A Review of Shale Oil Development and Its Impact on Crude Oil Prices

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ABSTRACT

Shale oil production has gained popularity in the oil industry recently, with US shale oil production substantially increasing since the mid-2000s which plays a central role in US crude oil production. This rise, centred on the US, is seen as a revolution that is expected to cause significant changes in the oil market. However, at less than 5 million barrels per day production capacity, it only represents a small proportion of the world's oil production capacity of 100 million barrels per day, although it is almost 50 percent of US total crude oil production. Therefore, it is not expected that shale oil has substantially affected crude oil prices, considering its 5 percent share of the global crude oil market. The main strength of shale oil is the abundance of its reserves. Its effect also critically depends on the percentage of reserves that are recoverable and the competitiveness of shale oil production costs compared with conventional oil. These points will determine whether shale oil becomes a major player in the oil market or just remains as a supplementary resource. The main purpose of this research is to review the shale oil sector, including contents, reserves, production capacity and technology, while primarily focusing on its effect on the oil market. Using the Autoregressive Distributed Lag method, the research examines long-term relations between shale oil production and WTI and Brent crude oil prices. This analysis shows that there is a long-term relation between shale oil production and WTI oil prices but not between shale oil production and Brent spot oil prices. This indicates that, so far, US shale oil development has an impact on local oil prices rather than global prices.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

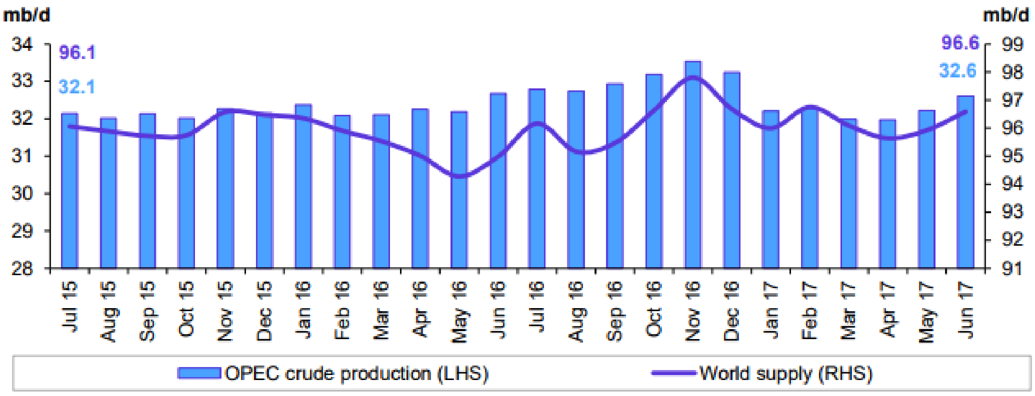
1. INTRODUCTION

The term “shale oil” refers to all crude oil produced from unconventional oil formations, primarily tight oil, oil sands and oil shale. The main characteristic of such formations is their very low permeability that makes extraction and distillation harder than for conventional oil formations. Initially, drilling technology was insufficiently advanced to enable shale oil production while shale oil projects still face feasibility constraints due to high production costs, despite new developments in drilling technology. However, unexpected increases in oil prices since 2010 have made now shale production profitable, with expansion in shale oil project investments, scaled up production capacity and production beginning in new shale plays. Although the 2014 oil price crash badly affected the shale industry, companies have managed to reduce their production costs while maintaining high production capacity.

Shale oil development has thus undergone a positive change during the last decade. Technological improvements and the economic success of shale oil have created a new competitive source of oil products in the world market. Having jumped since the beginning of 2010, by 2014 US shale oil production was more than any OPEC country’s crude oil production except for Saudi Arabia, which leads the world oil market (ExxonMobil, 2016).

No single factor accounts for this development. Rather, several reasons lie behind growing unconventional oil production worldwide. Firstly, as Figure 1 shows, 33 percent of world oil supply was met by OPEC, the organization of fourteen oil exporting countries led by Saudi Arabia. This share allows them to behave like a cartel and non-OPEC countries can use unconventional oil to compete with them. Secondly, conventional oil supplies will not be able to meet the continued increase in world oil demand. Thirdly, unexpected interruptions in production, such as natural disasters, political issues, or terrorism may cause critical problems. These factors have motivated producers to turn to unconventional oil (Enefit, 2017).

Figure 1: OPEC and World Crude Oil Supply



Source: (OPEC, 2017)

The main objectives of this study are first to comprehensively review the characteristics of shale oil and its development in recent years. It then investigates whether shale oil development has a substantial impact on global oil prices, through an econometric analysis using an Autoregressive Distributed Lag (ARDL) model in Eviews(9) econometric software. Specifically, it examines the long-term relationships between shale oil production and the WTI and Brent crude oil price benchmarks. Section 2 describes the characteristics of unconventional oil formations, section 3 considers shale oil reserves and section 4 explains the drilling technology required for shale production. Given that the project focuses on the US, section 5 describes US shale plays specifically. Section 6 explains some similarities and differences between shale oil and gas developments in relation to the shale gas revolution before section 7 outlines the position of shale oil in the total oil market and assesses recent OPEC-led oil production cut. After the econometric analysis in section 8, section 9 draws some conclusions about shale oil development.

1.1. Literature Review

Umekwe and Baek (2017) investigated whether crude oil prices are important determinants of US shale oil production over decades. Their analysis helps to understand the working of the ARDL method also used in this study. However, while they used shale oil production as an independent variable, this project uses it as a regressor to oil prices. The model used here demonstrates an asymmetric short-term relationship between crude oil prices and US shale oil production. That is, US shale production is more responsive to crude oil production increases than decreases. This also explains why recent oil price slumps have not significantly affected shale oil output. In contrast, there is no evidence of long-term effects.

Murtazashvili (2017) took a different perspective to the shale oil boom by focusing more regionally on legal and practical reasons and consequences of the growth in US shale oil and gas production facilities. He found that the legal mineral rights of the land owners encouraged shale production in the US more than in other countries, particularly exemptions in the legal framework, such as flexibility in the compulsory pooling needed for hydraulic fracturing and contracting between land owners and drilling companies, or protection of drillers from land boundary line lawsuits. In addition, the strong US economy enabled crucial technological inventions. Therefore, this article facilitates the understanding of legal and practical terms that pave the way for shale evolution in US.

De Silva et al. (2016) investigated shale gas developments from an economic perspective, focusing on Australia and Europe. In Australia, shale developments are mainly based on a fiscal regime that incentivizes the shale market to compete with conventional gas resources whereas the European market concentrates on reducing production costs through encouraging the local supply cycle and enhancing production levels. Australia and Europe also differ regarding the objective of steady shale gas production. While Australia aims at keeping certain domestic gas prices through increasing LNG exports with the help of shale, Europe tries to supply its primary energy needs with shale production. Thus, this study demonstrates differences in shale gas development between the two regions and between unconventional oil and gas process.

Asche et al. (2012) investigated how European gas prices, which are cost effective and a substantial indicator in the global gas market, are affected by shale gas production, and also explored the relationship between oil and gas prices. Most estimates are optimistic about oil price futures but rather pessimistic for future gas prices. Their analysis of the relationship between oil and gas prices demonstrates a substantial short-term difference between them although this gap narrows in the long term owing to continual price shocks.

Behar and Ritz (2017) clarified the basic market determinants behind OPEC's latest strategy. They concluded that the main reasons are rising US oil production, decreased global oil demand, a weakening of solidarity within OPEC, overall production increases in non-OPEC countries and reduced shale oil drilling costs. OPEC's production cut agreement was less successful than predicted in late-2016. Although US shale oil production dropped slightly, a larger fall had been anticipated due to the crude oil price shock. Thus, OPEC members found their agreement costly because US shale oil output only fell slightly, perhaps because shale costs were overestimated by the authorities, despite the substantial short–term fall.

Auping et al. (2016) investigated the potential indirect effects of the shale revolution on the domestic stability of major oil and gas exporting countries. They found effects of oil and gas price increases on the political situation of energy exporter countries, known as rentier states. Their simulations show that if shale oil supply can meet increasing global oil demand then short-term oil prices may drop dramatically regardless of long-term cyclic effects. Such decreases would severely affect rentier states, especially those highly dependent on oil exports.

According to Baumeister and Kilian (2015), some researchers claim that the unanticipated increase in crude oil supply explains the sharp decline in oil prices in the second half of 2014. Others, however, believe that the cause was OPEC’s decision to maintain current production levels despite the substantial increase in non-OPEC countries’ oil production. While both explanations are plausible, this study demonstrates that more than half of the decline was foreseen at the beginning of June 2014 due to the cumulative decrease in demand until June 2014 and predictable oil supply increases. Another factor was decreasing oil inventories due to low oil prices and declining oil prices because of global economic depression in late 2014. In evaluating the role of shale oil production in the 2014 oil crash, the paper helps to understand other causes of the oil price shock.

Finally, from their wide-ranging review of North America’s shale oil revolution in its initial stages, Alquist and Guénette (2014) conclude that it did not have a significant impact on crude oil prices. Moreover, they claim that such large-scale shale oil production would not be so easy elsewhere as it has been in the US, particularly due to difficulty in deploying shale drilling technology, infrastructural deficiencies and legal or geopolitical risks, such as concerns over water consumption or redundant drilling. While the US was initially adversely affected by oil price increases, this later became profitable for them because high oil prices make shale oil production economically viable. Moreover, it shifted US crude oil trade from being an importer to an exporter. The idea presented in this dissertation also draws on these arguments.

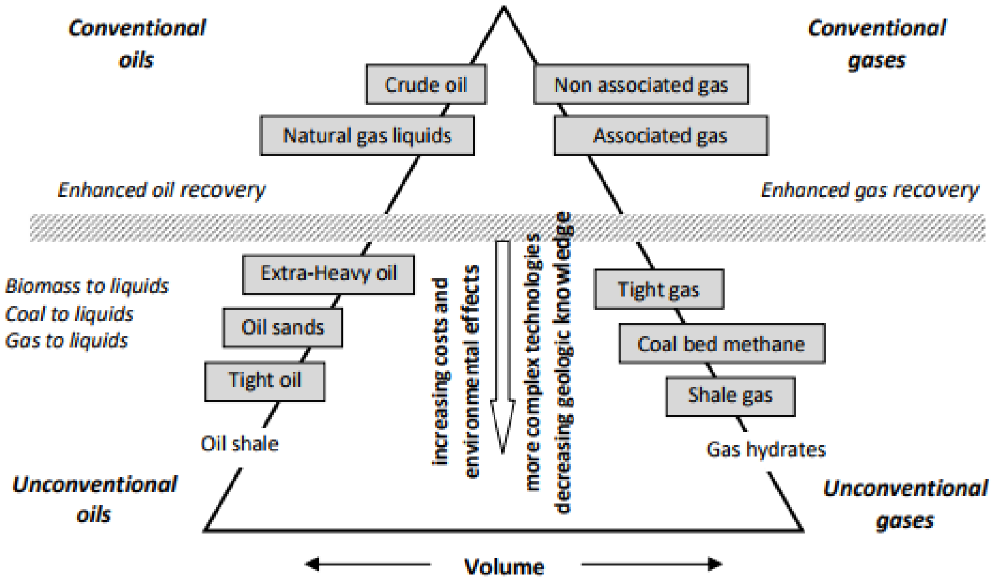
2. UNCONVENTIONAL OIL

This section reviews unconventional oil types in order to define them and clarify the key differences between them. As generally known, underground liquid oil sources are formed from dead organisms over millions of years under particular conditions of pressure and heat. There are two kinds of oil production: conventional and unconventional. Conventional oil is relatively easily extracted from underground using traditional drilling methods whereas the geological characteristics of unconventional oil resources require the use of advanced drilling methods. Unconventional oil is trapped in the rock formation as liquid or non-liquid state.

The massive resource potential of unconventional fossil fuels has stimulated various technological developments and inventions to enable their commercially viable extraction (Ekins et al., 2015). Under US leadership, shale oil has attracted widespread attention, both industrial and academic. However, there remains remarkable ambiguity regarding shale oil, including even its definition. Unconventional oil can be split into three basic classes: oil shale, tight oil and oil sand. Most experts in the sector prefer to refer to shale oil instead of tight oil. In the US, however, although shale oil and tight oil can be used interchangeably, US oil and gas sector experts generally use tight oil to refer shale oil and other tight oil formations (EIA, 2013c). After explaining their differences, this section will refer to both tight oil and shale oil reserves and products as “shale oil” to avoid any confusion.

Figure 2 categorizes conventional and unconventional oil and gas extraction. Moving from the apex down the triangle, production costs and environmental effects increase while geological knowledge decreases, more complex technology is needed but the volume of reserves increase.

Figure 2: Oil Resource Triangle



Source: (Arkonsuo, 2013)

2.1. Oil Shale

Oil shale contrasts to conventional oil regarding containment as it consists of sedimentary rock that includes a solid blend of hydrocarbons called kerogen, composed of around 80 percent carbon, 10 percent hydrogen, 6 percent oxygen, 3 percent nitrogen and 1 percent sulphur. Kerogen's specific geochemical complex content varies with time and heat. The shale rock slowly burns inside the stone, clay and mud mixture, hence its name of "the rock that burns". Although oil shale lies closer to the surface than other unconventional oil types, drilling is still difficult. Its main component, kerogen, can be converted to liquid hydrocarbons by heating shale rock at a high temperature to artificially complete the required natural geological processes for oil formation. This can be done either by mining oil shale and retorting for a period between just a few hours and three to four years or by retorting in-situ without mining. Producers can also benefit from this resource as a source of heat energy like brown coal (Ekins et al., 2015).

Some distinctive features of shale oil are its high level of aromatic contents that hinder petroleum fractionation, a low hydrogen to carbon ratio, lower sulphur levels than most other crudes, a semi-liquid product due to retorting of the rock in oil vapour and low or medium levels of metals. Hence, advanced procedures are required to upgrade the properties of shale oil products, specifically distillation, coking, hydrotreating, hydrocracking, catalytic cracking and reforming (Speight, 2012a).

Raw shale oil, produced from oil shale with varied composition, has a higher specific gravity (between 0.9-1.0) than conventional oil because of heavy nitrogen and oxygen compounds. In addition, shale oil has a comparatively high pour point and smaller amounts of arsenic and iron ore. The existence of polar constituents, nitrogen and oxygen, is the main disadvantage of shale oil. These two types of oil only differ slightly in sulphur compounds. Before blending shale oil and conventional petroleum to input into the normal refining process, shale oil's incompatible contents have to be distilled out (Speight, 2012b).

A final source of confusion is the slight difference between oil shale and tight oil substance accumulation. While oil shale is rich in clay and fissile content and is located in massive claystone in long horizontal seams, tight oil is common in siltstone or mudstone with a mixture of several minerals without clay content (Maugeri, 2013).

2.2. Tight Oil

Tight oil, unlike conventional oil, is trapped in rock formations with low porosity and permeability, which makes extraction difficult. Tight oil can be found intimate or contiguous to carbon rich rock formations that include silty clay or chalky stone (World Energy Council, 2013). Because production of tight oil takes too much effort, time and money using traditional drilling, extraction was only viable after the required technological and economic conditions were met, although the oil and gas potential of such rock formations had been long known (Ekins et al., 2015). More specifically, since the 1970s, horizontal drilling and hydraulic fracturing have made tight oil production technically and economically viable. Although oil reserves were known, producers could not begin exploration or extraction until the 21st century. The US was the instigator of the unconventional oil production boom at this stage, with tight oil basins in the US, such as Bakken, Eagle Ford and Permian becoming important oil production centres once oil prices went up.

The US Energy Information Administration (EIA) has focused on shale oil technological improvements, estimation of reserves and management of production in the US's huge oil shale reserves and tight oil production capacity (EIA, 2013c). Fundamentally, tight oil has similar hydrocarbon characteristics to conventional oil. Therefore, the difference between conventional and tight oil concerns the difficulty of extraction because of the rock formation. For this reason, there was almost no tight oil production until the 21st century.

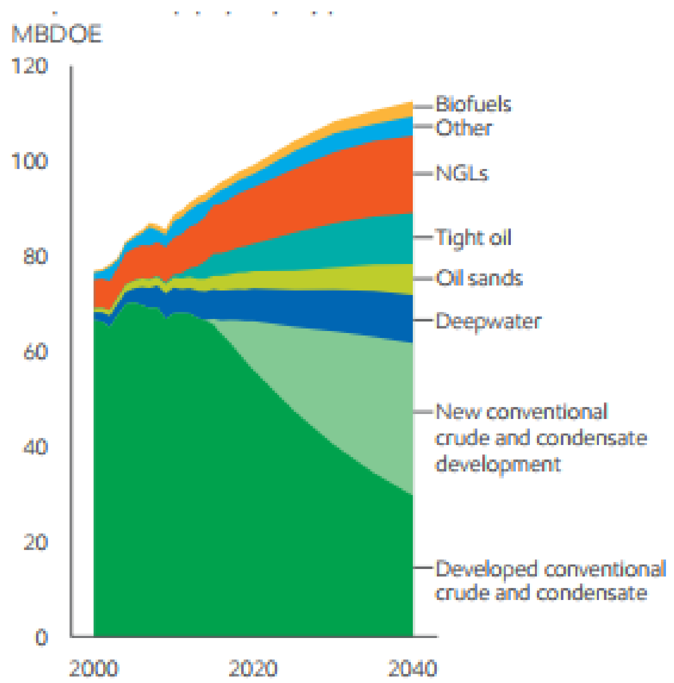
2.3. Oil Sand

Oil sands, also called tar sands, are another type of unconventional oil deposit that include sand, bitumen, clay, minerals and water. Oil is produced from the bitumen, which is a high-viscosity hydrocarbon. Crude bitumen is the black, sticky, extra heavy oil within sandstones. Oil sands are composed of approximately 83 percent sand, 10 percent bitumen, 4 percent water and 3 percent clay. The majority of oil sand reserves are located in Canada, Venezuela, Russia and Kazakhstan. With 70% of total estimated total reserves, Canada has a high production capacity. As for other unconventional oils, drilling, extraction and refining of oil sands is difficult and complex. The depth of reserves determines the type of drilling technology. For large-scale reserves, less than 75 metres from the surface, mining can be carried out. Otherwise, the in-situ method extensively explained in section 4 may be preferable (Ekins, Bradshaw and Watson, 2015).

3. SHALE OIL RESERVES

ExxonMobil outlook (2016) predicts that existing conventional oil production will represent almost 30 percent of global liquid oil production in 2040, by decreasing more than half. Newly developed conventional oil production is expected to account for around 30 percent of world liquid energy supply. On the unconventional side, Figure 3 shows that tight oil and oil sands production will make up almost 10 percent of output by 2040.

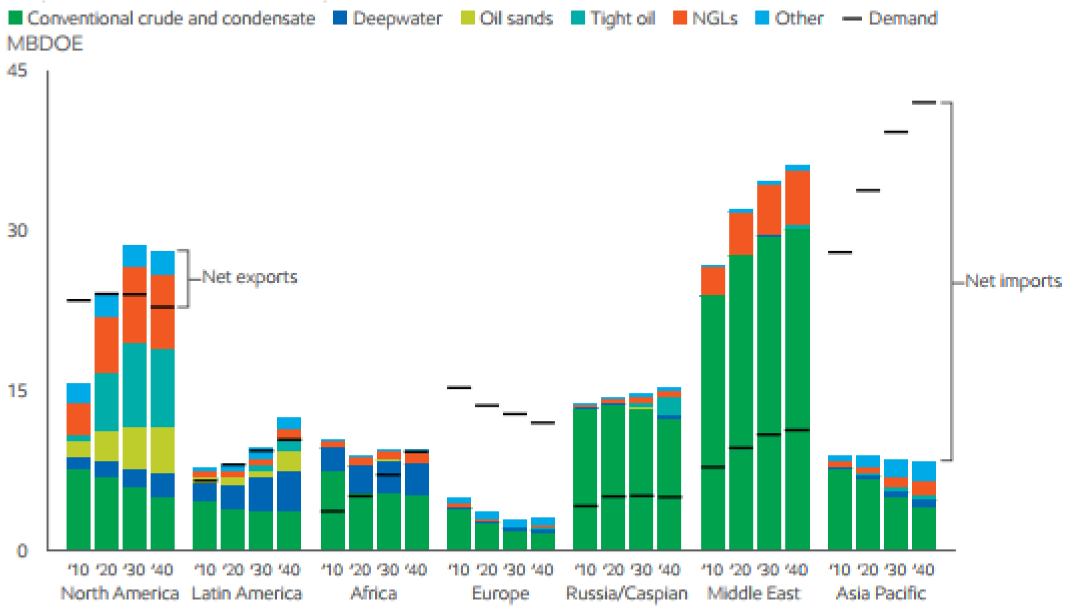
Figure 3: Liquids supply by type



Source: (ExxonMobil, 2016)

With its wealth of liquid oil, North America is the second biggest liquid producer after the Middle East. After the US applied its shale gas expertise, such as horizontal drilling and hydraulic fracturing, to shale oil fields, it became successful more quickly than expected. Between 2010 and 2016, crude oil production rose by approximately 75 percent, mostly from the shale oil boom and NGLs. As can be seen from Figure 4, rising US production led to a shift in its trade position from importer to exporter (ExxonMobil, 2016).

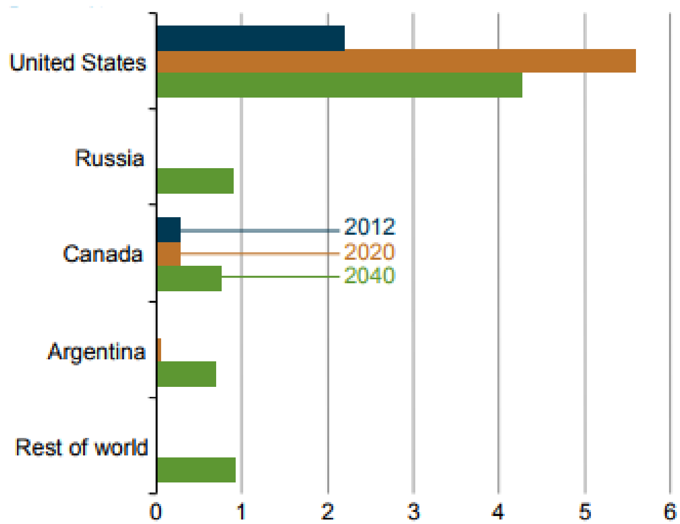
Figure 4: Liquids trade balance by region



Source:(ExxonMobil, 2016)

The EIA also forecasted the shale oil production outlook on a country basis for 2020 and 2040. This suggests that US production will substantially increase until 2020 to more than 5 million barrels per day, although it is expected to decrease to around one million barrels per day between 2020 and 2040 because of reserve depletion. Thus, this outlook confirms the Exxon Mobil outlook overall.

Figure 5: World Shale Oil Production Outlook (million barrels per day)



Source: (EIA, 2016)

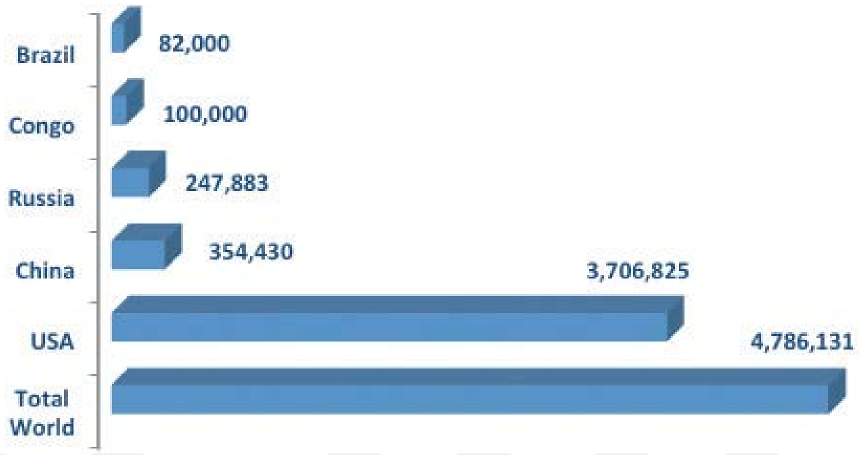
As explained in the previous section, oil shale and tight oil differ in content, reserves, production, etc. Since this study specifically investigates tight oil, or shale oil, in the US, the next section focuses on research into US shale oil reserves. Currently, it is hard to find a reliable source that gives accurate figures for reserves, which may be because the definition of shale oil or unconventional oil differs from source to source. Moreover, while some references prefer including just proven resources, some include predicted reserves.

For shale oil, there is no direct correlation between the size of reserves and production capacity because the productivity of wells varies substantially according to the depth of the reserve and over short distances due to shale rock heterogeneity, even in nearby wells. For instance, wells in Lower Bakken Play are more productive than those in Upper Bakken Play. Moreover, the productivity of wells may differ in the same neighbourhood, even within the same wells at different spots. This makes business difficult for shale producers, who need to minimize drilling costs. Thus, despite of drilling many wells, they may not gain accurate information about the profitability of a reserve. In addition, heterogeneity refers to shale oil and gas reserves in one formation. Transition layers between oil to natural gas have narrow transition formations of around 20 miles, such as in Eagle Ford shale play (EIA, 2013c).

The frequency of these zones between oil and gas is significant for three reasons. First, each well's production compounds determine profitability because crude oil, natural gas and natural gas liquids have different prices. Second, transportation options and a country's domestic demand vary. While oil is more portable than natural gas, a country that has enough gas supply may prefer to export gas although this is costlier instead of consuming it domestically. Finally, producers need natural gas to form at least 15 percent of oil liquids to enable sufficient flow through the well bores. Otherwise, it decreases the economic viability of shale oil to some extent (EIA, 2013c), The following chapter examines production technology and US shale plays in more detail.

Oil shale resources with high kerogen content are estimated to be an abundant resource, almost three times more than conventional oil reserves. However, the crude oil equivalent of raw oil shale source is low. Scotland became the first oil shale producer in the 1950s with around 100,000 tonnes/year. However, production ceased in the 1960s because it was no longer economically viable. Russia and China then developed oil shale production in the 1980s. The US has the largest estimated oil shale reserves in the world at over 70 percent of the total, with a giant basin in western US under Utah, Colorado and Wyoming (Shepherd and Shepherd, 2003).

Figure 6: Oil Shale Resources (million barrels): Top 5 countries



Source: (World Energy Council, 2013)

Three countries (Estonia, China and Brazil) produce around 45,000 bopd (barrels oil per day) from oil shale rocks. Estonia is the leader at 25,000 bopd, Chinese output is about 17,000 bopd and Brazilian produces roughly 4,000 bopd. This level of production will not become a substantial proportion of world oil production for some time, until more than a half million bopd. However, it is expected that oil shale production will spike in the near future when the cost of drilling falls to economically viable levels (World Energy Council, 2016b).

Table 1 shows the technically recoverable shale oil and gas resources according to the EIA and Advanced Resources International Inc. (ARI). The figures given in parenthesis are taken from ARI's data. As can be seen, the US is the second biggest producer of shale oil and ranked fourth for shale gas. Russia has the largest shale oil resources at more than 20 percent of the total while China leads in shale gas reserves with around 15 percent.

Table 1: Top 10 countries with technically recoverable shale (tight) oil and gas resources

Rank	Country	Shale oil (billion barrels)		Rank	Country	Shale gas (trillion cubic feet)	
1	Russia	75		1	China	1,115	
2	U.S.[1]	58	(48)	2	Argentina	802	
3	China	32		3	Algeria	707	
4	Argentina	27		4	U.S.[1]	665	(1,161)
5	Libya	26		5	Canada	573	
6	Australia	18		6	Mexico	545	
7	Venezuela	13		7	Australia	437	
8	Mexico	13		8	South Africa	390	
9	Pakistan	9		9	Russia	285	
10	Canada	9		10	Brazil	245	
	World Total	**345**	**(335)**		**World Total**	**7,299**	**(7,795)**

Source: (EIA, 2014a)

Comparing actual EIA and ARI data concerning unproved technically recoverable shale (tight) oil and gas resources, the figures coincide. However, there is a substantial increase in shale oil resource estimates between 2014 and 2017.

Figure 7: U.S. unproven technically recoverable shale (tight) oil and gas resources

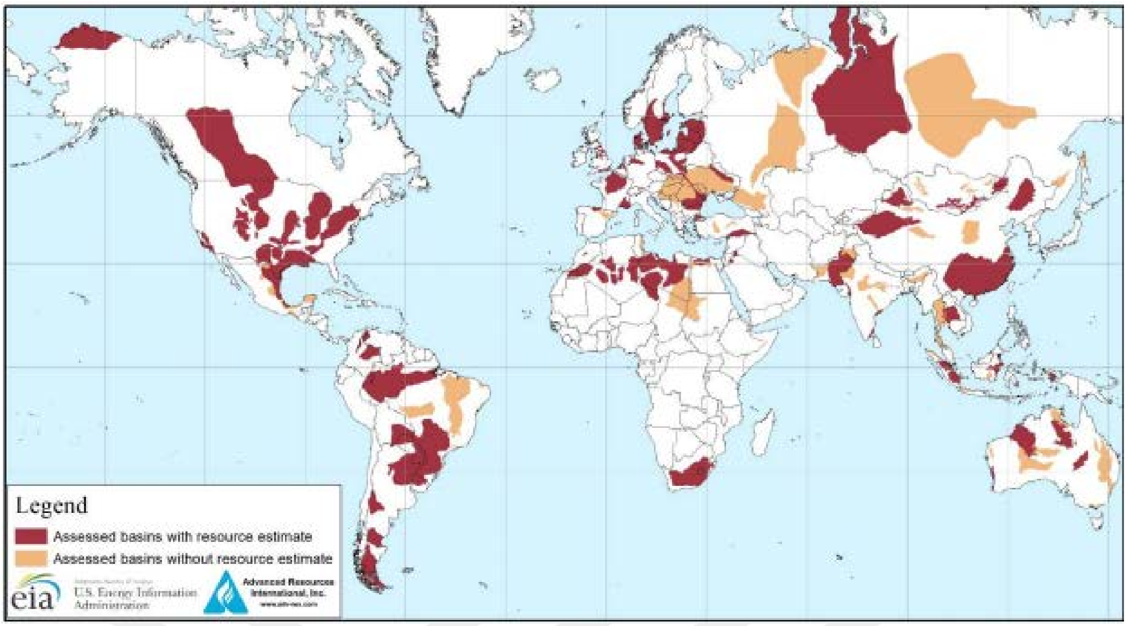
	Technically Recoverable Resources		
	Crude Oil (b)	Natural Gas (Tcf)	NGPL (b)
Total Tight/Shale	**90.3**	**1,052.9**	**50.7**

NGPL: Natural Gas Plant Liquid

Source: (EIA, 2017a)

To sum up, these data from different authorities provide a framework for the size of global shale oil and gas resources. However, it should not be forgotten that these estimates cannot be directly contrasted with proven conventional crude oil reserves (Ekins, Bradshaw and Watson, 2015). Figure 8 and the figures given before indicate that, under US leadership with its intensive technology and economic interest, China and Russia will shape the shale oil market in future.

Figure 8: Map of basins with assessed shale oil and gas formations



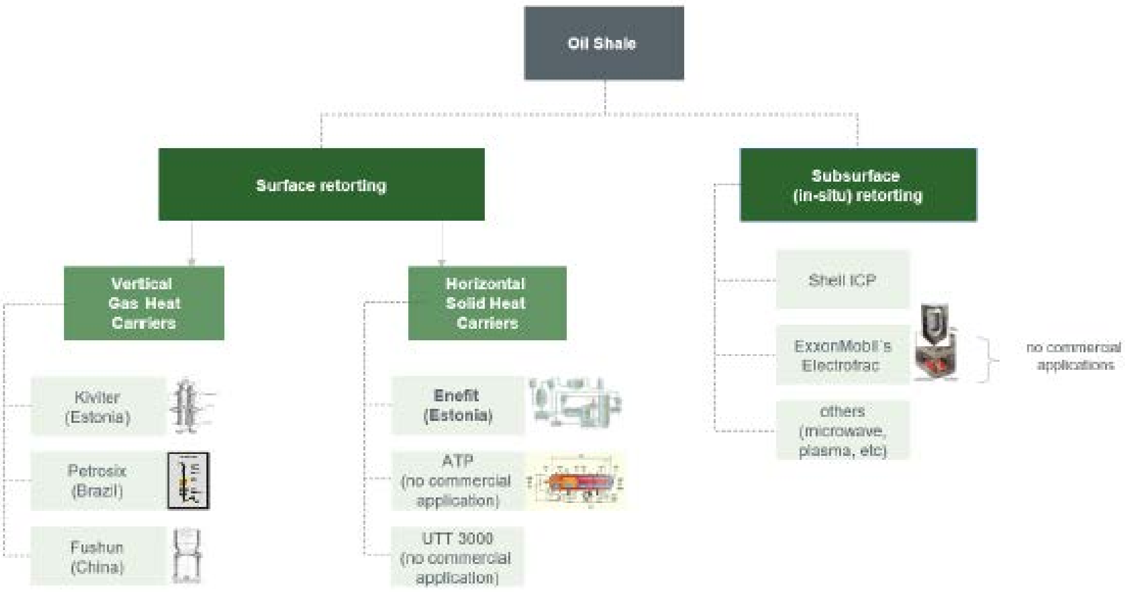
Source: (EIA, 2013c)

4. PRODUCTION TECHNOLOGY AND PROCESS

This section reviews technological developments in the oil and gas sector and how it has changed the shale oil industry. It focuses on surface (mining) and subsurface retorting for oil and gas extraction respectively. It also explains horizontal drilling and hydraulic fracturing, and conventional oil extraction. These advanced techniques are important for facilitating shale oil production in terms of cost, productivity and time.

Figure 9 categorizes oil shale drilling methods as surface retorting or mining and subsurface retorting or in-situ methods, which are becoming more important. As well as its small-scale production capacity, oil shale production differs considerably from other resources due to its heat energy needs.

Figure 9: Oil shale retorting process with examples of companies



Source: (World Energy Council, 2016a)

4.1. Shale Oil Mining

When US shale oil production first started, well drilling took between 40-60 days, after which the operator had to wait for experts to conduct hydraulic fracking. Thus, successful drilling of shale plays took months to complete. However, once the US developed enhanced shale drilling techniques after 2011, the time required was almost halved for depths down to around 5,000 metres. The increase in shale oil productivity was due to extended horizontal drilling length by up to two miles, sand volume and synthetic sand types to facilitate drilling and more fracking operations for each well (Maugeri, 2013).

Another strategic reason for the upsurge in shale production was that operators mostly started to focus on the richest reservoirs to maximize output whereas such basins are normally left till last. Therefore, some believe that the shale oil boom will collapse once the most productive basins have been depleted. Others argue that it is reasonable to concentrate production on more productive areas rather than leaving them till last because much more production can be gained by developing new techniques to increase production from the easiest basins. In addition, fast-developing drilling technologies, instability of proven shale reserves, which are re-estimated annually, fluctuating oil benchmark prices and the existence massive best shale areas vindicate the latter opinion (Maugeri, 2013).

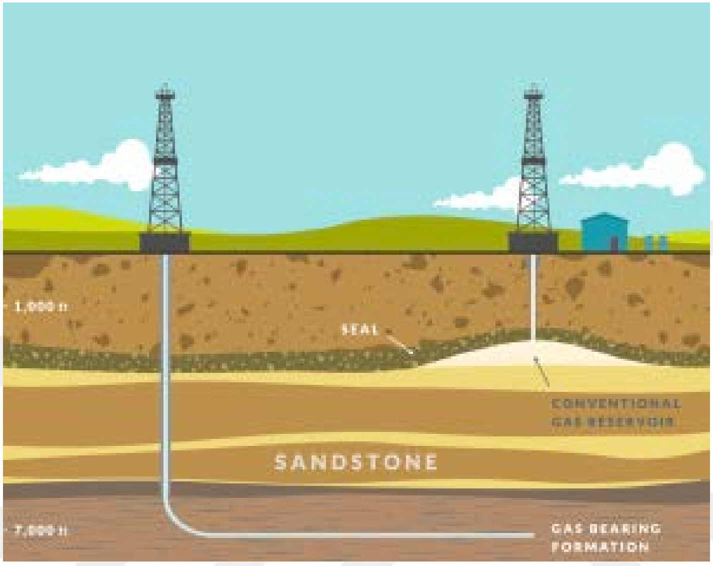
The significant challenge in processing oil shale is the necessity for high levels of heat energy to transform the kerogen into oil or gas products. To produce one barrel of oil equivalent, more than one ton of oil shale must be heated to around 425 to 525 degrees Celsius. During this operation, it is essential to optimize heat energy use. Three problems require solution: reutilising heat energy gained from the spent shale, dealing with the waste of spent shale and the generation of large volumes of carbon dioxide (Speight, 2012b). One of the main disadvantages of oil shale retorting is that fine dust from pulverising the rocks is aerosolized, which poses a danger for US wheat farmers (Shepherd and Shepherd, 2003).

The most recent significant innovation in drilling technology that interests all operators is laser techniques. Researchers at the Colorado School of Mines have been working on commercializing high-power lasers by increasing laser intensity from kilowatts to megawatts, which allows wells to be drilled more quickly than with conventional drilling methods. This helps to reduce both operating time and cost (World Energy Council, 2016a).

4.2. Horizontal Drilling

Horizontal drilling has become a widely-used technique, particularly in shale oil and gas production. It enables operators to access more reserves than is possible through vertical drilling, which increases the production scale of wells. As Figure 10 illustrates, wells are drilled until they arrive above the oil reserves. The well then turns horizontally parallel to the targeted reservoir. This technique saves money and time over vertical drilling, and is essential if the overlying rock formation is too hard to be drilled vertically or where the reservoir is particularly wide (Zendehboudi *et al.*, 2017).

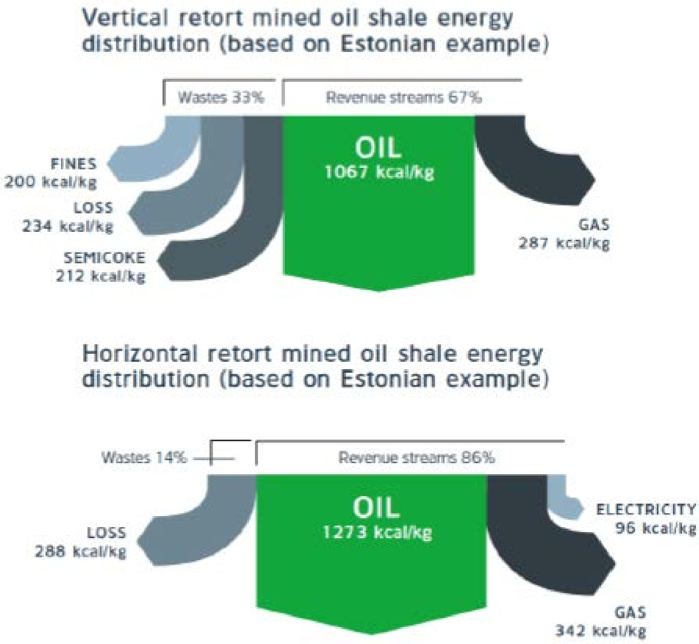
Figure 10: Horizontal drilling technique



Source: (Crone, 2015)

Figure 11 compares horizontal and vertical drilling methods using the leading oil shale producer, Estonia. In this region, while vertical drilling wastes 33 percent of total energy used, horizontal drilling wastes just 14 percent.

Figure 11: Vertical versus horizontal drilling in Estonia

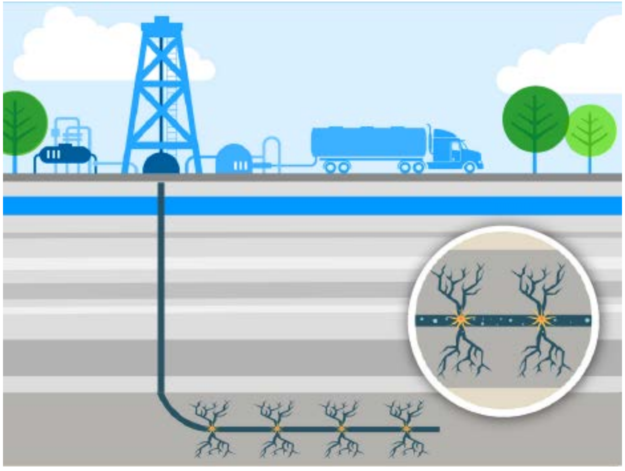


Source: (World Energy Council, 2016a)

4.3. Hydraulic Fracturing

In addition to horizontal drilling, unconventional oil reserves require intervention from the well bore itself. Because shale oil formations have low permeability, oil cannot easily flow into the drill pipe. Hydraulic fracturing solves this problem by facilitating the flow of shale oil from tight rock formations through the well bore to the surface. Hydraulic fracturing involves pumping a liquid that comprises water, sand and chemicals into shale formations to reduce tightness and increase permeability. As Figure 12 shows, this penetrates the shale formation by opening pathways rather like a tree root system (Zendehboudi *et al.*, 2017).

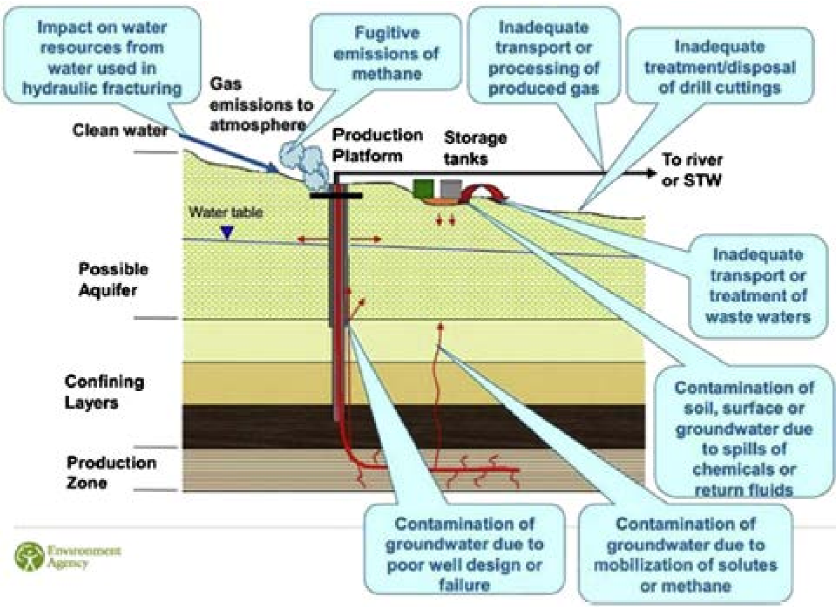
Figure 12: Hydraulic fracturing



Source: (Hamilton, 2014)

While it is geologically and economically beneficial, hydraulic fracturing also wastes large volumes of water and causes environmental contamination. Approximately three barrels of water are required to produce one barrel of shale oil during the drilling stage alone (Shepherd and Shepherd, 2003) while some of the chemicals mixed with the water and sand may contaminate underground habitats and drinking water sources. Hydraulic fracturing may also cause blowouts or landslides due to uncontrollable underground events (Zendehboudi *et al.*, 2017). Figure 13 illustrates various environmental concerns about inadequate treatment of waste water accumulated on the surface and drill cuttings.

Figure 13: Environmental effects of hydraulic fracturing



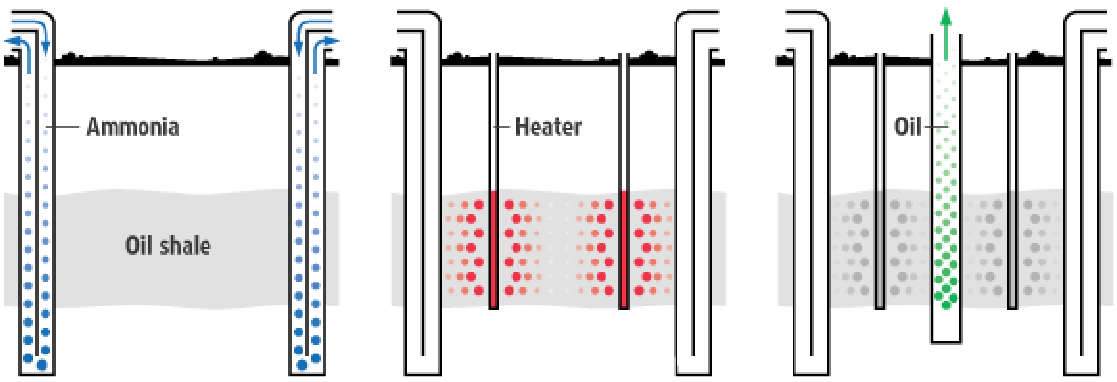
Source: (Zendehboudi and Bahadori, 2017)

4.4. In situ Combustion

The latest method in the oil shale industry is in-situ combustion, carried out underground so that oil shales do not have to be surface mined. Pipes are first placed in holes excavated by hydraulic power or explosives before scorching liquids or gases are injected to heat the oil shale to complete the natural combustion process to create liquid oil. The time required depends on the kerogen content. The key factor is that the energy of the heated portion of reserves is sufficient to retort the remaining areas. Once the kerogen in the oil shale has been converted to a liquid form, it can be drained to the surface through the well-bores. Although this complicated technique is more expensive and onerous than surface retorting, it is believed that, like other technological developments, its efficiency will be improved (Shepherd and Shepherd, 2003).

Shell has implemented in-situ retorting in Colorado. In the first step, as shown in Figure 14, pipes containing ammonia are placed around the reserve to protect the existing habitat, including water, from any contamination. The shale rocks are then heated steadily with electric heaters to 425-525 degrees Celsius over the next two years, after which the liquid shale oil can lifted to ground conventionally.

Figure 14: Shell's in-situ combustion method



Source: (Research, 2017)

There are many advantages to in-situ combustion. By avoiding surface mining, it creates far less shale waste. It also prevents groundwater contamination through the protection zone, or freeze wall, illustrated in Figure 14. Finally, it also avoids using large volumes of water and hazardous chemicals (Research, 2017).

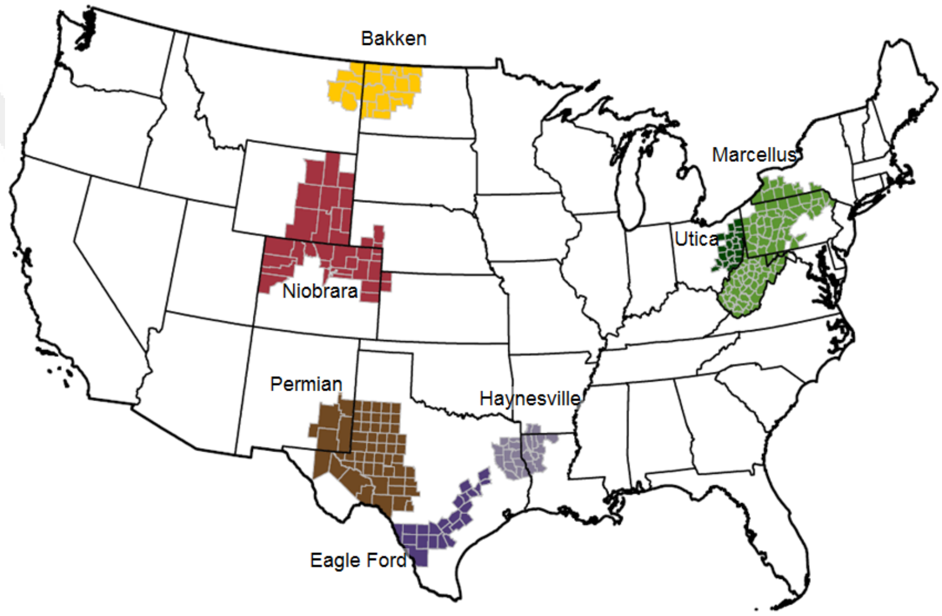
In contrast, surface retorting causes significant environmental problems and incurs extra operational costs due to waste material disposal, which comprises around eighty percent of the extracted shale rock. To optimize production, it is necessary to maximize the liquid oil output from the oil shale and minimize the chemical reactions that create coke deposits or hydrocarbon gases. Nearly half of shale oil reserves contain heavy crude oil, which is equivalent to ten gallons of crude oil per tonne of oil shale. This cannot be mined economically without in-situ technology. Thus, the in-situ method is reasonable as long as the reserve is not too deep or the grade of the shale is not too poor (Speight, 2012c).

In-situ technologies continually develop to become more commercially viable. One of the most developed projects is that carried out by JOSCO, a Jordanian subsidiary of Shell, which has drilled 340 wells in a 1,000 m^2 leasehold since September 2015 at a small scale. It produced crude oil just a few months after starting while the heating process continued (World Energy Council, 2016a).

5. US SHALE PLAYS

The US is considered the homeland of the shale oil and gas industry, and leads in production capacity and estimated shale reserves. Just as it pioneered the shale gas boom, it is again leading the shale oil phase. This section describes the main US shale plays at Baken, Eagle Ford, Permian, Niobrara, Utica, Marcellus and Haynesville, as shown in Figure 15.

Figure 15: US major shale oil plays



Source: (EIA, 2017b)

The EIA's Drilling Productivity Report (EIA, 2017b) presents the recent data, including existing drilled wells and projected ones, in the seven major plays mentioned above. These are most productive and account for the biggest proportion of total US oil production growth. Wells are not distinguished in terms of oil and gas because the majority produce both.

Table 2: New-well oil production per rig (barrels/day) in US shale plays

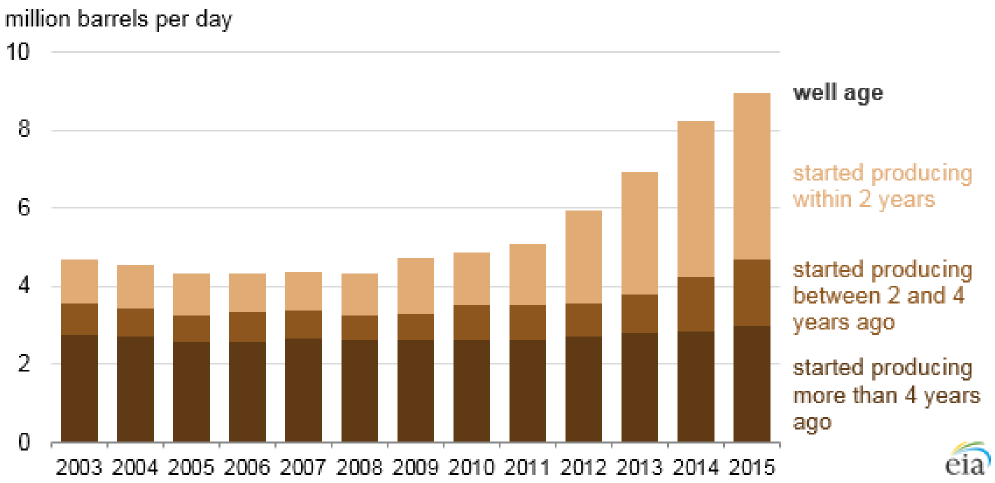
Region	July 2017	August 2017	change
Bakken	1,169	1,173	4
Eagle Ford	1,433	1,410	(23)
Haynesville	33	33	-
Marcellus	70	70	-
Niobrara	1,288	1,289	1
Permian	607	597	(10)
Utica	247	259	12
Total	720	713	(7)

Source: (EIA, 2017b)

As Table 2 shows, Eagle Ford remains the most productive US shale play, although production decreased between July and August 2017. Marcellus and Haynesville are the less prolific plays but with more stable output.

US shale oil production increased from half million barrels per day (bpd) in 2009 to 4.8 million bpd in 2015 to account for 50 percent of total crude oil production. Due to decreasing oil prices, shale oil production dropped 8 percent in the second half of 2015, as did total oil production, which could not recover as rapidly as shale oil. The Bakken, Eagle Ford and Permian basins accounted for 80 percent of shale oil production by the end of 2015. Advanced drilling technologies accelerated production by increasing initial production rates per rig, although this reduces well life span so producers must continuously launch new drilling well projects to maintain high production rates. As Figure 16 confirms, almost half of US crude oil production in 2015 came from wells aged under two years (EIA, 2016).

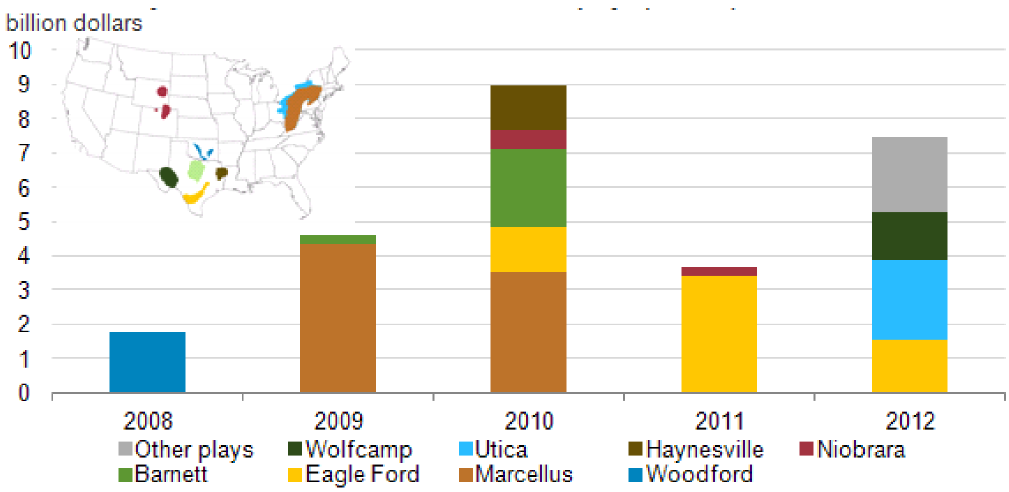
Figure 16: U.S. crude oil production by age of well



Source: (EIA, 2016)

Unsurprisingly, considering the attractive characteristics of US shale, almost twenty percent of US shale oil investment, around 130 million dollars, came from foreign investments between 2008 and 2012. The rest was either acquisitions, Australian BHP Billiton's takeover of Petrohawk Energy Corporation, or were joint ventures by US companies. In general, foreign investors purchase part of a shale area on the condition that giving an upfront payment for drilling costs to cover their own area during an agreed time frame, normally from two to ten years (EIA, 2013b).

Figure 17: International joint venture investment in US shale plays (2008-2012)



Source: (EIA, 2013b)

US shale oil production has several significant advantages over that of other countries: usage rights to underground resources belong to the landowner; experts and advanced equipment are easily found; post-production facilities like transportation are good; and there are sufficient water resources for hydraulic fracturing (EIA, 2013a).

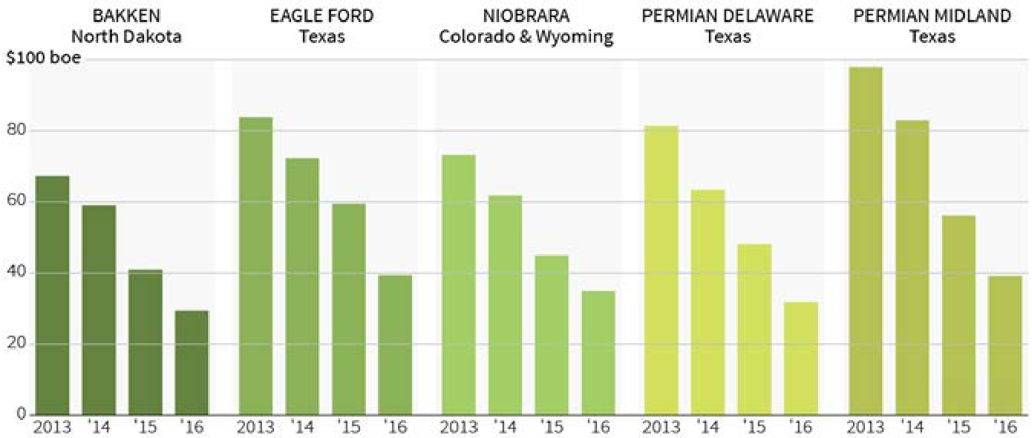
US producers also benefit from weaker environmental regulations, such as the lack of a carbon emission tax on shale oil production. It is estimated that crude oil from shale oil emits approximately one and a half times more carbon than conventional oil. Thus, the operating costs of oil shale production would increase sharply if an emission tax were implemented in the US (World Energy Council, 2013).

In addition, in 2005, the US Congress supported the oil shale industry with several helpful actions. In particular, the Energy Policy Act of 2005 aimed at developing sufficient technology and taking care of environmental conditions. The legislation also provided incentives for the shale oil industry (Speight, 2012b). However, The Obama administration unexpectedly abolished the shale oil production and development leases introduced by the Bush administration in the Energy Policy Act of 2005. Companies are wary of investing millions of dollars in uncertain shale oil production without government support. For example, Shell's agreement with Jordan to invest 500 million dollars for shale oil exploration was balanced by the right to extract the explored reserves. Otherwise, the private sector must take on all the investment risk alone (Research, 2017). Some researchers therefore conclude that shale oil's increased share of total US oil production, which was not supported by the Obama administration, occurred despite his government's efforts (Egan, 2016b).

Another problem for US producers is that more than 70 percent of oil shale reserves lie within federal land in the Green River Formation. Thus, the federal government determines the future of these oil shale resources although they do not have enough information about oil shale strategy and development compared to the private sector. Because these reserves are particularly prolific reserves and close to the surface, companies would prefer to mine them as this is easier and does not require the advanced drilling techniques of in-situ retorting. However, mining would cause land contamination and increase production costs (Bartis *et al.*, 2005).

Due to the financial bottleneck for the oil industry in 2014, some companies cut production capacity and new investment while some were even bankrupted. However, operators learnt from this downturn to operate more smartly, which led to costs of oil shale plays falling to the extent that they remained profitable even at crude oil price of 50 dollars. Figure 18 presents changes in the breakeven prices for five important shale regions between 2013 and 2016 (Kemery, 2017)

Figure 18: Wellhead breakeven oil prices



Source: (Kemery, 2017)

5.1. Bakken-Three Forks

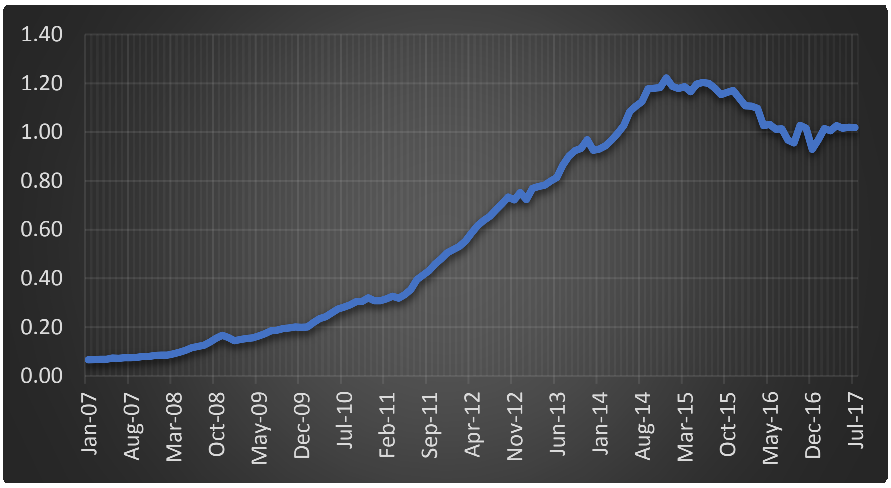
The Bakken-Three Forks shale play lies inside the Williston Basin as show in Figure 19. This large basin covers approximately 300,000 square miles between North and South Dakota and Montana, as well as part of Manitoba in Canada (Maugeri, 2013).

Figure 19: The Bakken-Three Folks shale play

Source: (Mainstream Investors, 2017)

Although only about 12,000 square miles is considered productive, exploration work and deeper drilling continue in other parts. EOG Resources, who started the real shale development, took the first significant step by using rail transportation to send them to Louisiana Light Sweet, which is higher than the WTI benchmark (Maugeri, 2013).

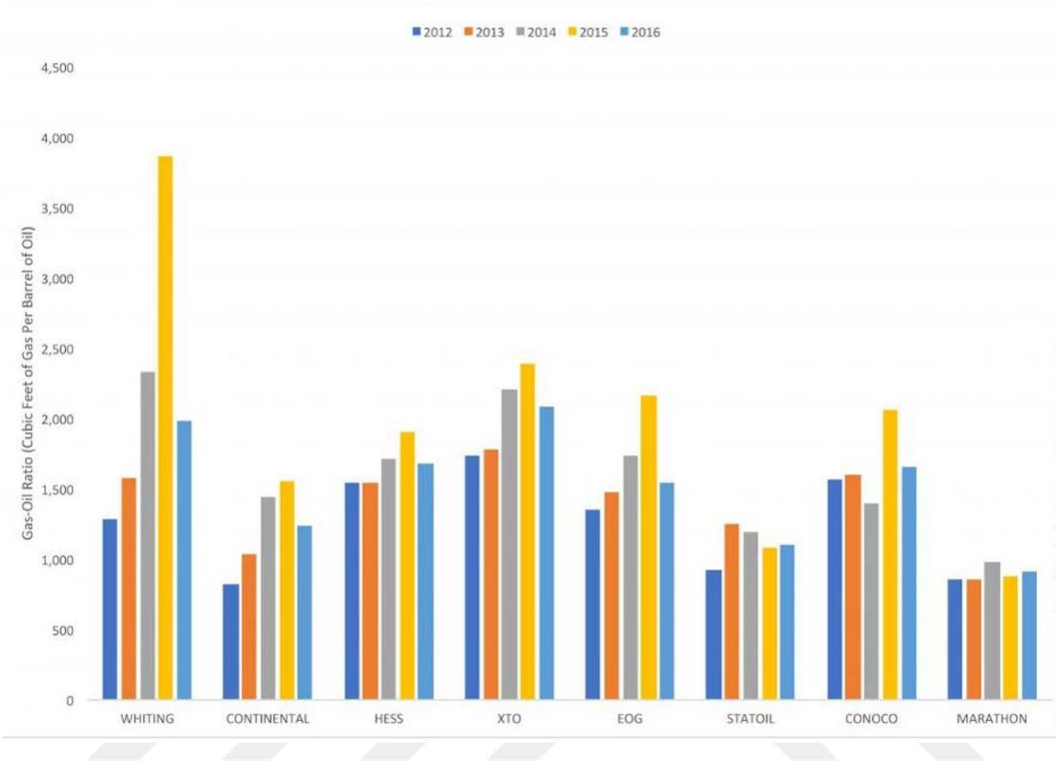
Figure 20: Bakken play oil production capacity (million barrels per day)



Source: (EIA,2017)

As Figure 20 shows, oil production from Brakken declined to around 200,000 barrels per day from the beginning of 2015 after a steady increase. Despite advanced technology improving efficiency, all operators' estimated ultimate recovery (EUR) rate fell in 2015 (Berman, 2017b).

Figure 21: Bakken gas to oil ratio between 2012 and 2016



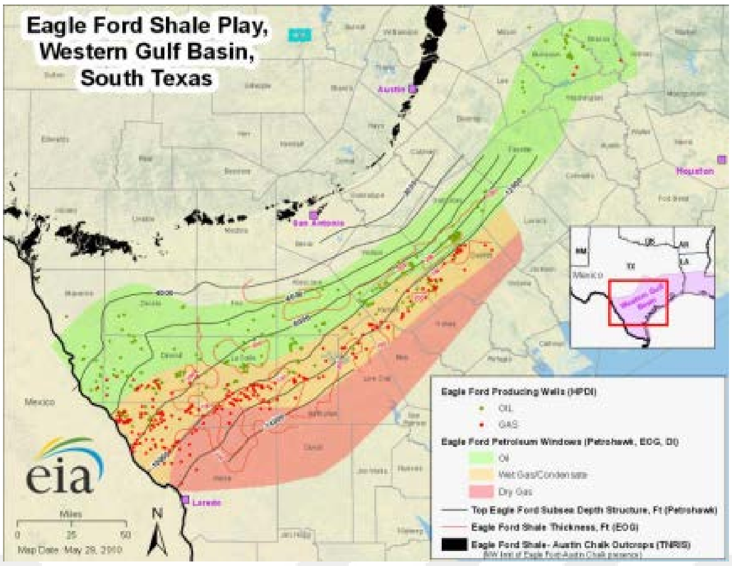
Source: (Berman, 2017b)

The gas to oil ratio also declined in Bakken in 2016, which can be interpreted as indicating a decrease in reservoir energy since decomposed gas creates pressure that raises oil liquids to the surface. The sharp decrease in gas ratio thus suggests that the reservoir faced oil depletion due to the decrease in reservoir pressure (Berman, 2017b).

5.2. Eagle Ford

Eagle Ford Shale is located in Western Texas from the Mexico border to the northeast of Austin (see Figure 22). Although it covers more than 300,000 square miles area, only around 6,000 of it is predicted to be prolific. Eagle Ford consists of dry gas in the south, gas liquids in the centre and oil in the north-eastern zone. Due to high levels of carbonate, its shale product is considered frackable (Maugeri, 2013).

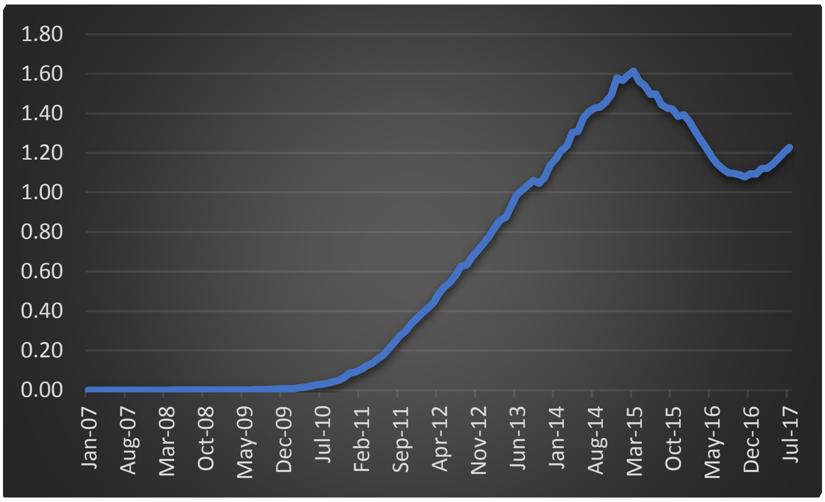
Figure 22: Eagle Ford shale play map



Source: (EIA, 2014b)

Petrohawk, American Oil and Gas Company carried out the first exploration and production in 2008. However, the shale boom in this region was delayed until 2010 because of global economic crises and existing production in other shale plays. Eagle Ford's shale reserves lie closer to the surface and have more permeability than the Bakken basins, which makes production costs much more competitive than the others (Maugeri, 2013). As Figure 23 shows, oil output increased from a very low level to 1.6 million bpd by early 2015, after which production declined to about 1.1 million bpd by mid-2016 due to the oil price downturn.

Figure 23: Eagle Ford shale oil production capacity(bpd)

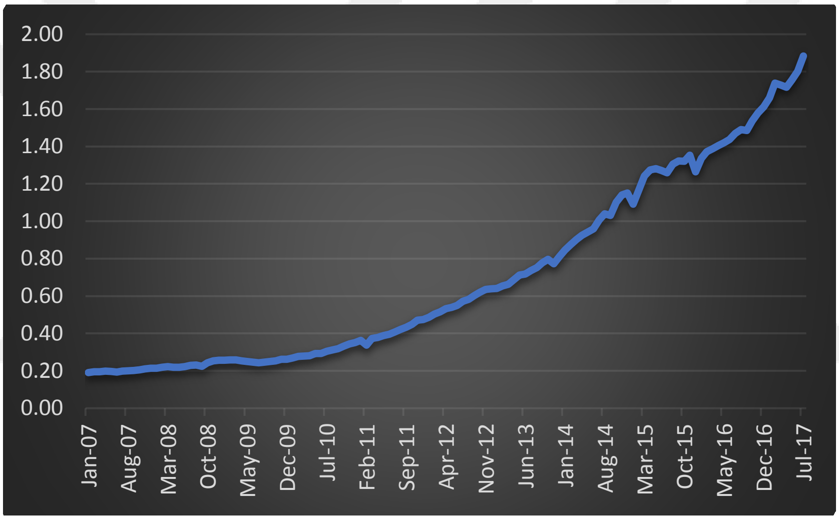


Source: (EIA,2017)

5.3. The Permian Basin

The Permian shale play, which includes several basins, lies between West Texas and south-eastern New Mexico. The major parts are the Midland and Delaware basins. The Permian play is currently the most productive shale region in the US at 1.8 million barrels per day. It is estimated that its massive reserves are greater than the total reserves produced so far. Because horizontal drilling and hydraulic fracturing techniques were implemented around 2011/12, which is later than at Bakken or Eagle Ford plays, Permian's production capacity only caught up with the others by 2012, after which it moved ahead (Maugeri, 2013).

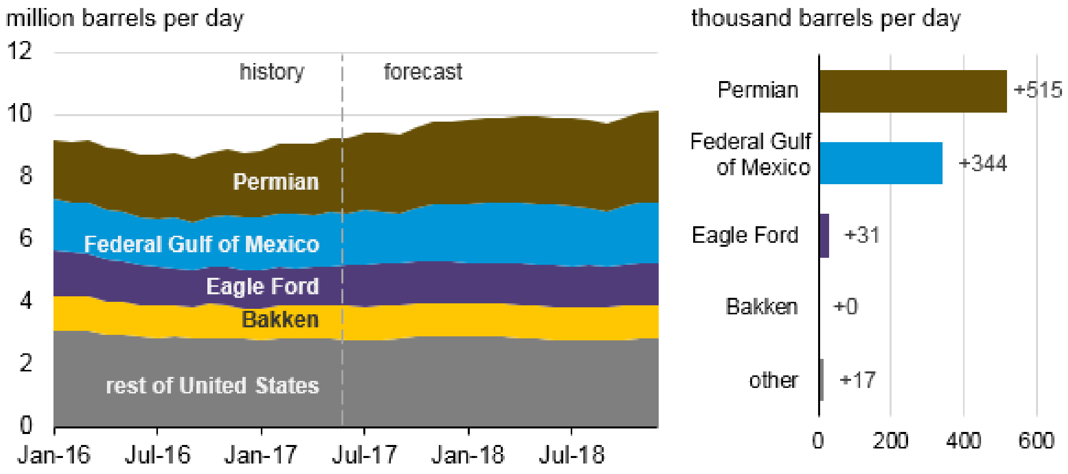
Figure 24: Permian Basin shale oil production capacity(bpd)



Source: EIA-2017

The Permian basin is predicted to produce the largest share of total oil production and have the highest increase, mostly from shale oil, primarily due to its low production cost and high production capacity. In addition, producers' hedging activities at an offer price that is higher than the WTI benchmark price has increased profits. The resulting cash flow has encouraged operators to increase the number of rigs, which boosts production (EIA, 2017b).

Figure 25: Monthly U.S. crude oil production by region and forecasted change

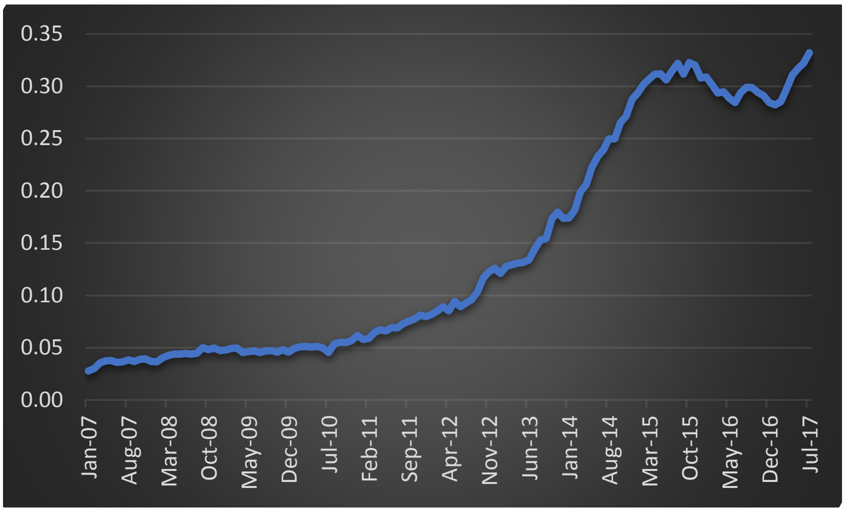


Source: (EIA, 2017b)

5.4. Niobrara and Utica Basins

These two shale plays have the fourth and fifth highest shale oil production capacity in the US. The Niobrara shale stretches through Northeast Colorado, Northwest Kansas and parts of Nebraska and Wyoming. Colorado plays the most important role in production for this region, followed by Wyoming (Maugeri, 2013). Production capacity is currently around 320,000 barrels per day (see Figure 26).

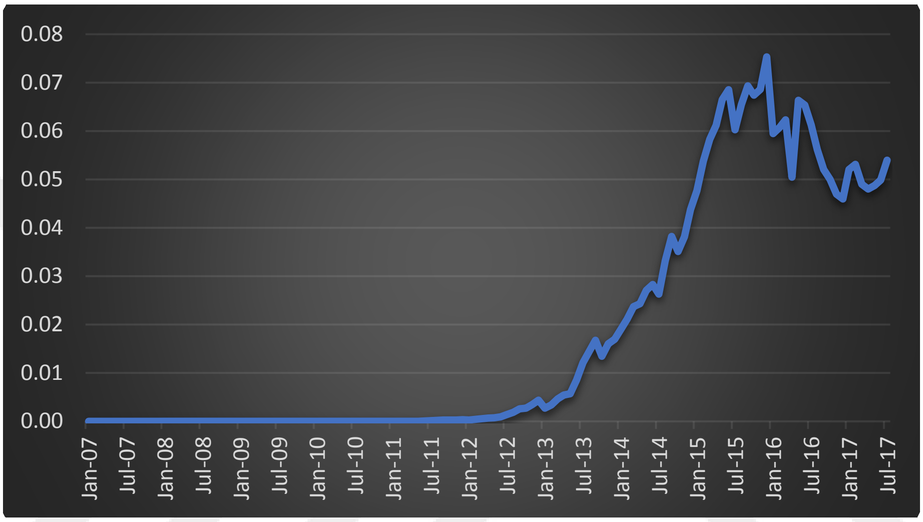
Figure 26: Niobrara shale oil production capacity(bpd)



Source: (EIA,2017)

The Utica basin is composed of massive shale rock formations through eight states, from Tennessee to New York State and across Quebec. However, production is mostly conducted in Ohio. Like Eagle Ford shale, Utica shale contains oil, wet and dry gas, making it suitable for hydraulic fracturing due to the rich carbon content. Yet despite a substantial increase in production capacity since 2013, it has not yet taken a significant proportion of US shale production (Maugeri, 2013).

Figure 27: Utica shale oil production capacity(bpd)



Source: (EIA,2017)

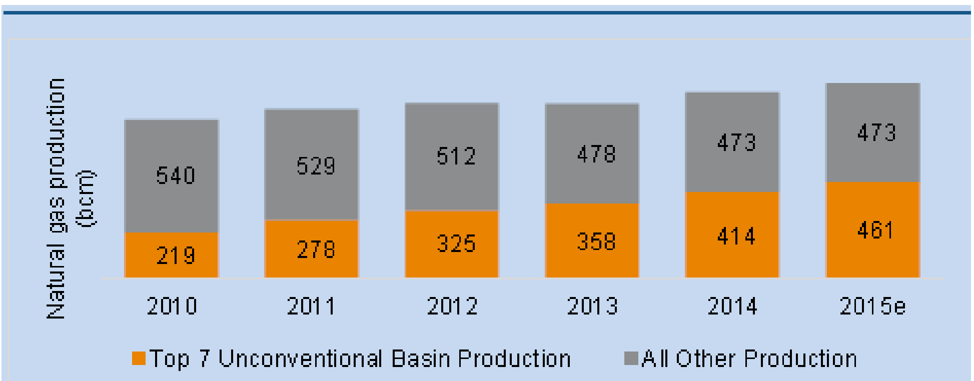
6. THE SHALE GAS REVOLUTION

This this section compares the shale gas revolution to the evolution of shale oil development to show that the former has not been completely successful. In particular, rapidly-depleted productive reserves and an insignificant effect on global gas prices suggest that shale gas development has had a restricted impact on gas prices.

One of the important factors that distinguishes shale oil and shale gas is storage. While oil can be stored as it is, gas must first be liquefied, which is costlier than oil. Although only a slight difference, it can severely harm shale gas development (Auping *et al.*, 2016).

Shale gas exploration boomed in the 2000s in an effort towards energy independency in the US. Rising gas prices supported the development of shale gas during these years, with companies focused on new investments. As a result, the US switched from being an importer to an exporter. In addition, the domestic energy mix also changed as gas prices fell due to growing gas production. While electricity operators preferred natural gas to coal, the petrochemical market shifted away from naphtha to gas which became as important as the other sources (Ekins et al., 2015).

Figure 28: US Natural Gas Production between 2010 and 2015



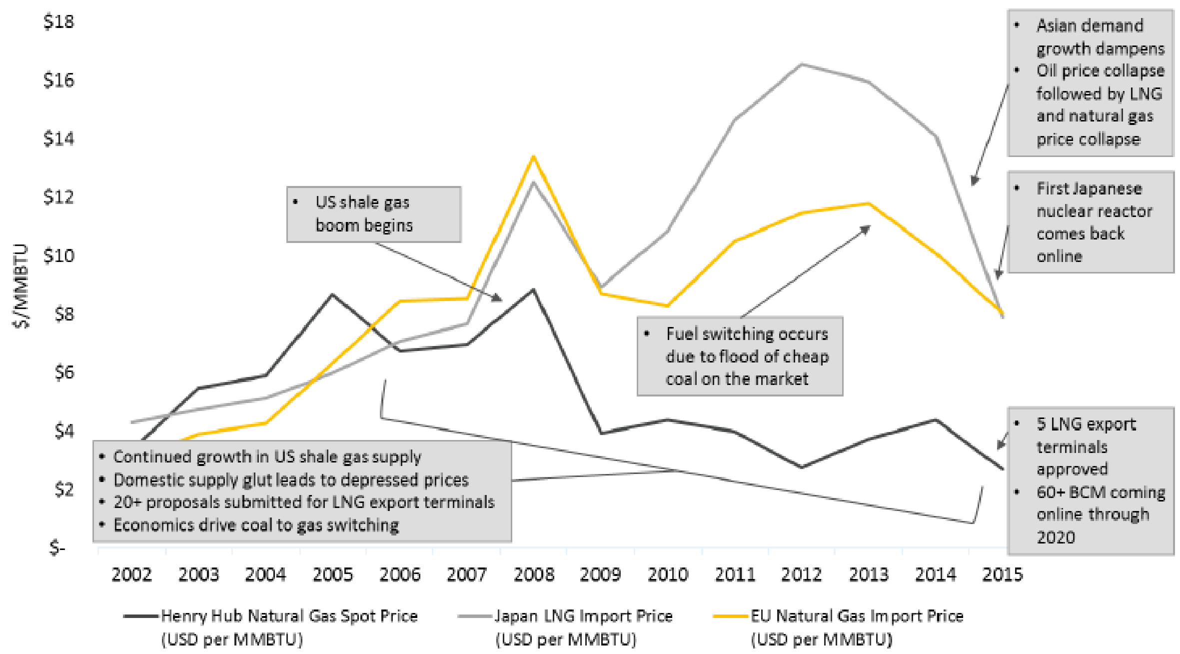
Source: (World_Energy_Council, 2016)

Figure 28 shows, increasing shale gas production constituted almost half of total US natural gas production in 2015.

Shale gas development did not just change US domestic energy consumption; it also changed Europe's energy mix. Previously, the US consumed 92 percent of its own coal production. However, as gas production declined due to the shale boom, US consumers shifted from coal to natural gas as it became more affordable. This reduced coal prices to a four-year low in late 2013, which encouraged European consumers to switch from gas to newly cheap coal. It also reduced carbon prices in Europe under the EU's Emissions Trading System to allow coal burning (Strzelecki, 2013).

However, regarding shale gas productivity, it is suggested that almost 70 percent of existing shale reserves will be depleted after just one year of production. A University of Texas study predicts that by 2030, 13,000 wells will be added to the existing 15,000 wells in the Barnett Shale Formation. Thus, production is expected to peak rapidly before declining sharply until 2030 to half of the current rate. Thus, it concludes that the shale gas boom is already experiencing its most productive period (Zendehboudi and Bahadori, 2017).

Figure 29: Regional natural gas price benchmarks used in North America, Europe and Asia



Source: (World Energy Council, 2016)

Figure 29 presents changes in three global benchmark prices: Henry Hub spot price, EU import price and Japan LNG import price. Until 2008, when the shale boom occurred in North America, these three benchmarks were rising. After the US shale gas boom began, prices for all three declined for one year before recovering. Then increased shale gas supply caused a domestic supply glut that depressed prices again, while the gap between Henry Hub and the other benchmarks grew (World_Energy_Council, 2016). Considering that the EU import price decreased due to cheaper coal and the Japan LNG price declined because of reduced LNG growth, it is not clear that shale gas significantly affected global gas markets.

To sum up, shale gas can be considered a normal rather than an extraordinary or revolutionary supply source. Shale reserves are abundant but not infinite. For instance, producers are currently concentrating on other shale plays like Marcellus or Utica rather than previously popular ones like Barnett or Fayetteville due to a decrease in productive areas, which need less money for production in these regions. Analysts mostly focus on how large the shale plays are and the history of technology that made shale production possible. However, the oil industry should instead emphasise the productive usage of these plays and reducing operating costs (Berman, 2017a).

7. THE POSITION OF SHALE OIL IN THE GLOBAL OIL MARKET

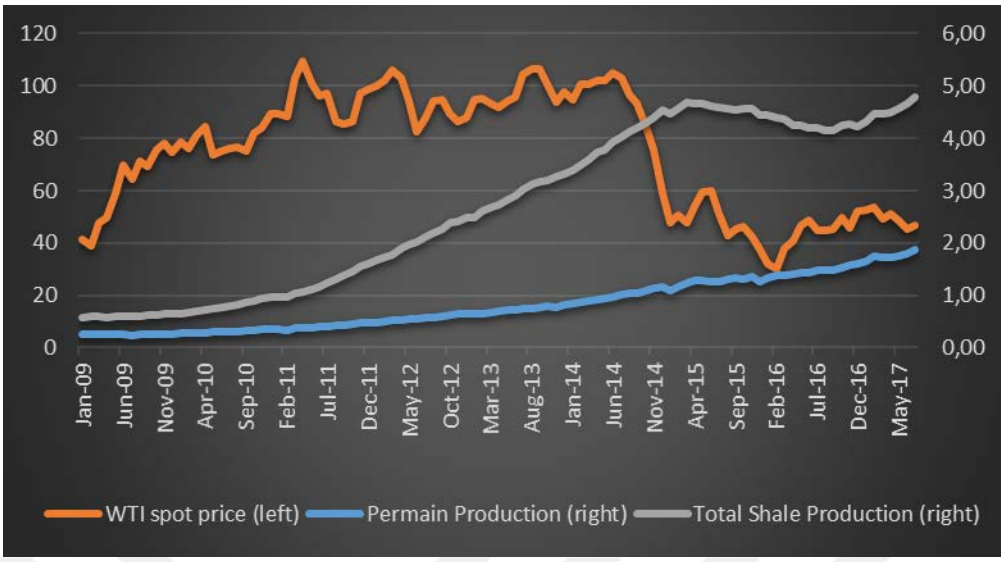
While geopolitical factors have certainly helped raise oil prices, which reached more than 100 dollars in 2014, higher production costs due to increasing unconventional oil output have also raised crude oil prices. For instance, exploration investment of around 80 billion dollars in 2012 was almost four times higher than in the previous ten years (World Energy Council, 2013). On the other hand, the crude oil price crash in 2014 was mainly due to increased production of shale oil, declining global oil demand, uncertainty about OPEC policies and US dollar appreciation (Baffes *et al.*, 2015) .

The US shale industry faced a severe financial depression after the sharp falls in oil prices in the beginning of 2014 and 2016. Shale oil income dropped, the sector suffered from low cash flow and companies urgently required loans. This forced small companies to sell their assets to meet unexpected losses so they had to cut their production. Gaining new loans was challenging then because banks were worried about being repaid due to the liquidity problem. Companies are usually evaluated for their reserve value when they apply for credit, which made them appear weaker than usual at this time due to sagging oil prices. Because of this short-term debt deficiency, companies needed enough cash to sustain their drilling programs without selling redeemable assets (Economist, 2017).

Shale producers vacillated between two approaches. One was to extract more oil to increase revenue to fight against the financial crises. However, this could make the oil price collapse due to oversupply. The US therefore lifted its almost four-decade ban on crude oil exports, although this surprisingly did not increase crude oil exports (Kennedy, 2016). Compared to the previous year before lifting the ban, crude oil exports decreased by around 5 percent. Some concluded that this was because it remained unprofitable to export US crude oil so long as the price gap between Brent crude and WTI was 4 US dollars or less per barrel (Egan, 2016a).

The producers’ other approach was to cut their production capacity and survive on their cash balance until oil prices recovered. Accordingly, between 2015 and 2016, shale production for the first time experienced a steady decline. All shale plays produced less in the first half of 2015 than before except for the Permian basin (Economist, 2017).

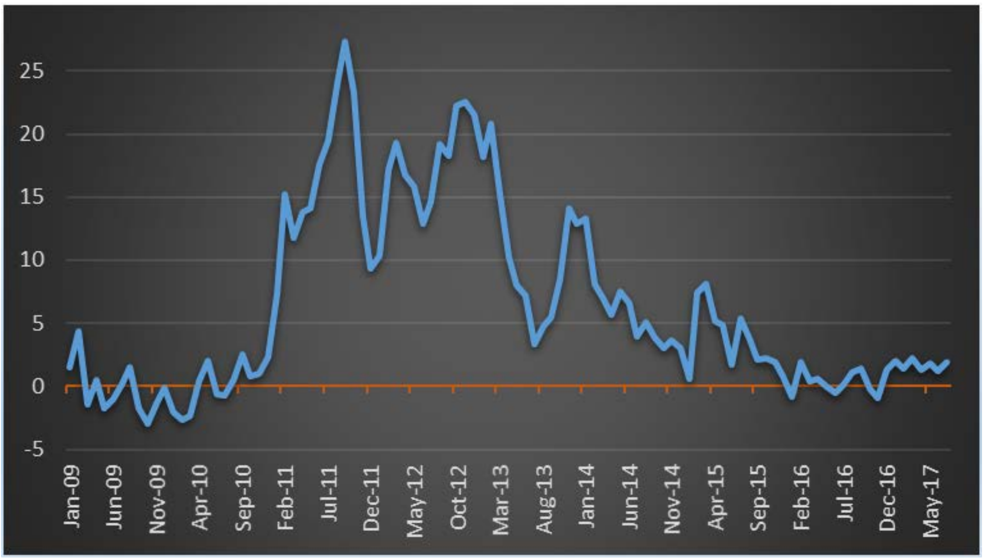
Figure 30: WTI spot oil price vs US shale production(bpd) between 2009 and 2017



Source: (EIA,2017)

In contrast, US oil infrastructure is configured to refine imported oil before selling it back on the world market. When the unexpected shale oil upsurge occurred, the US stored this extra crude in pipelines based in Cushing, which reduced WTI prices at which shale oil is sold. This widened the Brent-WTI price spread, as can be seen in Figure 31, which forced shale oil producers to sell at a lower price than conventional oil producers. As can be seen from the spread at the beginning of 2012, when pipeline companies constructed new projects, WTI prices recovered to some extent (DiLallo, 2016).

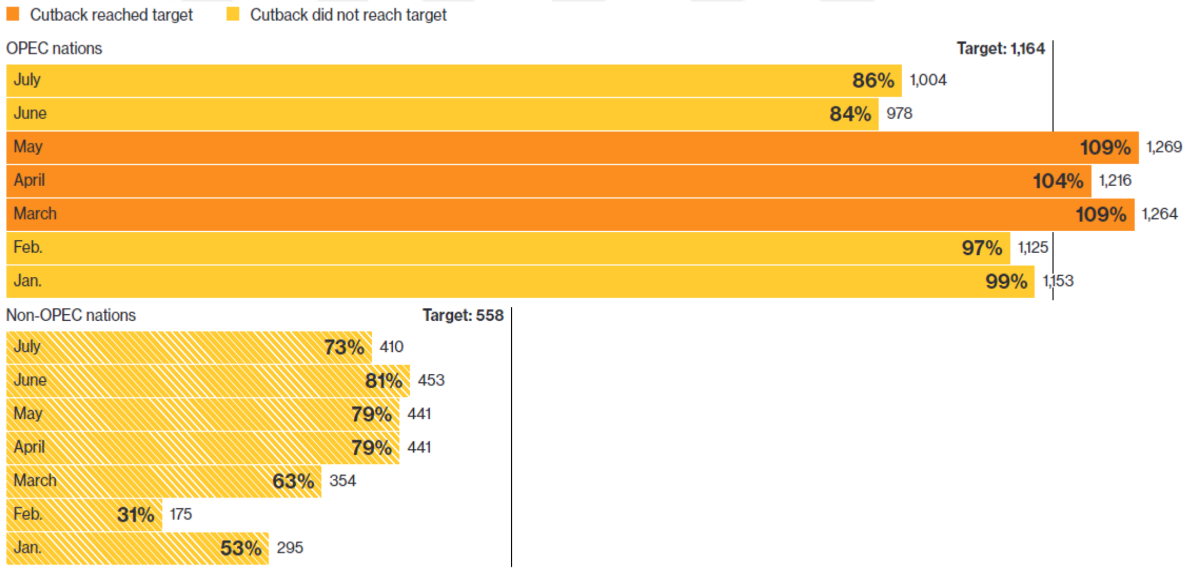
Figure 31: Brent and WTI Crude Oil Prices Spread between 2009 and 2017



Source: (EIA,2017)

Moreover, traders were sceptical about the impact of OPEC's production cut announcement at the end of 2016, in terms of the response of both OPEC countries and non-OPEC supporters like Russia. They agreed to cut production to prevent increasing oversupply from the beginning of the 2017. However, crude oil prices in 2017 indicate that this strategy failed because the Brent oil price fell 13 percent to 47 dollars shortly after the agreement was signed (Raval, Anjli; Sheppard, 2017). Analysts argued that OPEC's cut failed for several reasons. Firstly, even Saudi Arabia and Russia, as leading members and major participants failed to meet their targets as part of the total target of around 1.6 million barrels per day. Second, two OPEC members that were not involved in the agreement, Libya and Nigeria, maintained their production levels. The final reason was growing US shale oil production (Wingfield, 2017).

Figure 32: OPEC-led Oil Cut Target



Source:(Wingfield, 2017)

Although US shale oil production increased by around 550,000 bpd between December 2016 and July 2017, this could not compensate for OPEC's actual production cut of about 90 percent of what it intended (EIA, 2017a). In other words, shale oil production is not yet a mature player that can resist a cartel like OPEC.

However, even if OPEC could achieve its aim of raising oil prices, US shale producers can benefit from this more than OPEC countries. In 2018, serious conflict is expected between

OPEC and US shale producers. Pioneer Natural Resources Co., one of the biggest US shale producers, expects to increase its output by 19 percent compared to the previous year. A company executive claimed that they can remain profitable even in a 40-dollars oil price market (Blas, 2017b). Most managers in the US shale industry agree with this. Shale producers also learnt a lot from the 2014 recession so they will not repeat their mistakes regarding cash flow between 2010 and 2015. For example, Marathon Oil Co. announced that they anticipate scaling up production by around 20 percent in the next 5 years unless the oil price drops below 50 dollars. They believe that this can be achieved with rational steps in operating costs and without paying a dividend for a while (Blas, 2017a). Conversely, the price of futures contracts for one or two years are lower than current crude oil prices, which may reduce the number of wells drilled and crude output even if this is in line with OPEC's production cut (DiChristopher, 2017).

8. ECONOMETRIC ANALYSIS

This section investigates whether there is a significant relationship between US shale oil production and the WTI and Brent oil price benchmarks in order to explore the long-term effects of shale production on oil prices. The impact on benchmarks is also analysed for its local or global effects. First, a correlation matrix is constructed to show the direction and degree of correlation between each time series, monthly shale oil production and the two spot oil prices time series between January 2007 and July 2017. The data was collected from US Energy Information Administration (EIA) and Thomson Reuters Datastream. The Autoregressive Distributed Lag (ARDL) regression is then applied to examine the long-run relationship between each dependent variable (WTI and Brent spot oil prices) and the independent variable (shale oil production) in two separate regression models.

8.1. Hypotheses

The analysis aims to test two hypotheses regarding the separate relationships between US shale oil production and the WTI and Brent spot oil prices.

Hypothesis 1

H_0: There is no significant long-run relation between US shale oil production and the WTI spot oil price.
$H_{1:}$ There is a significant long-run relation between US shale oil production and the WTI spot oil price.

Hypothesis 2

H_0: There is no significant long-run relation between US shale oil production and the Brent spot oil price.
$H_{1:}$ There is a significant long-run relation between US shale oil production and the Brent spot oil price.

8.2. Methodology

Phillips-Perron (PP) Test

Time series can be examined with various unit root tests, one of which is the Phillips-Perron Test. It tests whether the series is stationary or not. A stationary time series means that the mean, variance and autocorrelation structure does not change over time. Phillips and Perron have developed a more comprehensive theory of unit root non-stationarity. This test often gives the same conclusions and suffers from same limitations as other tests. The null hypothesis of this test is that the time series has a unit root; in other words, it is non-stationary (Brooks, 2014). The Eviews Unit Root Test can be automatically used by choosing lag length and other parameters.

Autoregressive Distributed Lag (ARDL) Method

ARDLs are standard least squares regressions that include the lags of both the dependent and explanatory variables as regressors (Greene, 2008). Although ARDL models have been used in econometrics for decades, they have recently gained popularity through the work of Pesaran et al. (2001) for examining cointegrating relationships between variables.

ARDL has a number of advantageous features over conventional cointegration testing. These include the following that it can be used with a mixture of I(0) and I(1) data. Additionally, it is created by just one equation, which makes it simple to examine and interpret. Furthermore, variables can have different lags and different permutations can be occur. The main advantage of this method is that it applies irrespective of whether the underlying variables are I(0), I(1) or a combination of both. In such situation, the application of ARDL approach to cointegration can provide realistic and significant estimates. It is only necessary to ensure none of the variables are I(2), as such data will invalidate the methodology. Therefore, it is best to first perform unit roots, though not as a necessary condition, in order to ensure that none of the variables is I(2) or beyond, before carrying out the bound F-test (Nkoro and Uko, 2016).

The statistical background of this model will be shown in order below. The basic form of the ARDL model equation is:

Equation 1: Basic form of the ARDL model equation

$y_t = \beta_0 + \beta_1 y_{t-1} + \cdots + \beta_k y_{t-p} + \alpha_0 x_t + a_1 x_{t-1} + \cdots + a_q x_{t-q} + \varepsilon_t$ where y is the dependent variable, x is fixed regressor and e is the error term. On the other side, in terms of Bound Testing, the equation is as follows:

Equation 2: Bound Testing Equation

$$\Delta y_t = \beta_0 + \sum \beta_i \Delta y_{t-i} + \sum \gamma_j \Delta x_{1_{t-j}} + \sum \delta_k \Delta x_{2_{t-k}} + \theta_0 y_{t-1} + \theta_1 x_{1_{t-1}} + \theta_2 x_{2_{t-1}} + \varepsilon_t$$

The F-test of the hypothesis is performed using the Bound Test. While the H_0 hypothesis is like H_0: $\theta_0 = \theta_0 = \theta_0 = 0$; against the alternative that H_0 is rejected. As in conventional cointegration testing, the model is tested for the absence of a long-run equilibrium relationship between the variables. Absence equates to zero coefficients for y_{t-1}, $x_{1(t-1)}$ and $x_{2(t-1)}$ in the equation 2. A rejection of H_0 implies that there is a significant long-run relationship. (Giles, 2015)

Assuming that the Bound Test indicates cointegration, the long-run equilibrium relationship between the variables can be estimated as:

Equation 3: The long-run relationship equilibrium

$$y_t = \alpha_0 + a_1 x_{1_t} + a_2 x_{2_t} + \varepsilon_t$$

In addition to the conventional error correction model:

Equation 4: The error correction model equation

$$\Delta y_t = \beta_0 + \sum \beta_i \, \Delta y_{t-i} + \sum \gamma_j \, \Delta x_{1_{t-j}} + \sum \delta_k \, \Delta x_{2_{t-k}} + \varphi_{z_{t-1}} + \varepsilon_t$$

where z_{t-1} equals to (y_{t-1} -a_0 - $a_1 x_{1t-1}$ - $a_2 x_{2t-1}$) and the (a)s are the ordinary least squares estimates of the α in Equation 3. The long-run effects can be extracted from the unrestricted error correction model. Looking back at Equation 2 and noting that in the long-term equilibrium $\Delta y_t = 0$, $\Delta x_{1t} = \Delta x_{2t} = 0$, it can be seen at the long-run coefficients for x_1 and x_2 are $-(\theta_1/ \theta_0)$ and $-(\theta_2/ \theta_0)$, respectively.

Exact critical values for the F-test are not available for an arbitrary mix of I(0) and I(1) variables. However, Pesaran et al. (2001) supply bounds on the critical values for the distribution of the F-statistic. In each case, the lower bound is based on the assumption that all of the variables are I(0) while the upper bound is based on the assumption that all of the variables are I(1). In fact, if the computed F-statistic falls below the lower bound it can be concluded that the variables are I(0) so no cointegration is possible by definition. If the F-statistic exceeds the upper bound, it can be concluded that there is cointegration. Finally, if the F-statistic falls between the bounds, the test is inconclusive.

8.3. Models

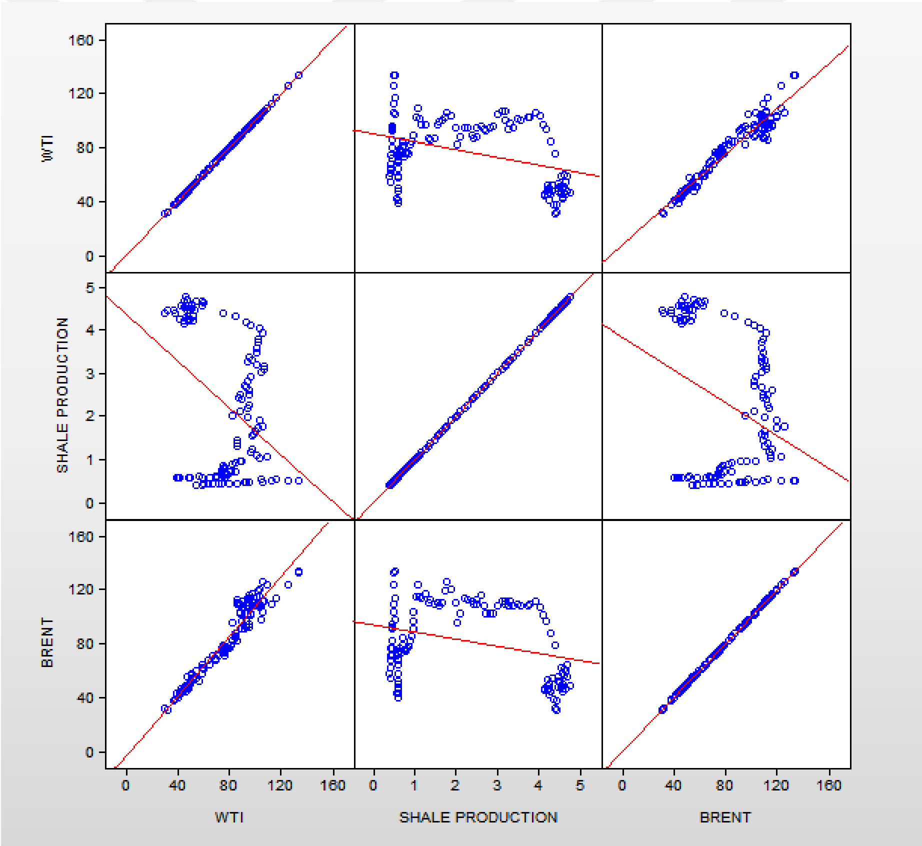
Correlation Matrix

Table 3: US shale oil production, WTI and Brent spot oil price correlation matrix

	WTI	Shale Production	Brent
WTI	1.0000	-0.3949	0.9669
Shale Production	**-0.3949**	1.0000	-0.3175
Brent	**0.9669**	**-0.3175**	1.0000

Source: Author (in Eviews)

Figure 33: US shale oil production, WTI and Brent spot oil price correlation scatterplot matrix



Source: Author (in Eviews)

As can be seen from Table 3 and Figure 33, there are negative moderate correlations between shale production and both the WTI and Brent oil prices of around 39% and 31% respectively. As expected theoretically, when shale production increases, oil prices decrease and vice versa. Although it is not possible to say that this negative relationship is valid for the scenario that if oil prices increase, the shale production decrease. However, it is a good indicator as it is more than a low correlation and WTI has more similarities than Brent, as it should do. As expected, WTI and Brent oil price benchmarks are perfectly correlated.

Phillips-Perron Unit Root Test

Table 4: Unit root test results

p-value	WTI	Brent	Shale
Level	0.28	0.34	0.73
First Difference	0.00	0.00	0.00

Source: Author (in Eviews)

Table 4 shows the probability of the unit root test for each series at level and first difference. All series have unit root at level so they are non-stationary. However, the first differences do not have unit root so they are stationary at the first difference (see Appendix 1).

ARDL Model 1

The first model was created with the WTI as the dependent variable, shale oil production as the fixed regressor and a dummy variable capturing the recent oil price shock in the fourth quarter of 2014. This has a value of 0 if the year is before July 2014 when oil prices fell dramatically and equals 1 if the year is July 2014 or later. The model selection method was Akaike info criterion (AIC), maximum dependent lags was 12 with monthly data and the ARDL (4,0) model was selected as the best model. Except for WTI (-2), all variables were significant at 10% significance level. The model was significant and has a high R^2 of 94% (see Appendix 2.1).

One of the main purposes of estimating an ARDL model is to use it as the basis for applying the Bounds Test. The null hypothesis is that there is no long-run relationship between the variables. As reported above, all the variables were stationary at first difference I(1) so the upper bound value should be set as 4.78 at 10%. Therefore, the null hypothesis can be rejected. That is, there is long-term relation between the WTI spot oil price and US shale oil production (Appendix 2.2).

Appendix 2.3 gives the ARDL Cointegrating and Long Run Form. The error-correction coefficient is negative (-0.102) and statistically significant as required. This means that the error terms are adjusted next term by 10% each time. Importantly, the long-run coefficients from the cointegrating equation are reported as well. Regarding the long-run coefficients, it can be interpreted that a 10% increase in shale oil production results in a long-term decrease of 1.6% in the WTI price and vice versa.

<u>ARDL Model 2</u>

The second model considers the Brent oil price and shale oil production. ARDL (2,2) model was selected as the best model. Two lag differences of both Brent and Shale production are significant at 10% significance level. Thus, the model is statistically significant and has a high R^2 of 95% (Appendix 4.1).

The bound test table shows that the F-statistic (3.324) is lower than the I(1) bound so the null hypothesis cannot be rejected. That is, there is no long-run relation between Brent spot oil price and US shale oil production (Appendix 4.2).

Appendix 4.3 gives the ARDL Cointegrating and Long Run Form. The error-correction coefficient is negative (-0.06) and statistically significant as required. This means the error terms are adjusted next term by 6% in each time period. Importantly, the long-run coefficients from the cointegrating equation are reported as well. Regarding the long-term coefficients, Logshale is insignificant.

<u>Diagnostic Test</u>

Table 5: Diagnostic Tests Results

	Model-1 (WTI & Shale)	Model-2 (Brent & Shale)
LM Test	**0.910**	**0.171**
RESET Test	**0.068**	**0.102**
ARCH Test	**0.293**	**0.007**
Output	Appendix 3.	Appendix 5.

Source: Author (in Eviews)

Diagnostic tests were used to assess the two models. In order to examine serial correlation and functional misspecification, Lagrange Multiplier (LM) and Ramsey RESET tests were conducted. At 10% significance level, both models have no serial correlation. While model 2 has no misspecification possibility, Model 1 may be better approximated by a polynomial or other non-linear function, although there is no misspecification risk at 5% significance level. In addition, Model 1 is homoscedastic whereas the model 2 is heteroscedastic. To correct this, the covariance method can be changed from ordinary to Huber-White.

8.4. Result

From the above analysis, we can reject null hypothesis 1 and conclude that there is a long-run relationship between the WTI spot oil price and US shale oil production at a 10% significance level. However, null hypothesis 2 cannot be rejected so we conclude that there is no long-run relationship between the Brent spot price and US shale oil production at a 10% significance level. Since this analysis shows that US shale oil production impacts WTI, which is the US-based benchmark, but not Brent, which is a European benchmark, we can also conclude that US shale production has a local rather than global effect on the oil industry.

9. CONCLUSION

Oil secures its place as a leader in energy sector throughout the history. For this reason, it is generally discussed by energy analysts when the oil will be run out. Although it is asserted that oil has the limited lifetime which ends up soon, increase in productivity by help of advanced technology and new founded recoverable reserves sustains the power of oil. Storage advantage compare to natural gas and having less carbon dioxide than coal make it preferable in worldwide. Therefore, shale oil was created as a new player which is indeed one and the same with conventional oil, but it was introduced as a competitor against conventional. In fact, it is related to the conflict that occurs between countries who have sufficient conventional oil reserves or not. However, it is concluded in this study that shale oil cannot entirely compete with conventional oil in near future as long as it has several disadvantages. For now, it can be predominantly operated in the US and needs to be dispersed around the rest of the world. Furthermore, the majority of the production output comes from the tight oil which is more productive and easier for extraction than oil shale or sands.

This study showed that there is no significant relationship between US shale oil production and the Brent global oil benchmark price. However, it did find such a relationship between US shale production and the WTI spot price. Given that both shale oil production and the WTI spot price are centred on the US, we can infer that US shale oil production has not yet affected global oil prices. Nevertheless, it influences the oil industry and, more importantly, it is believed that US shale oil has a bright future given the vast reserves. However, it still needs to overcome several disadvantages such as high production costs and decreasing productivity ratios. After it deals with these difficulties, it may perhaps be considered as revolutionary or creating a significant long-term difference in the global oil industry rather than as a temporary alternative to conventional oil.

9.1. Outlook for Shale Oil

The growth of shale oil has various economic effects. It is expected that shale oil production capacity will reach 14 million barrels per day or 12 percent of total oil supply by 2035. Because of adequate oil production, oil prices can be expected to fall, which may depress GDP in major oil exporters, such as Saudi Arabia and Russia, by 4-10 percent even if they do not begin shale oil production. In addition, it will decrease the dependency of shale producer countries on oil imports and weaken the current dominance of OPEC countries. It will also change the oil industry. For instance, companies may shift to onshore shale oil production instead of complicated offshore extraction while low oil prices due to the shale oil boom may encourage other sectors like automotive, airlines or petrochemicals to switch the inputs for oil products as they become more affordable (PWC, 2013).

The future of shale oil should not be envisaged only concerned with technological advancement but also in terms of private sector investments, legal regulations and market structure in order to predict how the industry will develop. Firstly, shale producer companies should be able to find the required financial resources to maintain drilling activities sufficiently even in difficult situations like 2014. Secondly, before starting new projects in a shale producer country, its approach to royalties, taxes or carbon regulations should be discussed properly. Lastly, the shale industry should analyse the determinants of the energy mix and motivate the sector about the advantages of shale oil (Ekins et al., 2015).

10. APPENDICES

1.1.

Null Hypothesis: LOGWTI has a unit root
Exogenous: Constant
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		Adj. t-Stat	Prob.*
Phillips-Perron test statistic		-1.999961	0.2866
Test critical values:	1% level	-3.482879	
	5% level	-2.884477	
	10% level	-2.579080	

*MacKinnon (1996) one-sided p-values.

Residual variance (no correction)	0.008826
HAC corrected variance (Bartlett kernel)	0.016266

1.2.

Null Hypothesis: D(LOGWTI) has a unit root
Exogenous: Constant
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		Adj. t-Stat	Prob.*
Phillips-Perron test statistic		-7.547426	0.0000
Test critical values:	1% level	-3.483312	
	5% level	-2.884665	
	10% level	-2.579180	

*MacKinnon (1996) one-sided p-values.

Residual variance (no correction)	0.007694
HAC corrected variance (Bartlett kernel)	0.008089

1.3.

Null Hypothesis: LOGBRENT has a unit root
Exogenous: Constant
Bandwidth: 4 (Newey-West automatic) using Bartlett kernel

		Adj. t-Stat	Prob.*
Phillips-Perron test statistic		-1.875672	0.3428
Test critical values:	1% level	-3.482879	
	5% level	-2.884477	
	10% level	-2.579080	

*MacKinnon (1996) one-sided p-values.

Residual variance (no correction)	0.008525
HAC corrected variance (Bartlett kernel)	0.016197

1.4.

Null Hypothesis: D(LOGBRENT) has a unit root
Exogenous: Constant
Bandwidth: 4 (Newey-West automatic) using Bartlett kernel

		Adj. t-Stat	Prob.*
Phillips-Perron test statistic		-7.397119	0.0000
Test critical values:	1% level	-3.483312	
	5% level	-2.884665	
	10% level	-2.579180	

*MacKinnon (1996) one-sided p-values.

Residual variance (no correction)	0.007379
HAC corrected variance (Bartlett kernel)	0.007405

1.5.

Null Hypothesis: LOGSHALE has a unit root
Exogenous: Constant
Bandwidth: 9 (Newey-West automatic) using Bartlett kernel

		Adj. t-Stat	Prob.*
Phillips-Perron test statistic		-1.053445	0.7324
Test critical values:	1% level	-3.482879	
	5% level	-2.884477	
	10% level	-2.579080	

*MacKinnon (1996) one-sided p-values.

Residual variance (no correction)	0.000457
HAC corrected variance (Bartlett kernel)	0.002027

1.6.

Null Hypothesis: D(LOGSHALE) has a unit root
Exogenous: Constant
Bandwidth: 8 (Newey-West automatic) using Bartlett kernel

		Adj. t-Stat	Prob.*
Phillips-Perron test statistic		-8.598854	0.0000
Test critical values:	1% level	-3.483312	
	5% level	-2.884665	
	10% level	-2.579180	

*MacKinnon (1996) one-sided p-values.

Residual variance (no correction)	0.000380
HAC corrected variance (Bartlett kernel)	0.000727

2.1.

Dependent Variable: LOGWTI
Method: ARDL
Date: 08/26/17 Time: 18:47
Sample (adjusted): 2007M05 2017M07
Included observations: 123 after adjustments
Maximum dependent lags: 12 (Automatic selection)
Model selection method: Akaike info criterion (AIC)
Dynamic regressors (12 lags, automatic): LOGSHALE
Fixed regressors: DUMMY C
Number of models evalulated: 156
Selected Model: ARDL(4, 0)
Note: final equation sample is larger than selection sample

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LOGWTI(-1)	1.233215	0.091776	13.43716	0.0000
LOGWTI(-2)	-0.115468	0.143356	-0.805462	0.4222
LOGWTI(-3)	-0.366855	0.142905	-2.567119	0.0115
LOGWTI(-4)	0.146525	0.088575	1.654246	0.1008
LOGSHALE	-0.016635	0.009089	-1.830188	0.0698
SER01	-0.047828	0.018033	-2.652172	0.0091
C	0.472067	0.130360	3.621266	0.0004

R-squared	0.944305	Mean dependent var	4.295214
Adjusted R-squared	0.941424	S.D. dependent var	0.344513
S.E. of regression	0.083381	Akaike info criterion	-2.075572
Sum squared resid	0.806472	Schwarz criterion	-1.915529
Log likelihood	134.6477	Hannan-Quinn criter.	-2.010563
F-statistic	327.7935	Durbin-Watson stat	1.997838
Prob(F-statistic)	0.000000		

2.2.

ARDL Bounds Test
Date: 08/26/17 Time: 18:49
Sample: 2007M05 2017M07
Included observations: 123
Null Hypothesis: No long-run relationships exist

Test Statistic	Value	k
F-statistic	6.715786	1

Critical Value Bounds

Significance	I0 Bound	I1 Bound
10%	4.04	4.78
5%	4.94	5.73
2.5%	5.77	6.68
1%	6.84	7.84

2.3.

ARDL Cointegrating And Long Run Form
Dependent Variable: LOGWTI
Selected Model: ARDL(4, 0)
Date: 08/26/17 Time: 18:48
Sample: 2007M01 2017M07
Included observations: 123

Cointegrating Form

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOGWTI(-1))	0.335798	0.086461	3.883811	0.0002
D(LOGWTI(-2))	0.220330	0.090841	2.425456	0.0168
D(LOGWTI(-3))	-0.146525	0.088575	-1.654246	0.1008
D(LOGSHALE)	-0.016635	0.009089	-1.830188	0.0698
D(SER01)	-0.047828	0.018033	-2.652172	0.0091
CointEq(-1)	-0.102583	0.028805	-3.561335	0.0005

Cointeq = LOGWTI - (-0.1622*LOGSHALE -0.4662*SER01 + 4.6018)

Long Run Coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGSHALE	-0.162160	0.087470	-1.853880	0.0663
SER01	-0.466232	0.155457	-2.999107	0.0033
C	4.601794	0.114643	40.140370	0.0000

3.1.
Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.500215	Prob. F(12,104)	0.9103
Obs*R-squared	6.711814	Prob. Chi-Square(12)	0.8761

3.2.
Ramsey RESET Test
Equation: UNTITLED
Specification: LOGWTI LOGWTI(-1) LOGWTI(-2) LOGWTI(-3) LOGWTI(-4)
LOGSHALE SER01 C
Omitted Variables: Powers of fitted values from 2 to 3

	Value	df	Probability
F-statistic	2.739133	(2, 114)	0.0689

F-test summary:

	Sum of Sq.	df	Mean Squares
Test SSR	0.036978	2	0.018489
Restricted SSR	0.806472	116	0.006952
Unrestricted SSR	0.769494	114	0.006750

3.3.

Heteroskedasticity Test: ARCH

F-statistic	1.201173	Prob. F(12,98)	0.2932
Obs*R-squared	14.23276	Prob. Chi-Square(12)	0.2861

4.1.

Dependent Variable: LOGBRENT
Method: ARDL
Date: 08/26/17 Time: 19:23
Sample (adjusted): 2007M03 2017M07
Included observations: 125 after adjustments
Maximum dependent lags: 12 (Automatic selection)
Model selection method: Akaike info criterion (AIC)
Dynamic regressors (12 lags, automatic): LOGSHALE
Fixed regressors: DUMMY C
Number of models evalulated: 156
Selected Model: ARDL(2, 2)
Note: final equation sample is larger than selection sample

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LOGBRENT(-1)	1.279689	0.084383	15.16528	0.0000
LOGBRENT(-2)	-0.341596	0.082285	-4.151381	0.0001
LOGSHALE	-0.245911	0.443101	-0.554977	0.5800
LOGSHALE(-1)	-0.636654	0.636580	-1.000116	0.3193
LOGSHALE(-2)	0.867227	0.441212	1.965558	0.0517
SER01	-0.063713	0.019532	-3.262029	0.0014
C	0.329990	0.131013	2.518762	0.0131

R-squared	0.953021	Mean dependent var	4.347679
Adjusted R-squared	0.950632	S.D. dependent var	0.369126
S.E. of regression	0.082016	Akaike info criterion	-2.109446
Sum squared resid	0.793732	Schwarz criterion	-1.951060
Log likelihood	138.8404	Hannan-Quinn criter.	-2.045102
F-statistic	398.9597	Durbin-Watson stat	2.046864
Prob(F-statistic)	0.000000		

4.2.

ARDL Bounds Test
Date: 08/26/17   Time: 19:24
Sample: 2007M03 2017M07
Included observations: 125
Null Hypothesis: No long-run relationships exist

Test Statistic	Value	k
F-statistic	3.324864	1

Critical Value Bounds

Significance	I0 Bound	I1 Bound
10%	4.04	4.78
5%	4.94	5.73
2.5%	5.77	6.68
1%	6.84	7.84

4.3.

ARDL Cointegrating And Long Run Form
Dependent Variable: LOGBRENT
Selected Model: ARDL(2, 2)
Date: 08/26/17   Time: 19:23
Sample: 2007M01 2017M07
Included observations: 125

Cointegrating Form

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOGBRENT(-1))	0.341596	0.082285	4.151381	0.0001
D(LOGSHALE)	-0.245911	0.443101	-0.554977	0.5800
D(LOGSHALE(-1))	-0.867227	0.441212	-1.965558	0.0517
D(SER01)	-0.063713	0.019532	-3.262029	0.0014
CointEq(-1)	-0.061906	0.030487	-2.030611	0.0445

Cointeq = LOGBRENT - (-0.2477*LOGSHALE -1.0292*SER01 + 5.3305)

Long Run Coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGSHALE	-0.247748	0.174558	-1.419292	0.1585
SER01	-1.029183	0.510574	-2.015738	0.0461
C	5.330465	0.623718	8.546271	0.0000

5.1.

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.788517	Prob. F(2,116)	0.1718
Obs*R-squared	3.739256	Prob. Chi-Square(2)	0.1542

5.2.

Ramsey RESET Test
Equation: UNTITLED
Specification: LOGBRENT LOGBRENT(-1) LOGBRENT(-2) LOGSHALE
LOGSHALE(-1) LOGSHALE(-2) SER01 C
Omitted Variables: Powers of fitted values from 2 to 3

	Value	df	Probability
F-statistic	2.327858	(2, 116)	0.1020

F-test summary:

	Sum of Sq.	df	Mean Squares
Test SSR	0.030628	2	0.015314
Restricted SSR	0.793732	118	0.006727
Unrestricted SSR	0.763105	116	0.006578

5.3.

Heteroskedasticity Test: ARCH

F-statistic	2.461826	Prob. F(12,100)	0.0074
Obs*R-squared	25.76955	Prob. Chi-Square(12)	0.0116

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