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Review

The Status, Obstacles and Policy Recommendations of Shale Gas Development in China

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Abstract: The Chinese government has introduced numerous policies and development plans to boost its shale gas industry in recent years. However, China's shale gas exploration and development is still in the initial stage and has been confronted with many challenges. This paper systematically analyzes the current status of China's shale gas industry from five aspects for the first time—resource situation, exploration and development status, policy and planning situation, technology status and international cooperation—then respectively elaborates on the different obstacles of shale gas development in the short run and the medium and long term. We argue that short-term barriers to the Chinese shale gas industry mainly include objective factors, such as geological and surface conditions, shale gas proven reserves, technology innovation and environmental concerns, while some man-made obstacles (except for water scarcity) may restrict shale gas development in the medium and long term. In order to better tackle the short-term challenges, this paper proposes policy recommendations from five perspectives: strengthening the investigation and evaluation of China's shale gas resources; perfecting shale gas industry policy; establishing a national shale gas comprehensive experimental zone; enhancing scientific and technological research; and establishing a shale gas regulatory system with an emphasis on environmental protection and supervision.

Keywords: China; shale gas development; challenges; policy recommendations

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1. Introduction

With economic development and population growth, world energy demand has grown rapidly since the 21st century. To satisfy the increasing demand and to safeguard the security of energy supplies, many countries have begun to tap into unconventional oil and gas resources in recent years. Shale gas, an important unconventional natural gas, has also emerged as a hot spot in global oil and gas exploration. The United States is the pioneer in the exploitation of shale gas resources in the world and also the first country to realize large-scale commercial production. In 2000, U.S. shale gas production accounted for only 1.6% of its total gas output [1]. Soaring shale gas production has been achieved due to theoretical innovation and technological progress in the shale gas industry. In 2012, the output reached 9.7 trillion cubic feet, making up 40% of the total natural gas production [2]. Thanks to the substantial shale gas production, the U.S. has become the world's largest natural gas producer [3] and has become less reliant on energy imports.

The success of U.S. shale gas motivates other countries, like Canada, Poland, Ukraine, Argentina and Indonesia, to tap into shale gas resources. To optimize its energy structure and to promote economic and social progress, China has also begun to conduct basic research and exploration of domestic shale gas since 2005. In 2012, the Shale Gas Development Plan (2011–2015) (hereinafter referred to as the Plan) was jointly issued by the Ministry of Finance (MOF), the Ministry of Land and Resources (MLR) and the National Energy Administration (NEA). Based on national conditions, the Plan reveals the goals, major tasks and supporting measures of the shale gas industry in the Twelfth Five-Year period, which fully demonstrates China's strategic intention for the utilization of shale gas.

In order to render better guidance for China's shale gas development, numerous scholars are committed to doing research on shale gas from different perspectives [4–10]. On the whole, this research can be classified into three categories. The first category mainly focuses on geological theories of shale gas [11–13]. The second category concentrates on the current technologies in shale gas exploration and development [5,14,15].

The remaining category is directed toward studying the challenges and strategies of shale gas development in China, and this is the area where most researchers focus [4,16–22]. Hu and Xu [4] argue that a lack of key technologies, environmental risks, a shortage of water and a method of how to create a good industry-community relation are challenges facing China's shale gas development. Zhao *et al.* [18] utilize the SWOT method to analyze the shale gas development environment and develop four different strategies for Chinese policymakers. Zeng *et al.* [19] find that various obstacles, such as resource exploration problems, policy problems, technical problems and insufficient pipeline infrastructure, will restrict China's efforts to develop its shale gas industry. Wan *et al.* [21] analyze some man-made institutional barriers limiting China's shale gas development. In addition, the factors influencing the Chinese shale gas sector are raised by other researchers, such as Wang *et al.* [8], Wang *et al.* [16], Zhai *et al.* [17] and Zhang [22]. However, there is still no consensus among them. Some researchers suggest that technical problems are the primary obstacles hindering shale gas development in China [19,20], while others argue that man-made institutional barriers are the main restrictive factors [21,22]. It is obvious that the existing studies confuse the barriers to Chinese shale gas development in the short run with the obstacles in the medium and long term.

The main objectives of this paper are to provide a comprehensive in-depth analysis of the current status of shale gas development in China, to accurately distinguish between the short-term challenges of the shale gas industry and potential barriers in the medium and long term and to explore reasonable solutions for tackling various challenges. Our findings merit particular attention from Chinese policymakers and researchers.

2. The Status of Shale Gas Industry in China

2.1. Resource Status of Shale Gas in China

The MLR conducted a preliminary survey and evaluation of the potential of China's shale gas resources in 2011. The evaluation result was widely cited by researchers [4,18,19], since it was the only prediction released by the Chinese government. According to the survey result, China's shale gas geological resource potential is 134.42 trillion cubic meters, and the recoverable resource potential is 25.08 trillion cubic meters (excluding Qinghai-Tibet). From a provincial perspective, the shale gas potential in Sichuan, Xinjiang, Chongqing and Guizhou is of relative abundance, reaching 66.71 trillion cubic meters, 49.65% of the nation's total [23]. Figure 1 shows the shale gas geological resource potential of Chinese provinces.

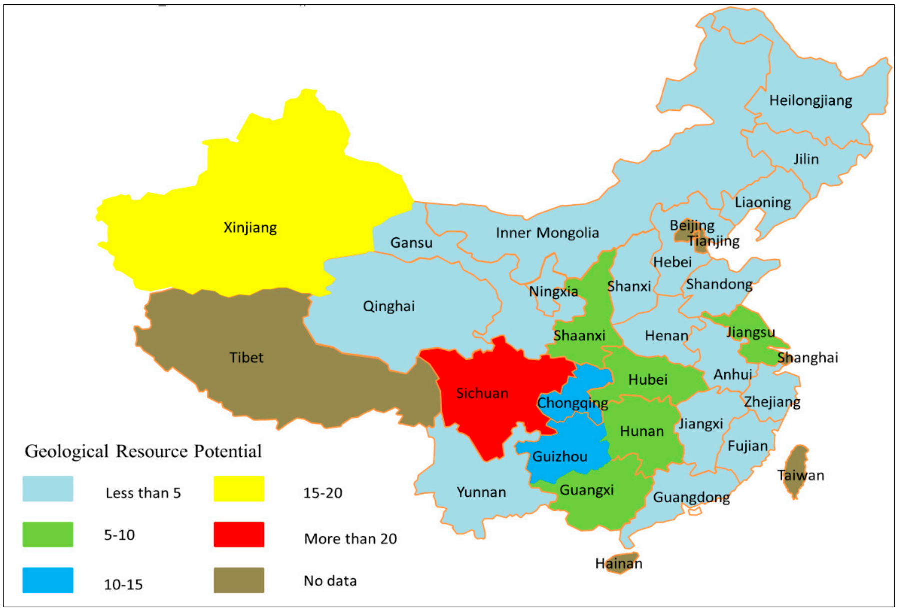

Figure 1. Shale gas geological resource potential of Chinese provinces (trillions of cubic meters). Data source: Zhang [23].

2.2. Development Status of Shale Gas in China

2.2.1. Exploration and Development Status

China's shale gas exploration and development started fairly late and has mainly gone through three phases. Before 2005, China primarily followed North America's progress of shale gas development and studied its shale gas geological characteristics [24]. During 2005–2008, the Chinese government, major oil companies and universities conducted basic research and focused on analyzing the geological conditions of China's shale gas [11,24]. Since 2009, China has begun to carry out pilot tests of domestic shale gas and made certain breakthroughs in shale gas exploration and development [19]. Figure 2 illustrates the development stage of China's shale gas. According to the MLR, China has already drilled about 400 shale gas wells (including 130 horizontal wells) and produced 0.68 billion cubic meters of shale gas as of July 2014 [25].

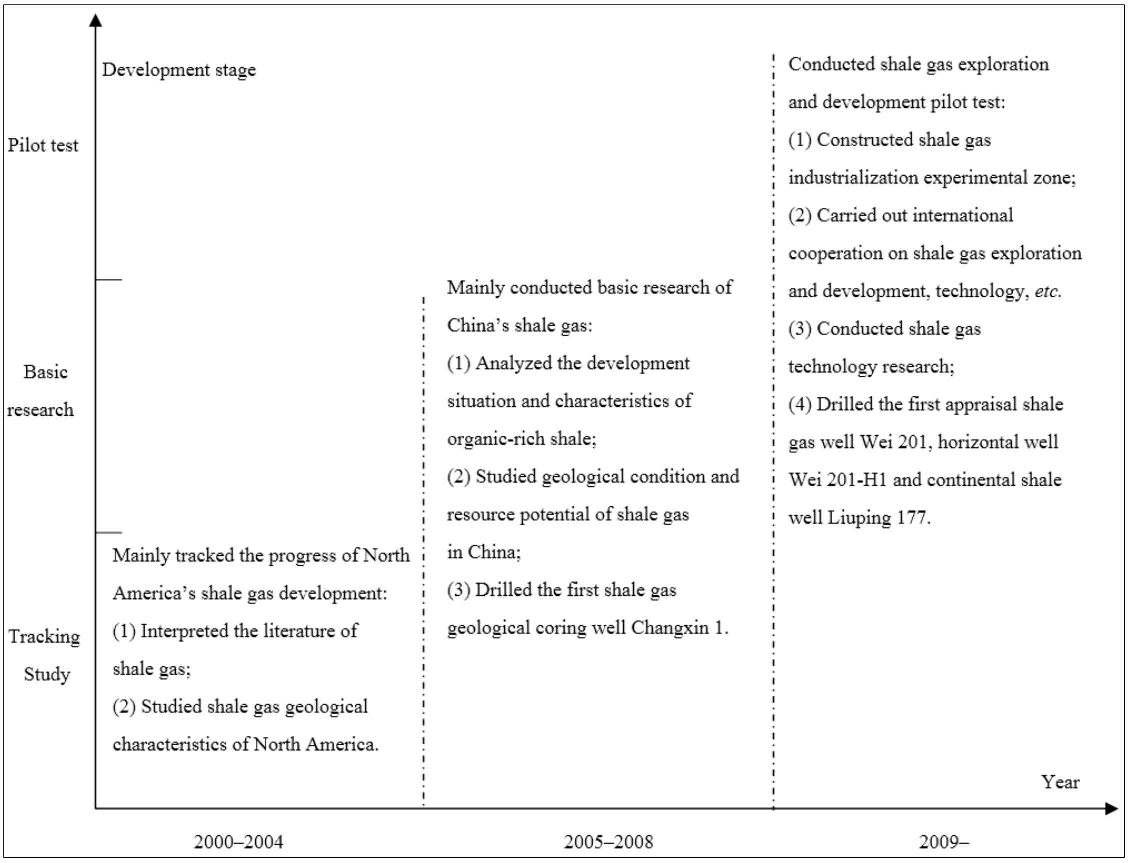

Figure 2. The development stage of shale gas in China. Source: Dong *et al.* [24]; Zeng, Liu and Li [19]; Zou *et al.* [11].

Influenced by the U.S. shale gas revolution and China's supportive policies, major oil and gas companies, including China National Petroleum Corporation (CNPC), China Petrochemical Corporation (Sinopec Group), Shaanxi Yanchang Petroleum Group (Yanchang Petroleum), China National Offshore Oil Corporation (CNOOC), China United Coalbed Methane Corporation (CUCBM) and Henan Provincial Coal Seam Gas Development and Utilization Corporation (Henan CBM), have taken a proactive role in shale gas exploration and development and achieved considerable progress (see Table 1). The major exploration areas of CNPC and Sinopec Group lie in Sichuan Basin and its surrounding regions, while Anhui-Zhejiang and Ordos Basin are the main exploration areas of CNOOC and Yanchang Petroleum, respectively. Since shale gas was identified as an independent mineral, Chinese non-oil-gas enterprises have begun to enter the shale gas industry in succession. These enterprises, including large coal enterprises, power companies and steel enterprises, enter the shale gas industry mainly by means of strategic partnerships with local governments, cooperative exploration with domestic entity companies and independent development.

Table 1. Shale gas exploration and development status of China's oil-gas enterprises.

Enterprise	Exploration and Development Status
CNPC	By the end of 2013, drilled 50 shale gas wells (27 horizontal wells, 23 vertical wells), completed 2D seismic exploration of 4,411 kilometers and 3D seismic exploration of 359 square kilometers.
Sinopec Group	By the end of 2013, drilled 79 shale gas wells (52 horizontal wells, 27 vertical wells), completed 2D seismic exploration of 4,467 kilometers and 3D seismic exploration of 594 square kilometers.
Yanchang Petroleum	By the end of 2013, drilled 39 shale gas wells and completed 34 shale gas fracturing wells.
CNOOC	In June, 2014, drilled 1 shale gas exploratory well.
CUCBM	By the end of 2013, completed 3 shale gas parameter wells.
Henan CBM	By the end of 2013, completed 2D seismic exploration of 524 kilometers, drilled 1 geological shallow well.

Source: Authors' summary and compilation based on related literature and news.

2.2.2. Policies and Planning Situation

To promote shale gas development in China, the Chinese government has introduced a series of shale gas industry policies and development plans since 2009. Major development plans include the 12th Five-Year Plan for Natural Gas and the Shale Gas Development Plan (2011–2015). Shale gas industry policies mainly include financial and tax policy, technology R&D support policy, resource management policy, shale gas price policy, pipeline network policy and international cooperation policy (see Table 2).

Table 2. Shale gas industry policies in China.

Policy Types	Dates	Major Contents
Financial and tax policy	2012	Shale gas producers will receive a subsidy of RMB0.4 per cubic meter of shale gas production from 2012 to 2015.
	2012	Shale gas mining royalties and mineral resource compensation should be reduced or exempted according to the law.
	2013	The imported devices that cannot be manufactured in China shall be exempt from customs duties in accordance with relevant regulations.
Technology policy	2011	Set up research project "key techniques of shale gas exploration and development".
	2010–2014	Build eight national/provincial shale gas key laboratories.
Resource management policy	2011	Identify shale gas as No. 172 independent mineral resource.
	2012	Relax the restrictions for bidders and allow private enterprises to participate in the bidding.
Price policy	2013	Shale gas should be priced according to the demand and supply of the market.
Pipeline network policy	2014	The pipeline operators should offer pipeline facilities to the third party equally.
International cooperation policy	2011	The form of foreign investment in China's shale gas exploration and development should be "joint venture or cooperation".
	2013	Encourage shale gas enterprises to conduct technical or exploratory cooperation with foreign institutions or enterprises with advanced shale gas technologies.

Source: Authors' summary and compilation based on various government documents on policies and regulations.

2.2.3. Technology Status

Realizing the importance of the independent research of shale gas exploitation technologies, China combines mature shale gas techniques abroad with conventional oil and gas technologies at home and initially developed multiple applicable techniques of shale gas exploration and exploitation. These techniques have been mainly mastered by the three state-owned oil companies (CNPC, Sinopec Group, Yanchang Petroleum), covering the method of the characteristics of the shale gas reservoir and accumulation, the method of shale gas geological evaluation and favorable block selection, the assessment method for shale gas resources, the shale gas well-logging identification and interpretation technology, the method of seismic data acquisition and processing, horizontal well drilling technology, *etc.* [26]. However, none of these companies fully grasp the whole set of exploration and development technologies and only have certain advantages in some aspects of shale gas techniques at present [27]. More specifically, CNPC possesses only a rudimentary grasp of the staged fracturing of horizontal wells, microseismic monitoring technology, *etc.*; Sinopec Group has made certain progress in the research of completion tools, horizontal well drilling fluid and fracturing fluid; and Yanchang Petroleum preliminarily has mastered the continental shale gas horizontal well drilling and completion technology and has conducted CO_2 fracturing technology trials of shale gas wells [28,29].

2.2.4. International Cooperation Progress

Since 2009, a series of cooperation agreements have been signed by the Chinese government and American government, including the Sino-U.S. Memorandum of Understanding on Cooperation of Shale Gas, the Sino-U.S. Shale Gas Resource Task Force Work Plan between the U.S. Department of State and China's National Energy Administration and the Joint Fact Sheet on Strengthening Sino-U.S. Economic Relationship. These agreements propose that the two countries shall strengthen cooperation on shale gas resource evaluation, exploration and development, standards, technology and policy. However, shale gas cooperation between the Chinese government and the American government has not achieved any substantial breakthroughs. During 2009–2013, the two sides only accomplished one shale gas cooperative project, named the Eastern Depression of Liaohe Basin's Shale Gas Resources Assessment.

In addition, cooperation on shale gas blocks, engineering equipment, technology and pipeline network construction between Chinese enterprises and international oil and gas companies has been enhanced in China's domestic market since 2007 [23]. Chinese companies, at the same time, have actively participated in overseas shale gas acquisition to absorb foreign experience and techniques.

3. Barriers to the Development of Shale Gas in China

In recent years, China has made progress in shale gas resources survey, exploration and development, but overall, the shale gas industry is still in its infancy with many serious problems. These issues mainly include: shale gas exploration and exploitation is less optimistic, and breakthroughs have been made only in the marine local formations of the Sichuan Basin; state-owned oil companies have already successfully produced a small amount of shale gas, but have endured heavy losses (according to Tian *et al.* [30], Sinopec and CNPC had invested a total of $1.01 billion in shale gas development by late 2013, while the two oil companies' total revenue from shale gas production is $54.4 million. This implies that Sinopec and CNPC's short-term losses from shale gas development by late 2013 were close to $1 billion.); and many of the bid-winning companies have achieved slow exploration progress [21]. In view of the above issues, the NEA plans to adjust China's shale gas production target for 2020 from 60~100 billion cubic meters to 30 billion cubic meters [31], and the MLR has postponed the third bidding round for shale gas exploration rights. This reveals that China's previous shale gas output target is impractical and that the effects of shale gas industry policies (e.g., resource management policy, financial subsidy policy) carried out by the Chinese government are not significant. The root cause is that the Chinese government has failed to accurately understand the major barriers to the current shale gas industry. To help Chinese policymakers develop more reasonable polices for shale gas development, we divide the obstacles into two categories: the objective barriers restricting shale gas development in the short run; and secondly, the man-made barriers (except for water scarcity) limiting shale gas development in the medium and long term. Figure 3 illustrates the factors influencing the Chinese shale gas industry: the four factors (geological condition, shale gas proven reserves, technology innovation, environmental concerns) in the internal square constrain the shale gas sector in the short term; the four factors (pipeline monopoly, technology transfer, geological data use mechanism, water scarcity) around the internal square may affect shale gas production in the medium and long term.

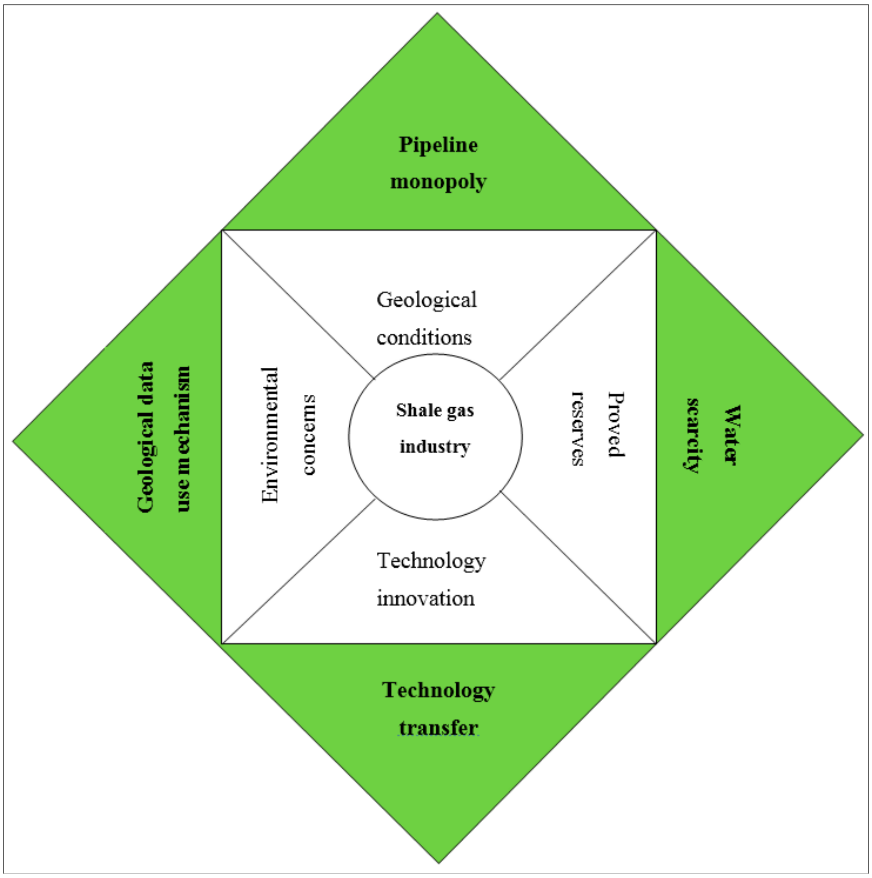

Figure 3. Restrictive factors of shale gas industry in China.

3.1. Major Barriers in the Short Term

3.1.1. Complex Geological and Surface Conditions

Compared with the U.S., China's shale gas geological and surface conditions are more complicated. Thus, this not only makes shale gas exploration and development more difficult, but also increases evaluation costs. First, the organic-rich shale in the U.S. is mainly marine sediment, while China has developed marine-continental transitional shale and continental shale in addition to marine shale. The organic-rich shale sediment in China has undergone complicated tectonic movement, thus the shale gas enrichment regularity is much more complex than in the U.S. Furthermore, the burial depth of the organic-rich shale in China is deeper, with a preliminary estimate of over 3500 m in more than 65% of shale rocks [26], while in the United States, it is much more shallow, with an average level of 1500 m to 3500 m [26]. Lastly, the plains serve as the geographical feature of shale gas blocks in the U.S., while mountains and hills dominate Southern China's blocks. Complex surface conditions constrain massive transportation and frequent large-scale operations.

3.1.2. Unclear Understanding of Proven Reserves

Thus far, systematic and in-depth evaluation work on shale gas resource has not yet been conducted, and China's strategic survey of shale gas resources is still in its infancy. Since 2008, many researchers and institutions (including the MLR) have made forecasts of China' shale gas resources, but the prediction results are very rough and vary wildly (see Table 3) [23,32–37], which indicates an unsophisticated view of China's shale gas technically recoverable resources.

Table 3. Resource prediction of onshore shale gas in China.

Year	Unit	Scholar	Technically Recoverable Resources (Trillion Cubic Meters)
2008	China University of Geosciences (Beijing)	Zhang *et al.*	23.5
2010	China University of Geosciences (Beijing)	Liu *et al.*	30.7
2012	CNPC	Qiu *et al.*	11
2012	PetroChina Exploration & Production Company	Zhao *et al.*	10
2012	Strategic Research Center of Oil and Gas Resources	Zhang *et al.*	25.1
2013	Energy Information Administration (EIA)		31.6

Data sources: EIA [33]; Liu, *et al.* [34]; Qiu and Deng [35]; Zhang, *et al.* [23]; Zhang, *et al.* [36]; Zhao, *et al.* [37].

Additionally, we need to make clear the distinction between "proven reserves" and "technically recoverable reserves." According to the U.S. Geological Survey, "technically recoverable resources" are "resources in accumulations producible using current recovery technology but without reference to economic profitability" [38]. The EIA defines "proven reserves" as "those volumes of oil and gas that geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions" [39]. Based on these definitions, we can see that "technically recoverable resources" and "proven reserves" are different in many aspects. "Technically recoverable reserves" include oil and gas that may not be producible with current prices and other economic conditions. Thus, this can be a much larger figure than "proven reserves." Table 3 shows that at present, China has an estimated value for the technically shale gas recoverable resources, but lacks statistics for the shale gas proven reserves. The extent to which technically recoverable resources will prove to be economically recoverable is not yet clear.

Furthermore, according to Hughes [40], high productivity shale plays (*i.e.*, sweet spots) are not ubiquitous, and 88% of the shale gas production in the U.S. comes from six major plays (Haynesville, Barnett, Marcellus, Fayetteville, Woodford and Eagle Ford). Therefore, even if China's shale gas proven reserves are abundant, there will not always be many sweet spots favorable for large-scale development. Precisely pinpointing the locations of those sweet spots is also somewhat tricky. This can be proven by the fact that only the Fuling shale gas field in China has made significant progress. Lastly, shale gas wells peak and decline much more rapidly than conventional wells. Mitchell and Casman [41] analyze the production curve for EQT Corporation's Marcellus Shale operations and find that the shale gas production rate has been in a steep decline for a couple of years. The production rates of other shale gas plays in America have also experienced a similar downward trend. In order to sustain high levels of production, the shale gas industry in America continues to drill new wells, which requires substantial investment. Relevant statistics show that America spends $42 billion/year to maintain production, and this investment exceeds the sales of $33 billion in 2012 [40]. High individual well decline rates also represent a challenge for China's shale gas industry.

3.1.3. Technology Innovation

The key shale gas technologies and equipment in China are underdeveloped, which leads to a high cost of exploration and development. According to Bao [42], shale gas technologies in Canada are at the market promotion stage, while China has just optimized a batch of applicable shale gas techniques and carried out technical research. Many shale gas key technologies (horizontal wellbore trajectory control, fracture detection, *etc.*) and crucial equipment and tools (bridge plug, experimental analysis tools, *etc.*) need to be imported [27]. To make use of foreign technologies and equipment, China still requires improvements and innovations according to complex geological and surface conditions, and this represents a great challenge.

3.1.4. Environmental Concerns

America's successful commercial production of shale gas has also encountered a series of environmental risks. Studies have shown that shale gas exploration and development may raise environmental concerns, such as water contamination [43–46], air pollution [47], climate change [48–51], earthquakes [52], nuisances [53] and health concerns [54,55] (see Table 4).

Compared with the U.S., China's ecological environment is more severely stressed with lagging environmental technologies. Thus, shale gas exploration and development may do more harm to the Chinese environment. Firstly, most of China's surface water bodies have been polluted to alarming degrees [56], and 90% of the groundwater has also been contaminated to different degrees [57]. Shale gas development may make this situation worse. Additionally, while shale gas is a relatively clean energy, its exploitation process results in methane leakage, which could aggravate the greenhouse effect, harming China's climate. As estimated by Wigley [58], even if we disregard the greenhouse gases emissions, only if the leakage rate for the new methane can be kept below 2% will substituting gas for coal prove to be an effective means of reducing the magnitude of future climate change. However, the Chinese government has no plans as of yet to deal with methane leakage in shale gas development. In fact, it is not even mentioned in documents, such as the Shale Gas Development Plan (2011–2015) and the Policy for Shale Gas Industry [59]. Lastly, in addition to the Tarim and Junggar Basins, most of China's shale gas resources are located in densely-populated areas. Problems, such as water contamination, air pollutants and noise pollution caused by shale gas development, pose threats to public health. Therefore, if shale gas companies cannot adopt reasonable measures to prevent eco-environmental damage and public health hazards, opposition from society and residents will be aroused.

Table 4. Environmental concerns of U.S. shale gas exploration and development.

Researchers	Environmental Concerns	Major Contents
Vengosh *et al.* (2014) [44]	Water contamination	Contamination of shallow aquifers by "stray gases"; contamination of surface water and shallow groundwater from spills, leaks and disposal of inadequately treated wastewater; accumulation of toxic and radioactive elements in soil or stream sediments; over-extraction of water resources.
Moore *et al.* (2014) [47]	Air pollution	Ozone precursor emissions, air toxic emissions, and particulate emissions.
Schneising *et al.* (2011) [50]	Climate change	Greenhouse gas (primarily methane) emissions.
Werner *et al.* (2014) [53]	Nuisances	Noise, trucking, light.
Adgate *et al.* (2011) [54]	Public health concerns	Chemical and nonchemical stressors (mortality, exposure to hazardous materials).
Wang *et al.* (2013) [52]	Earthquakes	The fracking drilling technique and the injection of wastewater into the subsurface induces earthquakes.

Sources: Vengosh, *et al.* [44]; Moore, *et al.* [47]; Schneising, *et al.* [50]; Wang, *et al.* [52]; Werner, *et al.* [53]; Adgate, *et al.* [54].

To make things worse, China's Ministry of Environmental Protection has not fully recognized the environmental risks of shale gas exploitation, nor developed targeted environmental regulatory standards, regulations and policies in response. The force of existing laws, such as the Environmental Protection Law and the Water Pollution Prevention and Control Law, is not enough [60]. What is more, the existing regulatory institutions, especially the local environmental protection bureaus, are often ineffective. The local governments tend to focus on economic development rather than environmental protection [56]. Under the control of these governments, the local environmental protection departments are unable to enforce laws and regulations for environmental protection.

3.2. Potential Barriers in the Medium and Long Term

3.2.1. Natural Gas Pipeline Network Monopoly

In the short term, infrastructures, such as the pipeline network, are not barriers to China's shale gas industry. The NEA's shale gas output target of 30 billion cubic meters by 2020 will be achieved mainly by Sinopec and CNPC, and both companies possess relatively developed natural gas pipeline network, as well as knowledge of pipeline construction. In addition, China has obtained mature small Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG) technology, which will provide shale gas development and local use with technical support. Currently, most of China's shale gas production comes from three national shale gas demonstration zones (Fuling National Shale Gas Demonstration Zone of Chongqing, Dian-Qian North Zhaotong National Shale Gas Demonstration Zone and Changning-Weiyuan National Shale Gas Demonstration Zone of Sichuan Province) [27]. This situation is likely to continue in the next few years. Then, we are going to take these three demonstration zones' shale gas utilization as an example to illustrate that the pipeline network and other basic facilities will not constrain China's shale gas development in the short term. The Fuling shale gas field is China's first large shale gas field with a cumulative shale gas production of one billion cubic meters from January, 2013, to the end of October, 2014 [61]. It is projected to produce 3.2 billion cubic meters in 2015 and 4.8 billion cubic meters in 2016, respectively [62]. Table 5 displays that shale gas produced in Fuling at present is mainly transported to local markets in Chongqing through natural gas pipelines, such as the Jiaoshi-Baitao pipeline and the Changshou-Nanchuan pipeline. In upcoming years, natural gas pipelines, such as the Baitao-Zili double-track and the Fuling-Wangchang pipeline, will have enough capacity to transport the projected production of Fuling shale gas to markets in Chongqing, Central China and East China. Additionally, in Zhaotong and the Changning-Weiyuan National Shale Gas Demonstration Zone, CNPC has also started to build infrastructure, like natural gas pipelines, to solve the problem of shale gas entering the market [63].

Table 5. Major pipelines for Fuling shale gas.

Name	Gas Transmission Capacity (One Hundred Million Cubic Meters per Year)	Market	Owner	Progress
Jiaoshi-Baitao	3.6	Local enterprises in Fuling	Sinopec Group	Completed
Changshou-Nanchuan	21	Sichuan Vinylon Works, downtown area of Chongqing	Chongqing Gas Group Corporation	Completed
Baitao-Zili double-track	20	Downtown area of Chongqing	Chongqing Gas Group Corporation	Under construction, to be completed in 2015
Fuling-Wangchang	60	Connecting Sichuan-East China gas pipeline, Central China and East China	Sinopec Group	Under construction, to be completed in April, 2015
Sichuan-East China pipeline supercharging project	Expanding the capacity of Sichuan-East China pipeline to 15 billion cubic meters per year	Central China, East China	Sinopec Group	Under planning, to be completed in November, 2016

Source: Authors' summary and compilation based on related literature and news.

In the medium and long term, however, the pipeline network may constrain the sound development of shale gas, since China's pipeline network is underdeveloped and has only over 60 thousand kilometers as of 2013 [64], which is much less than the 1.98 million kilometers in the U.S. in the same period [65]. Furthermore, China's pipeline network is operated by state-owned monopolies, such as CNPC and Sinopec Group, and this will be unfavorable for shale gas produced by other enterprises to go into the pipeline network. Although the Regulatory Approach of Fair and Open Access to Oil and Gas Pipeline Facilities (Trial) (short for Regulatory Approach) issued by the NEA demands that pipeline operators offer pipeline facilities to third parties equally, many problems will also arise during the actual practice. According to the Regulatory Approach, the precondition of open pipeline facilities is that "the operators have surplus pipeline capacity." Nevertheless, the length of China's natural gas pipeline is apparently not long enough, and the existing pipelines have already been overloaded without the extra capacity for a third party. In addition, "surplus pipeline capacity" is not clearly defined in the Regulatory Approach; thus, the conditions of a third party's shale gas entering the pipeline network are still decided by pipeline operators.

3.2.2. Water Scarcity

The process of shale gas drilling and hydraulic fracturing requires a large consumption of water [52]. In the short run, water resources will not restrict Chinese shale gas development. Most shale gas production areas, such as Chongqing and Sichuan, have relatively sufficient water resources [21]. Furthermore, to the extent that shale gas displaces coal production, shale gas may provide substantial water savings [66]. However, water supply may become a barrier to shale gas production in the medium and long term. China is known for its uneven distribution and shortage of water resources. According to the Food and Agriculture Organization of the United Nations, the total actual renewable water resource per capita in China was estimated at 2,017 m^3/year in 2012, which only accounted for 1/5 of the U.S. and 1/41 of Canada [67]. The problems of seasonal water shortage and regional water shortage are also very serious.

3.2.3. Technology Transfer

Based on both theory and the U.S. experience, Tian *et al.* [30] separate shale gas development into two stages: an innovation stage and a scaling-up stage. State-owned oil companies will play the most important role in overcoming the problem of shale gas technology innovation, since these companies account for over 90% of oil-and-gas technical service enterprises and carry out most of the shale gas scientific research [30]. With the large-scale development of shale gas, state-owned oil enterprises must compete with more non-oil-and-gas companies. By then, even if technical service enterprises owned by national oil companies obtain perfect shale gas exploration and development techniques, they will restrict the technology transfer in consideration of competition with non-oil-and-gas enterprises.

3.2.4. Immature Geological Data Submission and Use Mechanism

In order to fully consider the role of geological information, the Chinese government established a geological data submission and use mechanism. However, this mechanism is far from perfect, and the existing legal provisions have not been fully implemented, which emerges as a prominent problem in the oil-and-gas industry. Currently, oil and gas geological data is mainly controlled by state-owned oil companies and could not be shared within the shale gas industry [19]. The restraining effect of such an issue on the shale gas sector is limited in the short run, because national oil companies will continue to be the main force of shale gas development, and these enterprises will focus on shale gas exploration and exploitation in their own conventional oil-and-gas blocks in the next few years. However, in the medium and long term, incomplete geological data submission and use mechanisms will increase repetitive geological work and capital investment, thereby affecting shale gas exploration and development progress.

Of course, the short-term constraints and medium and long-term barriers discussed in the paper are not absolute. However, if the Chinese government continues to ignore the short-term barriers and blindly emphasizes the production target of shale gas, these factors will limit China's shale gas development in the long term.

In addition to the obstacles discussed, the development of other energy industries (coal, oil and new energy) will also influence China's shale gas industry. In general, the coal industry will hinder shale gas development to a certain degree. While China's natural gas pricing mechanism reform makes the domestic natural gas price go up dramatically, the price of coal remains fairly low. This often results in the unusual phenomenon of "substituting coal for natural gas" [68], which influences the demand for shale gas. On the other hand, because of the overcapacity of coal production and air pollution, the Action Plans for Energy Development Strategy (2014–2020), the Notice on Regulating Scientific and Orderly Development for Coal-To-Liquids (CTL) (and Synthetic Natural Gas (SNG) and other policies issued by the Chinese government in 2014 encourage moderate development of coal-based SNG. According to the statistics released by the Development Research Center of the State Council, the cost of Fuling shale gas is around 1.8 yuan per cubic meter [68], which represents the lowest cost in China's shale gas industry. Without considering other factors, provided that the domestic coal price can be kept under 400 to 430 yuan per ton, SNG will be more competitive than shale gas and will thereby have an adverse influence on shale gas development and utilization (see Table 6).

Table 6. Production cost and sales price of synthetic natural gas (SNG) under different coal prices.

Coal Price (RMB/ton)	120	200	250	300	350	400	450	500
Unit cost of production (RMB/cubic meter)	1.09	1.28	1.39	1.5	1.62	1.73	1.85	1.96
SNG price (RMB/cubic meter) (the internal rate of return is calculated as 10%)	1.6	1.81	1.94	2.1	2.2	2.34	2.46	2.59

Source: Han [62].

4. Policy Recommendations

In the next few years, major objective factors, such as geological conditions, shale gas proven reserves, technological innovation and environmental problems, will restrict China's shale gas development. Other factors, like pipeline monopoly, may not be barriers to the shale gas industry. In light of the short-term obstacles, this paper offers the following recommendations.

4.1. Strengthen the Investigation and Evaluation of Shale Gas Resources

As a key task of encouraging the development of the shale gas industry, the evaluation work requires more investment and R&D support to encourage China Geological Survey, the research institutes, universities and enterprises to establish research unions and conduct national shale gas resource evaluations. What is more, a standard system for shale gas investigation and evaluation that regulates geological survey and exploration work should be built according to China's geological characteristics [69]. With strategic investigation and evaluation, we can get a full picture of the national shale gas potential, preferentially select shale gas prospect areas and favorable blocks, provide exploration targets and guide shale gas exploration and exploitation.

4.2. Perfect Shale Gas Industry Policy

Chinese shale gas geological conditions are complicated, and the preliminary exploration cost of enterprises is huge with high risks, especially for non-oil-and-gas companies. Although the existing shale gas industry policies concentrate on the encouragement of shale gas production, the support for exploration work is not enough. Therefore, we recommend that a national shale gas exploration fund should be established and that the shale gas preliminary exploration work should be financed by the government, so as to identify the proven reserves of shale gas and collect shale gas geological data as soon as possible. What is more, the Chinese government should allot a certain amount of annual funding for the research of key exploration and development techniques and reward the enterprises achieving localization of shale gas technology and equipment [70].

4.3. Establish a National Shale Gas Comprehensive Experimental Zone

Before promoting large-scale shale gas exploitation activities, the Chinese government should establish a national shale gas comprehensive experimental zone in regions with a certain basis of shale gas exploration and development (e.g., Chongqing, Sichuan). Major work in the experimental zone should be developed from three aspects: conducting further research on shale gas basic geology and exploring appraisal methods and key geological parameters for screening shale gas plays; exploring the factory mode of operation and perfecting theory and technology systems for shale gas exploration and utilization; and conducting trials on the reform of shale gas management systems. Through innovations of shale gas technology, management systems and other aspects, the national shale gas comprehensive experimental zone can help China develop more practical shale gas industry policies.

4.4. Enhance Scientific and Technological Research

First, China should pool the research resources of major oil enterprises, universities and research institutes and increase investment in key technologies with a focus on tackling technical problems in horizontal well drilling, staged and anhydrous fracturing and build a technological system for exploration and exploitation matching for China's shale gas geological conditions [70]. In addition, China should strengthen international cooperation on shale gas technologies [71]. With regard to government to government exchanges, China should also introduce techniques, such as horizontal drilling and hydraulic fracturing used by countries, such as the United States. When it comes to enterprise-to-enterprise cooperation, China's shale gas development companies can acquire cutting-edge technologies by working with foreign oil companies to tap into resources abroad and jointing venture with international oil enterprises to explore China's shale gas resources.

4.5. Establish a Shale Gas Regulatory System and Strengthen Environmental Supervision

An effective regulatory system serves as an important safeguard to shale gas development. China must accelerate the building of a supervision system to promote sound and orderly progress in the shale gas industry. First, energy and energy market supervision laws need to be formulated to further regulate the energy market. Second, a unified energy supervision institute and professional regulatory team is needed to strengthen supervision of shale gas market access, access to the natural gas pipeline network, land utilization and the process of shale gas production. Third, a system of on-site verification should be set up, and operating rules and industry standards of the overall process of shale gas exploration and development should be regularly checked and established [72].

Severe environmental problems may occur in shale gas exploration and development, and thus, strengthening environmental supervision is necessary. First, environmental risk assessment and supervision of the whole process of shale gas exploration and development (including seismic exploration, wellsite selection and construction, transportation, drilling, well cementation, casing, hydraulic fracturing, water supply and use, air emission, flowback, solid waste and sewage treatment, wellsite closure and reclamation) should be established. It is necessary to pay special attention to the supervision over shale gas well site closure and reclamation. Because the Chinese government and enterprises tend to focus more on profits, they often disregard the risks that abandoned gas wells impose on the environment, human health and safety. In addition to strengthening the environmental regulation of well site closure, market-based approaches proposed by some scholars [41,73], including assurance bonds, environmental liability insurance and predrilling fees, to ensure effective closure should also be adopted in China. What is more, developing a system of environmental technology standards based on China's specific geological conditions is recommended. Lastly, China should strengthen the environmental enforcement of local environmental protection bureaus and establish a comprehensive punishment mechanism to increase the costs to enterprises for illegal activities and decrease the possibility of environmental accidents [8].

5. Conclusions

Shale gas resources have huge potential in China, and its development will increase China's natural gas supply, optimize the energy structure and safeguard the security of energy supplies. In an effort to boost the shale gas industry, the Chinese government has introduced numerous polices and has actively taken part in shale gas international cooperation in recent years. Major oil-gas enterprises and non-oil-gas companies in China have also been involved in the shale gas industry and made progress in shale gas exploration and technologies. However, China's shale gas exploration and development is still in its infancy and faces many challenges. This paper argues that the short-term barriers to the Chinese shale gas industry mainly include objective factors, such as geological and surface conditions, shale gas proven reserves, technology innovation and environmental concerns, while pipeline monopoly, water scarcity, technology transfer and an imperfect geological data use mechanism may be the obstacles in the medium and long term. In the next few years, China should focus on tackling the various short-term challenges and make good preparations for shale gas large-scale development. To this end, the policy recommendations proposed in this paper are as follows: strengthening investigation and evaluation work to obtain confirmed shale gas proven reserves in China; perfecting shale gas industry policy and stimulating shale gas exploration work; building a national shale gas comprehensive experimental zone; enhancing scientific research to form a technological system for exploration and exploitation matching for China's shale gas geological characteristics; and establishing a shale gas regulatory system with emphasis on environmental protection and supervision.

This paper will help researchers get a full picture of China's shale gas development, as well as accurately understanding different barriers to the shale gas industry in the short run and medium and long term. In addition, it will help the Chinese government formulate more suitable development strategies and policies for the shale gas industry. Future research should attach importance to the impact posed by the U.S. shale gas development on the global energy landscape, especially on China's energy market, which may help to point out a strategic positioning and development pattern for China's shale gas industry.

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Author Contributions

Guanglin Pi wrote the paper. Xiucheng Dong made contributions to the design of the article. Cong Dong and Jie Guo collected and analyzed the data. Zhengwei Ma provided much valuable advice.

Conflicts of Interest

The authors declare no conflict of interest.

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