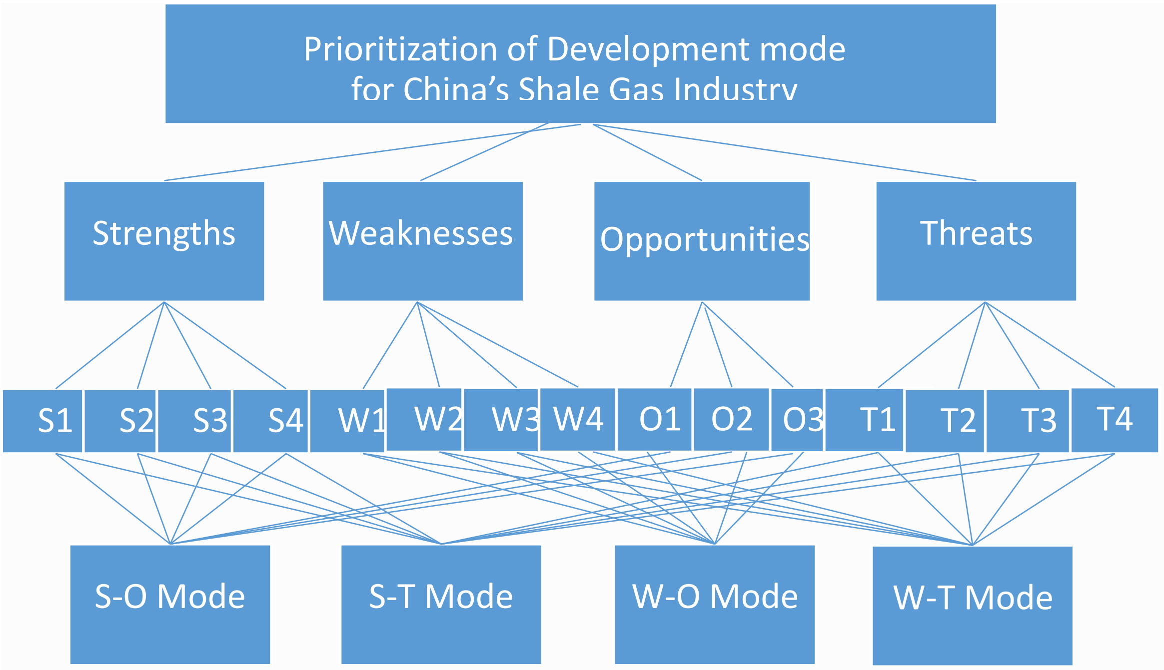


Figure 7. Hierarchy of Development Mode Choices

In the next step, a questionnaire survey is conducted with 5 experts from China University of Petroleum and Jinan University to obtain data for the AHP analysis. After generating data from survey, the pairwise comparison among SWOT factors and sub factors is done and presented as several tables below. (See Table 6)

Table 6 Priorities of SWOT factors Consistency Ratio CR: 2.2%

With respect to the goal	**Strengths**	**Weaknesses**	**Opportunities**	**Threats**
Strengths	1	2.27	1.15	1.89
Weaknesses	0.44	1	0.87	1.82
Opportunities	0.87	1.15	1	1.64
Threats	0.53	0.55	0.61	1

Table 7 Priorities of sub factor- strengths Consistency Ratio CR: 0.6%

With respect to the goal	**S1**	**S2**	**S3**	**S4**
S1	1	2.95	1.89	0.89
S2	0.34	1	0.67	0.37
S3	0.53	1.50	1	0.70
S4	1.12	2.69	1.43	1

Table 8 Priorities of sub factor-   weaknesses Consistency Ratio CR: 1.0%

With respect to the goal	**W1**	**W2**	**W3**	**W4**
W1	1	0.94	0.39	0.89
W2	1.06	1	0.66	1.43
W3	2.55	1.52	1	1.95
W4	1.120.700.511	1.120.700.511	1.120.700.511	1.120.700.511

Table 9 Priorities of sub factor- oppoptunities Consistency Ratio CR: 0.0%

With respect to the goal	**O1**	**O2**	**O3**
O1	1	0.76	1.76
O2	1.32	1	2.35
O3	0.57	0.43	1

Table 10 Priorities of sub factor- threats Consistency Ratio CR: 0.4%

With respect to the goal	**T1**	**T2**	**T3**	**T4**
T1	1	0.56	0.43	1.74
T2	1.77	1	0.72	2.35
T3	2.32	1.38	1	3.05
T4	0.57	0.43	0.33	1

Then the priorities of sub factors (S1, S2,S3, S4,W1,W2,W3,W4,O1,O2,O3,T1,T2,T3,T4) within SWOT factors (Strengths, Weaknesses, Opportunities and Threats) can be calculated based on the results above. And the results are presented a Table below.

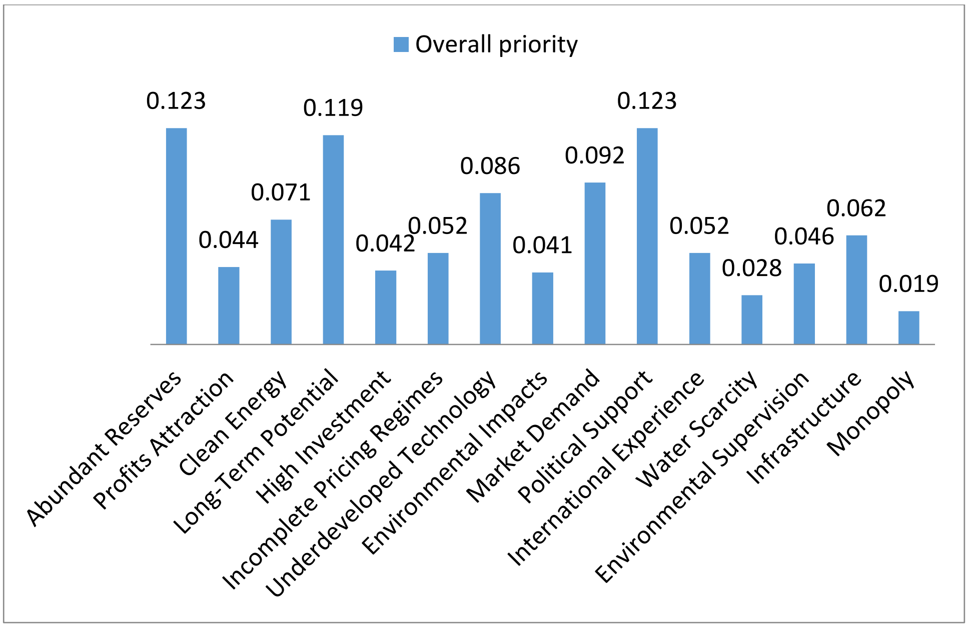
Table 11

Priorities and CRs of SWOT factors and SWOT sub factors

SWOT factors	**Priority of the group**	**SWOT sub factors**	**Priority of the factor within the group**	**Overall priority of the factor**

Strengths	0.3584	Abundant Reserves	0.344	0.123
		Profits Attraction	0.1239	0.044
		Clean Energy	0.199	0.071
		Long-Term Potential	0.3331	0.119
Weaknesses	0.2196	High Investment	0.1807	0.042
		Incomplete Pricing Regimes	0.238	0.052
		Underdeveloped Technology	0.3928	0.086
		Environmental Impacts	0.1886	0.041
Opportunities	0.2674	Market Demand	0.3457	0.092
		Political Support	0.4584	0.123
		International Experience	0.1959	0.052
Threats	0.1546	Water Scarcity	0.1827	0.028
		Environmental Supervision	0.2978	0.046
		Infrastructure	0.399	0.062
		Monopoly	0.1204	0.019

Figure 8 shows the relative importance of 15 sub factors based on previous pairwise comparison results. It is obvious that, among 4 SWOT factors, Strengths and Opportunities have more influence on China's shale gas industry development than Weaknesses and Threats. Abundant shale gas reserves, sufficient policy support from government and potential for long time development are the three most influencing sub factors.



Figue 8. Overall Priority of Each SWOT Sub Factor

Evaluation of Development Modes

With respect to previous analysis, there are four potential development modes (SO, WO, ST, and WT) to promote China's shale gas industry development. In this step, the relative importance of these modes will be evaluated through pairwise comparison. (See Table 12). Figure 9 illustrates priorities of 4 development modes. The S-T mode is the most favourable one with a relative importance of 42.89%, indicating that more attention should be paid to strategies in accordance with strengths and threats in China's future shale gas development.

Table 12. Evaluation Matrix for Development Modes

Swot factors	**SWOT sub factors**	**Overall priority of the factor**	**Development Modes**			
			S-O	**S-T**	**W-O**	**W-T**
strengths	abundant reserves	0.123	0.250	0.750		
	profits attraction	0.044	0.167	0.833		
	clean energy	0.071	0.857	0.143		
	long-term potential	0.119	0.125	0.875		
Weaknesses	high investment	0.042			0.750	0.250
	incomplete pricing regimes	0.052			0.333	0.667

	underdeveloped technology	0.086			0.8	0.2
	environmental impacts	0.041			0.25	0.75
Opportunities	market demand	0.092		0.750	0.250	
	political support	0.123		0.667	0.333	
	international experience	0.052		0.667	0.333	
Threats	water scarcity	0.028	0.833			0.167
	environmental supervision	0.046	0.833 0.143			0.167
	infrastructure	0.062	0.333			0.857
	monopoly	0.019				0.667
	SUM	1	0.188501	0.428905	0.207641	0.171723

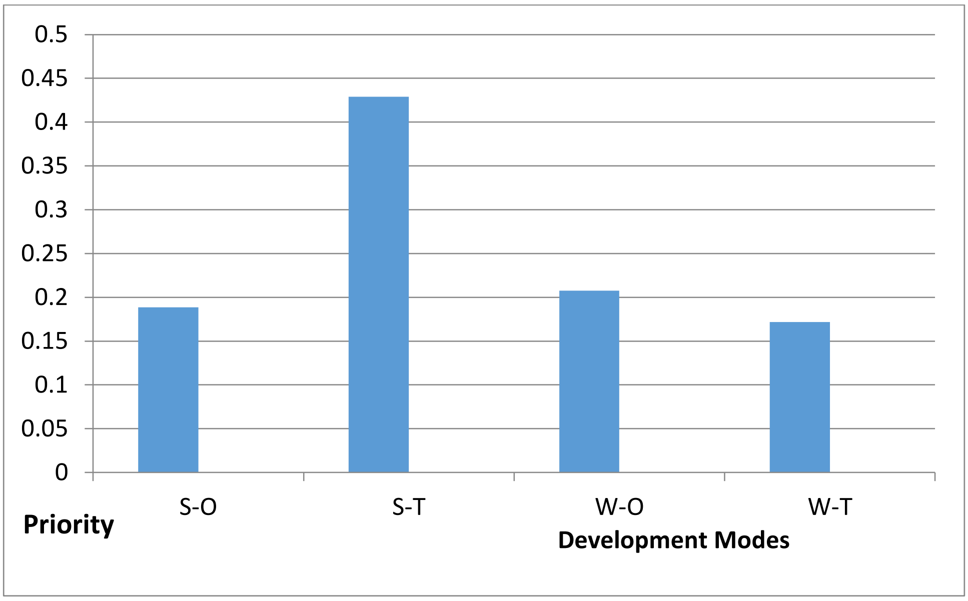


Figure 9. Priorities of Development Modes

5. Results and discussions

According to previous AHP analysis, the shale gas industry in China should choose Strengths-Threats strategy. Although China has rich shale gas resources and promising development prospects and potentials, domestic shale gas industry remains in the preliminary stage and lacks advanced technologies and infrastructure. As a consequence, people should hold optimistic attitudes towards Chinese shale gas development with full consideration of this issue. In such circumstances, it is urgent to explore proper development mode of the shale gas industry in combination with national conditions and refer to the experience of America and other countries. Only in this way could the shale gas industry obtain development according to local conditions and meet the growing demands of natural gas consumption in China.

5.1 Assessing Shale Gas Resource Reserves

5.1.1 Enhancing Shale Gas Strategic Planning

In order to make a systematic assessment of the shale gas resources in China, the first step is to stand from a general stance to coordinate the strategic investigation, exploitation, and market development of shale gas resources and make scientific planning and reasonable layout. At present, China mainly depends on industrialization and extensive growth economic development mode. The energy consumption amount remains high in China and China has exceeded America to become the first major energy consumption power across the world. The greenhouse gas emission of China also ranks in the first place. The exploitation and development of the shale gas should start from the national strategic level to turn shale gas industrialization as the important mode to guarantee energy resource security and transform economic growth mode. At the same time, by formulating and implementing a series of supporting policies in favour to develop shale gas industry, the government is able to guarantee the status of whole development process. The formation of local government development measures should depend on the policy of the central government. Consequently, it is feasible to consider the shale gas resource advantages of each region across the country. Key attention need to be focused on the development of regions with abundant resources. In addition to the policy support in capital, talent and tax revenues, the country should formulate relevant laws and regulations to guarantee policy implementation and guide regions and governments at all levels with advantageous resource endowment to focus on the development of shale gas. Moreover, local government should deliver shale gas development concepts to companies in each region through shale gas strategic planning and positively implement tax revenues, technical innovation, and industrial support policies to support shale gas development.

5.1.2 Investigating Shale Gas Resource Potentials

Chinese government should primarily explore specific resource distribution conditions in China and figure out total shale gas resource reserves and a series of basic conditions in shale gas enriched region. Meanwhile, a comprehensive assessment of shale gas across the country should be made. In such conditions, the first step is to conduct shale gas field investigation and resource assessment, observe domestic shale gas conditions, and establish appropriate shale gas development technical standards so as to help China quickly realize shale gas commercialization development. In the long run, a shale gas industry chain will be formed to relieve present shortage conditions of conventional energy resources.

The second step is to establish a new shale gas exploitation and development mechanism. Strenuous efforts should be made to introduce powerful companies in shale gas exploitation, set up shale gas industry entry threshold and qualification, establish and improve mining right system and bidding system, and forbid enclosure issues.

5.2 Enforcing Policy Support and Fostering Market Development Mechanism

At present, China does not have a profound understanding of the potential environment influences of shale gas and remains in the initial research and development stage. In addition, targeted at the long payback cycle, high risks, great investment in the initial stage, high technical requirements in the industrialization process, the government should formulate a series of targeted policies so as to support shale gas development.

5.2.1 Improving Shale Gas Development System

The first step is to establish the shale gas mining right management system. The government could determine shale gas as the independent mining category different from conventional natural gas and build special shale gas registration system. By reference to the American experience and domestic conditions, the government could design the mining right management system which is able to improve the initiative of local government and companies. Shale gas registration could try to adopt new mining category registration method and mining right assignment could be made in a competitive form. Owners of mining right who are not up to investment requirements or standard output requirements within stipulated time should be forced to exit. The second step is to enact preferential fiscal and tax policies.

The establishment of shale gas tax system could refer to normal energy resource, coalbed methane, and foreign policy support measures. Likewise, fiscal tax policies are supposed to be made in accordance with specific national conditions. Besides basic tax policies including exemption and value-added tax, the government could exempt relevant fees of mine owners in exploitation and mining as well as the customs duty on production equipment imported from overseas countries. The execution of these policies could decrease corporate costs and encourage companies to make equipment investment.

5.2.2 Fully Exerting the Role of Private Companies

In the development system of shale gas in China, state-owned companies occupy the leading status. For instance, state-owned companies like, SNP, CNPC and CNOOC basically monopolize the overall shale gas industry chain. While in America, approximately 600 SMEs have devoted to each link of the shape gas industry chain. The marketing openness degree of China has nothing in common with that in America. In comparison with energy resource development system in America, China requires to widen the market and realize investment diversification. The development mode in America follows an up-down mode. The exploitation and development of shale gas made by small companies boost the confidence of oil giants to enter into shale gas industry. The exploitation mode in China belongs to the first-level centralized mode. Classified as special mining category by Ministry of Land and Resources in China, shale gas is exploited in state demonstration zone. The practice not only further controls the mining and exploitation right of shale gas, but also forms an effective planning and integration system for state shale gas development. However, the development of shale gas should not be totally undertaken by the country or otherwise; the development speed would be rather slow caused by the limitations in investment technology and the problems in resource monopoly. Therefore, in the initial state of industry development, the government is supposed to properly lower market entry threshold, increase the diversity of investment subjects, fully exert the role of private companies, support and encourage technical research and development and cultivate professional service system according to the specific plan. In the meanwhile, the government has to make scientific market entry standards and encourage any SMEs and private investment proper for development conditions. Accordingly, the government should pay attention to the role of different market subjects, give preferential entrance policy treatment to private companies and adopt differential supporting policy for state-owned companies and private companies on the basis of full consideration of their endowment difference.

5.3 Enhancing Pipeline Network and Relevant Infrastructure Construction

The ultimate purpose of shale gas development is utilization while the key in the utilization of shale gas is infrastructure. Firstly, the transmission pipes could be directly constructed in development regions with relatively mature natural gas pipe network and transport the shale gas with natural gas pipe network. Secondly, as for the shale gas region distant from natural gas pipe network, the central government could establish fair shale gas pipe network entrance mechanism and encourage local government and companies to independently build the pipe network. Thirdly, the central government should accelerate the construction of pipeline network in accordance with the status of shale gas development. At present, China could learn from the American experience, encourage competition and enhance market supervision. Based on pipe network facility construction, more and more SMEs should be allowed to enter the market in line with market competition mechanism and win shale gas region construction right through tendering. The investment capital could be collected by the rent of pipe network.

5.4 Enhancing Environment Supervision

One of the prime reasons why shale gas obtains more and more attention from many countries as a clean energy source is that it could reduce environment pollution in practice. However, potential environment problems will be inevitably caused during the exploitation process, such as water pollution and air pollution in the local region. At present, America, Canada, and other countries successively enact prudent environment protection policies and obtain favourable effects. China should refer to the environment protection policies of these countries and propel the economical and effective development of shale gas on the premise of protecting underground water and reducing ground pollution.

5.4.1 Establishing Strict Technical Standards

A series of technical standards should be established prior to the orderly large-scale shale gas development for the sake of efficiency. The government should focus on the assessment of shale gas development potential as well as local environmental impacts. In particular, special attention should be focused on water resource planning based on thorough evaluation. For environmental supervision and establishment of technical standards, experience could be drawn from the development of coalbed methane industry in China.

5.4.2 Establishing Sophisticated Supervision System

Chinese shale gas development is generally in a start-up stage and confronts different problems and challenges compared with the United States. For instance, government supervision systems, market-based competition system, mining right management in China are all different from those in America. As a consequence, the improvement of relevant laws and regulations in China can contribute a lot to shale gas development. Besides, specific development conditions of China should be taken into account when introducing successful overseas experience. The establishment of a complete supervision system could boost the initiative of oil and gas companies in shale gas development, propel the orderly progress of shale gas industry and legalization of resource development and relieve energy resource supply tension in China.

5.4.3 Executing Strict Control Measures

In addition to the formation of relevant supporting policies and measures, the Chinese government should enhance environment protection in shale gas development regions, introduce laws and regulations concerning water resource, air quality, and land usage, encourages public participation to supervise shale gas development better. The development of shale gas should avoid causing damages to the living environment of local residents by implementing pollution control measures. Only in this way can Chinese shale gas industry achieve sustainable development and contribute to a win-win situation between economy and ecology development.

5.4.4 Establishing Early Warning System

There exist many unknown risks during the exploitation and production process of shale gas. To avoid these risks and quickly respond to hazards and other emergent issues, for instance, methane leakage, it is urgent for Chinese government to establish early warning system. With an early warning system, the government is enabled to take corresponding prevention measures to reduce potential damages appeared in shale gas development.

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