Journal of World Energy Law and Business, 2021, 00, 1–15
doi: 10.1093/jwelb/jwaa037
Article

What prospects for shale gas in Asia? Case of shale gas in China

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ABSTRACT

The issues of energy and the environment are one of the main challenges for humanity today. Global growth in energy demand is facing environmental concerns, especially in fast-growing regions such as Asia. Transferring traditional energy sources such as coal, oil, to cleaner energy sources and renewables is an inevitable trend in the future. With good characteristics compared to other fossil fuels, natural gas can play an essential role in the energy transition process towards a low-carbon economy. The success of the shale gas revolution in the USA has created a lot of interest globally, especially in countries with potential for these resources. Asia, especially China, is estimated to have the world's largest shale gas resource. However, the question about the development of these resources is still a big question. This article will evaluate shale gas development prospects in Asia, particularly in China, by analysing the fundamental conditions that are important factors for the success of shale gas in the USA.

1. INTRODUCTION

Currently, natural gas is the third largest source of primary energy in the world. It contributes significantly to the global energy economy. This trend is expected to continue according to the main energy scenarios available. The International Energy Agency, the World Energy Council, BP, Shell or Exxon-Mobil expect significant growth in gas demand in the coming decades.[1,2,3] Indeed, in most scenarios, the gas should be one of the main sources of the global energy mix in 2050. In 2011, the International Energy Agency even predicted that the world would quickly enter a 'golden age of gas'.[4]

In recent decades, Asia has emerged as a region whose growth, but also demographic growth has been among the highest. Therefore, the energy needs of this area are considerable. Energy demand in Asia has risen sharply, leading some countries to become major importers of hydrocarbons and profoundly altering

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1 IEA, 'World Energy Outlook 2011' (2011); IEA, *World Energy Outlook 2012* (IEA 2012); IEA, *World Energy Outlook 2013* (IEA 2013); IEA, *World Energy Outlook 2014* (IEA 2014); IEA, 'World Energy Outlook 2015' (2015).

2 IEA, *World Energy Outlook 2017* (OECD Publishing 2017) <http://public.eblib.com/choice/publicfullrecord.aspx?p=5160837> accessed 22 March 2019.

3 BP, 'BP Energy Outlook - 2016 Edition' (2016); ExxonMobil, 'The Outlook for Energy: A View to 2040'.

4 IEA, 'World Energy Outlook - Are We Entering a Golden Age of Gas?' (2011).

global trade flows. China has become the world's largest importer of oil, while Japan is already the world's largest importer of liquefied natural gas (LNG). Faced with the challenges of economic growth, the security of supply issues has become a significant objective of energy policies in Asian countries.

At the same time, the climate issues in this region are considerable and will strongly influence the countries' energy policies. Air pollution has become a particularly serious problem in China, India . . . as well as the need to reduce greenhouse gases. These problems require a rapid and strong change in the energy mix of the Asian region. Faced with this constraint, gas is considered as a possible transition energy insofar as the economic, institutional and organizational constraints for rapid penetration of renewable energies in place of coal appear strong. Under these conditions and in the presence of energy security objectives, the question of large-scale development of the potential of non-conventional resources in the Asian region is particularly acute, as are the necessary conditions for this development.

Unconventional gas resources provide a geographical diversification in relation to the location of conventional gas resources. Unconventional gas resources, in particular shale gas, appear almost everywhere in the world. These resources are increasingly accessible, thanks to the development of technologies in exploration and exploitation, lower production costs and the development of gas infrastructures. In recent years, growth in unconventional gas and shale gas production, particularly in the USA, has contributed to the increase in global gas production. As a result, the development of unconventional gas could play an increasing role in global gas supply.

Thanks to the development of shale gas, the USA has become the world's largest gas producer in Russia since 2009. The strong growth in shale gas production allows the USA to return to self-sufficiency in terms of natural gas and could turn it into a significant gas exporter.[5,6,7,8] The development of shale gas also improves the economy such as job creation, economic growth, lowering the price of natural gas and electricity, improving the trade balance, etc.[9,10,11,12] In addition, the extraordinary growth of unconventional gas in North America is also changing the environmental issue. The two reports of the International Energy Agency (IEA) and the US Energy Information Administration (EIA) in 2013 showed that carbon emissions from fossil fuels in the USA have declined sharply in recent years.[13,14] In 2012, the data indicated that carbon emissions from fossil fuels in the USA are expected to return to 1990 levels.[15]

Since then, many countries have been interested in the development of this resource, especially those with significant resource potential, for example in Europe, Poland, the UK and Asia, China.

5 Thierry Bros, *After the US Shale Gas Revolution* (Technip 2012).

6 Charles K Ebinger, Kevin Massy and Govinda Avasarala, 'Liquid Markets: Assessing the Case for U.S. Exports of Liquefied Natural Gas', The Brookings Institution <http://www.brookings.edu/research/reports/2012/05/02-lng-exports-ebinger> accessed 21 September 2014.

7 Jeppe KOFOD, *Impact Economique et Strategique de la Revolution des Petrole et gaz Non Conventionnels* (Assemblée Parlementaire de l'OTAN 2013).

8 Daniel Yergin, 'The Global Impact of US Shale', *Eco-Business*, 2014 <http://www.eco-business.com/opinion/global-impact-us-shale/> accessed 15 July 2015.

9 Stephen Brown and Mine Yücel, 'The Shale Gas and Tight Oil Boom: U.S. States' Economic Gains and Vulnerabilities', *Council on Foreign Relations*, 2013 <http://www.cfr.org/united-states/shale-gas-tight-oil-boom-us-states-economic-gains-vulnerabilities/p31568> accessed 10 March 2015.

10 Sylvie Cornot-Gandolphe, 'Impact Du Développement Des Gaz de Schiste Aux États-Unis Sur La Pétrochimie Européenne' (IFRI 2013) <https://www.ifri.org/fr/publications/enotes/notes-de-lifri/impact-developpement-gaz-de-schiste-aux-etats-unis-petrochimie> accessed 5 May 2015.

11 Thomas Spencer, Oliver Sartor and Mathilde Mathieu, 'Unconventional Wisdom: An Economic Analysis of US Shale Gas and Implications for the EU' (2014) 2 IDDRI Study 14.

12 Frédéric Barbier, 'L'impact Économique de l'exploitation de Gaz de Schiste' (Assemblée Nationale 2014).

13 EIA, 'Annual Energy Outlook 2013' (2013).

14 IEA, *World Energy Outlook 2013* (n 1).

15 Qiang Wang and others, 'Natural Gas from Shale Formation – The Evolution, Evidences and Challenges of Shale Gas Revolution in United States' (2014) 30 Renewable and Sustainable Energy Reviews 1.

If the Asian region is likely to experience significant growth in gas production, especially from the development of unconventional gas. Indeed, the growth of clean gas production is the one that would respond to the energy security issues that are an important aspect of the energy policies pursued in the region. Unconventional gases, including shale gas, provide an opportunity for expansion of natural gas production in Asia and their development would reduce dependence on gas imports.

To do this, it is important to identify the conditions necessary for the large-scale development of unconventional gases, in particular shale gas. This work will characterize the possibilities of reproducing this gas development in Asia.

2. THE DETERMINANTS OF SHALE GAS DEVELOPMENT: THE US EXPERIENCE

The USA is the first country in the world to develop shale gas in commercial quantities. Until recently, unconventional natural gas production has been an almost exclusively American phenomenon. According to Annual Energy Outlook 2016, shale gas production will increase from about 400 Bcm, or about half of total natural gas production in 2015 to 810 Bcm in 2040, or 70 per cent of total production.[16] Although it is very difficult to definitively define the conditions necessary or sufficient to stir up a shale gas boom, a historical review of the American experience can be instructive.

There are many varied but concurring opinions on the reasons for the success of the shale gas revolution in the USA. According to Frédéric Barbier, there are three main favourable factors that have created the "revolution" of shale gas in the USA. This is the presence of a network of very dynamic companies, the development of a new production method thanks to the combined use of two widespread techniques—hydraulic fracturing and horizontal drilling; and a favourable legal framework—a weak environmental regulation at the outset and a basement property owned by the landowners.[17] Other experts add high natural gas prices in the 2000s, market structure, favourable geology, availability of water and natural gas pipeline infrastructure.

The USA is the cradle of the unconventional gas revolution, and its regulatory changes at both the federal and state levels strongly influence those of other countries. From the late 1970s, the US government adopted a series of specific policies to promote the development of new sources of natural gas. They include incentive awards, tax credits, unconventional gas R&D programs and the promotion of industry restructuring.[18] In fact, according to another study,[19] the USA has a favourable regulatory framework for development and competition, available natural gas infrastructure, transportation services, dynamic marketing and non-rigid mining rights. These encouraged the rapid development of shale gas.

Our analysis of the determinants of the shale gas revolution in the USA shows that although geological conditions are important, they are not sufficient to ensure their development on a large scale and at the rate of that of the USA. The large-scale development of shale gas depends on other factors such as institutional factors (taxation, regulation, environmental policy), organizational (competitive gas market), economic (gas prices, technology), and social (degree of social acceptability on the part of the population). The success of the shale gas "revolution" in the USA is a great lesson for other countries that want to develop this resource. Policymakers in these countries need to understand the basic conditions for developing shale gas. We want to stress the importance of the following conditions for the development of shale gas.[20,21]

16 EIA, 'Annual Energy Outlook 2016' (2016).

17 Frédéric Barbier (n 12).

18 Zhongmin Wang and Alan Krupnick, 'A Retrospective Review of Shale Gas Development in the United States: What Led to the Boom?' (Social Science Research Network 2013) SSRN Scholarly Paper ID 2286239 <http://papers.ssrn.com/abstract=2286239> accessed 20 March 2015.

19 Kenneth Barry Medlock III, 'Modeling the Implications of Expanded US Shale Gas Production' (2012) 1 Energy Strategy Reviews 33.

20 Minh Thong Le, 'The Role of Conventional and Unconventional Gas in the Energy Transition in Asia' (Theses, Université Grenoble Alpes 2017) <https://hal.archives-ouvertes.fr/tel-01587295> accessed 21 November 2018.

21 Minh-Thong Le, 'An Assessment of the Potential for the Development of the Shale Gas Industry in Countries Outside of North America' (2018) 4 Heliyon e00516.

***These are the geological and natural conditions*:** In the USA, shale gas deposits are extensive and rich in organic matter, they are distributed in different regions. In general, shale gas formations are shallower compared to others in the world. The shale layers are thicker too. The deposits are also in favourable locations where the population density is low, the water is available and the topography is fairly flat. These conditions are therefore favourable to extraction and have a significant impact on the cost of shale gas exploitation. In addition, the condition on water resources is very important. As we said above, shale gas extraction needs a huge amount of water. So for countries that want to develop shale gas development, the geological conditions of their deposits, and the availability of water are very important.

The second condition that strongly influences the development of shale gas is technology: in particular horizontal drilling and hydraulic fracturing. These play an important role in increasing production and lowering the cost of exploitation. Apart from these essential methods, other techniques and technologies are used in other drilling processes, for water treatment, methane storage, etc. Americans are masters of advanced and modern technologies in this industry, companies also have a lot of experience, and the federal government has funded programs to research and develop new technologies. Existing technologies now can help other countries to develop shale gas quickly. However, many innovations will still be needed to adapt existing technologies and develop new technologies for more efficient exploitation of shale gas deposits in all countries where geological conditions and water resources are significantly different from those in the USA.

The need for a system of appropriate policies, regulations and shale gas development stimulus: the USA has formalized policy approaches aimed at and encouraging the development of shale gas, and has established regulations to protect the environment simultaneously with the development of shale gas. Regulatory systems vary (laws, federal, state, local regulations). In particular, in the USA, the private ownership of the land resource has created favourable conditions for the operators, which has contributed to the development of shale gas. Tax policies have encouraged investment in this sector, in particular through the incentive price and tax credit policies. In addition, appropriate and transparent regulations, in particular regulations concerning the protection of the environment in the shale gas development process, will create trust and public acceptance. Policymakers in countries that want to develop these resources need to generate appropriate policies and regulations.

The competitive market with developed infrastructure and the appropriate price regime: In the USA, the natural gas market is liberalized and competitive. Prices are the result of the confrontation of supply and demand in the spot market. The USA has pipelines, compressor stations, storage facilities that are very dense and heavily meshed. So the infrastructures are very developed, they make the transport and the use easier, they make the cost less expensive. Therefore, countries that want to develop shale gas should focus on market adjustment towards liberalization, investments in infrastructure improvement, as well as progressive reform of the gas pricing mechanism.

3. THE PROSPECT OF SHALE GAS RESOURCES IN ASIA

The success of shale gas development in the USA has created a lot of interest, attention from other countries around the world, especially countries that have potential for these resources. In the context of growing import dependence, the development of unconventional gas, including shale gas, is emerging as a means of reducing dependency and addressing the energy security issue which is a central theme of the policies. Asia and especially China. Asian countries have ambitious targets for future production of unconventional gas. If these goals are achieved, the impacts on regional and global gas markets will be profound.[22]

Asia would have a significant potential for shale gas. In particular, according to the EIA report update to 2015, China has the largest shale gas reserves in the world. Apart from China, other Asian countries have

22 P Andrews-Speed and C Len, 'The Legal and Commercial Determinants of Unconventional Gas Production in East Asia' (2014) 7 The Journal of World Energy Law & Business 408.

Table 1. Shale gas estimates in Asia

Institution—year	*Resources in place (Tm^3)*	*Technically recoverable resources (Tm^3)*
Rogner—1997	100	–
EIA—2011	160	39
EIA—2013 (update 2015)	184	40
IEA—2012	–	57

Source: [24,25,26,27]

great shale gas potential: India, Pakistan, Indonesia. However, these estimations are only initial; the volume of shale gas in place is subject to a first calculation which takes into account the permeability and porosity of rocks, the thickness of the layers, their surface and the carbon content.[23] The assessment of the development potential of shale gas in Asia is still very imprecise and uncertain. Moreover, the development of shale gas in the world is still controversial because of its impact on the environment, health, landscapes, etc.

So far, the estimated shale gas resource potential in Asia is very different, highly questionable and leads to a lack of confidence that is a problem for rigorous analysis of the situation. There is still no comprehensive and detailed research on shale gas in this region. Most estimates of Asian shale gas come from institutions or researchers outside of this zone, mainly from the USA, such as the EIA, the US Geological Survey (USGS) in the USA, and the IEA. In the majority of research, the method of analogy is mainly used, so the available results are unreliable and the confidence is insufficient. At the moment the EIA estimated results are most often used as a basis. Table 1 below presents the main results of shale gas estimation in the Asian region.

According to estimates above, most shale gas resources in Asia are concentrated in China. Shale gas resources account for 70-80% of total shale gas resources in Asia. China would hold the largest shale gas reserves of technically recoverable resources accounting for about 17% of the global total.[28] It is also the country whose government has strong ambitions to rapidly develop shale gas resources.[29,30] However, most fundamental estimates come from institutions outside of China. The main method in shale gas estimates in China uses comparison and analogy, so the precision of the results is weak and uncertain. Although China is estimated to have the largest shale gas resource in the world, the estimated results are very different.[31,32] The first estimate of shale gas resources in China was carried out by the University of Chinese Geoscience in 2008. It estimated the technically recoverable reserves of shale gas in China at around 26 Tm^3. After a year, the Research Institute of Petroleum Exploration and Development, PetroChina of Petrochina published more modest data of 10 to 20 Tm^3. In 2010, on the basis of analog analyses, the CNPC estimated shale gas resources in large basins and regions of China from 21.5 to 45 Tm^3.[33] In 2011, according to the Ministry of

23 Benjamin Dessus and Global Chance, 'Les Gaz de Schiste: Enjeux et Questions Pour Le Développement'.
24 HH Rogner, 'An Assessment of World Hydrocarbon Resources' (1997) 22 Annual Review of Energy and the Environment 217.
25 EIA, 'Review of Emerging Resources: US Shale Gas and Shale Oil Plays' (EIA 2011).
26 EIA, 'Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the US' (EIA 2013).
27 IEA, 'World Energy Outlook 2012' (2012).
28 EIA (n 26).
29 Desheng Hu and Shengqing Xu, 'Opportunity, Challenges and Policy Choices for China on the Development of Shale Gas' (2013) 60 Energy Policy 21.
30 Paolo Davide Farah and Riccardo Tremolada, 'A Comparison between Shale Gas in China and Unconventional Fuel Development in the United States: Health, Water and Environmental Risks' (Social Science Research Network 2013) SSRN Scholarly Paper ID 2341738 <http://papers.ssrn.com/abstract=2341738> accessed 21 September 2014.
31 Christophe McGlade, Jamie Speirs and Steve Sorrell, 'Methods of Estimating Shale Gas Resources – Comparison, Evaluation and Implications' (2013) 59 Energy 116.
32 Neil Gunningham, 'A Shale Gas Revolution for China?' (2014) 14 Climate Policy 302.
33 Shiwei Yu, 'Evaluation of Socioeconomic Impacts on and Risks for Shale Gas Exploration in China' (2015) 6 Energy Strategy Reviews 30.

Lands and Resources of China, shale gas reserves in China amounted to 134.42 Tm^3; the total potential of technically recoverable resources in China is around 25.1 Tm^3.[34] Other estimates[35] indicate that the potential for shale gas in China was at three different levels. In the lowest case, the technically recoverable resources of shale gas in China are 4.2 Tm^3, and in the highest case they are 39.8 Tm^3. Most shale gas resources are found in the south and northwest with 46.8 per cent and 43 per cent, respectively.[36]

Finally, Asia is assessed as having great potential for shale gas resources in the world, but lacks concrete and detailed studies. The geological characteristics of shale deposits can vary considerably, affecting the profiles of production potentials.[37] In addition, conditions such as the regulatory system, the organization of infrastructure, pricing mechanisms, environmental and resource management, societal challenges ... can significantly influence the scale of future development of shale gas in Asian countries.

4. ASSESSMENT OF CONDITIONS FOR SHALE GAS DEVELOPMENT IN ASIA: CASE CHINA COMPARED TO THE USA

The shale gas revolution in the USA has triggered worldwide research for shale gas on other continents, other countries. However, the conditions for the development of these resources are different from one region to another, from one country to another and very different from the conditions in the USA. The success of the shale gas revolution in the USA is the combination of a number of favourable factors.[38] The US experiences are lessons for other countries or regions wishing to develop the shale gas industry. In this content, we analyse shale gas development conditions in Asia, focusing on China on a comparable basis to the USA to clarify the potential development of shale gas in Asia.

Geological and natural conditions

Geological condition

These conditions strongly influence the volume and the quality of a shale gas deposit, and likewise the development and exploitation potential. The natural characteristics of the deposits such as their thickness, their permeability, their porosity, have a direct influence on the flow rates of the wells. Their depth is decisive for the cost of drilling and fracturing operations. The success of the shale gas revolution in the USA is the result of several reasons, but the most important factor is the very favourable geological conditions of the shale gas basins in the USA. In the USA, shale gas deposits are large and rich in organic matter. Shale gas formations are shallower, averaging about 800–2600 m.[39] The shale layers are thick and have no defects. The gas content in a ton of shale in the USA is quite high: about 40–330 scf/ton.[40]

Compared with the geological characteristics of shale gas deposits in the USA, those observed in Asia are very different, very variable and very complex. So these are unfavourable factors for developing shale gas in Asia. According to the EIA study, the deposit area in each Asian country is highly variable. It ranges from 2,270,000 square miles for the formation of shale gas in India to 611,000,000 square miles for the formation of the Yangtze platform in China. The shale gas veins in Asia are quite thick compared to those in the USA. According to the EIA report, the thickness of the shale layers in Asia is 20–200 m, but the layers of the shale gas deposits in Asia have many flaws. According to the data in Table 2, we see that the depth of shale gas

34 ibid.

35 Christophe McGlade, Jamie Speirs and Steve Sorrell, *A Review of Regional and Global Estimates of Unconventional Gas Resources* (UK Energy Research Centre 2012).

36 Jane Nakano and David Pumphrey, *Prospects for Shale Gas Development in Asia: Examining Potentials and Challenges in China and India* (Center for Strategic and International Studies 2012).

37 ibid.

38 Le (n 21).

39 Hu and Xu (n 29).

40 NETL-National Energy Technology Laboratory, *Modern Shale Gas Development in the United States: An Update* (DOE, NETL 2013).

Table 2. Geological characteristics of shale gas deposits in Asia

Country	Area (square mile)		Thickness (feet)		Depth (Feet)		Total organic carbon (%)		Concentration (Bcf/square mile)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Chine	14 440	611 000	150	500	5 500	14,700	1.1	6.6	12.6	162.6
Mongolie	6,730	24,560	250	300	7,000	8,000	3	4	23.6	31.3
Thaïlande	32,400		200		9,000		3		83	
Indonésie	7,510	45,170	266	600	5,000	11,500	1.5	6.0	19.6	213.8
Inde	2,270	9,100	100	500	5,000	14,500	2.3	6.0	6.9	228
Pakistan	169,000		200	250	5,000	13,000	2.0		14.3	82.7
Jordanie	4,700	6,700	60	80	5,500	8,500	2.0	4.0	3.7	25.3
Turquie	6,500	32,100	207	250	9,000	15,000	2.0	3.6	34.7	104.1

Source: [41,42]

Table 3. The geological characteristics of the main shale gas deposits in China

Deposit	Area (square miles)	Depth (feet)	Thickness (feet)	Total organic carbon (%)	Concentration (Bcf/square mile)
– Sichuan	74,500	9,700–13,200	251–400	3.0–4.0	109.8–162.6
– Yangtze Platform	611,000	11,500–13,200	275–400	3.0–3.2	99.4–147.1
– Tarim	234,200	10,790–14,620	160–240	2–3	12.6–85
– Songliao	108,000	3,300–8,200	500	4–5	45

Source:[45]

formation in Asia is greater than that in the USA. The depth of shale gas in Asia is between 1,600 and 5,000 meters. Organic content in Asia is lower than in the USA.

China is the country with the largest shale gas potential in Asia, its shale gas resources are abundant and widely distributed. The shale gas resources are mainly distributed in the Upper Yangtze and the Dian-Qian-Gui area, North and North-East of China, the mid-lower Yangtze and in South-East China, the North-West of the China with respectively, 39.6 per cent, 26.7 per cent, 18.5 per cent and 15.2 per cent of the total recoverable shale gas resources in China.[43] However, in terms of geography and tectonics, the geological conditions of shale gas deposits in China are very different from those in the USA. Much of the shale gas in China is buried at a depth of more than 3,000 m or more than 6,000 m, such as in Sichuan, and in a structurally more complex soil with many faults.[44] According to the EIA's 2013 work, the most frequent depth of shale gas deposits in China is between 1,700 and 5,500 m (Table 3) while the most frequent depth in the USA is between 800 and 2,600 m.

41 ibid.

42 EIA (n 26).

43 Zhao Xingang, Kang Jiaoli and Lan Bei, 'Focus on the Development of Shale Gas in China—Based on SWOT Analysis' (2013) 21 Renewable and Sustainable Energy Reviews 603.

44 Ella Chou, 'Shale Gas in China: Development and Challenges' (2013).

45 NETL-National Energy Technology Laboratory (n 40).

In addition, schists in most Chinese basins are rich in clay and the thickness of shale layers is also less than that of the USA. The total organic carbon content in shale gas in China tends to be lower than in the USA, the TOC index (the total organic carbon content) in shale gas in China is 1.1 per cent at 6.6 per cent. These factors make fracture more difficult and lower productivity. Therefore, for the development of shale gas in China, more advanced technologies are needed and the costs of extraction are higher than in the USA.[46] Drilling costs in China can be as high as $15 million per well, while costs in the USA are around $3 million.[47]

Apart from the above geological difficulties, shale gas deposits in China greatly overlap with conventional oil and gas pools.[48] Some shale gas deposits also contain high concentrations of toxic gases or contain many more non-hydrocarbon gases. In particular, shale gas formations in southern China contain high levels of hydrogen sulphide. For example, the concentration of hydrogen sulphide in the Weiyuan block of Sichuan is 0.8–1.4 per cent, and in the northern block of Sichuan it reaches 15 per cent.[49] This means that the quality of Chinese shale gas is low, and therefore the processing costs are higher. In the long term, China needs to define ways to make gas more usable.[50]

The geological conditions of shale gas in Asia are therefore less favourable than those in the USA. The deposits in Asia are smaller, deeper, more complex, with a lower organic matter content, so they encounter more difficulties in exploitation processes such as hydraulic fracturing. In addition, success in shale gas requires a good understanding of regional geology. Unlike the USA, where reliable data covering large areas of prospecting has been accumulated through decades of conventional drilling and seismic studies, Asia lacks geological data.[51]

Population density

Topographic and demographic conditions have exacerbated the difficulties of access to land for large-scale drilling, transportation, installation of heavy equipment essential for the development of shale gas.[52,53,54] In the USA, the population density is low, water is available and the topography is fairly flat. These conditions are therefore favourable for extraction and have a significant influence on the cost of shale gas development in the USA. The population density in Asia is often much higher than in other regions of the world. According to data from the World Bank, the average population density in Asia is 136 people per km^2, while in North America and Europe it is much lower, about 16 people per km^2.[55]

With a population close to 1.4 billion people, China has one of the highest population densities in the world, 145 people/km^2 compared to 34 people/km^2 in the USA. Most shale gas deposit in China are also often located in mountainous, rocky, desert terrain and a significant portion of Eastern China is located in areas with high-population densities. The high-population density means that there are many buildings and infrastructure scattered across the regions and the security zones around these areas also occupy a space. These will create a lot of obstacles for operators who want access to the land to develop shale gas. The high-population density will make the cost of drilling more expensive. Therefore, access to land in relation to high

46 Hu and Xu (n 29).

47 Philip Andrews-Speed and Christopher Len, *China Shale Gas: Can the Pace Be Sustained?* (Energy Studies Institute - NUS 2015) <http://esi.nus.edu.sg/publications/esi-publications/publication/2015/01/12/china-shale-gas-can-the-pace-be-sustained-> accessed 11 May 2015.

48 Fan Gao, *Will There Be a Shale Gas Revolution in China by 2020?* (Oxford Institute for Energy Studies 2012).

49 Yu (n 33).

50 Farah and Tremolada (n 30).

51 Asian Development Bank (ed), *Asia's Energy Challenge* (2013).

52 Gunningham (n 32).

53 'Shale Gas: A Game Changer for China's Energy Consumption Pattern?' <http://www.nortonrosefulbright.com/knowledge/publications/64018/shale-gas-a-game-changer-for-chinas-energy-consumption-pattern> accessed 13 May 2015.

54 Gao (n 48).

55 'Insee - Territoire - Population, Superficie et Densité Des Principaux Pays Du Monde En 2014' <http://www.insee.fr/fr/themes/tableau.asp?reg_id=98&ref_id=CMPTEF01105> accessed 13 October 2015.

population densities is a big challenge in the shale gas development process in Asian countries in general, and in China in particular.

The condition of water

The process of hydraulic fracturing in the development of shale gas consumes huge amounts of water. According to the IEA estimate, during the hydraulic fracturing process, each well may require up to 20,000 m^3. In China, water is an urgent problem, with relatively limited resources. While, the report by the Asian Development Bank said that more than three quarters of Asia are facing severe water shortages. It is a real threat to the development of Asia in the future. In China, the volume of water available per person is very low, and water resources are unevenly distributed.[56] About 300 million people in China have insufficient access to water. More than two-thirds of cities suffer from water shortages and one-sixth are seriously affected. The United Nations lists China as one of 13 countries with the most severe water shortages.[57] Unfortunately, many of China's shale gas reserves are facing water supply problems. Most of the major basins containing shale gas in China are located in arid or semi-arid regions, with rainfall of less than 800 mm per year, and many of these basins are densely populated with a high voltage to ensure the water supply.[58] The areas that have shale gas potential and areas of water scarcity overlap, like the regions in Northeast and North China. Therefore, the large-scale development of shale gas in these areas will only exacerbate these problems.

Technical and technological conditions

Another condition that strongly influences the development of shale gas is technology and technology, particularly horizontal drilling and hydraulic fracturing. They play an important role in increasing production and reducing operating costs. The technologies and techniques for shale gas exploitation now in the USA are the results of the accumulation of research and practice in this area for 30 years.[59] So, Americans have mastered advanced and modern technologies in this sector, companies also have a lot of experience. In addition, the USA has many service companies that have a lot of experience and have mastered the technology and techniques, with the right equipment and experienced staff, at competitive prices. As a result, the USA has advantages in developing shale gas compared to other countries in the world.

Although the Asian region has been estimated to hold a rich potential for shale gas resources, the lack of studies, information and uncertainties about the potential of shale gas have reduced the interest of governments in this region. Until now, the techniques and technologies for exploiting shale gas in Asia are embryonic. In the Asian region, China is the pioneer country in shale gas. However, according to the judgment of experts and researchers, China's biggest challenge is technological. Although China has a strong ambition to quickly develop shale gas; it has programs and policies to encourage the development of technologies in this area. However, shale gas development in China is still at the primary stage, with major technologies such as horizontal drilling and hydraulic fracturing still in the research stage.[60,61] So, China lacks the equipment, the necessary personnel and the experiments to develop shale gas on a large scale. In addition, the geological conditions in China are more complex. Therefore, for shale gas extraction, China needs more advanced technologies with higher costs.[62] No doubt, technology is also a major obstacle to the development of shale gas in Asia.

56 Farah and Tremolada (n 30).
57 Gao (n 48).
58 Yu (n 33).
59 ibid.
60 Xingang, Jiaoli and Bei (n 43).
61 Zeng Ming, Liu Ximei and Li Yulong, 'China's Shale Gas Development Outlook and Challenges', *POWER Magazine*, 2014 <http://www.powermag.com/chinas-shale-gas-development-outlook-and-challenges/> accessed 13 May 2015.
62 Desheng Hu and Shengqing Xu, 'Opportunity, Challenges and Policy Choices for China on the Development of Shale Gas' (2013) 60 Energy Policy 21.

The institutional factor

The opinion and policies for developing shale gas

The success of the USA with shale gas is the result of the combination of favourable federal legislation, the diversity of state laws, and an encouraging energy policy. The USA has formalized policy approaches aimed at and encouraging the development of shale gas. They established regulations to protect the environment simultaneously with the development of shale gas. Regulatory systems are variable and popularized, including laws, federal, state and local regulations. Shale gas development policies are the combination of federal laws, state regulations and local governments. The transparent regulatory regime, with specific limitations in federal and state regulations, has helped investors take risks and have encouraged them to invest vigorously in new shale basins.[63] It has also helped to build public confidence in shale gas.[64] A series of federal laws govern most of the environmental aspects of shale gas development, for example: the Clean Water Act, the Safe Drinking Water Act, the Clean Air Act, the National Environmental Policy Act, etc. The federal support has catalysed the initiatives of the gas operators.

On the contrary, the political system that governs the development of shale gas in Asia still poses a big question. Due to the political regimes of Asian countries which are very different, the policies and regulations of each country are also variable. Regulations and policies are concentrated in the hands of the government, and tend to remain close to a state monopoly, as in China for example. Even, the system of regulations and policies in general overlap and lack transparency. Except China and India have policies related to shale gas development, the rest of the Asian countries have hardly expressed clear interest in shale gas.

In Asia, the Chinese government has identified shale gas as a very important resource in the future energy development strategy that aims to increase energy self-sufficiency, improve energy structure and ensure energy security. The Chinese government has established a program to achieve its ambition of developing shale gas. In order to stimulate shale gas extraction, the Chinese government has enacted a series of policies to promote shale gas development. This policy system includes four main aspects: industrial planning, support for research and development, tax concessions and subsidies and innovation in management mechanisms.[65,66] The concrete objectives of shale gas development policies were evidently expressed in China's 12th and 13th five-year plan for shale gas development.

However, most of these policies and regulations in China are imprecise and lack enforcement mechanisms and procedures. China's current regulatory framework lacks consistent and satisfactory provisions for shale gas extraction and related environmental concerns. The Chinese legal system has a tripartite structure: the National People's Committee adopts the laws; the Council of State adopts the regulations; various ministries create rules, and departments within ministries create other normative legal documents.[67] Therefore, China needs a regulatory model to encourage cooperation and delegation of responsibility between the central government and the provinces for effective development of shale gas resources.

The politics of land use

In the USA, the mining regime is very particular because the ownership of the resources of the subsoil is traditionally attributed to the surface owners. This right of private property which extends to the basement entitles to substantial royalties, encouraging land owners to accept this type of exploitation. The owners derive profits from the producers' activities. Producers can access land and resources with less difficulty. They therefore have a direct interest in welcoming the oil companies to their homes, which has considerably simplified

63 Farah and Tremolada (n 30).

64 Alan J Krupnick and others, 'The Natural Gas Revolution' <http://www.rff.org/rff/documents/rff-rpt-naturalgasrevolution.pdf> accessed 21 September 2014.

65 Hu and Xu (n 62).

66 Yu (n 33).

67 Farah and Tremolada (n 30).

the issue of environmental acceptability. In addition, a financial incentive has been created for private landowners to compensate for disruptions associated with shale gas development.[68] Drilling authorization procedures are often less complex and encourage the spread of drilling on a site.[69,70,71] So this has been one of the main causes of the rapid development of shale gas in the USA.

In Asia, gas resources are owned by the state and access rights to the resource are administered by the central government. Parties that occupy and use the land does not earn a direct financial benefit from the exploitation and sale of shale gas resources. Therefore, there are many challenges with companies that want to use the land to explore and exploit shale gas in Asia.

Due to its socialist and Maoist heritage in the 20th century, contemporary China lacks private property rights over land and mineral resources. The Mineral Resources Law of China has defined a licensing model for all. However, this law is rather imprecise. Thus, there is overlap between the land use right, the mineral right and the exploitation right in the same place. Although shale gas is recognized as an independent mineral resource, shale gas deposits are generally buried deep underground, which may lead to overlap with other minerals such as coal or oil. In practice, blocks of shale gas being explored or developed largely overlap with areas where China's NOCs have rights to oil and conventional gas.[72] In addition, the Ministry of Land and Resources administers all areas of shale gas. These overlaps can create a lot of trouble for other companies wanting to enter the shale gas sector in China, although the Chinese government is committed to making shale gas developers a priority when applying for a land use permit.

Tax policy

Among the reasons that led to a very rapid development of shale gas in the USA are the incentive price and tax credits, notably section 107 of the Natural Gas Policy Act, the section 29 of the Crude Oil Windfall Profit Tax Act and the Tax credit for unconventional gas.[73] Section 107 of the Natural Gas Policy Act defines an incentive price for shale gas and other forms of unconventional gas. The section 29 of the Crude Oil Windfall Profit Tax Act on tax credits applied to unconventional natural gas has stimulated the development of unconventional gas and increased financial returns and therefore reduced the risk of investment in this resource. It has thus stimulated investment in technology development and improvement activities.[74,75]

In China, energy companies that invest in the shale gas sector should be supported by specific fiscal policies. In fact, to promote shale gas exploration and development, the Chinese Ministry of Finance issued an opinion in 2012 on the shale gas development and use subsidy policy. The policy reveals that the central government has allocated special funds to support the development and use of shale gas: the standard subsidy for shale gas companies is 0.4 yuan per cubic meter from 2012 and until 2015, the subsidy will decrease after 2015.[76]

Apart from the shale gas subsidy policy, the Chinese government is studying other tax policies. The Chinese government will reduce the cost of mineral resource compensation and fees for mineral rights for

68 Paul Stevens, 'The "Shale Gas Revolution": Developments and Changes' (2012) 4 Chatham House Briefing Paper <http://kms2.isn.ethz.ch/serviceengine/Files/ESDP/152859/ipublicationdocument_singledocument/5a2f29de-7bb0-4dfe-bfd1-380c7e64a7de/en/bp0812_stevens.pdf> accessed 21 September 2014.

69 Juan Roberto Lozano Maya, 'The United States Experience as a Reference of Success for Shale Gas Development: The Case of Mexico' (2013) 62 Energy Policy 70.

70 Wang and Krupnick (n 18).

71 Benjamin Dessus and Global Chance (n 23).

72 Ella Chou (n 44).

73 Farah and Tremolada (n 30).

74 MR Hass and AJ Goulding, 'Impact of Section 29 Tax Credits on Unconventional Gas Development and Gas Markets' (Society of Petroleum Engineers 1992) <http://www.onepetro.org/doi/10.2118/24889-MS> accessed 15 April 2015.

75 Wang and Krupnick (n 18).

76 Hu and Xu (n 62).

shale gas exploration companies.[77] In addition, the government will investigate and implement incentive policies through the resource tax such as the exploration exemption for mining royalties, VAT, income and other taxes in the future. In addition, imported equipment for shale gas exploration and development will be duty-free.[78,79]

The factors of infrastructure and market

Infrastructure conditions

An essential element for supplying gas to the market is sufficient infrastructure, including for gas treatment, storage and compression facilities, as well as a sufficiently developed pipeline network to transport gas from the places of production. In the USA, there is a network of pipelines which is very dense and strongly meshed. The interstate and interstate transportation network in the USA is more developed and dense than in any other country in the world.[80] It is also less expensive. A study has indicated that outside of the USA where services are not readily available and need to be mobilized, the cost of drilling can be almost 400 per cent higher than that observed in the USA.[81] According the Department of Energy, the USA has more than 210 natural gas pipeline systems; more than 1,400 compressor stations, approximately 305,000 miles of interstate and intrastate transmission pipelines with more than 11,000 delivery points, 5,000 receipt points and 1,400 interconnection points. There are also 400 underground natural gas storage facilities and several liquefaction and regasification plants.[82] It makes transportation and use easier, it makes the cost less expensive and so that the gas market is very develop in the USA.[83,84] The USA has a well-functioning liberalized gas market and the price is the result of the confrontation of supply and demand in the spot markets.

Conversely, gas infrastructure is still limited in Asia due to geographic, political, geopolitical, economic problems. The pipeline network is not yet developed in Asia. Access to gas pipeline networks is strictly limited and third-party access regulations do not exist. These are factors that will slow the development of shale gas in Asia. Below, we will analyse the infrastructure conditions and the market in China in the shale gas development process. In China, most of shale gas reserves are located in areas that are far from the existing pipeline network and far from the consumer market. Although China has intensified its pipeline development in recent years, pipeline construction has not kept pace with the rapid growth of demand. Currently, China has more than 43,000 km of natural gas pipelines. Numerous studies point to bottlenecks in pipeline transportation, which add to the high costs of development.[85]

Market structure

The USA has a fully liberalized market for natural gas, but the Asian gas market is a complex, fragmented and monopolistic market. Gas markets in Asian countries are relatively immature, with a high degree of government control, and normally domestic oil companies in Asian countries dominate the market. The success of the USA rests on the initiative of thousands of independent small and medium-sized businesses, and in a competitive market. Small independent and specialized operators have been pioneers in the exploration and

77 Yu (n 33).
78 Hu and Xu (n 62).
79 Yu (n 33).
80 Krupnick and others (n 64).
81 Jerry Kepes, Barry Rodgers and Pedro van Meurs, 'Gas Prices, Other Factors Indicate Changes in North American/Shale Play Fiscal Systems' (2013) <http://www.ogj.com/articles/print/volume-109/issue-14/exploration-development/gas-prices-other-factors-indicate-changes-in-north.html> accessed 13 March 2015.
82 EIA, 'Natural Gas Pipeline Network - Transporting Natural Gas in the United States' (2010) <http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/index.html> accessed 3 June 2015.
83 Gao (n 48).
84 Gunningham (n 32).
85 ibid.

significant increase in shale gas production in the USA.[86] The USA has a large number of small oil companies that are very dynamic and willing to promote technological innovation, either as an operator or as an oil services company (drilling, cementing, logging, etc).[87,88]

Unlike the USA, China does not have thousands of independent oil and gas companies competing with each other. The oil and gas industry in China is one of the industries under monopoly for a long time through national oil companies (NOCs). Most of China's oil and gas exploration and production licenses are split between NOCs including the rights of the most attractive areas for shale gas. Moreover, these NOCs dominate and control almost all pipelines and the lack of clear regulations for third-party access has limited foreign investors' participation in shale gas.[89] According to some experts, the monopoly of oil and gas in China is difficult to break in the short term.[90] Monopoly can create a lag in technological innovation, and slow the development of shale gas in China.

The price mechanism

Since 1978, the Federal Energy Regulatory Commission have aimed to liberalize the US market. Regulations to liberalize gas prices, to allow third party access to transmission networks, have led to a spectacular development of the North American spot market. In 1992, almost all long-term contract prices that remained were based on spot market prices.[91,92] Since the restructuring of the North American gas industry, the gas-on-gas competition price system has been the dominant model. Gas prices are set by supply/demand balances. It is competitive and transparent.

In contrast, the structure of domestic natural gas markets in Asia limits competition. In several countries, governments still participate directly or indirectly in the control of markets, in the determination of energy prices, including natural gas. With the objective of securing long-term supplies, imported gas is mostly through long-term contracts and the price of gas depends on crude oil or petroleum products. The price mechanism of the price of oil still dominates the Asian market.

China has a gas price system that is a compromise between the market price and the administered price. In China, the central government has for a long time controlled and determined energy prices, especially the price of gas. Government intervention in the price mechanism has limited competition in the gas market. The government's pricing policy has been to differentiate natural gas users and also leads to very different gas prices in the fields of fertilizer, electricity, industry, residential and trade. With very different prices, there is no consistency in taking into account the degree of scarcity of gas, supply and demand or the relationship with the price of alternative resources.[93,94,95] In addition, the large gap between domestic prices and the international price of natural gas will constrain the development of the gas and shale gas market as well.

86 Bauquis Pierre-René, *Parlons gaz de schiste en 30 questions* (La documentation Française 2014) <http://www.ladocumentationfrancaise.fr/informations/espace-presse/communiques-de-presse/cp000273-parlons-gaz-de-schiste-en-30-questions> accessed 9 March 2015.

87 Bruno Weymuller, 'Les Perspectives Du Shale Gas Dans Le Monde' [2010] Note de l'IFRI <http://ifri.org/downloads/noteenergiebweymullerproteg.pdf> accessed 29 September 2014.

88 Marcel Boiteux and others, *Energie: Economie et Politiques* (Première Édition, De Boeck 2010).

89 Philip Andrews-Speed, Christopher Len (n 47).

90 Yu (n 33).

91 Jean-Pierre Angelier, *Le gaz Naturel* (Economica 1994).

92 MIT study, *The Future of Natural Gas* (2011).

93 Boriss Siliverstovs and others, 'International Market Integration for Natural Gas? A Cointegration Analysis of Prices in Europe, North America and Japan' (2005) 27 Energy Economics 603.

94 Ting Wang and Boqiang Lin, 'China's Natural Gas Consumption and Subsidies—From a Sector Perspective' (2014) 65 Energy Policy 541.

95 Sergey Paltsev and Danwei Zhang, 'Natural Gas Pricing Reform in China: Getting Closer to a Market System?' (2015) 86 Energy Policy 43.

The acceptance of the population

A very important aspect of the development of shale gas is the 'social license' for activities in this sector. Many studies have indicated that in the process of shale gas development, the application of hydraulic fracturing requires the use of chemicals that can pollute groundwater and even surface water. Leaking chemicals are the cause of serious damage to the environment, in particular to the groundwater system. In addition, the operating process can lead to the escape of methane, a kind of greenhouse gas whose polluting effect is several times more powerful than that of carbon dioxide. In addition, the impact on the earth's surface is great in the process of exploration and development.[96] According to the IEA, in the publication of 'Golden Rules for a Golden Age of Gas' in 2013, the need to build a 'social license to operate' was highlighted.[97] So the lack of social acceptability, even the hostility of the majority of the population towards the development of shale gas will be the biggest restriction in the future. There is much controversy over local or global environmental issues in relation to shale gas technologies, not only in the USA but also in other regions, countries with gas potential shale. Although some shale gas operations are beginning to face an increase in local opposition in the USA, the USA has historic oil activities, low population density, abundant water resources, in addition the right of ownership of the basement is private. These important factors have made acceptance of shale gas development a reality in most parts of the USA.

In China, so far there has been no resistance report to communities on shale gas exploitation. While China's population density is very high in areas where shale gas is found. Potential risks to human health and safety may also be greater, and the general resistance of local communities may increase. In addition, the structure of Chinese society has created significant differences in the development of shale gas compared to other countries. The government owns the resources and also carries out pilot projects. However, if shale gas operations cause unacceptable damage to water, the environment, land or community life, especially in densely populated areas, local communities may begin to resist shale gas development plans in China.

CONCLUSION

The success of the USA in the development of unconventional gas in the past decade has been the subject of much debate and controversy around the world. Shale gas is the important additional gas source when conventional gas is running out. It can therefore play a major role in terms of energy security in the future. The success of the shale gas '"revolution' in the USA is a great experience for other countries who want to develop this resource. However, there are also many doubts, a lack of confidence, even a strong opposition to the development of shale gas. The problem of shale gas is complex and the impacts are only partially known. Shale gas resource estimates are highly variable and uncertain.

Asia has become a major center for growth in global energy demand and will remain so in the future. With an economic growth rate which has been maintained at a high level, in particular in China, India and in the countries of Southeast Asia, there will always be a strong growth of the GDP and the standard of living in Asia in the coming decades. The Asian region seems very rich in unconventional gas, especially shale gas in China is considered one of the greatest in the world. Nevertheless, there is still a lot of uncertainty in Asia about the development of natural gas in general and shale gas in particular, due to many factors such as geological, technological, political conditions, cost-effectiveness. The Asian region lacks a lot of independent research on the potential of shale gas. As a result, data and information on shale gas formations in Asia is unreliable. Estimates to date are still imprecise and uncertain. Asian countries need a long time to research, develop and perfect technologies that match the geological and operating conditions of shale gas reservoirs in this area. Other reasons are geography, economic conditions, gas infrastructure, particularly the undeveloped pipeline networks in Asia. This creates many unfavourable conditions in the development process of shale

96 Xingang, Jiaoli and Bei (n 43).

97 IEA, 'Des Règles d'or Pour Un Âge d'or Du Gaz' (EIA 2012).

gas. The monopoly of state companies in the energy sector of Asian countries also creates barriers for private companies and foreign investors wishing to penetrate this field and the natural gas market. Finally, the governments of Asian countries do not yet have definitively formalized shale gas policies.

In the Asian region, China is emerging as a pioneer in the development of shale gas. As the country with the largest shale gas resources in the world, the Chinese government has taken action to implement its ambitions in the exploitation of these resources. However, according to expert assessments, the development of shale gas in China will face formidable challenges. First, as with the rest of Asia, there are insufficient data and information on shale gas tanks in China, and they are unreliable. The geological conditions of shale gas deposits in China are very complex, while most of the deposits are located unfavourably, the population density is very high, water resources are scarce. In addition, the technology for the exploration and exploitation of shale gas in China is a learning and development process, the infrastructure is still very weak and insufficient. Besides, the gas market is under monopoly, the government controls the price, the opportunities of approach of the resources and the shale gas market by the private and foreign companies are very difficult.

Based on the factors that led to shale gas success in the USA, we analysed and compared them to those in Asia in general, particularly in China. The comparison of development conditions showed that there are many natural, institutional and organizational factors that are unfavourable for the development of shale gas in Asia, include China. Asia therefore needs time to research and surely assess the potential of shale gas, research and develop technologies appropriate to the conditions of shale gas reservoirs, and also formulate and enact appropriate policies. So, we can conclude that the 'shale gas revolution' of the USA is not reproducible in its magnitude or pace in Asia. Ultimately forecasting the development of shale gas in Asia in general and China in particular is very difficult.