A Comparative Examination of the Shale Industry Development Indices in the United States and China

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***Abstract*—To maintain economic growth, nations explore new energy sources for energy independence. The US initiated the shale oil and gas revolution, leading to self-sufficiency and exports oil and gas. This prompted China to emulate the US to meet gas needs and reduce pollution by replacing coal with shale gas. However, transferring an economic experiment depends on various factors. This study compares the American and Chinese experiences, highlighting that in China, government control provides environmental benefits but may slow production growth. In the US, private companies contribute to energy security, but the government lacks authority over production during price hikes. Factors such as geological complexity and R&D spending are crucial in developing the shale gas industry, influencing its future in China.**

***Keywords*—shale industry, energy, greenhouse gas, geology**

I. Introduction

The development and expansion of the shale oil and gas sector can be attributed to a multitude of direct and indirect factors, with hydraulic fracturing technology playing a crucial role. This low-cost technique gained significant popularity around the onset of the 21st century, particularly in the United States where corporations began enhancing shale gas production in 2000. Shale oil, on the other hand, experienced widespread growth starting in 2004. Primarily, two elements drive the progress of the shale oil and gas industry: hydraulic fracturing technology and rising global oil and gas prices. Consequently, an ideal environment was established for profitable commercial production. (Yang *et al.*, 2017; HUGHES, 2013).

In order to rejuvenate an exhausted resource, substantial reserves are crucial. The United States, spurred by George Mitchell's discovery of oil shale in 1978, placed its bets on this energy source as a means to attain energy independence and reduce dependence on oil-producing nations, primarily OPEC. Billions of dollars were invested in innovations and advancements to economically harness this resource. During the 1990s, the US constructed infrastructure and established pipelines in anticipation of an impending energy revolution, driven by the vast reserves of shale oil and gas that are projected to last for approximately a century (Salygin *et al.*, 2019; Zuhaira *et al.*, 2022; Andrews, 2006).

The shale oil and gas industry confront various challenges, primarily due to geological intricacies, as the properties of these resources differ significantly across different fields. This necessitates unique technological innovations for each region, subsequently increasing costs. Thus, the exploration of new fields involves either discovering geologically similar terrain, reducing total expenses, or encountering new geological formations that demand tailored technological advancements, raising the overall costs (Soeder, 2018); Saussay, 2018). Consequently, transferring technology from one country with a specific geological makeup to another with dissimilar geology may not be feasible. This exact scenario unfolded in China when attempting to employ American technology in their domestic gas fields, resulting in elevated drilling and completion expenditures, low initial production rates, and abbreviated well lifespans. Many global corporations withdrew from the shale gas market during the second decade of this century due to these complications. In response, the central government directed its subsidiaries to prioritize technological innovation and advancement as solutions to overcome these complex geological challenges and ultimately boost production rates (Soeder, 2018).

Consequently, our inquiry leads us to the following question: How does the American shale oil and gas revolution differ from its Chinese counterpart? What obstacles confront China's shale gas industry? And how do these industries affect global warming? In the body of our research, we will concentrate on addressing these questions. We will examine crucial factors (indicators) within the United States and Chinese shale oil and gas sectors.

II. Literature Review

Many studies address the US and China in the development and exploitation of oil and shale gas to China as a study (Salygin *et al.*, 2019) that examined the current problems and horizons for the development of oil and shale gas in the United States, China, Canada, India, Australia, and Russia used the methodology of statistical estimation to extract, export and reserves of recoverable rocky hydrocarbons. The study concluded that traditional oil and gas would dominate the market, and two rocky revolution centers will be formed, China and the United States. They became competitors soon (by 2020, China will boost its shale oil and gas production and export it to other Asian countries). What is wrong with this study is that it did not address the challenges equitably facing China, so the study was not successful estimating the development of the shale oil and gas industry in China in geological complexly.

There are studies (Yang *et al.*, 2017; Dong *et al.*, 2016; Guofeng *et al.*, 2019; Lei & Zhijun, 2019) that analyze the current situation of shale oil in China and what is the possibility of transferring the American experience to China. Studies have concluded that it is impossible to transfer the

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American experience to China as a result of market disagreements and geological complexity. These studies avoided highlighting the difference in geology within the United States and the difference in technology used according to type and depth.

The study (Huanquan *et al.*, 2019) concluded that it is impossible to transfer the American experience to China based on the geological complexity that caused the low production. The launch of the United States in the production of oil and shale gas is due to advanced technology and high oil prices. The study's fault is that it did not address the factors that led to technology development. And how government policies are in the growth of the oil and shale gas industry. In addition, the study did not address the role of companies in technological penetration and increasing production.

The study (Saussay, 2018) is used the comparative method of shale gas production between the United States and the European Union. The study used an analysis of the main determinants of a well's profitability. And used the Monte Carlo method to estimate the distribution of prices to more than 40,000 well in the United States. Then the comparison of the results with some wells was drilled in Europe for experimental purposes. The study concluded that the parity price in Europe is $ 10.1 per unit of British thermal and that the price is very sensitive to the initial production rate and the cost of drilling and production, and the study will not favor the possibility of transferring the American experience to Europe. We completely disagree with the result of this study. Although the legislation of the Environmental law is different, there are many similar economic factors between Europe and the United States, for example (the free market, high prices, ease of entry of companies into the shale gas industry, ease of borrowing and financing, advanced infrastructure, environmental trends towards gas, diversification of the size of companies and advanced technology). Thus, there is the possibility of reducing production costs. But from a geological point of view, there is a difference between Europe and the United States, so it will not be possible to transfer technology to give the same results, this case is similar to the case of technology transfer to China.

We note from previous comparative studies that there is a conviction in the difficulty of transferring the American experience to China or other countries that are the closest and most capable of developing unconventional fossil fuels outside the United States. Hence, our study has shed light on many differences' aspects between US and China. We seek to be a comprehensive study to surround all issues related to the development of unconventional fossil fuels in China and the US.

III. The Main Ten Indices of Shale Industry

A. Reserves

Reserves are the main factor on which all extractive industries (all types of fossil fuels and minerals) are based. The availability of oil and gas reserves, whether in the United States of America, China, or any other country, will be sufficient reason to start research and development operations to extract these resources from the ground. China and the United States of America are distinguished by huge reserves of oil and shale gas, as the latest statistics of the Energy Information Administration showed that the United States has more than 58 billion barrels of commercially available oil, offset by 32 billion barrels of shale oil in China. In contrast, in shale gas, the United States owns 1161 trillion cubic feet compared to 1115 trillion cubic feet commercially available in China as shown in Table 1 (US Energy Information Administration, 2013). Some may argue about the number of estimated reserves commercially available, as many institutions issue reports in different numbers on the size of the reserves, and these estimates come as a result of geological surveys; the more extraction technology develops, the greater the proven reserves, as well as the development of discovery and exploration technology, more accurate the numbers of existing reserves. As BP estimates revealed huge reserves estimated at 8.4 (Tcm)(Looney, 2021). As for the Chinese National Bureau of Statistics estimates, the reserves were estimated at about 6.62 (Tcm). OPEC estimated the reserves at 2.98 (Tcm). It is clear that OPEC did not consider shale gas reserves due to the lack of available information and the low volume of production relatively (OPEC, 2020), while the website of (offshore-technology) shows there is more than 30 Tcm of shale gas in China (Offshore Technology, 2022). Thus, China and the United States have met the basic condition for the establishment of the oil shale industry, which is the availability of reserves.

Table 1. Top 13 countries with technically recoverable shale oil and shale gas resources (us energy information administration, 2013)

No.	Country	Shale oil (billion barrels)	Shale gas (trillion cubic feet)
1	RUSSIA	75	285
2	USA	58	1161
3	CHINA	32	1115
4	ARGENTINA	27	802
5	LIBYA	26	122
6	AUSTRALIA	18	437
7	VENEZUELA	13	167
8	MEXICO	13	545
9	PAKISTAN	9	105
10	CANADA	9	573
11	ALGERIA	5	707
12	SOUTH AFRICA	0	390
13	BRAZIL	5	245
	World total	345	7201

It is noticed through the Table 1 that Russia, the United States, and China top the table in the quantities of reserves. But the United States is the only one capable of producing shale oil at low costs capable of keeping pace with the fluctuations of global oil prices. China is in the first steps in developing the shale oil industry. Many wells have been drilled and the production took place, but at very high costs compared to the United States of America. Russia does not need to enter this industry because of its large quantities of conventional oil production.

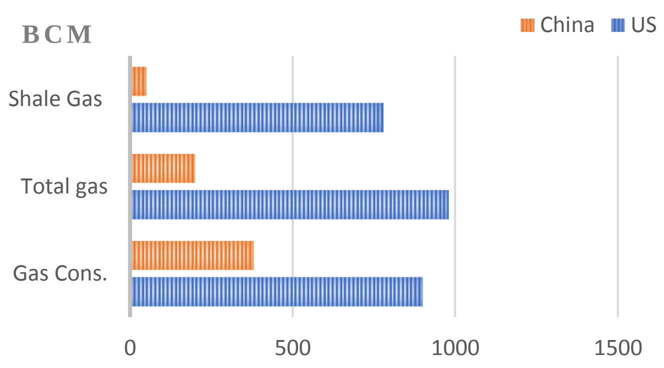
B. Production

Today, the United States of America is the first country in the amount of oil and shale gas production. This achievement comes as a result of the struggle that continued for more than two decades when the appropriate technology for extracting shale oil was discovered in the seventies of the last century until the beginning of the first decade of this century. When it began in The United States of America, the commercial production of shale gas guaranteed the producing companies more profits. We find that US oil production has reached the threshold of 7.2 million barrels per day in 2020. On the other hand, some references indicated that China's shale oil production does not exceed 35,000 barrels per day. Therefore, we see the vast difference between the two countries in shale oil production. As for shale gas, the United States reached 950 (Bcm) in 2020, while China reached 200 (Bcm) of shale gas as shown in Fig. 1, according to what some sources indicated. There is an important difference between oil and shale gas production between China and the United States: The United States produces oil and shale gas from the same well to reduce costs. China focuses on shale gas only, making it miss the opportunity to produce shale oil and shale gas together to reduce costs (Browning *et al.*, 2013).

We notice from Fig. 1 that the United States' production of shale gas is close to 800, while the total consumption is much less than that of the total production, which makes it a net exporter of gas. As for China, the total gas consumption is twice the total production, which makes it a gas importer, noting that shale gas production is very low.

C. Geology

The geological factor is important in determining the appropriate technology for extracting oil and shale gas. Geologists have pointed out a difference in the nature of the layers containing kerogen and gas particles between the Chinese and the American side, as the geology of the Earth in the United States of America is better than its counterpart in China. It will be detailed in Table 2.



Source: Chen Aizhu, Analysis: Chinese majors to struggle to extend shale gas boom beyond 2025, Reuter, 2021.

Fig. 1. Natural gas output and consumption: China vs US.

We note from Table 2, There is a difference in the sedimentary environment of shale oil between the two countries. The American shale oil and gas is of the type (marine), while the shale oil in China is of the type (Lake) in the basins (Ordos Basin, Huanghua Depression in Bohai Bay Basin, Santang Lake Basin). In contrast, the basins (Jianghan Basin, Jimsar Sag, Junggar Basin) are sedimentary (Saline Lakes). As for the depth of the sedimentary layers from the surface of the earth. There is a clear superiority of the American basins in their proximity to the earth's surface. On the other hand, some basins are perfect for depth from the Chinese side, such as the (Ordos Basin, Santang Lake Basin), and we also note that these two basins have a closer depth to the surface of the earth from some American basins.

Table 2. Comparison of geological conditions between major shale formations in china and the united states (Guofeng et al., 2019)

Shale formation	Wolfkamp Formation (Permian Basin)	Buchan Formation (Williston Basin)	Eagleford Special Group (Gulf of Mexico Basin)	Naiabulla Formation (Denver Basin)	Lucaogou Formation (Jimsar Sag, Junggar Basin)	7 segments long (Ordos Basin)	Kong Second Section (Huanghua Depression in Bohai Bay Basin)	Tiaohu Formation (Santang Lake Basin)	Qianjiang Formation (Jianghan Basin)
Sedimentary environment	Marine	Marine	Marine	Marine	Saline Lakes	Lake	Lake	Lake	Saline Lakes
Lithology	Carbonate rock, mudstone	Dolomite siltstone, mudstone	Calcareous mudstone	Carbonate rock, mudstone	Carbonate rock, siltstone, mudstone	Fine sandstone, siltstone, mudstone	Siltstone, mudstone	Tuff, tuffaceous mudstone	Argillaceous dolomite, lime mudstone
Buried depth / m	2500~3100	2400~3000	1200~3700	1200~4100	2500~4800	1600~2900	3200~3600	2000~2800	2200~4000
Thickness / m	20~150	5~12	75	45~100	13.4~67.5	5~15	200~400	15~20	5~10
TOC/%	2~9	5~10	2~12(4.25)	2~4	2~4.5	2~10	>2	>2	1~3(1.57)
Ro /%	0.7~0.9	0.5~1.3	0.45~1.4	0.6~0.9	0.8~1.0	0.9~1.1	0.6~1.1	0.5~0.9	0.55~1.2
Porosity/%	4~12	4~10	8~12(9)	5~10	8~12	2~12	5~10	5~15	1.1~29(12)
Permeability / md	0.01~1.0	0.01~0.1	0.01~1.0	0.01~0.1	<0.1	0.01~0.2	0.12	0.01~0.2	0.1~0.2
Formation pressure coefficient	1.1~1.2	1.2~1.5	1.35~1.8	1.1~1.4	1.31	0.77~0.84	0.9~1.2	0.9~1.16	>1.2
Brittle mineral content	30~40	30~40	10~29	25~40	20	20~40	25~35	31~45	35~50

As for the thickness of the sedimentary layer, we see a clear distinction for the Huanghua Depression in Bohai Bay Basin, as the thickness of the layer ranges between (200–400), but this basin is blamed for a decrease in Total Organic Carbon content (TOC) to less than 2%, and this is what is wrong with it. On the basins in China (low material content), the American basins have a high content, which means the ability to extract larger quantities from a single well.

(R_0): means the amount of maturity. If it is less than 0.5%, the maturity is low; if it is 0.5%–1%, the maturity is medium; if it is greater than 1%, the maturity is high. Of course, higher maturity is the best type for the possibility of extracting shale oil and gas (Hu *et al.*, 2020). Thus, we see that there is a high maturity in (Williston Basin, Gulf of Mexico Basin). It also corresponds to a high maturity in the Chinese basins (Ordos Basin, Huanghua Depression in Bohai Bay Basin, Jianghan

Basin).

As for the porosity and permeability, there is a disparity between the oil shale fields, whether they are American or Chinese: the porosity of the rocks is a measure of their ability to retain liquids. The open space in a rock is divided by the total volume of the rock (solid and space). Permeability is a measure of the ease of fluid flowing through a porous solid. Rocks may be very porous, but they will not have permeability if the pores are not connected. Likewise, the rock may have a few continuous cracks that allow easy fluid flow, but when porosity is accounted for, the rock does not appear to be very porous (Kamann *et al.*, 2007; Burnham, 2017; Xie *et al.*, 2019). Thus, these geological properties determine the appropriate technology for extraction.

D. Technology

The shale oil and shale gas revolution has been based on a major factor: technology. The more technology is developed, the higher the production quantity, the lower the production costs, and the minor damage to the environment. From here, we realize that technology is the deciding factor in this industry. Technology has advanced so much in the United States. It has come up with a technology that enables it to open wells that have exhausted their useful life and produce shale oil and gas again with lower production costs as well as a lower environmental cost (Middleton *et al.*, 2017).

The technology is also available in China, but it does not match the geological complexity found in the oil and gas fields. Consequently, production is lower, and costs are higher compared to the United States of America. Governmental companies are working to develop the technology and add some improvements. There has been a noticeable decrease in production costs in the Sichuan Basin by 40% for exploratory wells compared to 2010 levels and 25% for commercial wells compared to 2014 (T. Yang, 2018; Rodger, 2019). The oil companies are seeking to make more efforts to develop technology by increasing technological spending, and we can notice this by the Table 3.

Table 3. Some us energy companies spend on research and development

Company/year	2016	2017	2018	2019	2020
Exxon Mobil	1285	1269	1466	1790	1467
Chevron	1537	770	1210	864	1033
Chesapeake Energy	427	84	162	235	160
Hess Corporation	351	233	362	507	1442
EOG Resources	158.8	167.8	154.4	149.9	135.6
MS Energy	40.9	51.5	55.1	54.7	64.9
Continental Resources	17.7	14.6	7.6	12.3	16.9
Centerra Energy	15.4	20.2	113.8	21.5	27.6
Antero Resources	1.0	0.8	4.9	8.5	6.8
CNPC	2006	2081	2510	3419	3577
Sinopec	1660	1641	1623	1520	1407
CNOOC	1060	1058	1880	1773	858

Source: (China National Petroleum Corporation, annual report, 2017, 2021). https://www.macrotrends.net

The company's size plays a significant role in spending on research and development. The larger the company, the more spending on research and development, and thus the innovation of advanced technology. If we note by Table 3, we see that ExxonMobil and Chevron are two of the large companies, as their assets roam 332 and 239 billion dollars in the global stock exchange, respectively. As for the (Chesapeake) and (EOG) companies are considered medium companies, as their assets exceed 16.1 and 35.8 billion dollars, respectively. While Hess and MS are small companies with 4.3 and 5 billion dollars, we note that their spending on research and development is enormous compared to the value of their assets for 2020. As for the other companies are considered small companies, as we note that their spending in 2020 does not exceed 52 million dollars. As for the Chinese companies, there are three major companies that China depends on in the field of energy: China National Petroleum Corporation (CNPC), Sinopec, and China National Offshore Oil Corporation (CNOOC). Their spending on research and development is roughly equal to that of the leading US companies. The amount of spending on research and development for independent companies is determined by several factors, including the size of the company, the number of annual revenues, debts, operating spending, cost, the value of the company's shares on the global stock exchange, the company's plan, the board of directors' decisions about spending on research and development, previous achievements and technological innovations, and the extent of the board of directors' expertise. All of these variables are related to the company's independent spending. But suppose this happens, the company is wholly or partially affiliated with the government. In that case, the development plans set by the government will have a role in the spending process on research and development for the company. Thus, we observe a surge in Chinese companies' spending on shale gas research and development as a result of the Chinese government imposing the output cap that Chinese companies must meet to support the development process, on the one hand, and to promote energy security, on the other.

E. Infrastructure

Infrastructure is a major factor in reducing the cost of oil and shale gas reaching the consumer, and it is also one of the decisive factors for increasing production. Without an infrastructure capable of delivering large quantities of oil and gas, companies cannot increase production. It will be restricted to the quantities that the transfer stations, liquefaction, and pipelines can convey to the final consumer. The US infrastructure is highly developed and extensive due to the preparations made by the United States in the eighties and nineties of the last century to prepare to increase the expected imports of oil and gas and transport oil and gas from coastal areas to remote areas. The infrastructure was used to transport oil and shale gas within the United States and estimated at 500,000 km oil and gas in addition thousands of transfer stations and gas liquefaction stations.

In contrast, China lacks the infrastructure to transport oil or gas produced from the remote production areas to the city centers. Pipelines in China are estimated at 76811 km for gas and 57323 for oil, and only 2.3-tenth of the pipeline network in the United States, while large pipelines represent only 15,000 km in diameter (CEIC, 2020). As a result, insufficient gas transportation has constrained the growth of shale gas in China. Not to mention the few companies that have a monopoly on oil and gas transportation. Petro China pipeline mileage accounts for more than 75% of the gas mainline, and Sinopec and CNOOC control less than 20%, which results in a serious monopoly of gas resources and gas pipelines. While the United States has 200 private gas transmission companies and 1400–1500 domestic private and public distribution companies. Thus, these large companies create more competition among themselves (James *et al.*, 2006); Le, 2018; X. Dong *et al.*, 2015). The following Fig. 2 shows the difference in the development of oil and gas pipeline infrastructure between the United States and China.

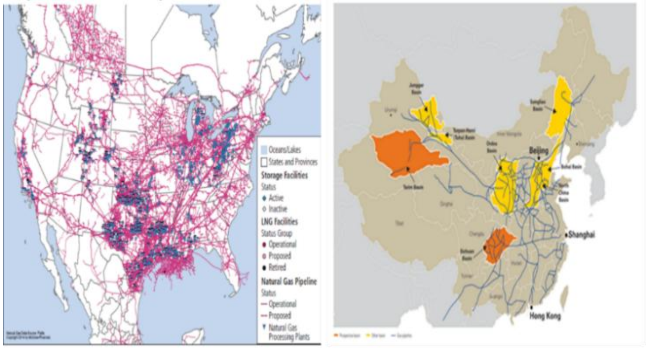
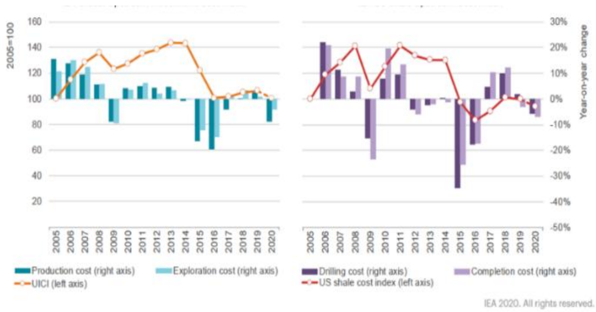


Fig. 2. Development of oil and gas pipeline infrastructure in China and US (Kretzmann et al., 2019)(KPMG, 2014).

F. Cost

The most crucial factor that delayed the development of the Chinese experience in extracting oil and shale gas is the high cost compared to selling prices in the local market, as China did not have the opportunity to produce oil and gas synchronized with the rise in global oil prices, as happened with the American experience, which with a rise Oil price have reached record levels, reaching more than $100 per barrel. As we mentioned earlier, the cost of producing US shale oil varies from one company to another and from one field to another. Some companies produce less than $30 per barrel and companies that produce more than $40 per barrel according to estimate of 2018 (Zuhaira *et al.*, 2021). About shale gas cost is less than $3 per MMBtu. While China, according to sources, the cost of producing a barrel of shale oil exceeds $80, while shale gas cost is more than 4.2$ per MMBtu in Sichuan Basin. As for the drilling cost of a shale oil well in the United States varies from field to field, in the Bakken field, $7.8 million. As for shale gas, the cost of drilling is $5 million in the Barnett field in 2018. In China, the cost of drilling for shale gas is about $8.2 million. As for shale oil, some sources indicated that it exceeds $9 million (Guofeng *et al.*, 2019; Hughes, 2019; Zhao *et al.*, 2015). The drop in global oil prices after 2014 had a major role in reducing the costs of producing oil and shale gas in the United States, and this can be seen in Fig. 3.



US shale operators have less room to manoeuvre in the 2020 crisis (Credit: IEA)

Source: IEA, US shale operation have less room to maneuver in the 2020 crisis, 2020

Fig. 3. Shale oil and gas production cost.

We note from the Fig. 3 the decline in production costs in the United States of America after the drop in international oil prices in 2014, and the decrease in cost comes for several reasons:

(1) Neglecting marginal wells and focusing on rich wells led to a reduction in operating expenses and a reduction in the labor force.
(2) Decreased demand for drilling rigs, which reduced the cost of renting a single rig, focusing on previously discovered sweet spots.
(3) Reducing the allocations of discovery and geological surveys.
(4) Many small and inefficient companies exited or merged, which reduced the overall average costs.
(5) The low interest rates for loans financed by the shale oil and gas industry.

If we compare these reasons with the Chinese side, we will reach the following conclusions:

(1) China cannot exploit the first point because China has a limited number of wells drilled, especially regarding shale oil wells.
(2) Drilling rigs are few and have a high cost due to the modest technology compared to its American counterpart, as well as the difficult geological characteristics that characterize the Chinese oil and gas fields.
(3) The exploration allocations for geological surveys are already low compared to their American counterparts. Reducing the allocations will generate a large gap, and it won't be easy to discover the rich sweet spots.
(4) The companies investing in the shale oil and gas industry in China are mostly large and governmental companies, which is a positive point for the Chinese oil and shale gas industry. Still, the fault on this point is the absence of competition between these companies as well as the absence of private and foreign companies.
(5) The financial financing of the oil and shale gas industry in China is carried out directly by large companies and the central and local government, reducing the cost. But the shale oil and gas industry is a huge industry and requires a lot of money. Can the central government and several companies finance this industry to reach production quantities comparable to the American production quantities?

G. Landholder Owner

Another facilitating circumstance is that US legislation grants the landholder owner-ship rights to what is underground, a rule not applied by many other countries. The US legislation avoids land rights problems since the landholder is in control and benefits from royalty payments. The country's long tradition of small, adventurous exploration enterprises helped to speed up the revolutionary process. The bureaucratic energy giants were initially slow to move into the field. Still, they became eager once the exploration firms identified the geological and economic potentials and offered to sell the discovered deposits. All these features help to understand why the USA took the lead in the revolution (Aguilera & Radetzki, 2014). n China, through the Chinese Ministry of Land and Resources (MLR), the central government owns all the lands (above ground and underground) that contain oil and gas resources. It will create a problem of differentiation and preference for government companies in investment bid auctions, one of the most important problems facing the shale oil and gas industry in China is the interference of other resources with the same spots that contain oil and gas. Which delays or reduces the chances of oil and gas companies to obtain investment licenses (Xia *et al.*, 2015).

H. Market and Financing

The market is one of the important factors for determining the amount of profit that oil and gas companies obtain. An increase in demand leads to an increase in prices, which leads to a rise in the companies' revenues. In contrast, if the market is controlled by the state and prices are predetermined, companies cannot increase their profits except by increasing production or decreasing Costs. Therefore, companies have no great incentive to enter this market, especially if the industry is new and has high costs. The most important characteristic of the launch phase of the oil shale industry in the United States is the free market and the high demand for oil and gas, as companies were able to start the production process in light of the high costs. As for the Chinese market, the central government is the one who controls prices and has set a specific price ceiling at the city gate, and these prices do not reflect the real value of the price of gas and oil in the Chinese market. Thus, foreign and private companies suffer from high costs and low market prices. It puts government companies responsible for increasing production to cover part of the market demand. As we mentioned earlier, the market price of shale gas in China is less than the cost of production, which makes the central government obliged to subsidize shale gas through subsidies directly. Later the Chinese government realized the importance of increasing market prices. The National Development and Reform Commission of China (NDRC) announced an average increase of 15% in gas prices through the city gate across the country. At the wellheads, this increase translates into an increase in producer returns of approximately 25% (Rogner & Weijermars, 2014). Producers and consumers can negotiate within ±10% of the specified prices. Perhaps some consumers will resort to low-priced imported oil and gas at the expense of locally produced oil and gas? The answer is that the Chinese government has a choice between two options: liberalizing markets and giving facilities to foreign companies to enter the oil and gas industry and competing with local companies, thus reducing costs and increasing production quickly, or controlling the market and holding government companies and it should have responsible for increasing production. It is worth noting that China is the second-largest consumer of oil in the world and the third-largest consumer of natural gas, and it has the highest growth in oil and gas consumption and therefore can effect global oil and gas prices (US Energy Information Administration (EIA), 2020; Rioux *et al.*, 2019; Le, 2018). The shale industry needs considerable financing, so the US relied on the private sector (oil companies, financial institutions, banks) to finance the industry. As for the Chinese side, government companies take it upon themselves to develop the industry Fig. 4, so we find reluctance and slow production.

Source: Chen Aizhu, Analysis: Chinese majors to struggle to extend shale gas boom beyond 2025, Reuter, 2021.

Fig. 4. China's dominant shale gas producers.

I. Economic Policy

There is a big difference between the government policies concerned with the shale oil industry between China and the United States. In terms of direct financial support, the United States did not support shale oil and gas producers directly but somewhat indirectly through tax cuts and financial discounts (Erickson *et al.*, 2017). Giving the basic technology to the producing companies without discrimination. Intellectual property rights law protects the innovative company, and there is no need to share technology with other companies. Allow companies without discrimination to enter the industry. In practice, significant financing is obtained by all companies from banks and financial institutions (Aggarwal and Jain, 2020). Existence of Chapter No. 11 to protect oil and gas assets (Zuhaira *et al.*, 2022) (*Chapter 11 - Bankruptcy Basics*, n.d.). An agreement is reached between the investing company and the landowner to purchase or lease the land (Suwailem & Selemankhel, 2021)(Sandler & Llp, 2020; Neiger, 2015).

As for the Chinese side, there is direct support for producers through subsidies and indirect support (tax cuts and discounts)—financing research and development centers and giving basic technology to companies. Foreign companies are not entitled to enter the Chinese oil and gas industry except through the participation of government and local companies, and therefore the need to share technology with local companies. Only large and government companies can enter the industry due to the tough conditions set by the central government. The central government finances the industry, local government, and large state corporations. The assets of oil and shale gas are held by the Ministry of Land and Resources of China. An agreement is reached between the investing company and the central government through land-use licensing contracts for a period specified by the central government (Xia *et al.*, 2015).

J. Greenhouse Effect

It is agreed that carbon dioxide emissions from gas are less than from consuming other fossil energy sources (coal and oil), but if gas is compared with renewable energy sources, the exact opposite will appear. Many environmental affairs researchers consider gas as a transitional stage for environmental development. This can be seen in the US shale gas industry; the shale gas industry has played a major role in reducing carbon emissions in the United States to record low levels. Shale gas produces roughly half the CO_2 as coal for the same heat output, facilitates the transition from coal-fired to gas-fired power generation, and is consequently responsible for US emissions falling to 1990 level. Shale gas also plays an important role as a bridge fuel to renewables, (Tan *et al.*, 2019; Grecu *et al.*, 2018). In addition, depleted shale gas formations offer significant opportunities for CO_2 storage due to their potentially enormous capacity, ability to sequester or trap CO_2 physically, and reduced sequestration costs by leveraging existing infrastructure (Middleton *et al.*, 2017; Yuan *et al.*, 2015).

The considerable change in shale gas has contributed to improving the environment. The rapid growth of shale gas production and the significant decline in natural gas prices in the United States has led to a reduction in coal consumption in the electricity sector and an increase in natural gas use in this sector simultaneously. Natural gas climbed from 25% to 30% of total electricity output in 2012, while coal decreased from 42% to 37%. IEA report in 2013 showed that CO_2 from fossil-fuel combustion in the US fell sharply in recent years. From 2007 to 2012, the United States reduced its carbon dioxide emissions (CO_2) by 450 million tons, the largest decrease recorded on the whole planet (Le, 2018; Sanzillo & Williams-derry, 2018). Fig. 5 shows that carbon dioxide emissions have decreased in the United States since shale gas production began in 2000. Thus, the United States can fulfill its environmental obligations toward the international community.

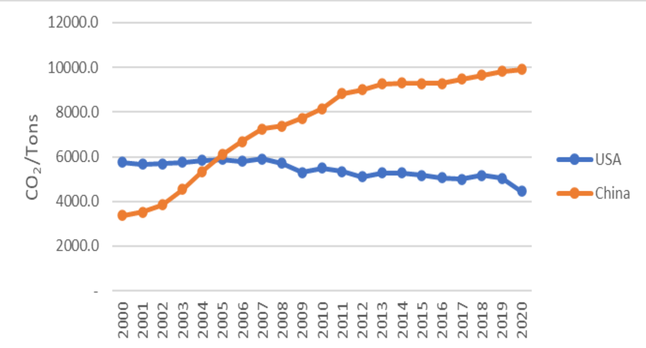


Fig. 5. CO_2 emission in the US (2000–2020; BP, 2021).

The United States has reduced its carbon emissions by developing the shale gas industry and increasing gas consumption at the expense of coal. From Fig. 5, we note a decrease in carbon dioxide emissions in 2020 to reach 4457 million tons, which is much lower than the levels of 1990, which were 4978 million tons. Thus, the United States reached the target set at the Kyoto Conference in 1998 (Sanzillo & Williams-derry, 2018; UNFCCC, 2008). On the other hand, we see an increase in carbon emissions in China as a result of industrial development and an increase in coal consumption.

Therefore, China strongly desires to enter this stage and increase gas consumption at the expense of coal in power stations. The study Xu (2019) (Apergis & Payne, 2010) argued the importance of increasing gas consumption in China. The results showed that natural gas consumption has a non-linear, inverted U-shaped effect on CO_2 emissions. CO_2 in the eastern region, but a positive, nonlinear, U-shaped effect in the central and western regions. The linear effect of natural gas consumption on carbon dioxide emissions in the central and east regions is higher than in the western region, due to differences in resource availability and energy prices.

IV. Conclusion

The significance of the shale oil and gas sector in China and the United States cannot be understated, as it holds the potential to enhance energy security and reduce CO_2 in both nations. An economic analysis of the industry reveals several key conclusions:

(1) The vast reserves in both countries encourage government policies and corporate investments aimed at developing and expanding the shale oil and gas sector.

(2) In the United States, production expansion relies on global oil prices, whereas in China, it hinges on finding suitable technological innovations to tackle complex geology.

(3) While China faces intricate geology and challenging terrain in its oil and shale gas fields, the United States encounters more favorable conditions.

(4) The United States had already established a comprehensive infrastructure prior to the shale oil and gas revolution, whereas China's infrastructure continues to evolve alongside exploration and production operations.

(5) Although China's government and local company acquisitions might hinder production expansion, but it will give them the control of environment impacts from the extraction. In contrast, the United States' private companies contribute to energy security through expansion but allow no government influence over production during periods of skyrocketing oil and gas prices.

(6) Production costs are lower in the United States when compared to global and domestic markets. In China, high production costs arise from technological limitations amidst complex geology and inadequate infrastructure.

(7) A notable disparity exists between government policies concerning the shale oil and gas industry in China and the United States. China favors state-owned enterprises or joint partnerships with complicated regulations for private and foreign entities. Government support comes in both direct subsidies and indirect measures. In the US, large international businesses and independent companies dominate the sector; government assistance is limited to tax incentives and regulatory exemptions.

(8) Major corporations like ExxonMobil and Chevron spend more to R&D, along with Chinese powerhouses CNPC, Sinopec, and CNOOC. Independent firms' R&D spending is influenced by factors such as size, revenue, debt, costs, stock value, strategy, board decisions, accomplishments, innovations, and expertise. Government ties also impact R&D funding as exhibited by Chinese shale gas firms pursuing growth and energy security in response to government-imposed production limits.

(9) Shale gas contributes to reduced carbon dioxide emissions in the US by enabling a shift from coal to gas-powered electricity generation and acting as a bridge fuel towards sustainability. This rise in shale gas production has resulted in decreased coal use and increased natural gas adoption in the electricity sector. Consequently, US CO_2 emissions have declined remarkably, allowing the nation to meet its environmental commitments to the global community.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Zaid Zuhaira contributed to the conceptualization of the study, designing research methodologies, and reviewing relevant literature; Hayder Dhahir Mohammed and Jizu Li collaborated on drafting and revising the manuscript; Israa Hasan Eissa collaborated on writing the manuscript feedback from the research team and linguistic revision; all authors had approved the final version.

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