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Techno-economic assessment of the conditions for the development of a potential unconventional gas and oil industry

Review of experiences outside Europe and analysis of the European potential

D'Amato A., Shastri A., Spathopoulos F., Spisto A., Zoli M.

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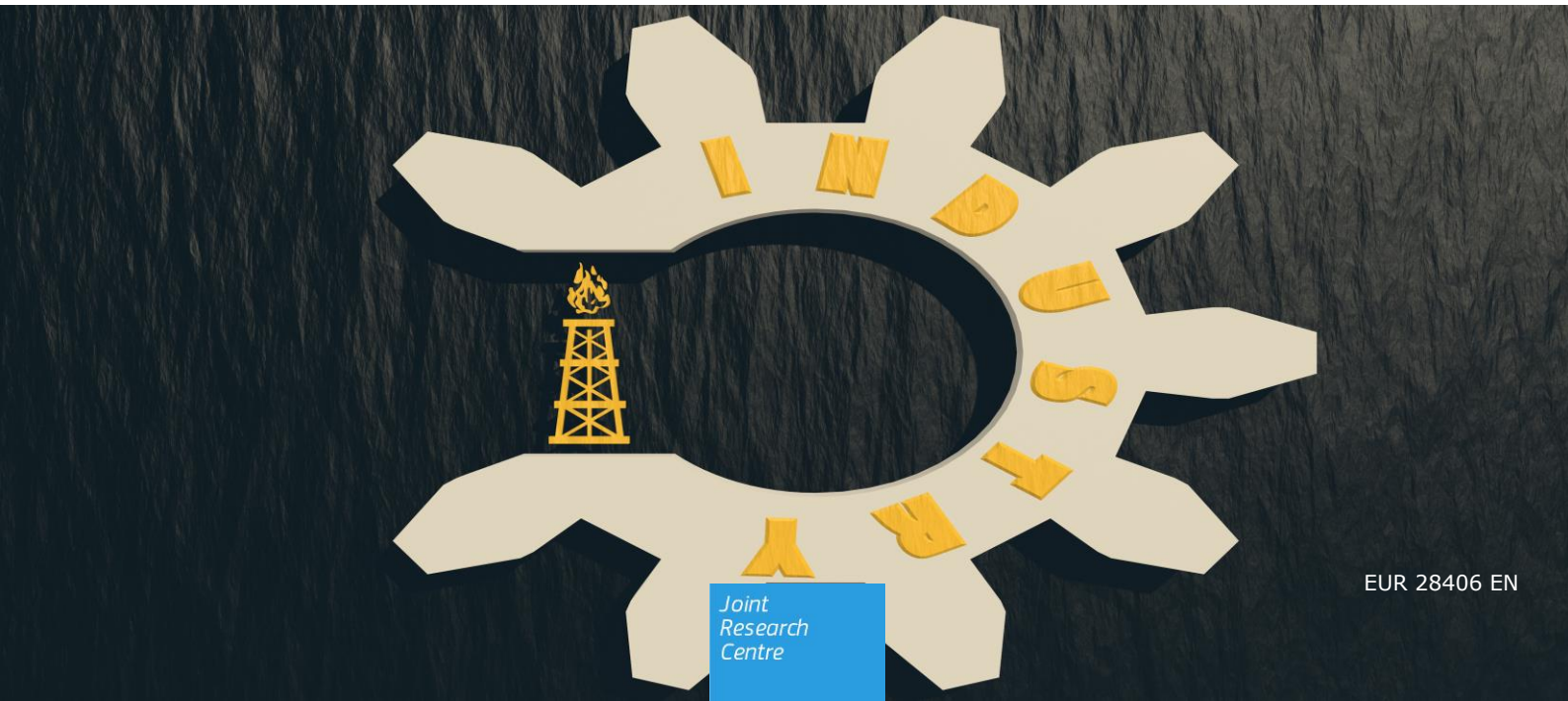

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Title *Techno-economic assessment of the conditions for the development of a potential unconventional gas and oil industry Review of experiences outside Europe and analysis of the European potential*

Abstract
The aim of this report is to provide a review of the key factors that have influenced the development of the unconventional hydrocarbon industry in selected countries outside the EU. The study extends the analysis to investigate the potential unconventional hydrocarbon industry development in Europe.

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Foreword

This report is part of the consultancy service provided by Alessio D'Amato, Ashutosh Shastri, Foivos Spathopoulos, and Mariangela Zoli, for the Joint Research Centre Directorate C for Energy, Transport and Climate within the tender JRC/PTT/2015/F.3/0056/NC, NL-Petten: "Study on the economic impacts on energy markets from the worldwide and potential European exploitation of unconventional gas and oil".

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Executive summary

In this study, we provide an introductory overview, based on existing literature and on industry knowledge, on the key factors that have influenced the development of the unconventional hydrocarbon industry in selected countries, namely US, China, Australia and Canada. The analytical framework used in this work connects the facts and variables that have shaped each country's experience to relevant segments of the supply chain.

The same approach is then used to understand the potential of an industrial development of the unconventional hydrocarbon sector in Europe, by analysing the existing technology, know how, and the features of correlated sectors that could support the emergence of this type of industry in Europe.

As it emerges from the analysis of the experiences in countries outside Europe, drivers and barriers to the industrial development change according to the economic culture in each region, the infrastructure endowment of the gas and oil sector, the availability of related industries and services in support of the unconventional resources exploitation, and the financial support or constraints from the public and private sectors.

The analysis for Europe aimed at assessing the conditions for the potential development of an unconventional hydrocarbon industry by analysing the features of the sector, not only in those European countries with an estimated resource potential but also in other countries, which, for example, may have an advantage in the provision of correlated services in specialized sectors.

A number of open issues exist in relation to the development of an unconventional hydrocarbon industry in Europe, such as the skill building strategy for EU member states, the development of institutions for imparting education in this thematic area, the availability of deeper resource knowledge, the features of existing value chains, etc.

An important consideration is also linked to the model for the unconventional hydrocarbon industrial development that may be chosen in Europe. Several crucial questions arise in this respect: e.g. what is the correct degree of centralisation? What kinds of regional specialisations can be developed on the basis of existing infrastructures and skills base?

It is perhaps appropriate to conclude that our assessments of the UH value chain elements, of the cost and economic structure and of the required skills to develop an industrial base suggest that the areas in which more knowledge is still needed include, amongst others:

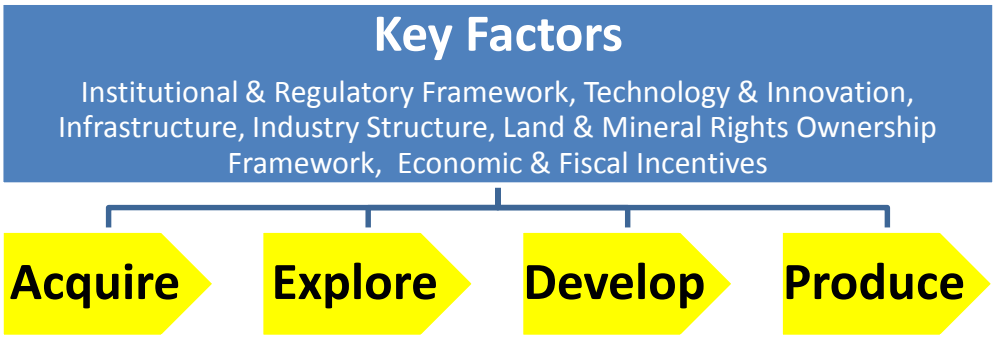
- A more detailed study aimed at understanding the success of EU players in the US Unconventional Industry and at exploring potential models for engagement.
- A synthesis study of the assessments made by member states geological surveys to assess the UH potential.
- A cross functional study to determine the potential role that the UH industry, if launched, could be expected to play in an evolving EU energy system.

Introduction

The aim of this chapter is to provide an introductory overview, based on existing literature and on industry knowledge, on the key factors that have influenced the development of the unconventional hydrocarbon (UH thereafter) industry in selected countries, namely US, China, Australia and Canada. The focus is therefore to understand the experience of UH industrial development in those countries outside EU, according to a number of important events/changes and key elements.

To provide a framework of analysis, we will connect each identified driver/barrier of the UH development to the relevant upstream part of the UH supply chain (Ernst and Young (2014a))[1]. Accordingly, key facts and variables relevant for the experience of each country will be related to the segment of the supply chain which is mostly affected. This approach aims at understanding the characteristics of the UH industrial development, starting from its main processes (Figure 1).

Figure 1. The analytical approach: key factors in the UH industry development and the standard segments of the supply chain of hydrocarbon resources



Further, in order to be able to grasp the features of the UH sector development and to study the evolution of UH industry in selected countries, we refer to the Industry Life Cycle (ILC) Theory. This theory was developed to explain the different stages of industry development by considering technological innovations, product innovations and changes in industry structure (Peltoniemi, 2011; Gustafsson et al., 2016). Broadly speaking, the following stages of evolution can be identified in the development process of each industry, with specific empirical regularities accompanying each different phase:

1) *Industry emergence,* defined as "the product of a technological opportunity which encourages the entry of a large number of firms and the introduction of various product innovations". The industry emergence process can be further articulated in three sub-phases:
   a) initial stage: the industry emergence process is set;
   b) co-evolutionary stage: the different elements of the emerging industry co-evolve and converge to form a new industry;
   c) (early) growth stage: the sales of the newly formed industry take off.
2) *Transition to industry maturity*, which is signalled by a shift across different kinds of R&D and a shake-out in firm numbers. In this phase, the following can be observed:
   a) Technological regimes hint at unexploited opportunities; economies of scale and past learning by doing advantages are exploited;
   b) Shake-out: market shares are reallocated to the most capable producers, and others exit the industry;

[1]See also IHS Economics (2014).

c) Effects of mature industries on feeding emerging industries with competence, entrepreneurs, employees and spin-offs (enabling the birth of new and technologically related industries).

Clearly, the different phases have no clear-cut boundaries and they may be quite industry-specific. In particular, the ILC analysis was initially developed to characterize especially manufacturing industries, where both product and process innovations are possible. In the UH industry, at the opposite, the product is homogeneous and opportunities for product innovation are absent; in this context, the only kind of innovations that can lead the evolution of the industry are process innovations (Wang and Xue, 2016). Accordingly, some adjustments have to be made in order to accommodate the theory to our specific industry case study (Figure 2).

Figure 2. Evolution of UH industry according to the paradigm of ILC theory (Peltoniemi, 2011; Gustafsson et al., 2016)

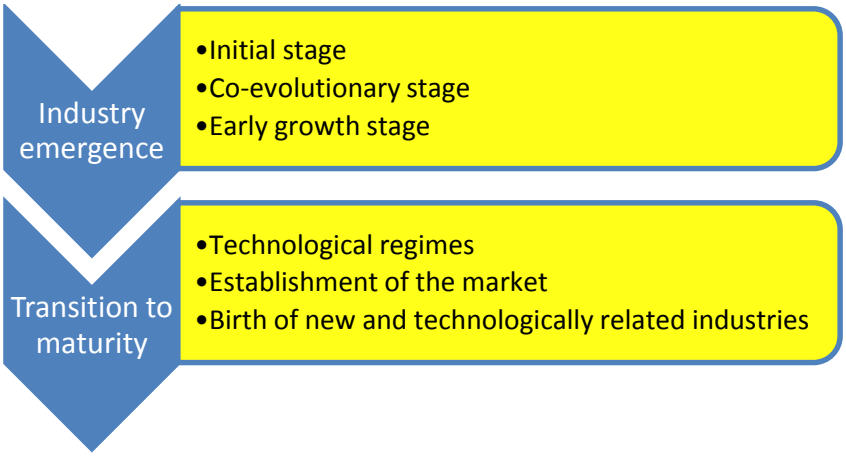


Figure 2 adapts the theoretical framework of industry emergence to the case of the experiences of UH industry development in the countries investigated in this report. The ultimate goal of this analysis is to understand the evolution of the UH industry by identifying the facts and key factors in correspondence with each segment of the supply chain of UH development.

While we have addressed the analyses from an integrated UH perspective, the sectoral activity so far has been concentrated within the shale gas, tight oil and coal bed methane (CBM) zone of the UH spectrum although with more emphasis on shale gas. In the next four Chapters, we explore the main factors that have affected the different development stages of the industry in different countries: the US, Australia, Canada and China. Our analysis is based on a wide review of the scientific literature, as well as of institutional, industry and stakeholders' reports.

In the following, we consider the selected countries separately and, for each of them, we first provide a brief introduction, which explains the resource potential and the current situation. Then we examine the main key factors that have characterized (or characterize) the exploitation of UH resources in each country and their role in the industry supply chain. This analysis provides the basis for a discussion of the different stages of the industry development in each country.

Finally, the outcome of the analysis for non-EU countries is applied to understand the potential of UH industrial development in the European countries and to identify the main hurdles and challenges.

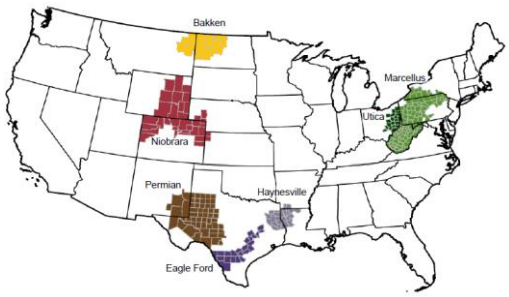
Unconventional hydrocarbons development in selected countries

2. United States

2.1 Resource potential and economic analysis

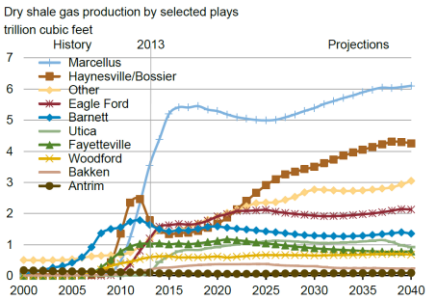
Over the past decades, the production of shale gas and oil has expanded particularly rapidly in the United States. Tight oil and shale gas production characterizes several areas in the US, but the most prolific regions, accounting for the great majority of oil production and natural gas production growth are located in the Lower 48 states[2] (see Figure 3).Figure 4 shows projections to 2040 for production in selected plays.

Figure 3. Key tight oil and shale gas regions



Source EIA, 2016a, p.1

Figure 4. Shale gas production projections in selected plays



Cumulative production
trillion cubic feet

	(1990-2013)	(2014-2040)
Marcellus	8	147
Haynesville/Bossier	9	79
Other	9	63
Eagle Ford	2	52
Barnett	13	38
Utica	0	27
Fayetteville	5	26
Woodford	3	17
Bakken	1	8
Antrim	3	2
Total	52	459

Source: Staub, 2015, p. 20

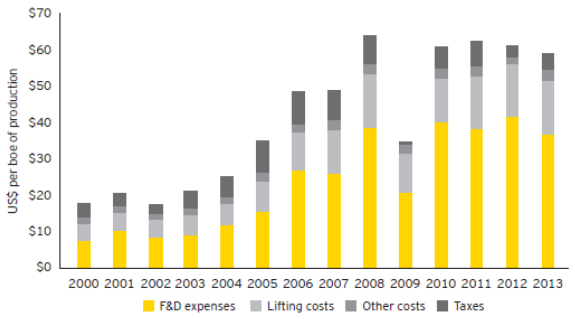
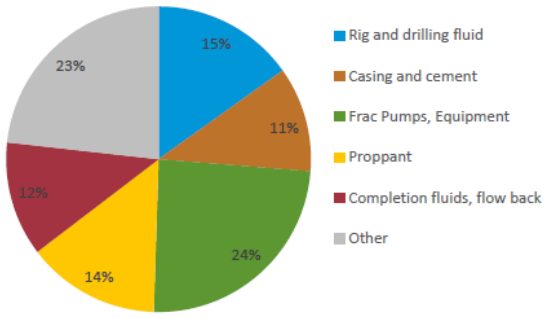
As far as estimates of technically recoverable shale oil and gas resources are concerned, they have continuously increased over the last decades, as more shale formations have entered into production. EIA estimates that the US has approximately 622.5 trillion cubic feet of unproved technically recoverable shale natural gas resources and 78.2 billion barrels of technically recoverable tight oil resources[3], leading the US to be ranked second globally after Russia in shale oil resources and fourth globally after China, Argentina and Algeria in shale natural gas resources[4].

By focusing on producing firms, it is worth to note that upstream oil and gas spending in the US increased rapidly with the beginning of the so-called "shale" revolution in the middle of the last decade. In particular, upstream finding and development spending (excluding spending on the acquisition of proved reserves) increased by an average of 13% per year between 2004 and 2013, while operating/production costs (lifting costs) increased by an average of 10% per year in the same period (Ernst and Young, 2014b). Globally, notional full-cycle costs have averaged over US$60 per boe since 2008 (with the exception of the period of the financial crisis in 2009), as shown by Ernst and Young (2014b) and reported in Figure 5.

[2] The seven basins are the Bakken in North Dakota and Montana; the Eagle Ford in South Texas; the Haynesville in East Texas and northern Louisiana; the Marcellus in Virginia, West Virginia, Ohio and Pennsylvania; the Niobrara in Colorado and Wyoming; the Permian in West Texas/eastern New Mexico and Utica.

[3] https://www.eia.gov/analysis/studies/worldshalegas/ (last accessed 07/08/2016).

[4] For more details, see http://www.eia.gov/todayinenergy/detail.cfm?id=14431 (last accessed 07/08/2016).

Figure 5. US full-cycle upstream costs (per flowing boe of production)	*Figure 6. Breakdown of cost for U.S. onshore oil and natural gas drilling & completion (%)*
	
Ernst and Young, 2014b; p.1	Source: EIA, 2016, p. 3

A recent report from Ernst and Young in 2016 shows that, despite the increase in the combined oil and gas production (+6% in 2015) and a reduction in production costs (-12% in 2015, mainly driven by a 45% drop in production taxes), companies revenues have been reduced by the low price environment in 2014 (**Error! Reference source not found.**).

Table 1. Revenues and results of operations

US – revenues and results of operations (millions) (a)

	2011	2012	2013	2014	2015
Revenues	$ 179,886.4	$ 174,103.1	$ 197,475.4	$ 220,449.6	$ 129,794.1
Production costs (b)	49,297.6	54,044.1	59,368.0	64,070.9	56,582.9
Exploration expense	5,515.0	6,662.8	7,485.5	9,173.1	12,450.8
DD&A	45,422.1	56,595.5	64,904.7	74,543.9	81,586.5
Impairments	4,485.1	19,689.1	7,096.6	23,373.4	141,811.9
Other expenses (c)	10,484.7	3,207.4	7,376.6	6,658.7	7,541.0
Pre-tax results of operations	$ 64,682.1	$ 33,904.2	$ 51,244.1	$ 42,629.7	$ (170,178.9)
Income taxes	22,048.6	11,463.3	17,298.0	14,299.3	(58,183.5)
Results of operations	$ 42,633.5	$ 22,440.9	$ 33,946.0	$ 28,330.4	$ (111,995.4)

(a) Includes the 50 largest companies based on 2015 US end-of-year oil and gas reserves. Activity related to acquired companies has also been reflected as described in the appendix.
(b) Includes production taxes and transportation costs for companies that separately disclose these expenses.
(c) Includes asset retirement obligation accretion and production-related general and administrative costs for companies that separately disclose these expenses.

Source: Ernst and Young, 2016; p. 4

By focusing on well development costs in more detail, a recent report commissioned by the EIA to IHS Global Inc. evaluates upstream drilling and production costs in five onshore regions (the Bakken, Eagle Ford, and Marcellus plays and two plays, Midland and Delaware, within the Permian basin) as well as the offshore federal Gulf of Mexico. In general, well development costs tend to be lowered by increased efficiency in drilling and completion and enlarged by longer wells and more complex completions, while trends in oil and natural gas prices affect markets for drilling and completion services through their effect on drilling activity. According to the report, average well drilling and completion costs in five onshore basins in 2015 were between 25% and 30% below their level in 2012, when costs per well were at their highest point (EIA, 2016b). Within upstream costs, five categories accounted for more than three quarters of the total costs for drilling and completion, as it is shown by Figure 6.

Clearly, as discussed in the EIA/IHS report, these costs have changed over time, reflecting best practices, improved drilling efficiency and well design. Further, wells in different basins have different costs mainly due to differences in geology, well depth, and water disposal options. For instance, Bakken wells are particularly costly because of their lengths and the use of high-cost artificial and resin coated proppants. At the opposite,

Marcellus wells are the least costly, because the wells are "shallower and use less expensive natural sand proppant"[5] (EIA, 2016; p. 4).

Another important aspect that characterized the success story of the shale gas revolution in the US has been the explosion of UH related activities, which led to a multiplicity of economic benefits, in terms, for instance, of taxes and royalties, job creation, and value added (IHS, 2012).

2.2. Development of the UH industry in the US: drivers and barriers

Even though shale basins in US plays are different and "the development of shale gas resources in each of these areas faces potentially unique opportunities and challenges" (Ground Water Prot. Council & All Consulting, 2009), it is possible to identify a common set of factors that concurred to drive the UH revolution in the US.

UH, in particular shale gas, exploitation has a long history in the US, as the first commercial well was drilled in New York in the late 1820s. Nevertheless, in the early 1980s, production from nearly 10,000 wells was still quite limited (from 3 bcm to 4 bcm per year) and increased very gradually. The large-scale development started at the beginning of 2000, stimulated by relatively high natural gas prices, which encouraged the drilling of vertical wells in conventional natural gas plays and some development of coalbed methane. The shale boom began in the Barnett shale play (located in the Fort Worth Basin of north central Texas), the first where experimentation of newer technologies and well designs resulted in consistently higher productivity (IEA, 2009). Specifically, the experience of the Barnett play proved that employing modern unconventional drilling and completion techniques, such as horizontal drilling and complex hydraulic fracturing (fracking), could lead to the successful and profitable development of shale gas. The success of the Barnett Shale grabbed the industry attention, and drilling activities increased more than ten-fold between 2000 and 2007, spreading to other areas in North America. Following the Barnett experience, the Fayetteville Shale development began by companies that applied the same techniques to similar formations situated in the Arkoma Basin of northern Arkansas and eastern Oklahoma (Sakmar, 2011). Specifically, Southwestern Energy, a relatively minor company in the oil and gas industry at the beginning of the 2000s, discovered that the new fracking techniques adopted in the Barnett Shale could be used also at the Fayetteville Shale. Having quietly invested to do research in the Arkoma Basin and to purchase leasehold positions in the area, Southwestern held most of the drilling areas in the shale, leaving other big companies (such as Chesapeake Energy and Shell Oil) in a marginal position. Southwestern Energy invested heavily in the shale play (over $800 million and $1 billion annually) between 2007 and 2013[6].

Hence, from the early 2000s, the key plays contributing to the rise in shale gas production have been the Barnett shale, the Haynesville-Bossier shale in eastern Texas and northwestern Louisiana, the Fayetteville shale, and, to a lesser extent, the Woodford shale in Oklahoma's Anadarko and Arkoma basins. After 2009, significant contributions to national production came from the Marcellus shale of the Appalachian basin and the Eagle Ford shale of southern Texas (NETL, 2013).

The evolution of shale gas and oil industries was clearly driven by trends in energy markets, and, in particular, by the increase in natural gas prices from 2001 through 2008. The oil prices rebound which followed the collapse in 2008 drove operators to explore new opportunities and to search for oil plays and gas plays.

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[5]The EIA/IHS study provides a very detailed analysis of different upstream costs in major US basins at sub-play level. For further details, see EIA (2016).

[6]See http://talkbusiness.net/2014/07/economic-impact-of-fayetteville-shale-play-ongoing-after-a-decade/ and http://www.oilshalegas.com/fayettevilleshale.html (last accessed 13/11/2016).

Nevertheless, together with international oil and gas price trends, several other factors have driven the successful development of shale gas plays in the US. According to IEA (2009), for instance, a list of those factors should include:

- early geological knowledge;
- rapid leasing of large prospective areas;
- experimentation and development of drilling and completion techniques
- awareness and acceptance by local communities;
- adequate network of infrastructures.

Several industry experts, entities involved in UH development as well as scientific articles have tried to identify other relevant factors. According to some observers, the most important factor that made it profitable for firms to produce large quantities of shale gas was technology innovation, resulting from both government research and development programs and the oil industry initiatives (Wang and Krupnick, 2013; Maugeri, 2013; Trembath et al., 2012; Montgomery and Smith, 2010; NETL, 2007; among others). Other contributing factors are identified in private land and minerals ownership, market structure, water availability, natural gas pipeline infrastructure and the associated open-access policy (Alquist and Guénette, 2014; Wang and Krupnick, 2013; Stevens, 2010, 2012).

Maugeri (2013) emphasizes instead the central role played in the early stage of UH development by drilling intensity[7], considering the relevance of bringing on line rapidly as many wells as possible, due to the dramatic decline in production that follows the early months of activity in each new well. The author reports the example of Bakken-Three Forks play, where by December 2012 about 90 new producing wells per month were needed just to maintain oil production of 770,000 barrels per day. Drilling intensity led US shale oil plays to increase the number of wells brought online from a few hundred before 2011 to more than 4,000 in 2012 (Maugeri, 2013).

According to Rogers (2011), one of the most important forces behind the expansion of UH activity has been the service sector capacity, in particular the development of drilling and completion service providers, investments in new, high-powered plant and equipment, as well as the rapid mobilization of skilled resources.

Table 2. A summary of the main drivers in the UH industry development in the US

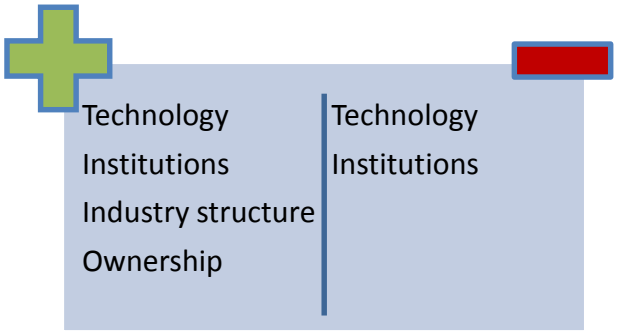
Drivers	Source
Early geological knowledge; rapid leasing of large prospective areas; experimentation and development of drilling and completion techniques; awareness and acceptance by local communities; adequate network of infrastructures	IEA (2009)
Government applied R&D investments programs (i.e. DOE's Unconventional Gas Research (UGR) Programs) technological demonstration and tax policy support the oil industry initiatives	Wang and Krupnick, (2013); Trembath et al. (2012); Montgomery and Smith, (2010); NETL (2007)
Private land and minerals ownership, market structure, water availability, natural gas pipeline infrastructure and associated open-access policy	Alquist and Guénette (2014); Wang and Krupnick (2013); Stevens (2010, 2012).
Drilling intensity in the early stage of UH development	Maugeri, (2013)

[7] Maugeri (2013; p. 5) states that "So far "drilling intensity" has been the key factor that has made possible to recover more oil than previously expected from the huge but hostile shale/tight oil formations existing in the U.S, thereby supporting the boom of the country's shale oil production".

Service sector capacity, investments in high-powered plant and equipment, rapid mobilization of skilled resources	Rogers (2011)
Domestically focused, independent upstream companies supported by a well-established and adaptable service sector	Stevens (2012) Maugeri (2013) Kefferpütz (2010)

By summarizing contributions provided by the literature (Table 2), in the following we will discuss in detail some of the main factors that have characterized the UH revolution in the US, by highlighting their enabling or limiting role. These factors are summarized in Figure 7, where the positive (or negative) impact of each factor is represented by a plus (minus) sign.

Figure 7. Drivers / Barriers of UH Industry Development - US

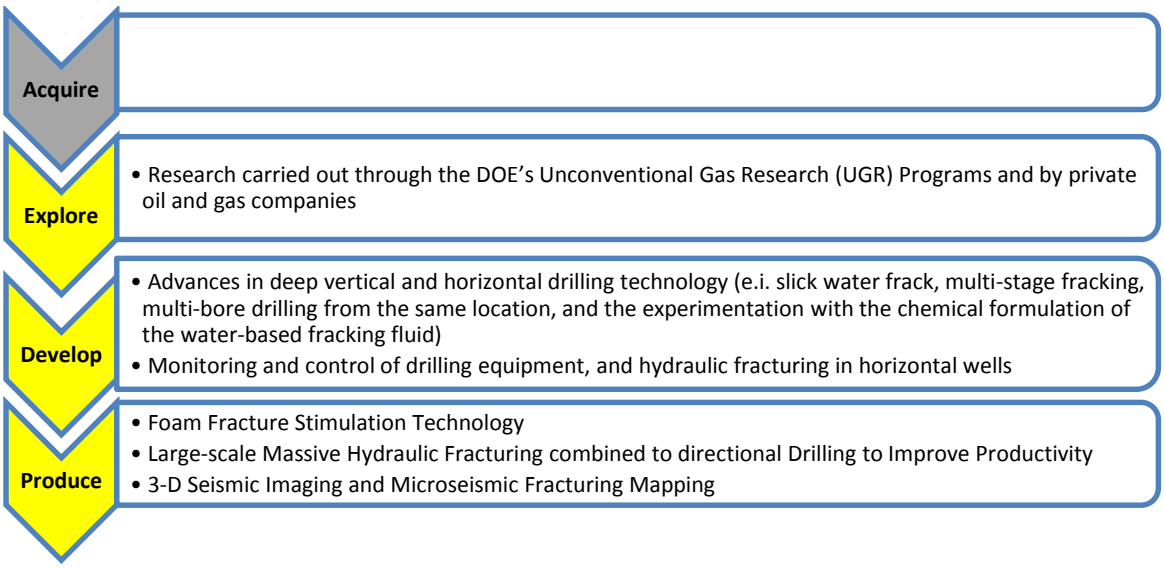


2.1 Technology and innovation

Technological innovations combined with experience in drilling and tough geological knowledge are among the most important factors that settled the appropriate conjuncture for UH industry emergence and expansion in the US. The US operators could benefit from a well-established conventional oil and gas supply chain, allowing them to exploit existing capabilities and knowledge. Indeed, modern drilling for UH resources requires much more sophisticated extraction technologies compared to conventional ones, and without major technological breakthroughs, the shale boom would not have occurred.

Technological innovations can be considered particularly relevant for the phases of the upstream part of the supply chain highlighted in Figure 8 (relevant supply chain phases are in yellow, while some of the main features are reported in each box).

Figure 8. Supply chain phases mainly affected by technology and innovation specificities in the US



Even though the possibility of extracting natural gas embedded in deposits of shale deep in the earth had been known for many years, commercial production was quite uneconomical until the most recent technology innovations. In the late 1990s, the development of shale gas was made economical by a series of technological advances: advances in deep vertical drilling technology, horizontal drilling technology, down-hole telemetry, monitoring and control of drilling equipment, and hydraulic fracturing in horizontal wells (Joskow, 2013). As noted above, the first applications of these technological development were introduced in the Barnett shale play in the early years of the century, increasing the number of operating horizontal wells (from 400 in 2004 to 10,000 in 2010) and production from almost nothing in 2000 to about five billion cubic feet per day today (Joskow, 2013).

These technological advances have been made possible by massive investments realized by both the government and private oil and gas companies. In the following, we will review some of the main interventions, by distinguishing the role of public and private investment programs.

- The technological boost from government fiscal and R&D programs

Several observers recognize that government support (in terms of applied R&D investments, technological demonstration and tax policy support) has been essential to stimulate technologies necessary for extracting unconventional resources, as most US gas producers were small and did not have enough incentives to undertake risky R&D investments (Wang and Krupnick, 2013; Trembath et al., 2012, among others). In particular, NETL (2007) notes that technology instruments needed for unconventional gas production would not have been available without the groundwork laid by research carried out through the DOE's Unconventional Gas Research (UGR) Programs.

Further, the development of shale gas in the Appalachian and Michigan Basins was stimulated by US government policies and by the introduction of some key technologies, such as microseismic fracture (frac) mapping, a project funded by DOE and carried out by Los Alamos National Labs in the 1970s. In particular, as the technology of microseismic fracture mapping required two decades to be fully workable, DOE's long-term support was critical for their development (NETL, 2007).

The six main components of the program[8] implied a total amount of about $220 million, about $15 million per year (Table 3).

Table 3. DOE's Unconventional natural gas research (UNGR) program going from 1976 to 1995

DOE's Unconventional natural gas research (UNGR) program going from 1976 to 1995	
the Eastern Gas Shales Program	1976 – 1992
the Western Gas Sands Program	1978 – 1992
the Methane Recovery from Coalbeds Program	1978 – 1982
the Deep Source Gas Project	1982 - 1992
the Methane Hydrates Program	1982 - 1992
the Secondary Gas Recovery	1987 - 1995

[8] The Eastern Gas Shales Program (1976-1992), the Western Gas Sands Program (1978-1992), the Methane Recovery from Coalbeds Program (1978-1982), the Deep Source Gas Project (1982-1992), the Methane Hydrates Program (1982-1992) and the Secondary Gas Recovery (1987-1995).

These investments provided the foundation for some of the most relevant technology development. NETL (2007) provides a detailed list of the technology products and extraction/production methodologies resulting from governments investments in R&D. Just to mention some of them:

- *Foam Fracture Stimulation Technology*: it allows sand to be transported by the fracture fluid while simultaneously reducing the volume of water used. According to NETL (2007; p.31) foam fracture reduced the water use "by 75 to 90% as compared to conventional water fracs". This technology was developed under the Eastern Gas Shales Program (EGSP) and by 1979 it became "the preferred commercial method of stimulation for Devonian shale gas wells" (NETL, 2007; p.31);

- *Large-scale Massive Hydraulic Fracturing*: It is a drilling process, which involves the injection of fluids at high pressure into a shale formation to fracture shale rocks. As the formation is fractured, a propping agent, typically sand, is pumped into the fractures to keep them open as the pressure is released. Fracture fluids are primarily composed of water and sand, which make up over 98% of the fracture fluid, with the rest consisting of various chemical additives. Natural gas flows out of the shale to the well from pores and fractures, together with the fracturing fluids, which return to the surface as "flow back". Ground water is protected during the fracturing process by a combination of casing and cement, installed when the well is drilled (Grant, 2016; Ground Water Protection Council, 2009). This technology was introduced through the EGSP to eastern Devonian shales. With financial assistance from DOE, Mitchell Energy in 1978 conducted the largest Massive Hydraulic Fracturing in a tight gas formation and quickly applied it to the Barnett shale (Wang and Krupnick, 2013).

- *Directional Drilling to Improve Productivity*: this technology enhancements were achieved due to the joint effort between DOE and industry partners from 1986 to 1990. Advancements in down-hole motors, down-hole telemetry, and other drilling equipment and technologies allowed the application and commercialization of this practice (now widely used) which enhances production from fractured shale reservoirs. In particular, the EGPS "was responsible for the first air-drilled horizontal shale well, the first recovery of core from a horizontal, air-drilled shale well, the first successful use of external casing packers in a horizontal well, and the first horizontal well completed with seven individual hydraulically fractured intervals" (NETL, 2007; p.4).

While previous technology advancements relate specifically to the drilling phase of the supply chain, other DOE R&D programs helped to develop important technologies for shale exploration, such as *3-D Seismic Imaging* and *Microseismic Fracturing Mapping*.

3-D Seismic Imaging has been a revolutionary technology for oil and gas exploration and development, as it uses sound waves propagated into the earth and reflected back to the surface to infer the structure and properties of subsurface rock layers. As noted by Bohi (1998; p.39), compared to the 2D methods, 3D seismology provides a better picture of the structure of subsurface rock layers and improves "the ability to locate new hydrocarbon deposits, to determine the characteristics of reservoirs for optimal development, and to help determine the best approach for producing a reservoir".

To give an idea of the relevance of this innovation in facilitating the shale revolution, Bohi (1998) suggests that the new technology increased the exploratory success rate from about 20% to about 50%, and the development success rate from about 70% to about 85%. 3D seismology had also an effect on overall exploration costs, by increasing surveying costs but reducing average finding costs by 40% and average development costs by 22% (Bohi, 1998).

Microseismic Fracturing Mapping is a technology which registers the seismic energy occurring underground: "by using sensors in a monitoring well to record the minor seismic events generated during the fracturing of a nearby well, microseismic fracturing mapping can reveal the height, length, orientation, and other attributes of induced fractures" (Wang and Krupnick, 2013; p.14). Since the early 2000s, microseismic monitoring has been used to optimize production and minimize the number of wells and

fractures required, by increasing reservoir productivity and/or reducing completion costs[9]. Even though one of the first places where this new technology was successfully applied is the Barnett Shale, the first microseismic monitoring tests in tight gas reservoirs were realized at the DOE Multiwell Site Experiment[10] in Colorado, where the accuracy of down-hole micro-seismic monitoring was validated (NETL, 2007).

Besides direct R&D investments for demonstration projects, the US federal government adopted a series of policies, incentive pricing and tax credits to promote the development of the UH industry (see also Section 2.2.2).

- The technological boost from oil and gas companies

Besides technology innovations resulting from partnership between government R&D programs and private entrepreneurship, a relevant push to the development of UH resources came also directly from the industry, which developed and/or applied some key technologies. Mitchell Energy & Development, for instance, is recognized as the first company that successfully implemented the technology necessary to unlock shale gas in the early 1990s. This company played the primary role in developing the Barnett play, and started to use massive hydraulic fracking for all Barnett stimulations in 1985. Beginning from 1994, in an attempt to reduce the costs of fracturing without reducing well productivity, Mitchell Energy eliminated nitrogen and pre-frack acid treatment from the fracturing design and started to use cheaper, lower-quality sand as a proppant (Wang and Krupnick, 2013). As a result of these changes, Mitchell Energy reduced average frack costs by about 10%[11]. Subsequently, in 1997, Mitchell engineers began to experiment slick water frack, a new fracturing method, developed by Union Pacific Railroad Corporation, which used water as the fracking fluid and a small amount of sand as the proppant. This technology can be considered as a major breakthrough as it reduced the cost of stimulation by about 50% (Wang and Krupnick, 2013; p.20).

In 2005, operators in the Barnett shale deployed horizontal drilling and hydraulic fracturing in a novel combination. Rogers (2011; p.123) notes that "subsequent refinement of this approach, including multi-stage fracking, multi-bore drilling from the same location, and the experimentation with the chemical formulation of the water-based fracking fluid, lies behind the sudden rapid growth in shale gas production post-2005 - on a scale which reversed what seemed at the time an inevitable continuing decline in aggregate US gas production".

After the successful application in the Barnett Shale, other companies started to use the same technologies in other basins. According to Maugeri (2013), together with drilling intensity, technological and management improvements are essential to continue to support the shale boom, by increasing the effectiveness of shale activity and well productivity. In particular, the author states that the shift of companies' investments from shale gas to shale liquids has increased the availability of services and associated labour, while the use of different drilling technologies has reduced drilling and completion time and their cost[12].

Another relevant factor that is considered essential by some observers to explain the success of the US experience is that the exploitation of shale formations has been

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[9] http://www.halliburton.com/en-US_stimulation_public/ps/microseismic-fracture-mapping-fracture-modeling.page?node-id=hhnxkn2a (last accessed 15/08/2016).

[10] The Multi-Site Experiment (M-Site) project was a joint effort funded by DOE and the Gas Research Institute, with the aim of having a field laboratory that could be used to develop and validate hydraulic fracture diagnostic technology, hydraulic fracturing mechanisms and improve hydraulic fracturing stimulation models. The project was realized from 1994 to 1996 (NETL, 2007; p.56).

[11] "Prior to these cost reduction measures, the stimulation cost of Barnett wells was about $350,000 to $450,000. Stimulation is a major cost component since the total cost of Barnett wells ranged from $750,000 to $950,000 at that time" (Wang and Krupnick, 2013; p. 19-20).

[12] Examples of technologies that have cut drilling time are steerable rotary bits (which have reduced drilling time in a typical Marcellus shale well from 14-18 days in the second half of 2011 to 6-10 days in the second half of 2012), pad drilling and multipad drilling, and zipper fracking (Maugeri, 2013).

dominated by smaller, domestically focused independent upstream companies[13], the so-called "momma and poppa" companies (Stevens, 2012), supported by a well-established and adaptable service sector. These entrepreneurial companies have had the possibility of moving on a micro-scale and on multiple micro-objectives (Maugeri, 2013), exploiting short-term opportunities, which characterize the unconventional market (as opposed to the conventional one). Further, they have continuously adapted their drilling techniques, by increasing productivity and reducing costs; as already shown in this Section, this aspect is particularly crucial given that shale formation are different, and require production processes to be continuously tweaked and improved (Kefferpütz, 2010).

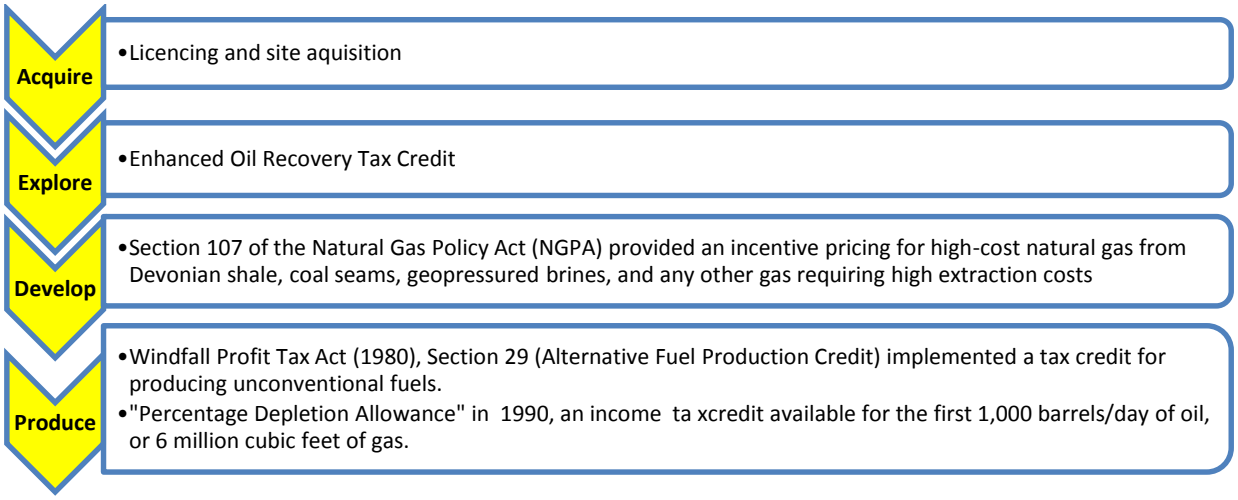
Even though technological innovations described above have had a key role in fuelling the shale boom, allowing the US to overcome limitations and costs which characterized the initial stages of early development, it is evident that continuous technological improvement are relevant also to sustain the shale industry development in the current, more mature phase.

2.2.2. Institutions and regulatory framework

Another key factor of the US shale revolution is represented by specific legal, regulatory and institutional features, which are among the most challenging issues in the development of the UH industry. In particular, the combination of a favourable fiscal regime and the lack of restrictive regulations on permitting and environmental aspects have triggered the shale revolution in the US. Nevertheless, even though the initial stages of UH industry development in the US have been characterized by a substantial absence of restrictive regulations, at federal or state levels, partly because the adopted techniques were so new and different that they simply were not considered in existing regulations, and partly for explicit political will, things are changing. The introduction of more restrictive regulations can represent a potential constraint for shale operations.

As it is shown in Figure 9, the regulatory framework is relevant for all phases of the upstream part of the supply chain. Also in this case, some of the main aspects of the regulatory framework are reported in the boxes.

Figure 9. Supply chain phases mainly affected by the institutional and regulatory framework in the US



The specificities of the policy framework in the US have been an important driver for the shale boom, providing fiscal reliefs to unconventional producers and ensuring a stable

[13] Bohi (1998) defines a major firm as one that operates in all stages of production, from exploration and production to refining and marketing, while an independent firm as one that specializes in exploration and production.

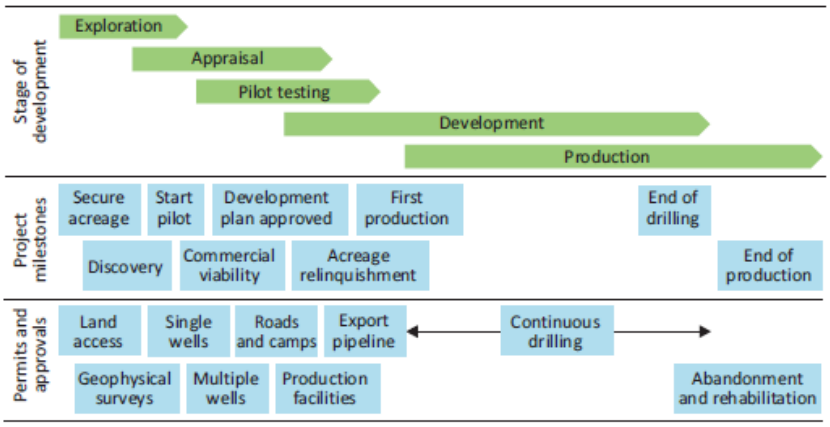
and predictable permitting process. On the one hand, several tax credits have been implemented since 1980, supporting UH production. On the other hand, historically, there has been relatively limited government and federal agency involvement in regulation of upstream oil and gas production (Wochner, 2015; Boersma and Johnson, 2012).

As it will be shown in the following brief review of the US regulations, exploration and production activities of both conventional and unconventional oil and gas in the US are regulated under federal, state, and local laws that address every aspect of the whole supply chain (exploration, production and transportation processes) and apply equally to shale and conventional resources. The Environmental Protection Agency (EPA) administers most of the federal laws, although UH development in federally owned land is managed primarily by the Bureau of Land Management (part of the Department of the Interior), and the U.S. Forest Service (part of the Department of Agriculture). Moreover, in each state where oil and gas are produced, one or more regulatory agencies permit wells (design, location, spacing, operation, and abandonment) and regulate activities with potential environmental impacts (including water withdrawals and disposal, waste management and disposal, air emissions, underground injection, wildlife impacts, surface disturbance, and worker health and safety) (NETL, 2013; Ground Water Protection Council, 2009). State laws govern also the interpretation of lease provisions and disputes between surface and mineral owners and mineral lessees about payments and surface damage (Richardson et al., 2013).

The regulatory system for UH resource development is complicated because of these multiple layers of government responsibility. According to some observers, complexities and heterogeneities arising in state regulations as well as the lack of transparency and difficulties to determine relevant regulatory requirements, often scattered throughout the laws or present only in uncodified regulations, can represent significant barriers for stakeholders, including firms seeking to comply with the law (NETL, 2013).

Another source of complexity is related to the peculiarity of the unconventional resources development path. While conventional oil and gas developments generally follow a well-defined sequence, the unconventional development path tends to proceed incrementally, and distinctions between the phases can be much less clear-cut. An idea of the specificities of UH resource development process is provided by Figure 10, provided by IEA (2012) and showing the way in which the different stages develop and overlap. As noted by the IEA (2012) analysis, due to this overlapping path, an operator may be involved in several different stages at the same time. For instance, the operator may be exploring or appraising part of a licence area, developing another part and producing from a third, with different regulatory approvals and permits applying at each stage. Further, in some cases interactions between operators and regulators can be very complex. In some states, for instance, regulations require the submission and approval of a detailed field development plan at a very early stage (i.e. the end of the exploration phase). In case of subsequent, even relatively small alterations, the operator may be obliged to resubmit the entire development plan for approval. This can make the process longer and burdensome for both operators and regulators (IEA, 2012).

Figure 10– Stages of an unconventional resource development and regulations



Note: The stages, milestones and permits shown here are not unique to unconventional developments, but the distinctive element is the overlap between stages of development, as opposed to a more sequential pattern for a typical conventional project.

Source, IEA, 2012; p.51

Finally, even though regulations were not particularly stringent in the early stages of UH industry development in the US, suggesting that the industry was steering the process and regulators and legislators were catching up, over the last few years government and state involvement has progressively increased, incrementally regulating and investigating various aspects of unconventional production activities. As shale development activities have increased over the past decade, concerns over potential environmental impacts resulting from that activity has also increased, stimulating deeper investigations of shale operation consequences. At the request of Congress, for instance, EPA conducted a new study[14] to better understand the impact of hydraulic fracturing on drinking water sources.

In the following, we review the most relevant aspects of the US policy framework related to UH resources.

- Tax policies and economic incentives

The first major incentive for modern UH production can be traced back to the Windfall Profit Tax Act, passed by the Congress in 1980, whose Section 29 (Alternative Fuel Production Credit) implemented a tax credit for producing unconventional fuels. The tax credit provided an incentive of about $0.50 per thousand cubic feet (Mcf) of natural gas produced from unconventional resources. In particular, in order to qualify for the tax credit, incentivized fuels (e.g. oil from shale and tar sands, gas from coal seams, tight sands, shale, and Devonian shales), had to be produced from wells drilled between 1980 and 1992, or placed in service during the same period. To reduce incentives to switch from unconventional gas to oil products following a fall in oil prices, the value of the credit varied with the price of oil and inflation[15], with the exception of tight gas, where the credit remained at $0.5/mcf. According to EIA (2001), the credit averaged from $1.02 per thousand cubic feet of gas during the 1990s and boosted the effective price received for eligible production by over 50%. The tax credit program expired at the end of 2002.

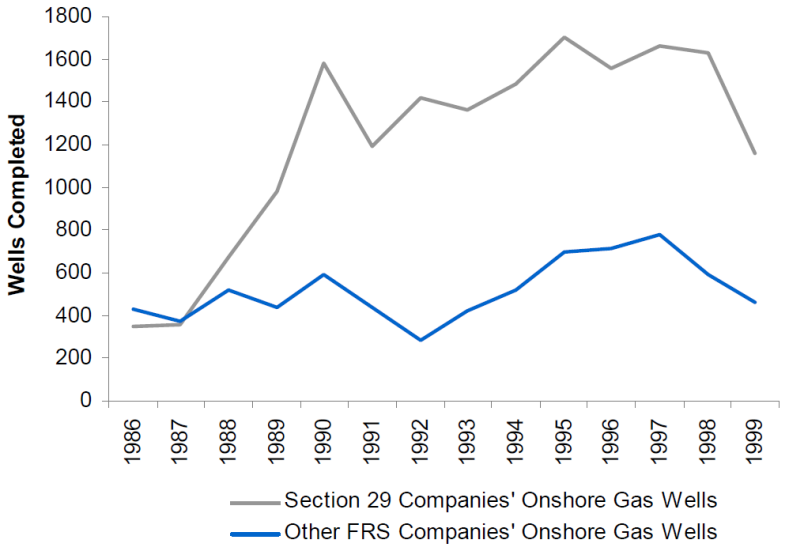
Even though the impact of tax credits on UH development has not been rigorously investigated, some studies suggest a relevant effect of the Section 29 tax credit. These credits stimulated the development of qualifying resources, by raising financial returns and reducing investments risks, pushing firms to use new exploration, completion, and

[14] EPA's Study of Hydraulic Fracturing for Oil and Gas and Its Potential Impact on Drinking Water Resources. The final report is available at https://www.epa.gov/hfstudy (Accessed 27 January 2017).
[15]As noted by Stevens (2010; p. 13), "Given that, after 1980, the wellhead price rarely exceeded $2 tcf, this was a significant incentive to attempt to develop unconventional gas".

production technologies (Kuuskraa and Stevens, 1995). According to Geny (2010), a striking illustration of the effect of incentives on gas-related developments is given by the difference in the pace of gas production increases between FRS[16] companies benefiting from Section 29 tax credits, which increased their gas production by 26% between 1990 and 1999, and companies which did not benefit, which reduced their production by 14%.

Even more impressive is the difference in terms of gas development activity. The FRS companies receiving Section 29 tax credits quadrupled their onshore drilling, passing from slightly under 400 well completions per year to about 1,600, between 1986 and 1990, while other FRS producers increased their drilling activity by less than 200 well completions over the same period (Figure 11**Error! Reference source not found.**).

Figure 11. US onshore natural gas wells completed by FRS companies



Source: Geny, 2010; p.33

Besides the Section 29 tax credit, the US regulations introduced several fiscal measures, which favoured oil and gas operators and supported the growth of UH industry.

Section 107 of the Natural Gas Policy Act (NGPA), for instance, provided an incentive pricing for high-cost natural gas from Devonian shale, coal seams, geopressured brines, and any other gas requiring high extraction costs (as determined by the Federal Energy Regulatory Commission). This policy intervention created a huge advantage for unconventional gas producers, considering that, in the early 1980s, deregulated natural gas price was more than twice the price of regulated natural gas (Wang and Krupnick, 2013). Later on, also tight gas was defined as a high-cost gas (allowing also the tight gas formation in the Barnett shale to benefit from the Section 107 high price ceiling).

The 1990 Tax Act introduced a special fiscal advantage for small oil and gas producers, known as the "Percentage Depletion Allowance", available only for the first 1,000 barrels/day of oil, or 6 million cubic feet of gas. This tax exemption allows 15% of the gross income from an oil and gas producing property to be tax free. According to the US General Accounting Office, the Percentage depletion allowance generated "a total tax incentive of $8.5 billion between 1990 and 2000 in real 2000 terms" (Geny, 2010; p. 34).

Oil and gas companies can benefit also from the Enhanced Oil Recovery Tax Credit (which applies to additional costs to increase the amount of oil extracted from a field) and the Marginal Well Tax Credit (which reduces tax liability for operators that produce

[16] FRS companies are major energy companies reporting to the EIA Financial Reporting System (FRS).

little or low-quality oil and gas). Further, companies can deduct Intangible Drilling Costs, i.e. costs to develop an oil or gas well for those elements that are not part of the final operating well, including costs of drilling, survey work, ground clearing, cementing, drainage, wages, fuel, repairs and supplies (Deloitte, 2013).

Various tax incentives (for marginal wells, enhanced wells, expanded wells and reactivated wells) are provided also at state level, with the aim of attracting industry business.

- Energy and environmental regulatory framework: the federal level

The US Environmental Protection Agency (EPA) implements federal environmental laws enacted by the Congress by promulgating regulations, including minimum standards for air quality, water quality and waste management. The EPA may delegate the authority to administer the federal regulatory programme to a state environmental agency, provided that the state programme is at least as protective of the environment as the corresponding federal programme.

In general, the federal environmental laws supplement state laws, even though states may enact stricter regulatory provisions or require types of protections also in the absence of federal provisions. With some exceptions (most federal and tribal lands), states are generally left to govern oil and gas activities within their borders (Norton Rose Fulbright, 2015).

The EPA develops guidelines for the issuance of permits for the discharge of materials into navigable waters, including wetlands, while the US Army Corps of Engineers (USACE) issues the discharge permits (Norton Rose Fulbright, 2015).

Another relevant agency with jurisdiction over oil and gas operations on federal and tribal lands is the Bureau of Land Management (BLM), which is responsible for issuing well permits to lessees or operators, including provisions for completion activities.

Currently, hydraulic fracturing is not regulated at federal level[17]. Even though the SDWA regulates the underground injection of fluids to protect underground sources of drinking water, fluids or propping agents (other than diesel fuels) related to hydraulic fracturing operations are explicitly exempted (as a result of the Energy Policy Act of 2005). This exemption remains despite failed attempts by the U.S. Congress to pass the Fracturing Responsibility and Awareness of Chemicals Act ("FRAC Act") in 2013 (Grant, 2016). At the opposite, flowback wastes may not be injected into the subsurface without a permit under the SDWA.

- Regulatory framework: state level

State regulations vary accounting for their different history, geology, demographics, and other factors, such as the public's tolerance for risk. Differences emerge also in the number of elements of the shale gas and oil supply chain regulated by states. Further, the regulatory framework evolves continuously, also due to the speed of UH development, which forces regulators to "catch up" with the development of oil and gas activity.

Generally, an operator must obtain a permit before drilling. The application for the permit requires providing information about the well's location, construction, operation and reclamation. In several cases, applications also require a fee, a plan of the site, a security bond, various operational plans and notice to nearby landowners (Norton Rose Fulbright, 2015).

In the Marcellus shale play (Pennsylvania), for instance, the well operator has to obtain a well permit from the Department of Environmental Protection (DEP) in order to drill the

[17] Despite some attempts have been made, for instance, by the BLM (see, for instance, https://www.bloomberg.com/news/articles/2016-06-22/federal-judge-strikes-down-obama-s-effort-to-regulate-fracking - last accessed 27 January 2017).

well. The permit application has to specify the location of the well, the proximity to coal seams, and distances from surface waters and water supplies. In particular, the DEP developed an addendum specifically to address additional environmental considerations related to shale gas well development. Considerable staff resources are devoted to review the additional information in the Marcellus Shale Addendum, because the technical staff has to consider several water quality and quantity issues not normally associated with gas well permit application reviews (Hefley et al., 2011).

A recent report by Resources for the Future[18] reviewing state regulations of shale gas in the US highlights the high degree of heterogeneity among different national contexts, in terms of both different policy approaches (the use of command-and-control tools vs performance standards or case-by-case permitting) and their stringency. Quite interestingly, states have reacted differently to the shale boom following the expansion of horizontal drilling and hydraulic fracturing adoption. Some states (like Colorado, Ohio, Pennsylvania, and West Virginia) have made relatively comprehensive revisions to their oil and gas codes while other states (like Arkansas, Montana, and Texas) have made more targeted changes. Some states have not only modified their regulatory content, but also expanded the number of oil and gas staff available to enforce regulations, providing new funding and training requirements for their staff (Richardson et al., 2013).

According to the study, the majority of state shale gas regulations are related to the initial and final phases of the development process, suggesting that regulators consider initial site selection and practices as well as the end of their productive life as the largest sources of risks associated with shale gas development. In contrast, relatively few state regulations apply to the production stage.

While regulations vary from state to state, they tend to share some common areas of focus. The main state regulations related to the upstream phases of the shale development process concern site selection and preparation, drilling, hydraulic fracturing, wastewater storage and disposal and excess gas disposal.

Concerning site selection and preparation, regulations in many states impose restrictions on wells locations or require groundwater to be tested before drilling. Several states have uniform well spacing requirements that limit the number of wells in an area, and most also have some form of setback rules limiting the proximity of wells to certain buildings or features. Within drilling units, for instance, states may regulate well spacing requiring a minimum distance from unit boundaries.

Further, several states have built setback restrictions, ranging from 100 feet to 1,000 feet from the wellbore, with an average of 308 feet. In some states (like Ohio and Colorado), setbacks tend to be larger in highly populated areas, while in other states, reductions or exemptions from setback restrictions can be provided, often contingent upon acceptance from the affected landowners in the area (Richardson et al., 2013). Quite interestingly, the authors of the study note that, in such cases, setback restrictions function as default rules around which landowners can contract.

Another relevant aspect is that, generally, setback restrictions (regarding buildings, water, or other features) do not appear to be addressed in permits. In other terms, even though all states require operators to declare the exact location of the well in permit applications, this information is used to confirm compliance with well spacing regulations, but it does not seem to be used to make the permits approval contingent upon setback restrictions compliance.

Concerning the drilling phase, as adequate casing and cementing practices are essential to ensure groundwater safety, they are heavily regulated by almost all states with shale gas development. Several states regulate the depth to which well casing must extend and be cemented. Some of them require casing to be set and cemented to a specified

[18] Richardson, et al., 2013, "The State of State Shale Gas Regulation," http://www.rff.org/RFF/Documents/RFFRpt - StateofStateRegs_Report.pdf

minimum depth below the base of layers or zones containing freshwater (between 30 and 120 feet, with an average of about 64 feet). Also cementing practices are regulated differently in the various states (Richardson et al., 2013).

According to the RFF report, horizontal drilling and hydraulic fracturing practices, which represent the main difference between unconventional and conventional resource development operations, are still not comprehensively regulated. Hydraulic fracturing is generally regulated through oil and gas well regulations or Class II injection well regulations. Some states (Arkansas, Oklahoma, West Virginia and Wyoming) require permits to be issued before hydraulic fracturing can be used, while other states have issued moratoriums on hydraulic fracturing. Vermont has completely banned hydraulic fracturing and New York recently announced that it will also do so (Norton Rose Fulbright, 2015).

The most common regulations relevant for hydraulic fracturing operations are related to water withdrawals and disclosure of the composition of fracturing fluids.

As the fracking process requires several million gallons of fracturing fluid, of which water represents the largest share, concerns over the effect of large water withdrawals on ecosystems and downstream users have led states to discuss rules about water withdrawal restrictions specific to the shale industry. Nevertheless, specific regulations have not been approved yet and states regulate surface and groundwater withdrawals under general regulations (Richardson et al., 2013). The regulatory burden varies considerably between states, with some states requiring only submission of a pre-withdrawal report, while others oblige operators to undergo lengthy approval and application processes to withdraw water.

Some states require permits for both surface and groundwater withdrawals, while others require permits only for withdrawals above a specified threshold: Ohio, for instance, requires withdrawals registration and reporting over 100,000 gallons per day, and does not require permits unless withdrawal is greater than 2,000,000 gallons per day. The state of Kentucky exempts the oil and gas industry from water withdrawal regulations, and Texas requires permits for surface, but not for groundwater withdrawals.

In Pennsylvania, irrespective of the location of the water sources, the Department of Environmental Protection (DEP) requires a water management plan specifying the full lifecycle of the water used in the fracking process for each Marcellus Shale well. In addition to the location and amount of the withdrawal, the water management plan incorporates other information regarding the expected impacts of the withdrawals on the water resources. Further, since 2008, gas companies are required by the Susquehanna River Basin Commission to seek permission to withdraw or use water to establish wells in the Susquehanna watershed. Without approval by the commission, gas companies are not allowed to start gas well construction, drilling or fracturing (Hefley et al., 2011).

Besides water, hydraulic fracturing fluids include also additives and chemicals, whose number and type vary depending on specific well conditions. Even though fracturing fluids disclosure is not regulated under the SDWA, concerns over the potential impact of these fluids on drinking water have led environmental groups to ask states for disclosure, independently of federal law. There are currently 25 states with disclosure regulations in force, while several others are considering to introduce regulations (Norton Rose Fulbright, 2015). Some states require disclosure to state agencies, while others rely on the FracFocus, developed by the Ground Water Protection Council (GWPC) and the Interstate Oil and Gas Compact Commission (IOGCC). The FracFocus is a publicly accessible website, where oil and gas well operators can voluntarily post information about the ingredients used in hydraulic fracturing fluids.

All states with disclosure requirements, however, provide exemptions for chemicals considered as confidential business information. According to a recent analysis by the EPA, based on more than 39,000 reports from the FracFocus, oil and gas operators designate 11% of all ingredient records as confidential business information and one or

more ingredients are claimed confidential in more than 70% of the disclosures (EPA, 2015).

Also the storage of flowback fluids is subject to permitting requirements: handling and storage of unused fracturing fluids or acids at an oil and gas site are regulated under the Resource Conservation and Recovery Act (RCRA) laws, while states require operators to obtain a permit before constructing a waste storage facility and to submit reports throughout operations. Generally, flowback fluids are first treated and then, depending on the state, may be discarded through injection into disposal wells, discharge into surface water and/or recycling back into the fractured well (Norton Rose Fulbright, 2015).

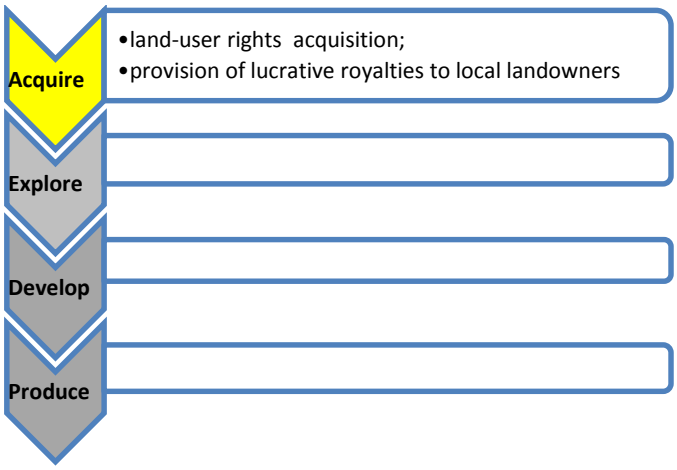
Injection is the most common and widely approved method for which, as noted above, the SDWA requires a permit to discharge underground. To discharge to surface waters, where allowed, operators must obtain a National Pollutant Discharge Elimination System (NPDES) permit. Even though flowback recycling has increasingly been encouraged by several states, it often presents regulatory, economic and logistical obstacles.

2.2.3. Land and mineral rights ownership framework

Among the legal and institutional features that have created an attractive environment for the development of the UH industry in the US, land-user rights have played a particularly relevant role. They have facilitated exploration and drilling activities through the provision of lucrative royalties to local landowners, in return for the mineral rights underneath their property. In this respect, the US context is unique: the owner of the land owns also the hydrocarbon resources underneath the property, differently from almost all other countries, where governments own subsurface mineral rights. When shale formations lie in private lands, drilling companies access the resource through private lease contracts, which provide a share of the value of production to mineral owners.

This driving factor of the UH industry development in the US has particularly affected the acquisition phase (in yellow in Fig.12) of the supply chain.

Figure 12. Supply chain phases relevant for land and mineral rights ownership framework



Acreage acquisition by extraction companies in the US has historically occurred through auction of minerals owned by federal or state governments, and, more importantly, through negotiation of private lease contracts with individual owners of mineral property (Brown et al., 2015). Indeed, in the US, private individuals own most of the subsurface

resources and property rights for underground minerals (such as oil and natural gas) are based on surface ownership[19].

Oil and gas leasing contract are signed before exploratory drilling occurs and are structured as multiyear option contracts that provide the firm the right to explore for oil and gas for a given time period. After the primary term, which lasts for a fixed number of years or months, the lease terminates, unless:

- the well is producing in paying quantities or has the potential to produce in paying quantities;
- qualifying drilling operations are in progress
- the lease is entitled to receive an allocation of production from an off-lease well.

The secondary term holds the lease in force by production from the lease. Federal competitive and non-competitive leases are for a term of ten years.

The negotiation process between the energy companies and the landowners may lead to purchase the rights to underground resources, while the landowners are allowed to retain the ownership of the surface for farming, forestry, and housing. Prices for mineral rights may vary, depending on the potential value of the resource. Accordingly, adjacent property owners may negotiate extremely different deals with energy companies, given their interest in the basin. Rights to disturb the surface in order to extract the resource through construction of roads, well pads, pipelines, etc. may also vary significantly.

The mineral owner (the lessor) generally receives a onetime payment ("bonus") for signing a lease (e.g. US$50 per acre) and, in addition, a royalty interest in all production from the lease.

The signing bonus is the "up-front" benefit recognized to the landowner by the operating company in order to have the possibility to drill on or under the property. It is intended to stimulate the owner to sign the lease and grants the rights of the land to an operating company for a given time period. This bonus is negotiated separately from the royalties and represents the most important factor in the negotiations. As there is always the possibility that the well will not be completed for several reasons (e.g. characteristics of the location, impossibility of creating the site, presence of other active wells in the area), the signing bonus can turn out to be the only source of profit for landowners (Hefley et al., 2011).

The royalty payment rate is calculated as a percentage of the produced amount of output (oil or gas), on the basis of the size of the land of the landowner. A royalty of 1/8 of production was common for many years, but royalty rates are now more negotiable (generally ranging from 1/8 to 1/4). Federal leases require a royalty of no less than 1/8. With a specific reference to the Marcellus shale play, for example, Hefley et al. (2011) state that the amount of royalties for landowners can exceed hundreds of thousands of dollars per year based on the prenegotiated royalty rate and size of the property. In that case, the average lease is calculated for a first period of five years, but after this period, the operating company may extend the lease for an additional five-year term. In this renegotiation phase, the landowner receives the signing bonus again. This gives the operating company the opportunity of completing the unit if it has not been developed within the first five years.

In some instances, the well's production may be limited or even stopped because of external factors that prevent processing and sale of the resource, such as the lack of available pipeline capacity. In these circumstances, to protect the lessee, leases generally have a negotiated "shut-in royalty" clause that allows the lessee to pay a set fee (e.g. US$50 per acre).

[19] Excluding when differently indicated, the main references for this Section are Norton Rose Fulbright (2015) and http://www.virginiaplaces.org/boundaries/splitestate.html (accessed July 2016).

By exploiting a proprietary dataset of 1.8 million oil and gas leases in the US, Brown et al. (2015) estimate that in 2014 the six major shale plays generated $39 billion of royalties, an amount corresponding to more than four times the royalty income received by the Federal government. Indeed, average royalty rates varied substantially across plays, ranging from 13.2% in the Marcellus play to 21.2% in the Permian basin, while royalty income ranged from $2.5 billion in Niobrara to $13 billion in the Permian. The authors note that, especially in scarcely populated areas, royalty incomes are economically extremely relevant for the resource owners, accounting for a large share of personal income (in the Bakken and Eagle Ford plays, for instance, local royalty income per capita was between $2,900 and $4,200 in 2014). Nevertheless, they also find evidence of a limited pass-through of UH resource abundance: even though oil and gas abundance may lead to higher signing bonus and greater total royalties, owners in richer areas are not able to negotiate significantly better lease terms, as a consequence of a combined effect of institutional factors, uncertainty about new resources, and market power.

This structure of land leases stimulates continuous drilling activity, providing an impetus to increase production levels rapidly. Further, the common law rule of capture, which establishes the ownership of "captured" natural resources, even though they are drained from the subsurface of another's land, creates a race to the resource, stimulating mineral estate owners to extract their oil and gas (and that of their neighbours) before someone else does.

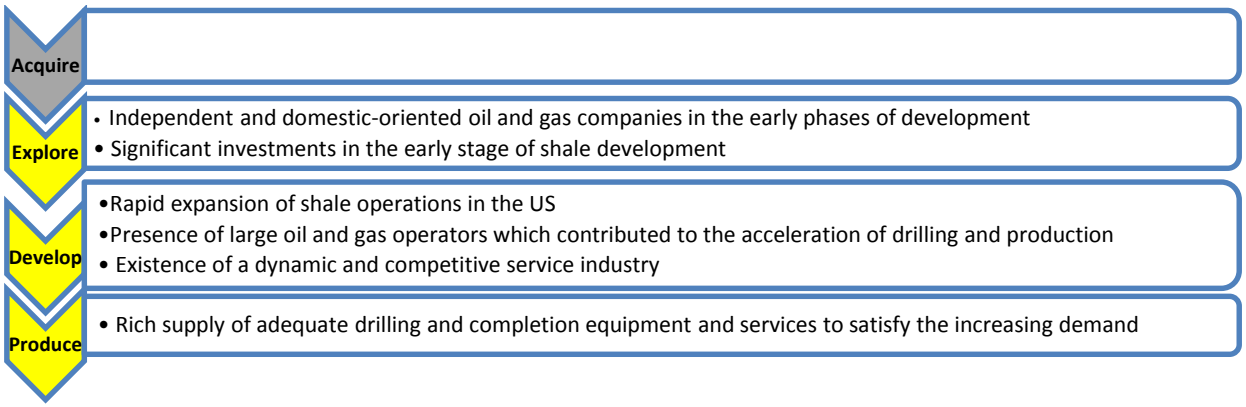
Oil and gas leasing on federal and Native American lands are, on the contrary, under the responsibility of the Bureau of Land Management (BLM) and governed by the Mineral Leasing Act of 1920 (as amended) and the Mineral Leasing Act for Acquired Lands of 1947 (as amended). According to the Federal Onshore Oil and Gas Leasing Reform Act of 1987, all public lands that are available for oil and gas leasing have to be offered by competitive auction.

2.2.4. Industry structure

The peculiar structure of the US oil and gas industry has been another enabling factor for the shale revolution in North America. First, until very recently, the development of the UH industry was undertaken by independent oil and gas companies, that made significant investments in the early stage of shale gas development. Second, the rapid expansion of shale operations in the US has been supported by the existence of a dynamic and competitive service industry able to respond quickly to the increasing demand for adequate drilling and completion equipment and services.

The peculiarities of the UH industry structure in the US have mostly affected the stages of the supply chain highlighted in yellow, as it is shown in Figure 13.

Figure 13. Supply chain phases mostly affected by the peculiarities of the industry structure in the US



The initial development of UH industry in the US has been mainly driven by investments of small independent oil and gas companies as, by the end of the 1970s, major companies had considered mature the onshore hydrocarbon resource base and decided to divert their investments towards offshore and international exploration.

By benefiting from government tax credits and low capital costs (until 2004), producers started acquire land, build well-developed plays and develop specialised drilling technologies for exploiting shales. However, initially, as conventional vertical wells and small hydraulic stimulations were used, production levels were modest. Production increased dramatically only after the introduction of the innovative combination of horizontal drilling and large slick-water-based fracking in the Barnett play in 2005 by Devon Energy, which acquired Mitchell Energy & Development Corp. in 2002. The merger between Devon Energy, one of the largest independent oil and gas operators in North America, and Mitchell Energy greatly accelerated the development of the Barnett play, suggesting that small firms did not have the financial or technical capabilities to make substantial risky investments in shale technologies (Wang and Krupnick, 2013). Supported by the availability of a well-developed service sector, the introduced technological breakthrough increased the number of fracs in the Woodford and Barnett Shale plays by nearly 500% from 2005 to 2008 and the rig count by 52% (Geny, 2010).

The UH industry development in the US has then been undertaken by larger oil and gas operators, that contributed to the acceleration of drilling and production since the middle of the 2000s, thanks to their strong investments and the availability of technologically competent teams. According to Barclays Capital analysts, large independents and midcap drillers were responsible for nearly 95% of rig additions in 2008[20].

The UH resource boom in the US has been supported also by a well-developed and flexible service sector, able to accommodate the growing demand by unconventional oil and gas producers. The existence of the service sector has been especially relevant, by considering that activities in the UH resource sector are highly service-intensive and require far more drilling and fracturing operations than in the conventional sector. In particular, UH production requires significant drilling and pressure-pumping capacity, together with rigs and equipment for fracturing. As noted by Geny (2010), the service availability has been essential, if one considers that the share of US onshore rigs having horizontal drilling capability increased fivefold in 10 years, passing from 6% in 1998 to 30% in 2008. By considering, for instance, pressure pumping capacity, which represents an indirect indicator of the fracking activity in a country, it roughly tripled between 2003 and 2008 in response to the growing demand for stimulation services (Geny, 2010).

This rapid reaction has been made possible by the ability of the US service sector to quickly respond to reductions in oil and gas prices. In particular, the two most important markets within the service sector for shale exploitation, the pressure pumping and the directional drilling markets, are dense and fragmented, but also dominated by a few companies, which hold a relevant share of the market in the US (around 75%). Halliburton, Schlumberger and Baker Hughes/BJ Services, for instance, dominate the pressure pumping market, while Patterson-UTI, Helmerich & Paye and Nabors Industries control the market for the directional drilling. The existence of these large companies in the market, having enough workforce, equipment stocks and financial resources, allowed to adapt the service supply to meet the fast rising demand from unconventional operators (Geny, 2010).

In addition to big companies, many small and specialized companies, in particular drilling contractors and technology developers, emerged, increasing the flexibility of the service sector and improving its capacity to respond to the demand from shale operators. Increasing competition within the service sector in the US has contributed to mitigate the

[20] http://www.oilandgasinvestor.com/who-drilling-large-independents-midcaps-are-ones-watch-465901#p=full (last accessed, February 2017).

rapid increase in service costs from 2004, and to explain also why this increase has been lower in the US than in other countries (Geny, 2010).

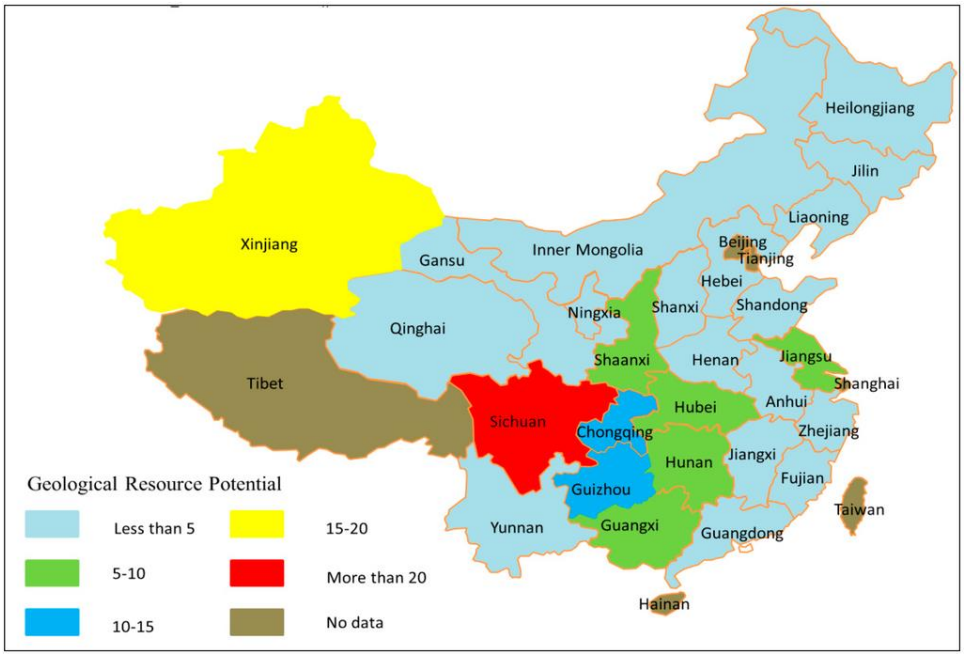
More recently, following general market conditions and oil price trends, service costs have fallen by about 30% in most shale regions (Curtis, 2015), where producers have seen service cost discounts, reflecting different contract structures, region of drilling, and other factors. The service sector reduced the costs of their services, with the aim of retaining their market share. Lower service costs, together with increased operational efficiencies, have contributed to reduce total drilling and completion costs. This partly explains why US unconventional production has proved to be more resilient than originally expected, despite low oil prices.

3. China

3.1 A brief account of the state of Resources in China

Following Pi et al. (2015a), the success of US shale gas has led other countries to start explorations related to UH resources. In 2012, a Shale Gas Development Plan (2011–2015) has been issued in China. According to a preliminary survey, conducted in 2011 by the Ministry of Land and Resources (MLR), China's shale gas geological resource potential was estimated at 134.42 trillion cubic meters, and the recoverable resource potential at 25.08 trillion cubic meters (excluding Qinghai-Tibet), albeit relevant uncertainties exist concerning the reliability of such estimates[21]. Sichuan, Xinjiang, Chongqing and Guizhou provinces account for 49.65% of the nation total. Figure 14 shows the share of Chinese provinces.

Figure 14. Shale gas resources in China.



Source Pi et al., 2015a

The relevance of shale gas resources exploitation for the Chinese economy is confirmed by the increasing reliance, at least in the recent past, on imported natural gas, as confirmed by Figure 15. According to the reported data, dependence on imported gas increased steadily since 2008. Turning to the state of unconventional oil resources, Figure 16 (from Wang et al., 2015) shows the Technically Recoverable Resources (TRR) related to the different kinds of unconventional oil sources.

[21] See, again, Pi et al. (2015a) for a discussion of this issue.

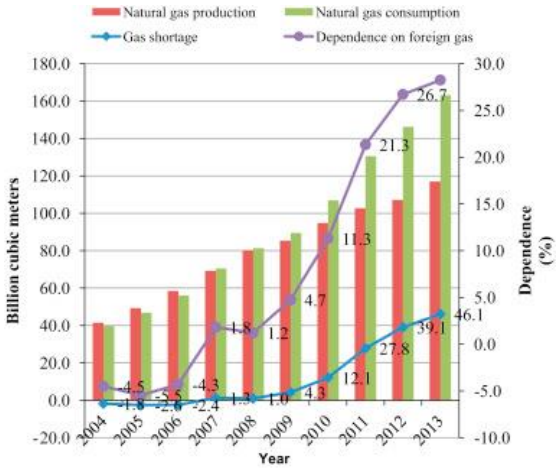
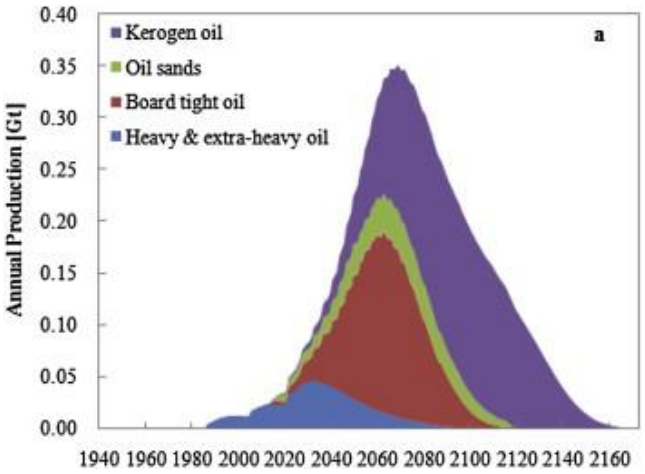
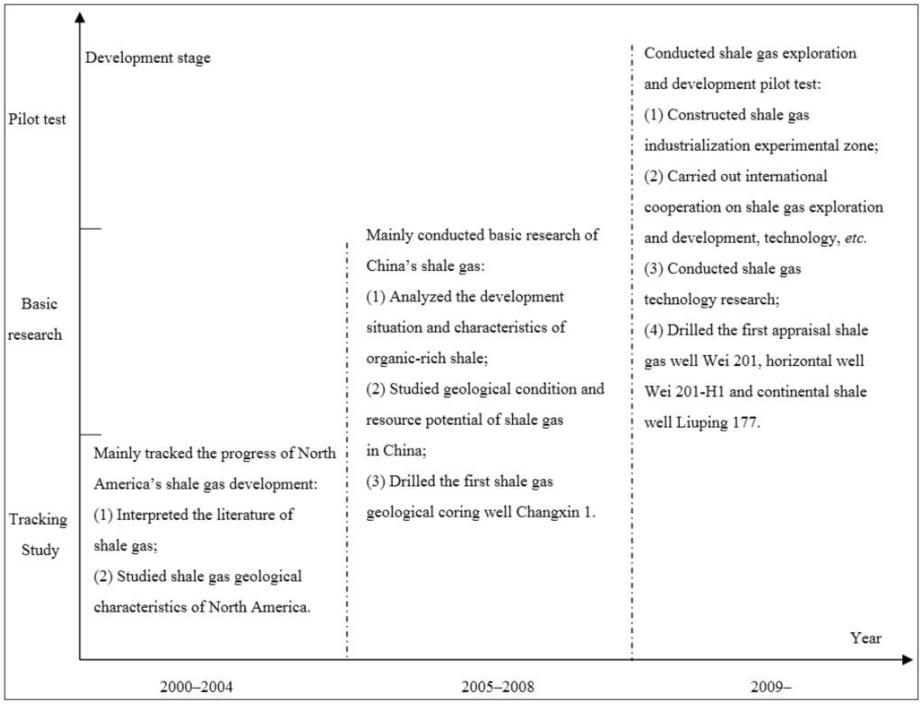
Figure 15. Natural gas shortage and dependence on imports	*Figure 16. Unconventional oil production technical recoverable resources projections in China*
	
Source Yuan et al., 2015	Source Wang et al., 2015

Figure 16 shows that if the TRR scenario can be achieved, it can lead to a significant increase in total supply. On the other hand, significant challenges are linked to the TRR scenario; as a result, the need for China to keep relying on imported oil cannot be excluded. Figure 17 reports the recent and current stages of shale gas development in China.

Figure 17.– Shale gas development stages in China

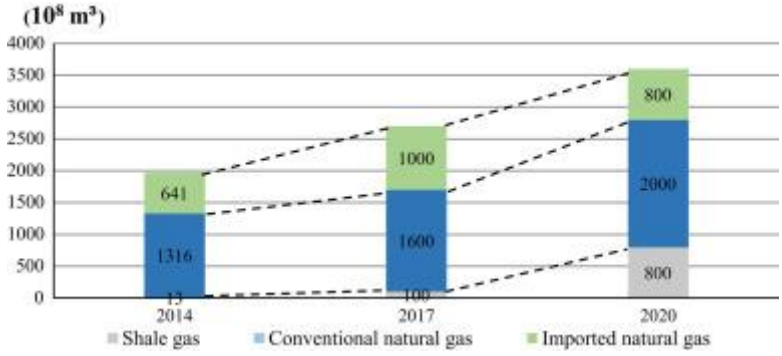


Source Pi et al., 2015

As a report by Norton Rose Fulbright (2015) points out, a preliminary geological survey took place in China in 2004. Since then, between 2006 and 2009 several surveys were performed, including more localized analysis (e.g. in the upper Yangzi region) and comparisons in terms of geological structure between US and China deposits. The first successful fracking attempt, using technology from the US, took place in May 2010. Only by the end of 2011 shale gas was labelled by MLR as a separate mineral with respect to

conventional hydrocarbons, and then listed by the National Development and Reform Commission (NDRC) as a priority. Figure 18 shows the forecasted role of UH (namely shale gas over total gas production) resources up to 2020, according to the MLR (Li et al., 2016). As it is clarified, UH resources are expected to play an increasing role over time in the Chinese energy production, albeit they are not expected to solve the dependency of China from imports.

Figure 18. China's natural gas structure 2017-2020

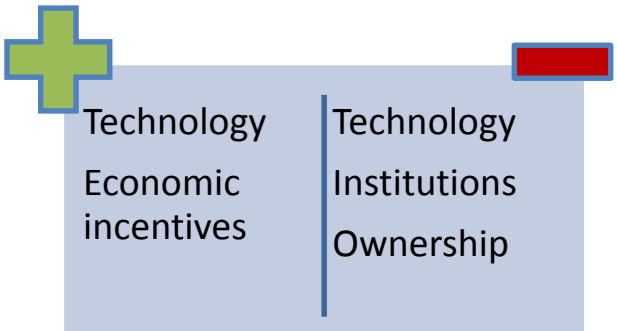


Source Li et al., 2016

3.2. Development of the UH industry in China: drivers and barriers[22]

The aim of this section is to provide hints on the main identified drivers and barriers to UH development in China. Enabling and harnessing factors can be summarized by Figure 19.

Figure 19. Drivers and Barriers of UH Development - China



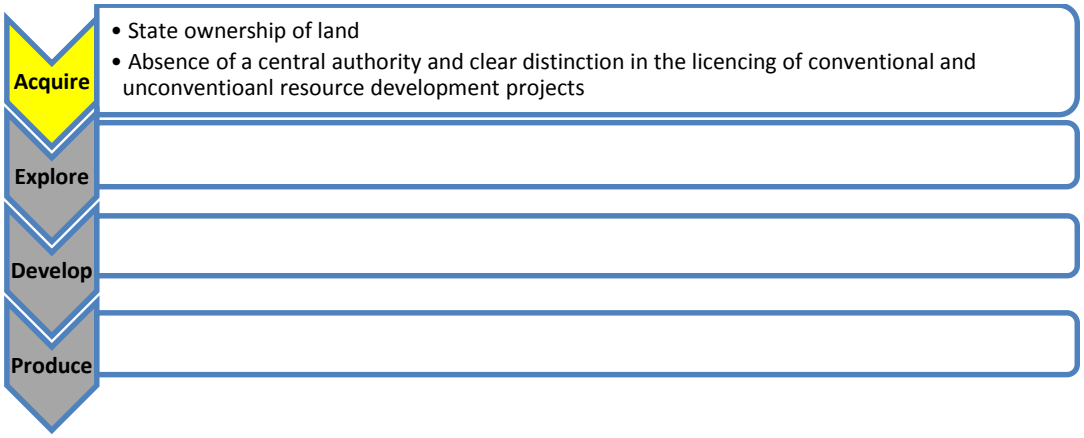
3.2.1. Institutions and regulations[23]

The complexities of the institutional framework appear to be a barrier to the development of the UH sector in China. More specifically, state ownership of land and the absence of a central authority may be limiting factors. Also, the licensing and permitting stage is affected by the fact that most of the unconventional resources overlap to conventional ones, and auctioned rights are concentrated on blocks outside the territories where the main conventional sources are located. These issues have led to an apparent stop in the licensing process.

The characteristics of the institutional framework mainly affect the first stage of the supply chain, as it is shown in Figure 20:

[22]We left environmental and geological/reserve related issues outside this brief survey, as they are more loosely linked to the sector development and have been the subject of other existing reports.
[23] The framework of this part is based on the analysis reported in Norton Rose Fulbright (2015).

Figure 20. Supply chain phases mainly affected by institutional and regulatory characteristics



China's shale gas sector involves four major governmental authorities:

- the already mentioned MLR, in charge of the administration of mineral issues, including the organization of research and planning activities, issuing of exploration and prospecting licenses, etc.
- the NDRC, in charge of designing the pricing system for oil and natural gas (and has therefore power to affect the pricing of UH)
- the National Energy Administration (NEA)
- the Ministry of Finance (MOF), that is responsible for providing fiscal support to the shale gas players in the prospecting phase.

The guidelines that define the legal framework in China are based on "Notice Regarding the Strengthening of Shale Gas Exploration, Prospecting, Supervision and Administration", issued by the MLR on 26th October 2012, which is supposed to support the action of both firms and government authorities.

The exploration rights are mainly conferred through public bidding and licensing processes. So, for example, the second bidding round (December 2012) saw two private Chinese firms and fourteen state owned enterprises as successful bidders (Alberta China Office, 2013). The winning bids were selected according to the largest amount of invested capital, and contained lower bounds to the amounts invested and the quantities to be extracted, in order to avoid speculative behaviour on licenses.

Land and mineral rights

In China, the state is the owner of urban land as well as of specific land types in rural areas. Rural land not owned by the state is collectively owned by farmers. The possibility by individuals or legal entities to carry out mining operations is subject to land use rights (LUR), which can be obtained following a licensing process made up of several stages including:

- a feasibility study,
- a national and local authorities' verification and approval
- a registration
- in cases where farming land is involved, it must be converted into construction land.

On the other hand, mineral resources are owned by the state. With reference to unconventional hydrocarbons, the MLR has initiated pilot schemes to grant provisional LUR by leasing out state-owned land to the relevant entities. This development has, in effect, 'freed' shale gas from Sinopec, PetroChina and CNOOC, the three state owned companies which dominate the Chinese oil and gas market. On the other hand, entities applying for licenses must be Chinese companies (fully domestic enterprises or joint ventures with a Chinese controlling shareholder, which are encouraged by the Foreign Investment Industry Guidance Catalogue, from January 2012, and can benefit of

administrative and tax advantages)[24]. The license holder must establish a project company in the region where shale gas resources are located.

Concerning the licensing stages, as already mentioned, shale gas exploration rights are obtained through public bidding. By the end of 2012, two rounds were launched. In the first one, six state-owned firms participated, while in the second, as seen above, also two private firms were allowed to enter. Table 4, reported by Wan et al., 2014, highlights some relevant features confirming, among other things, the limited involvement of private companies in the first two auctioning phases.

Table 4. First two rounds of tendering, June 2011 and October 2012

Terms	First round	Second round
Blocks put up for bidding	4 prospecting blocks of shale gas, each over 2000 square kilometers, a total area of approximately 11 thousand square kilometers	20 blocks, with a total area of 20.002 thousand square kilometers, distributed in 8 provinces (municipalities): Chongqing, Guizhou, Hubei, Hunan, Jiangxi, Zhejiang, Anhui, and Henan. Only the area of shale gas block in Hefeng, Hubei Province, exceeds 2 thousand square kilometers, while other blocks have areas less than 2 thousand square kilometers; 9 blocks have an area below 1 thousand square kilometers.
Bidding qualifications	Only state-owned enterprises are invited to bid.	Domestic enterprises and institutions and Sino-foreign joint ventures with Chinese side taking the holding position, with domestic registration, registered capital over 300 million RMB, having qualifications in oil and natural gas or gaseous mineral prospecting are allowed to bid.
Enterprises participating in the bidding	CNPC, SINOPEC, CNOOC, Shaanxi Yanchang Petroleum (Group) Corp., China United Coalbed Methane Co., Ltd., Henan Coalbed Methane Co., Ltd.	A total of 83 enterprises participated in the bidding, and 152 bidding documents were submitted. The private enterprises accounted for one-third of total bidders.
Obligations of the winning bidder	For every 1 thousand square kilometer, at least two wells should be drilled.	The prospecting rights put up for bidding have a term validity of 3 years. For every 500 square kilometers, at least two wells should be drilled. After winning the prospecting right, the enterprises should start operation within 6 months. Moreover, the winning bidders should make written commitments to the prospecting input, work load, and progress that have been specified in the prospecting implementation scheme, as the basis for supervision and inspection by the administrative authority.
Bidding results	The enterprises winning the bidding were CNPC and Henan Coalbed Methane Co., Ltd.	The bid failed for one block. Of 19 bid-winning enterprises, 17 are state-owned enterprises; 2 are private enterprises.

Source: Wan et al., 2014

In the licensing stage, there are significant minimum requirements, including minimum registered capital (300 million Yuan), and relevant mineral exploration qualifications (directly or in partner companies). This made it possible for international energy companies to form joint ventures with Chinese counterparties.

The winners gained a three-year exploration permission in a specific part. Also, the holders of existing oil and natural gas licenses could engage in exploration and prospecting for shale gas in their respective blocks, following a procedure to expand the scope of their license or through amendments of their mining rights. On the other hand, in situations where the shale gas potential must be subject to additional scrutiny and the existing oil and gas license holder is inactive, then the existing license can be withdrawn and a new prospecting and exploration license can be issued to be subject to public tendering.

The limits of the existing licensing and permitting processes are outlined by Pi et al. (2015b). Indeed, a significant part of the resources (80%) overlaps with already known oil-and-gas blocks owned by state companies. Given the preferential treatment of these firms, according to the "Notice on Strengthening the Exploration, Exploitation, Supervision and Administration of Shale Gas Resource" (MLR, November 2012), state-owned companies may affect the choice in terms of the specific kind of exploited unconventional hydrocarbon source (e.g. tight oil vs. shale-gas), leaving other resources unexploited. Another relevant issue is related to the fact that the bidding blocks provided by the MLR are mainly located in blank areas outside the current conventional hydrocarbons exploitation zones. This is expected to hinder the bidding

[24] According to information contained in Norton Rose Fulbright (2013), foreign investors must become partners of Sinopec or PetroChina (state controlled companies), and both parties must sign a Production Sharing Agreement (PSA) provided by the Ministry of Commerce (MOFCOM), that will also have to approve it (but this is no longer required since May 2013, under certain conditions). The first PSA relating to shale gas, between PetroChina and Royal Dutch Shell, was approved in 2012 with reference to southwest China's Sichuan province.

incentives and, therefore, may harm the perspectives of the sector in the long run. These problems are expected to act as barriers in the Chinese sector, and must be taken into account in other countries willing to develop a similar sector as well.

Enforcement

In China, a foreign company can enter into a joint venture with a Chinese company without particular limits if the joint venture refers to assets from outside China, at least in terms of the choice of the relevant legislation and court. Significant restrictions are instead present if investments relate to assets in the Chinese territory. In other terms, a Chinese/foreign joint venture contract related to exploration and development of natural resources in China must obey to the Chinese law. The already mentioned report by Norton Rose Fulbright (2015) suggests then that the main contractual arrangements for a foreign investor will very likely be governed by Chinese law, even in cases where this is not compulsory, due to the bargaining power of Chinese parties. This is expected to be coupled with general difficulties in resolving disputes in front of Chinese courts, as well as to enforce foreign provisions in China.

Foreign investment is also affected by the rigid controls China maintains in terms of foreign exchange. Foreign-invested companies must register with a local State Administration of Foreign Exchange authority. Each company can borrow up to a limit which is determined by total investment and by registered capital, and is also subject to specific conditions to be able to distribute profits to foreign shareholders. A withholding 10% tax is applied to profits sent outside China, unless other tax treaties exist making for a more favourable tax treatment (Norton Rose Fulbright, 2015).

Pi et al. (2015b) focus on the severe limits of the regulatory system in China as another potential relevant drawback harming the possibility of the UH sector to develop. Indeed, the absence of specialized laws, regulations and national standards has led to the need to rely on the "ability" of companies to self-regulate. It seems that while the limits for foreign investors and the way in which companies can enter the market have been set, no follow up regulation has led to strict boundaries to firms' activities. It is particularly important that no central regulatory institutions exist, and functions linked to regulation seem to be dispersed across different government layers, without effective supervisory boards or structures.

Recent Developments

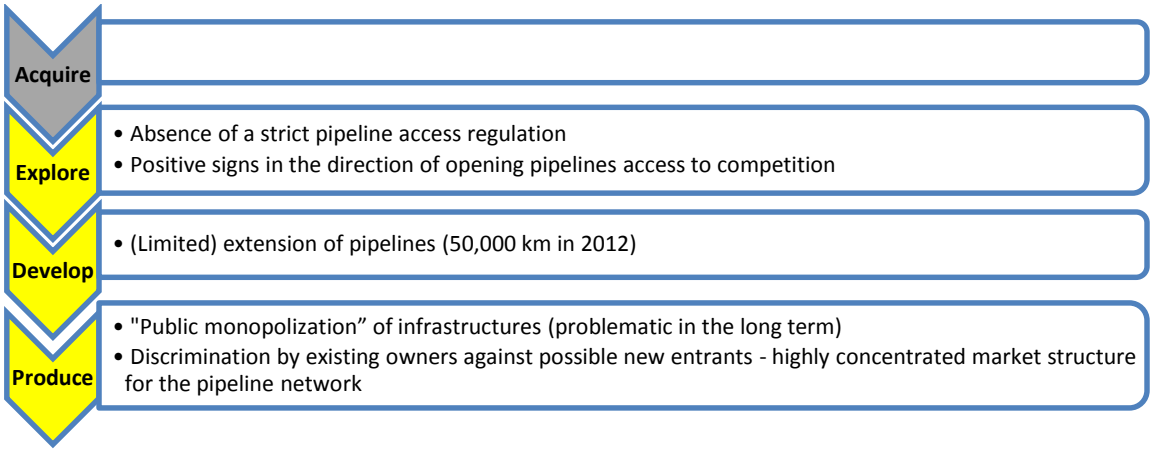
The regulatory issues identified above have been among the causes of a slowing down of the institutional development around UH exploitation in China. Indeed, according to Ratner et al. (2016), in March 2016 the China's 13th Five-Year plan (for years 2016-2020) has been approved. This plan seems to embed the idea of liberalizing extraction, together with an interest towards UH resources. An additional road taken by the government goes in the direction of liberalizing energy markets and prices, and to remove entry barriers for private companies, to level the playing field with respect to state owned companies. On the other hand, the slow development of the UH sector has led the MLR to further postpone the 3rd auction of mineral rights.

3.2.2. Infrastructures

The role of infrastructures is crucial in driving the development of the UH sector. In this respect, the existing scenario seems not to be worrying in the short run; on the other hand, the "public monopolization" of infrastructures in China may turn out to be an issue in the longer term.

The relevance of infrastructures and their specificities for the different stages of the UH supply chain is shown in Figure 22.

Figure 21. Supply chain phases relevant for infrastructures



In the short term, pipeline access should not constitute an issue with respect to the development of UH (and specifically of shale gas) industry. Indeed, for reasons already identified in the previous section and linked to regulatory issues, a significant part of the UH targets set by Chinese authorities is expected to be met by state owned companies (mostly Sinopec and CNPC) that feature a well-developed gas distribution network (Pi et al., 2015a), coupled to mature LNG and CNG related technologies. Most of Chinese existing shale gas extraction, for example, takes place in three demonstration zones (Fuling National Shale Gas Demonstration Zone of Chongqing, Dian-Qian North Zhaotong National Shale Gas Demonstration Zone and Changning-Weiyuan National Shale Gas Demonstration Zone of Sichuan Province).

Also, focusing on the Fuling shale gas field (the first large shale gas field), the extracted resource is mainly transported through existing oil and gas pipelines. On the other hand, several contributions suggest that significant problems are expected to arise in the medium and longer term.

Table 5. Market shares in Pipeline Network in China

Year	Pipeline length (km)	Market share				
		CNPC	SINOPEC	CNOOC	Inner Mongolia Western Natural Gas Co., Ltd.	Datang International Power Generation Co., Ltd.
2009	23084.5	0.908	0.045	0.033	0.012	0
2012	34219.0	0.893	0.049	0.022	0.023	0.01

source: Wan et al., 2014

Indeed, following Wan et al. (2014), the monopolization of the pipeline network will prove problematic in the longer run. The (smaller than in the US) pipeline coverage in China is mostly monopolized by the state owned company CNPC. More specifically, as Table 5 shows, CNPC, Sinopec and CNOOC had by far the largest market shares (respectively, 89.3%, 4.9%, and 2.2% in 2012) of the natural gas pipelines. Overall, they account for over 95%. The extension of the pipeline network in China was only around 50,000 km in 2012. The increase in the density of such network is a key aspect in the development of the UH industry in China.

Clearly, as suggested, again, by Wan et al. (2014), this is likely to affect significantly the degree of competitiveness of upstream producers, with the possibility for state owned companies to crowd out other potential participants, at least in the absence of a strict pipeline access regulation.

A highly concentrated market structure for the pipeline network can indeed be justified on the ground that the latter features substantial fixed costs and, therefore, significant economies of scale. On the other hand, the possibility that existing owners discriminate against possible new entrants is an actual barrier to the development of UH in China. The

potential policies to handle this issue, which are in part currently discussed by government bodies, including the National Development and Reform Commission, range from the possibility of vertical disintegration, separating the network from the production phase, to the preferential treatment and subsidization of new pipeline investment and use (Wan et al. 2014)[25].

Clear signs going in the direction of opening pipelines access to competition are indeed present (Norton Rose Fulbright, 2015). More specifically, in February 2014:

- the NEA published the Measures for Regulation of Fair and Open Access to Oil and Gas Pipeline Networks, for a trial period of five years. These measures grant access to oil and gas pipelines in case of 'excess capacity'[26].

- the NDRC published the Management Measures for Natural Gas Infrastructure Construction and Operation (the NDRC Measures), which aims to encourage (among other things) state-owned companies, private companies and foreign companies to invest in natural gas infrastructures.

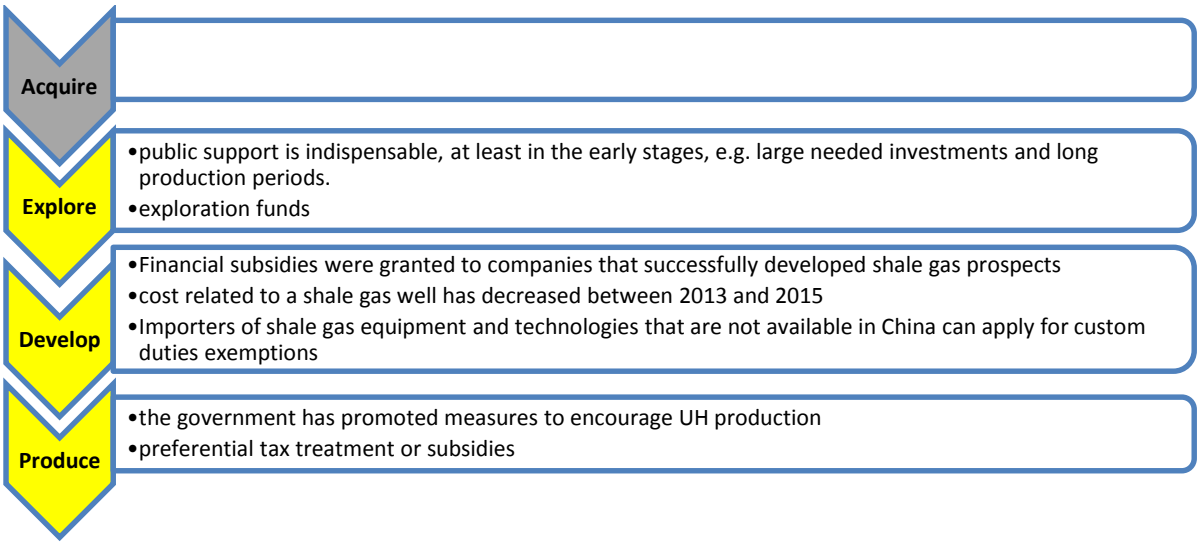
The government is also expected to encourage the construction of pipelines connecting production plants to the main oil and gas pipelines (Alberta China Office, 2013).

3.2.3. Economic incentives

Incentives towards UH exploration have been provided by the Chinese government, to make the sector more attractive and profitable.

Economic incentives are expected to be an important driver in the supply chain phases highlighted (in yellow) in Figure 23.

Figure 22. Supply chain phases relevant for economic incentives

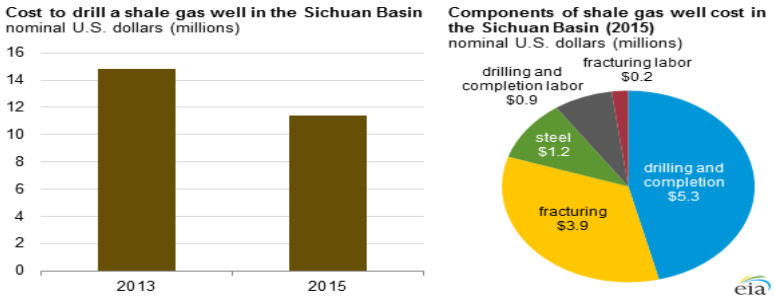


The costs structure in the UH sector in China can be summarized by

Figure 23, which is devoted to the example of shale gas drilling in the Sichuan Basin[27].

[25] Indeed, though no clear conclusion is possible in this respect, subsidies and preferential treatments are expected to remove barriers related to budget constraints and uncertainty, challenging therefore the existing market power.
[26] It must be noted, however, that elements of discretion remain in determining access to pipelines.
[27] US Energy Information Administration, September 2015. http://www.eia.gov/todayinenergy/detail.cfm?id=23152.

Figure 23. – Shale gas drilling costs



Source: EIA, 2015

As it clearly emerges, the cost related to a shale gas well has decreased between 2013 and 2015. As already outlined, this decrease has not been enough to lead to the full development of the sector. Even though in the past four years more than 700 shale gas wells have been drilled in China, reaching production levels of 0.38 Bcf/d, several steps are still needed. For these reasons, together with the already outlined regulatory and infrastructure ongoing reforms, the government has promoted measures to encourage UH production.

Table 6 summarizes some recent regulatory developments in China in relation to UH (Xin-gang et al., 2015). UH sector is indeed characterized by features that make public support indispensable, at least in the early stages, e.g. large needed investments and long production periods. As it is shown in Table 6, the Chinese government has indeed issued several policies, in terms of preferential tax treatment or subsidies. This did not remove, however, the main reasons for private enterprises to be cautious, related to the limits and barriers identified in the previous two sections. Examples of proposed additional schemes include, for example, exploration funds (according to Pi et al., 2015).

Table 6. Policies for shale gas in China

Year	Technology R&D support policy	Fiscal support policy	International cooperation policy
2010	Established the National R&D (experimental) Center of Shale Gas, enhance the research of shale gas theory, technology and equipment [15	NA	China and America signed an agreement on energy, "U.S. State Department and the State Energy Bureau of China on the Action Plan of Sino-US shale gas resources"
2011	Lanched a research project of key technologies of exploration and development, strengthen scientific and technological research to advance the step of shale gas development	NA	The National Development and Reform Commission issued "Catalog for the Guidance of Foreign Investment Industries (Amended in 2011)" to encourage foreign investment
2012	1. Strengthen the support for technology R&D in shale gas exploration and development through the Major Projects of National Science and Technology	1. Shale gas refers to the fiscal subsidy policies of coal bed methane. The Ministry of Finance issued "a notice on the issuance of subsidy policy of shale gas exploration and utilization". The notice stipulates the central financial subsidy for shale gas exploration firms is 0.4 yuan per cubic meter ($0.06535/m^3), and local finance should tender appropriate subsidy according to the situation of local shale gas development	Development and Reform Commission reported for approval from the State Council, enterprises who engage in shale gas exploration and development can cooperate with foreign experienced corporations and introduce relevant technologies
	2. Encourage domestic enterprises and institutions to carry out joint research of key technologies with foreign research institutions, absorb foreign advanced technologies, and form core technologies with Chinese characteristics	2. Mining right holders or applicants who obtain or apply for shale gas exploration right or mining right by laws can apply for relief fees of shale gas exploration right and mining right in accordance with the relevant provisions	NA
	NA	3. For the imported equipments (including the technologies along with the equipments) which cannot be produced at home can be exempted from tariffs according to relevant provisions	NA
2013	Under the approval of National Energy Board, Shale Gas Energy Industry Standardization Technical Committee was set up in Beijing [36]	Fiscal policy for shale gas will be more detailed in the upcoming "shale gas industry policy" [37]	The upcoming "shale gas industry policy" will encourage foreign companies to develop China's shale gas [37]

Source: Xin-gang et al., 2015

While a general overview of the implemented policies is included in Table 6, we can identify the following specific relevant mechanisms aimed at supporting UH development.

- License fees: Shale gas exploration and development licenses holders can obtain a waiver of the related license fees.
- Custom duties: Importers of shale gas equipment and technologies that are not available in China can apply for custom duties exemptions.
- Financial subsidies: Between 2012 and 2015, financial subsidies equal to Yuan 0.4/m3 were granted to companies that successfully developed shale gas prospects. This required the installation of metering systems able to measure precisely the amount of production. Local governments were given discretion, however, by the MOF in choosing the level of these subsidies. So, for example, the current subsidy rate to coal seam methane developers is Yuan 0.3/m3, which is the sum of Yuan 0.2/m3 from the central government, and Yuan 0.1/m3 from local ones. Subsidies were expected to be adjusted after 2015 (Norton Rose Fulbright, 2015).

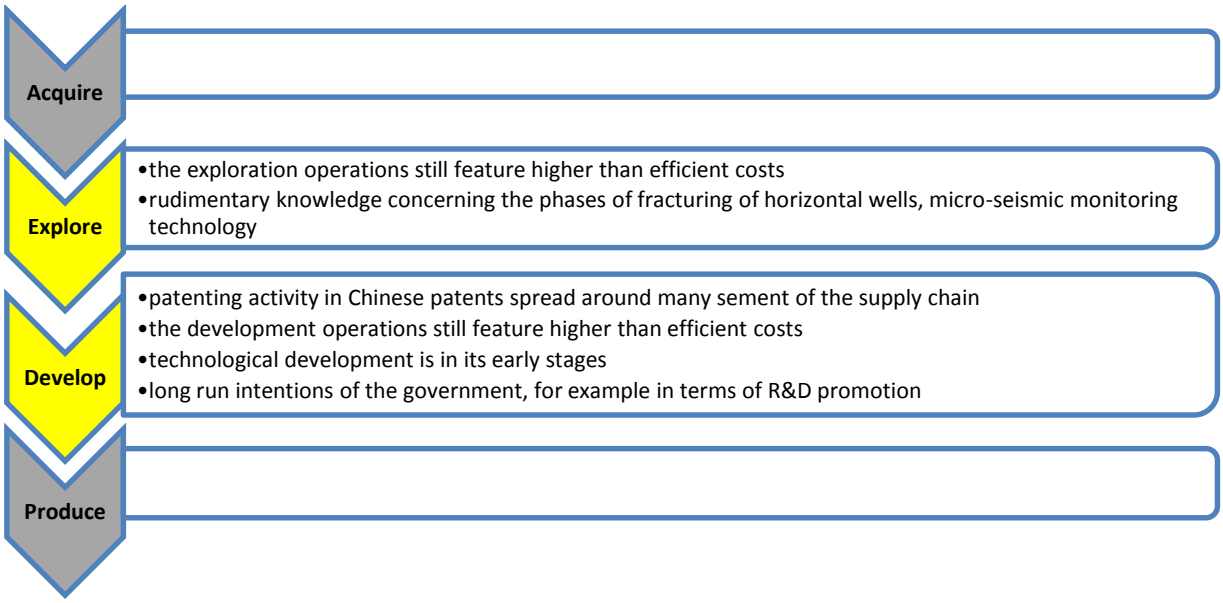
Yuan et al. (2015) have performed a simulation analysis, to investigate the performance of alternative support policies. Their work shows that indeed the current granted support is not enough to guarantee development in the UH sector (specifically in the shale gas industry). Several possible policies, including increases in the price or in the financial subsidies, are seen as potentially effective, followed by decreases in the corporate income tax rate, while, for example, reductions in the royalty taxes are seen as effective only if complemented by other policies, and similar conclusions hold for VAT reduction.

3.2.4. Technology

The state of technology is in general an enhancing factor for the industry development. Currently, however, it is a limiting factor in China, as most of the adopted technologies are imported. Nonetheless, research efforts are increasing. The barriers on the technological side seem to be related to the yet low involvement of the private sector.

The supply chain phases that are mostly affected by the technological drivers are shown in Figure 25.

Figure 24. Supply chain phases relevant for technology



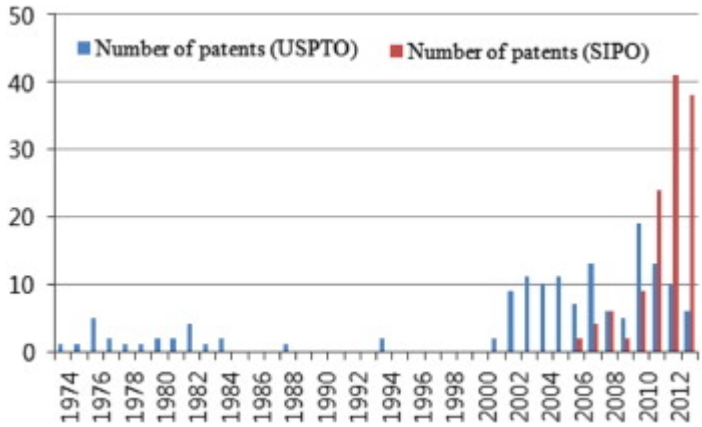
Currently, China combines mature UH imported technologies with conventional oil and gas technologies produced domestically (Pi et al., 2015a). However, according to Xin-gang et al. (2015), among others, key UH technologies and equipment still need development. Accordingly, the exploration and development operations still feature

higher than efficient costs. For example, CNPC only has a rudimentary knowledge concerning the phases of fracturing of horizontal wells, micro-seismic monitoring technology, etc. (Pi et al., 2015a). Sinopec Group has made progress with respect to completion tools, horizontal well drilling fluid and fracturing fluid. Overall, technological development is in its early stages (Li et al., 2016). The main causes of this situation are identified in the absence of a technological system suitable to adapt to the specific UH sector needs, so that, as already mentioned, the sector still relies significantly on imported equipment. Also, no clear technological roadmap has emerged so far to shed light on long run intentions of the government, for example in terms of R&D promotion. These issues are made worse by the lacking availability of skilled workers (e.g. technicians, managers). This can lead to a (potentially costly) "trial and error" approach.

Although at the moment key technologies come from abroad, it is interesting to investigate the R&D effort performed in China in latest years. Indeed, as shown by Lee and Sohn (2014) and as represented in Figure 26, the US patenting activity has been significant since early 2000s, while only in recent years a steady increase could be observed in China. Looking more specifically at the patents codes (the IPC codes), an important feature of Chinese UH patents arise. Indeed, while 60% of US patents had the E21B code, related to drilling, Chinese patent applications have a wider distribution across codes, namely 15% were G01N, 28% were E21B, and 16% were C10B. This shows a patenting activity much more focused on drilling in the U.S., whereas the Chinese patents are more widespread.

Additionally, the majority of patent applications in the SIPO (China) were made by national universities, whereas in the US, the majority of applications came from oil companies (Figure 25). This is because the commercialization of the shale gas industry is already completed in the U.S., and companies thus have patent authority.

Figure 25. Registered shale gas related patents, China (red) and US (blue).



Source: Lee and Sohn, 2014

Technological development is indeed a priority in China. The features of (at least a part of) the UH reserves make them substantially different from the ones in other parts of the world where technologies are more mature. This is the case, for example, of tight oil reserves: most of US unconventional tight oil reservoirs are marine deposits, while in China unconventional tight oil reservoirs are continental sedimentation, with all the related difficulties and the need to develop "dedicated" technologies (Luo et al., 2016). Similar considerations refer to shale gas resources, which are available at less favourable conditions in China, as compared to other countries (Tian et al., 2014).

The technological limits in the sector are well outlined by Tian et al. (2014). The authors focus on shale gas, and divide the development process in two stages: the first stage involves the development of cost-effective extraction technologies, to be obtained through learning by doing and innovations (innovation stage, roughly linked to the industry emergence phase in the Industry Life Cycle setting outlined in the introduction).

Then, shale gas development enters the second, scaling-up, stage (roughly linked to the industry maturity phase in the Industry Life Cycle setting) mostly involving increases in production, to be achieved through continued improvements in technologies, costs and profits.

Dividing the development in these two stages helps understanding the best possible structure in each of the two. So, larger concentration may be desirable if the sector is closer to the first stage, while more competition is helpful in the second stage. This seems to suggest a potentially counterintuitive conclusion: the state owned companies, featuring large comparative advantage as compared to potential new entrants, although being identified as one of the factors harming UH development under other respects, may instead be identified as the solution to the innovation problem. This can however be the case only if economic incentives are appropriately reshaped.

4. Canada

4.1. A Brief Outline on Resources Availability

Canada has substantial UH reserves, reaching the fourth place in the World. This can be assessed relying on data from the US Energy Information Administration (EIA, 2013). Table 7 (as reported by Lee and Sohn, 2014) summarizes the known shale oil and shale gas resources. Clearly, as Canadian provinces own primary powers in terms of UH development, the perspectives might differ across provinces.

Table 7. Shale oil and gas resources in Canada (source: US EIA, 2013)

Region	Basin / Formation	Risked Resource In-Place		Risked Technically Recoverable Resource	
		Oil/Condensate (Million bbl)	Natural Gas (Tcf)	Oil/Condensate (Million bbl)	Natural Gas (Tcf)
British Columbia / Northwest Territories	Horn River (Muskwa / Otter Park)	-	375.7	-	93.9
	Horn River (Evie / Klua)	-	154.2	-	38.5
	Cordova (Muskwa / Otter Park)	-	81.0	-	20.3
	Liard (Lower Besa River)	-	526.3	-	157.9
	Deep (Doig Phosphate)	-	100.7	-	25.2
	Sub-Total	**-**	**1,237.8**	**-**	**335.8**
Alberta	Alberta (Banff / Exshaw)	10,500	5.1	320	0.3
	E/W Shale (Duvernay)	66,800	482.6	4,010	113.0
	Deep Basin (Nordegg)	19,800	72.0	790	13.3
	N.W. Alberta (Muskwa)	42,400	141.7	2,120	31.1
	S. Alberta (Colorado)	-	285.6	-	42.8
	Sub-Total	**139,500**	**987.1**	**7,240**	**200.5**
Saskatchewan / Manitoba	Williston (Bakken)	**22,500**	**16.0**	**1,600**	**2.2**
Quebec	App. Fold Belt (Utica)	**-**	**155.3**	**-**	**31.1**
Nova Scotia	Windsor (Horton Bluff)	**-**	**17.0**	**-**	**3.4**
	Total	**162,000**	**2,413.2**	**8,840**	**572.9**

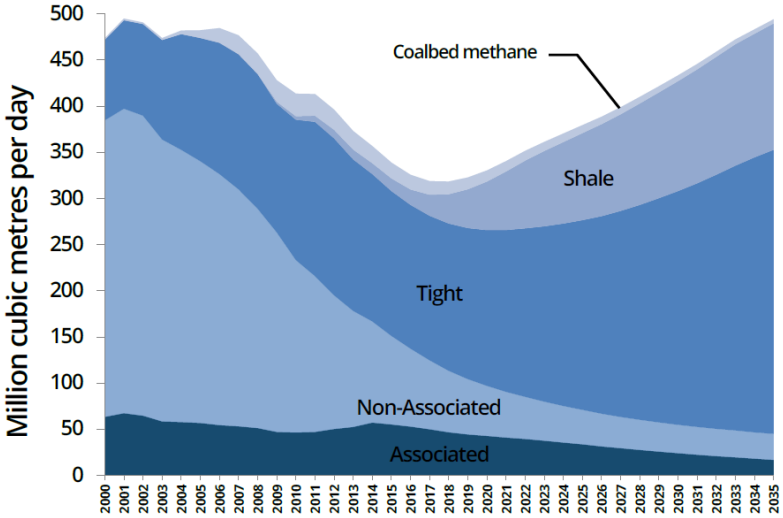
*Less than 0.5 Tcf

Source: Lee and Sohn, 2014

These considerations can be coupled with mixed evidence concerning market competitiveness. Indeed, according to Lozano-Maya (2016), market demand is weak, and the US are the most important destination for the Canadian market. On the other hand, the growing independency of US is expected to trigger the need for Canada to look for other trade partners overseas. Also, and clearly, the market competitiveness of Canadian resources is expected to depend on the specific regulatory settings in different provinces.

Turning to the role of UH in hydrocarbons production, the role of unconventional resources in Canada's production is expected to be significant. For example, focusing on gas, in 2013, Canada was the world's fifth-largest producer, and domestic production is increasingly driven by unconventional gas resources, including shale gas. According to the National Energy Board forecasts (see APERC, 2015 for details), the combined share of tight gas, coalbed methane and shale gas has grown from 19% in 2000 to 51% in 2012. This is represented in Figure 27, together with projections up to 2035. Unconventional gas resources are expected to increase to 91% of total gas production in 2035, with a decreasing role for conventional (associated and non-associated) sources.

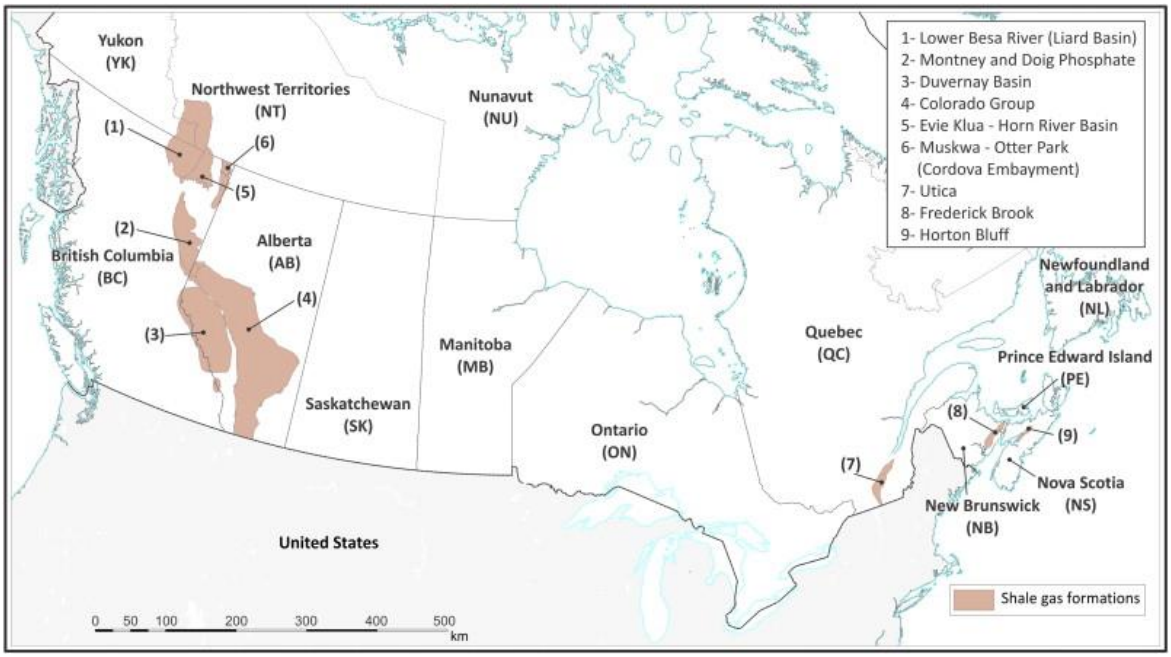
Figure 26. Share of Unconventional gas resources in Canada – projections to 2035



Source: APERC, 2015

According to the report by Norton Rose Fulbright (2015), there are promising UH resources that are in their early stages of exploitation and development. One example in this respect is the Horn River Basin in British Columbia. Other prominent UH sources are the Montney, Liard Basin and Cordova Embayment in British Columbia, the Colorado in Alberta, the Bakken in Saskatchewan, the Utica Shale in Quebec, and the Horton Bluff in the Canadian Maritimes. Figure 28 reports, as an example, the main Canadian shale gas resources.

Figure 27. Location of shale gas resources in Canada



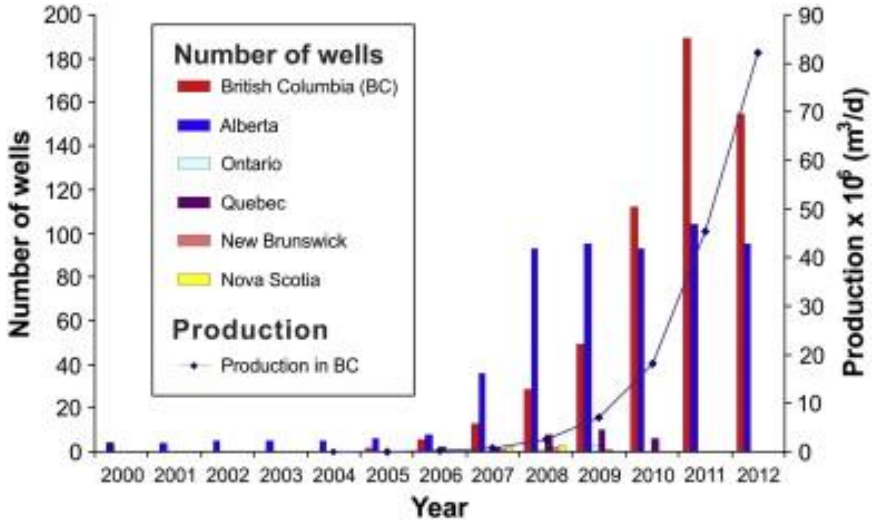
Source: Rivard et al., 2014

According to APERC (2015), shale gas is currently produced only in the Horn River basin and in the Montney formation (British Columbia, numbers 2 and 5 in Figure 28) and in Duvernay formation (Alberta, number 3 in Figure 28). Other provinces have recently

experienced explorations (New Brunswick and Nova Scotia, where further development is now banned) with not encouraging results (Rivard et al., 2014).

Figure 29 shows the number of wells for shale and tight sand gas in Canada and estimates of shale gas production in British Columbia. As Rivard et al. (2014) suggest, also Alberta produces shale gas, but in a not significant proportion both with respect to British Columbia (less than 1%) and with respect to conventional gas production in Alberta (about 0.1% of total gas production in the province). The authors conclude that, "…compared to the U.S., unconventional gas development in Canada is still in its nascent stages."

Figure 28. Number of drilled wells in Canada

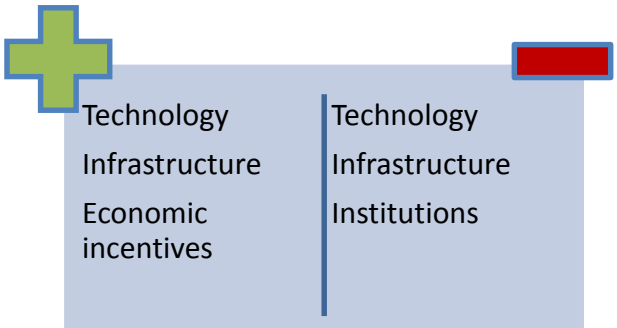


Source: Rivard et al. (2014)

4.2. Drivers and Barriers of UH development in Canada.

Driving and limiting factors relevant for the UH sector in Canada, with a specific attention to the provinces where the majority of wells were drilled (Alberta and British Columbia, according to Rivard et al., 2014) are summarized in Figure 30.

Figure 29. Drivers and Barriers of UH Development - Canada



4.2.1. Institutional Framework[28]

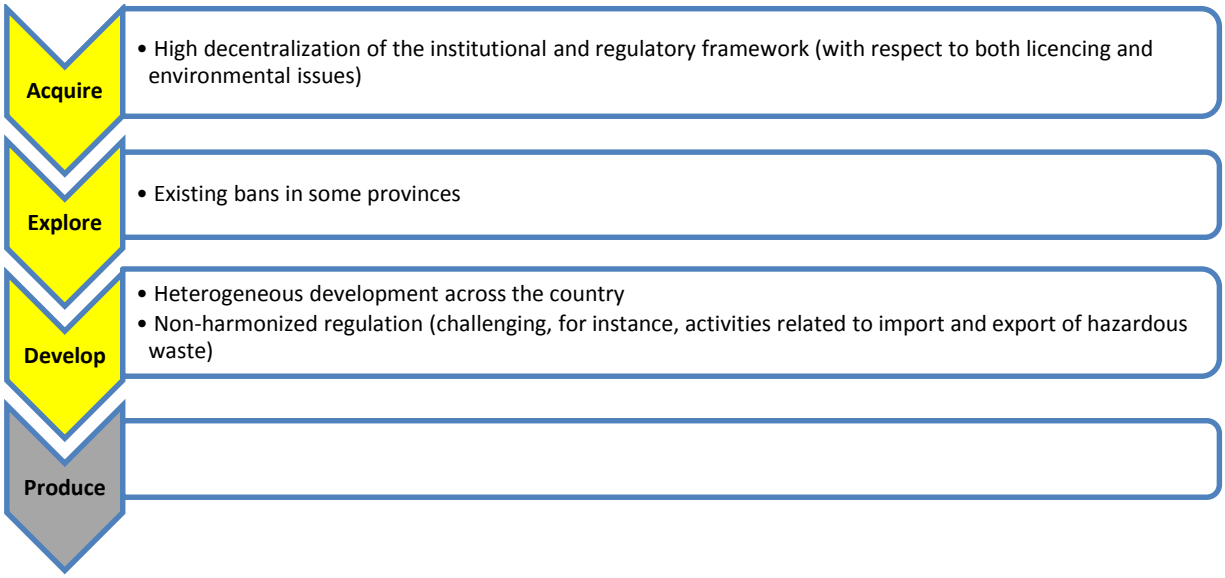
The institutional and regulatory framework in Canada is highly decentralized, involving potentially overlapping federal and provincial or territorial level structures. This may have acted as a barrier to a full development of the UH industry, also accounting for the existing bans in some provinces, and justifies,

[28] Where it is not otherwise stated, the structure of this part relies on information from Norton Rose Fulbright (2015) and APERC (2015).

together with resource availability, the heterogeneous development across the country.

The most relevant stages of the supply chain affected by the institutional framework specificities are highlighted in yellow in Figure 31.

Figure 30.Supply chain phases relevant for Institutional Framework



Energy governance in Canada is multi-layered, so that policy making and administration rest with several federal agencies, together with province level governments. The main agencies with respect to UH development include:

- Natural Resources Canada (NRC), in charge of developing policies and guidelines to set up the proper mix of sustainable natural resource use and economic competitiveness;
- National Energy Board (NEB), responsible for energy infrastructures, development and trade. The NEB is an independent federal regulatory agency that reports to the Parliament of Canada. A significant part of the regulatory activity, however, takes place at provincial level.

Provincial and territorial governments are in charge of energy policies within their boundaries, so that heterogeneous policies and initiatives can be observed across different provinces or territories. We here focus on the two most important provinces, under the point of view of UH exploitation.

Alberta. The provincial government owns 81% of the province mineral rights, while the remaining 19% are owned by individuals, companies or by the Federal Government. A "new" institution, the Alberta Energy Regulator (AER), a single agency founded in 2013 as the result of two previous agencies (Energy Resources Conservation Board and Environment and Sustainable Resource Development division) is in charge of energy related regulations. Leases can be acquired through a competitive (first price) bid auction that takes place every two weeks. Before auctions take place, however, the provincial agency can assess whether and to what extent important surface or environmental problems may arise. The call for bids can then be subject to changes and amendments accordingly. The first lease is for five years, but can be renewed indefinitely, if the leased lands prove to be productive. Regulation related to UH (and specifically to shale gas) mainly stems from standard natural gas regulations, covering the whole industry life cycle.

British Columbia. In British Columbia, the Ministry of Natural Gas Development is in charge of the oil and gas sectors. The Ministry is in charge of policy design and implementation, issuing of resource rights, taxation etc. The Ministry is also responsible for the Oil and Gas Commission (OGC), in charge of overseeing oil and gas related activities along the supply chain. Only 4% of mineral rights are owned privately in British Columbia, the rest being owned by the provincial government. This makes a significant difference with respect to other countries (the US are the most striking example), where mineral rights are instead part of land ownership rights, as in Alberta mineral rights are issued through public (first price) auctions, to access an agreement for exploration and development. The first term lasts for three years, but it can be renewed indefinitely.

Environmental regulation and the involved stakeholders are also important in the context of Canadian UH development. Indeed, the power over environmental issues is divided across federal and provincial layers of governments, with significant overlapping coupled with not very fruitful harmonization efforts. At a Federal level, the most important act is the 1999 Canadian Environmental Protection Act (CEPA), which includes broad enforcement powers and also regards import and export of hazardous waste. This is relevant for the UH sector due to the chemicals used in hydraulic fracturing and to the exports of oilfield waste, among others.

Other related acts provide strict regulation: the federal Fisheries Act (FA) forbids any deposit of dangerous substances in water featuring the presence of fish, or any act endangering fish habitats.

Also, the Canadian Environmental Assessment Act, 2012 (CEAA) engages the proponents of certain large projects, including those related to sour gas and LNG. After a screening procedure, some projects may indeed be subject to an Environmental Assessment (EA), which is "guided" by a designated agency, the Canadian Environmental Assessment Agency. The EA is performed by the proponents and is subject to public consultation. At the end of the process, that must be completed within 365 days from the starting date, the Agency passes the results to the Minister of Environment who issues a decision. If the latter identifies the possibility of significant environmental harm, then a federal Cabinet is involved. As a result, the project can be developed if the Environment Agency and the Minister declare that the project is not likely to cause significant environmental harm, or if the Cabinet concludes that such harm is justified. Federal legislation is coupled with provincial and territorial regulations. Several examples are available, including state level acts (such as Alberta's Environmental Protection and Enhancement Act) and aboriginal treaties that imply, in particular, that when projects are expected to potentially affect aboriginal rights, the involved populations must be consulted.

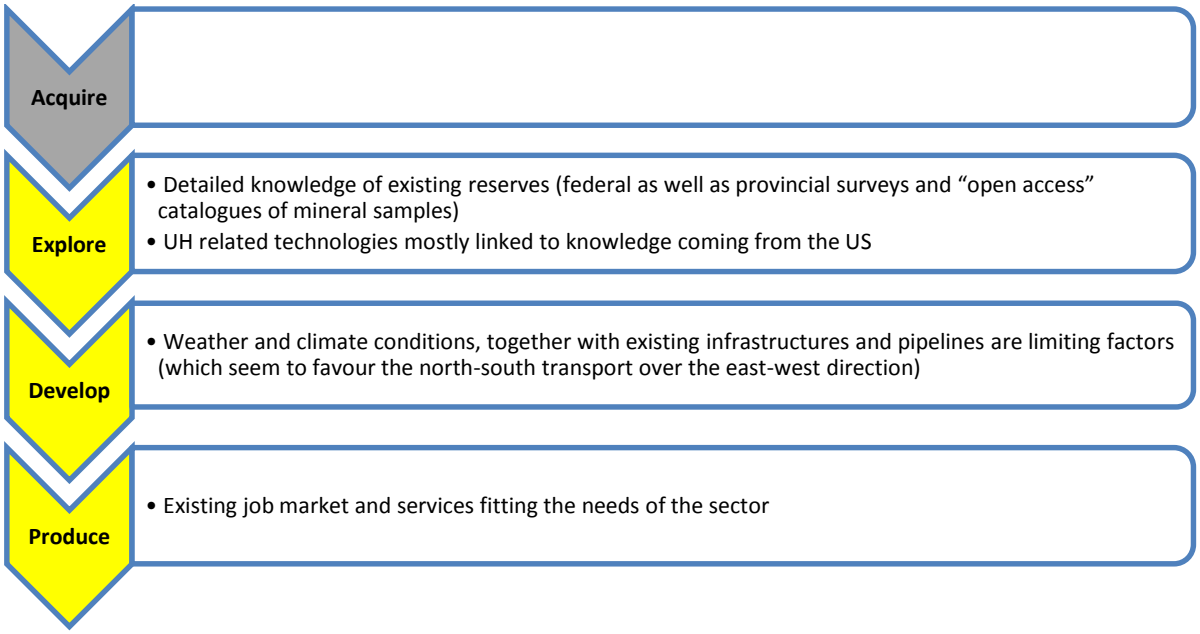
The complexity of these regulatory settings is expected to have played and to play an important role in UH development. Furthermore, according to Lozano-Maya (2016) the competitiveness of oil and gas projects requires offering attractive conditions to developers, including preferential regulatory and fiscal treatment. As a result, although regulation is improving in this respect, the management of risks related to UH exploitation is lagging behind projects development, and communities (aboriginal groups in particular) do not perceive their involvement as significant, resulting in distrust in governmental bodies.

4.2.2. Technology and Infrastructures

Canada features the expertise to implement technologies from the US, and also a detailed knowledge of existing reserves. Under an infrastructural point of view, however, the north-south bias of existing networks, together with the recent development of the sector in the US, may act as a limit to UH development.

Figure 32 outlines the most relevant stages of the supply chain for technology and infrastructure characteristics in Canada (in yellow).

Figure 31. Supply chain phases relevant for Technology and Infrastructures



Under a technological point of view, the proximity of Canada to the US implies that the UH related technologies mostly rely on knowledge coming from there. According to APERC (2015), the correct implementation of these technologies has been possible also due to the precise geological knowledge and understanding of existing reserves, thanks to federal as well as provincial surveys and "open access" catalogues of mineral samples.

We report an example testifying Canada's good position on the UH learning curve: the industry has deployed pad operations, such as the Apache Corporation's 70K and 34L pads in the Horn River field of British Colombia, implying costs savings and lower environmental harm, on the one hand, and the use of more advanced technologies, skilled workers and specific inputs, on the other (King, 2012). The Apache 34L pad in the Horn River Development of Northern British Colombia covers 6.3 acres where twelve wells recover gas from approximately 5000 acres.

The completed pad will only cover 0.3 acres. While the existing job market and services seem to fit the needs of the sector (Rivard et al., 2014), some limits can be found in the weather and climate conditions, especially in the north-eastern British Columbia, during the winter months (from December to March).

This is indeed another relevant issue where technological change can play a role. Also, the limits related to existing infrastructures and pipelines, which seem to favor the north-south transport over the east-west ones (Moore, 2015), may harm the potential for UH resources. A detail of the existing network is reported in Figure 33.

Figure 32. Gas distribution network in Canada

Source: APERC, 2015

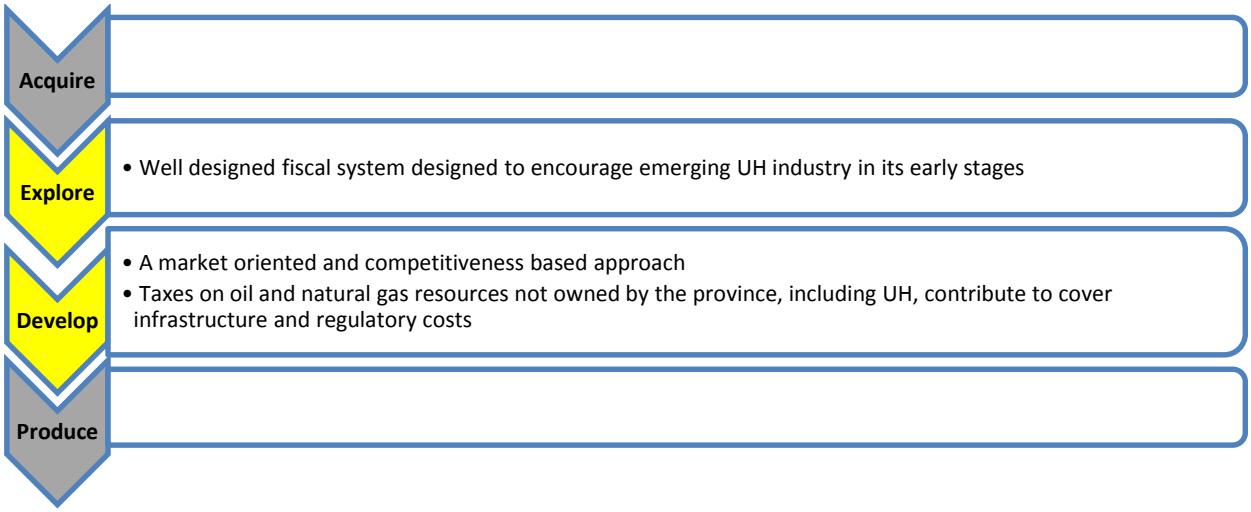
As it emerges from the above figure, most infrastructures (including upstream ones) are concentrated in the western part of the countries. Also, most of the exports have been concentrated towards the mid-west and western part of U.S. As a result, albeit the network also extends to the eastern part of Canada, the western part features a better development and a better integration with the U.S. network. The above considerations may be a source of concern for the UH sector in Canada. As APERC (2015) underlines, natural gas transport from east to west (to satisfy eastern Canada and north east US demand) may have suffered from the increases in shale gas production in US themselves. The New Brunswick's Canaport LNG import terminal, that started operating in 2009, has not been followed by other terminals of the same type, and exports plants are starting looking at other destinations (by September 2014, 17 LNG export terminals started the bureaucratic process to begin operations).

4.2.3. Fiscal treatment and economic incentives

The fiscal systems in the main UH exploiting provinces in Canada seem to be well designed to encourage the UH sector in its early stages, keeping at the same time a market oriented and competitiveness based approach.

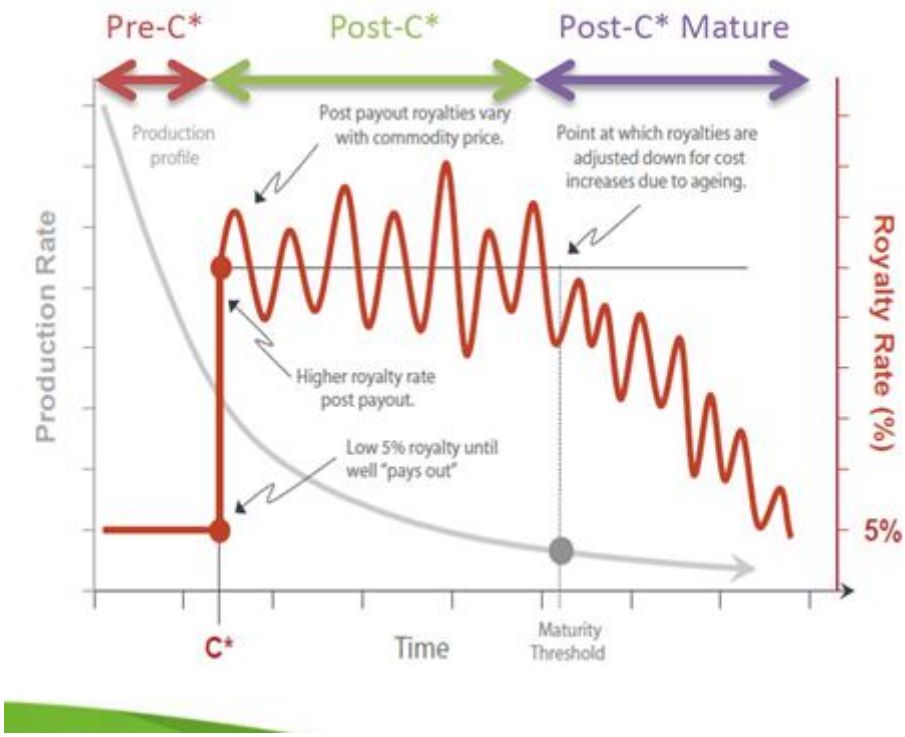
The relevant supply chain phases affected by the fiscal treatment in Canada are highlighted in yellow in Figure 34.

Figure 33. Supply chain phases relevant for fiscal treatment and economic incentives



The fiscal treatment of UH resources can be assessed starting from APERC (2015). In general, the fiscal regime is designed in such a way to encourage emerging UH industry in its early stages. An example of the design of royalties in Canada is the one existing in Alberta. According to Alberta Energy (2016), the aim of the system is to provide correct incentives to developing sectors without distorting market competition across different hydrocarbon sources. The working of the system can be assessed with the help of the Figure 35.

Figure 34. Royalties structure in Alberta



Source: Alberta Energy, 2016

A cost threshold C* is defined, based on average industry drilling and completion costs. As a result, it is also affected by the stage of development of a sector/technology, and is expected to be larger for relatively new (e.g. unconventional) techniques when these techniques are in their early stages and, therefore, feature a larger average cost. For revenues below this threshold, the wells pay a preferential 5% royalty rate. Above this threshold, well sites start paying higher royalty rates that are expected to vary with the market conditions as well as in terms of the specific resources. When wells get closer to maturity, the royalty rates start decreasing again[29]. The main aim of this system is to level the playing field, moving investors towards the best opportunities and incentivizing, at the same time, innovation in early stages.

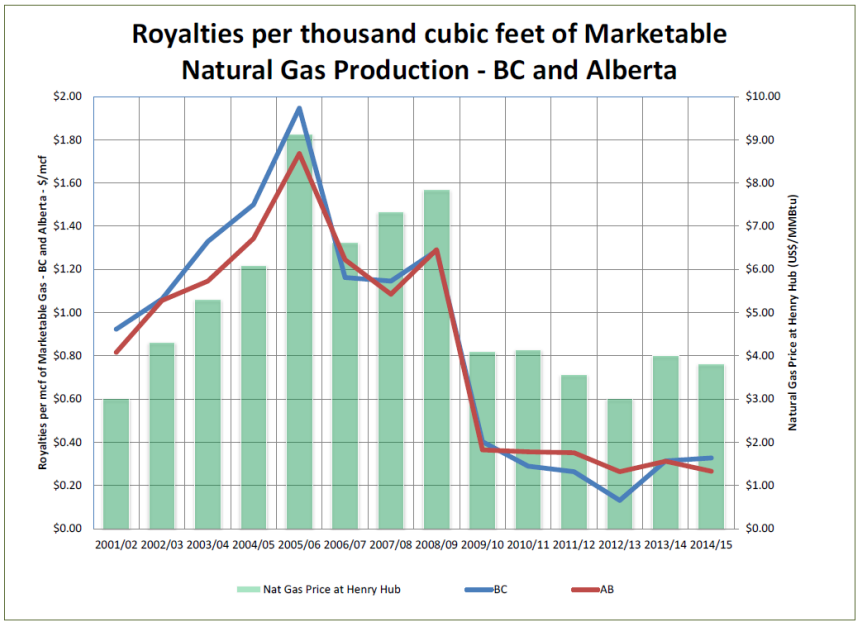
In addition (Norton Rose Fulbright, 2015), Alberta Energy collects a set of taxes on oil and natural gas resources not owned by the province, including UH, in order to guarantee an appropriate contribution to infrastructure and regulatory costs.

In British Columbia, royalties are determined monthly for each well. The calculation criteria include, among other things, ownership of the land, association with oil production, a reference price and inflation adjustments (APERC, 2015). According to the report by Norton Rose Fulbright (2015), British Columbia also created a net profit royalty programme, aimed at encouraging high-risk and high-cost oil and gas resources in their early stages. The required investment level is a minimum of 50 million C$ in five years,

[29] For details, see: http://energy.alberta.ca/About_Us/Royalty.asp.

excluding land acquisition. Developers which are entitled to access this program pay a net profit royalty starting from 2 per cent (of gross revenue) and then increasing along the project lifetime (as soon as the project turns out to be profitable). The design of the royalties system in British Columbia is intended to achieve four main objectives (British Columbia Ministry of Natural Gas Development, 2015), in terms of value maximization, innovation, equity and administrative ease. Figure 36 shows the royalties per cubic feet of natural gas production in British Columbia (BC) and Alberta (AB).

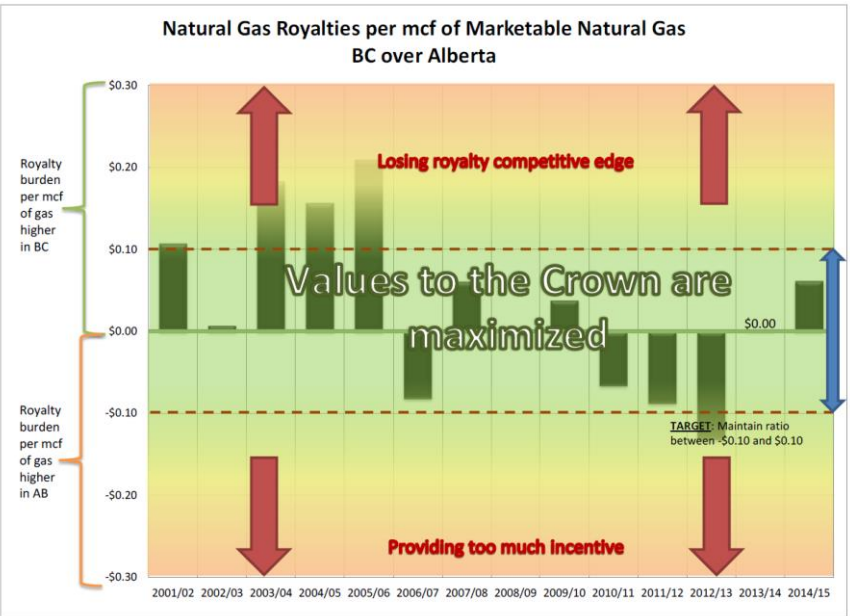
Figure 35. Royalties on Natural Gas



Source: British Columbia Ministry of Natural Gas Development, 2015

To assess the impact in terms of competitiveness, the British Columbia government compares the royalties with those arising in Alberta, as it shown in Figure 37.

Figure 36. Royalty differentials on Natural Gas



Source: British Columbia Ministry of Natural Gas Development, 2015

Figure 37 shows that the difference between Alberta and British Columbia has evolved over time: the royalty has been larger in British Columbia by at most 0.21 C$ in 2005/06, implying losses in competitiveness, while it has been larger in Alberta by at most 0.13 C$, in 2012/13, potentially implying too generous incentives in British Columbia. The target set by the British Columbia Ministry is to keep the royalty differential between -0.10 and 0.10 C$, to avoid harming competitiveness, on one hand, and to keep encouraging investment, on the other. This is important for the UH sector, as in British Columbia the recent evolution of natural gas production has implied that "…unconventional natural wells for shale and tight gas (using horizontal drilling) have emerged as the primary new source of production, and are the offset to older vintage wells…"(British Columbia Ministry of Natural Gas Development, 2015, p.7).

5. Australia

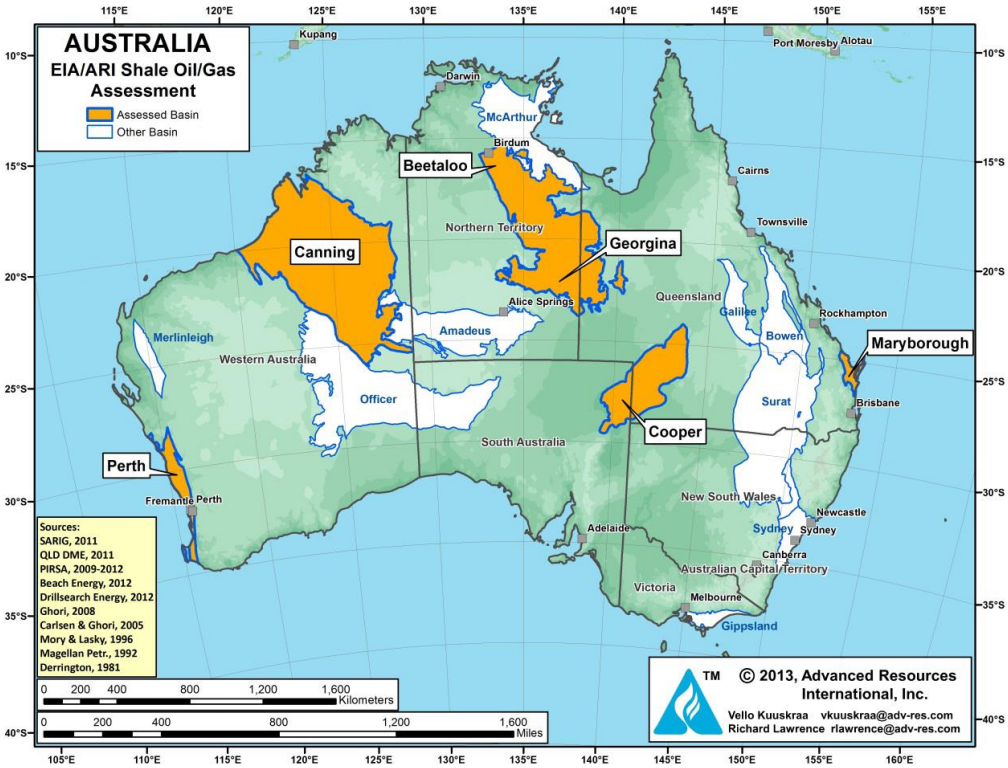
5.1 A brief overview of resource potential

The UH industry in Australia is still in a very early stage of development, and the full extent of shale resource opportunities is far from being identified. According to a report published by the US EIA/ARI in 2013, Australia enjoys geologic and industry conditions resembling those of the US and Canada, putting the country in the position of starting commercially viable shale gas and shale oil production in the next few years.

In the ranking provided by EIA for shale gas resources, Australia is placed seventh of the 41 countries, following Mexico and ahead of South Africa. The six major Australian oil and gas basins[30] hold an estimated technically recoverable shale gas resource of 437 TCF and an estimated technically recoverable shale oil resource of 17.5 billion barrels. Western Australia alone is estimated to hold the fifth largest reserves of shale gas in the world (Norton Rose Fulbright, 2015), which potentially contain 280 TCF of shale and tight gas. Of this, 235 TCF are in the Canning Basin (Kimberley and East Pilbara regions) and 45 trillion cubic feet are in the northern Perth basin (Midwest region) (Government of Western Australia, 2014).

Natural gas production in Australia has been increasing steadily for decades and, even though most of the production is derived from offshore conventional resources, coalbed methane (known as coal seam gas, CSG, in Australia) is commercially relevant. Estimated recoverable reserves of CSG, however, are lower compared to estimated technically recoverable shale gas resources. A picture showing high potential shale basins in Australia is provided in Figure 38.

Figure 37. Assessed Prospective Shale Gas and Shale Oil Basins in Australia



Source: EIA/ARI, 2013; p.III-1

[30]The six major basins are: the Cooper Basin in South Australia and Queensland, the Maryborough Basin in Queensland, the Perth Basin and Canning Basin in Western Australia and the Georgina Basin and Beetaloo Basin in the Northern Territory.

Estimates of Australian shale resources and their distribution are quite variable. For instance, according to the examination carried out by the Australian Council of Learned Academies (2013) on sixteen shale basins, the volume of potentially recoverable shale gas resources is much larger, corresponding to 1,416 TCF. Estimates of recoverable resources in shale basins included in the evaluation are provided by AERC (2015) and reported in Table 7.

Table 4.Australian shale gas resources by basin

Basin	Play	Area (km^2)	Best estimate recoverable resources - Tcf	Best estimate recoverable resources - Tcm
Amadeus	Horn Valley	7,267	16	0.5
Beetaloo	Kyalla	898	3	0.1
	Velkerri	6,092	16	0.5
Bonaparte	Milligans	2,752	6	0.2
Bowen	Black Alley	51,252	97	2.7
Canning	Goldwyer*	147,305	796	22.5
	Laurel*	48,285	169	4.8
Carnarvon	Byro Group	6,162	9	0.3
Clarence –Moreton	Koukandowie	4,407	11	0.3
	Raceview	4,407	10	0.3
Cooper	Roseneath, Epsilon, Murteree (REM)*	9,106	49	1.4
Eromanga	Toolebuc	93,263	82	2.3
Georgina	Arthur Creek	14,433	50	1.4
Gunnedah	Watermark	8,631	13	0.4
Maryborough	Cherwell	3,264	7	0.2
McArthur	Barney Creek*	2,867	7.4	0.2
Otway	Eumeralla	4,109	9	0.3
Pedirka	Purni	29,357	43	1.2
Perth	Kockatea*	14,123	23	0.7
Total		**457,980**	**1,416**	**40.1**

*This play includes wet gas resources

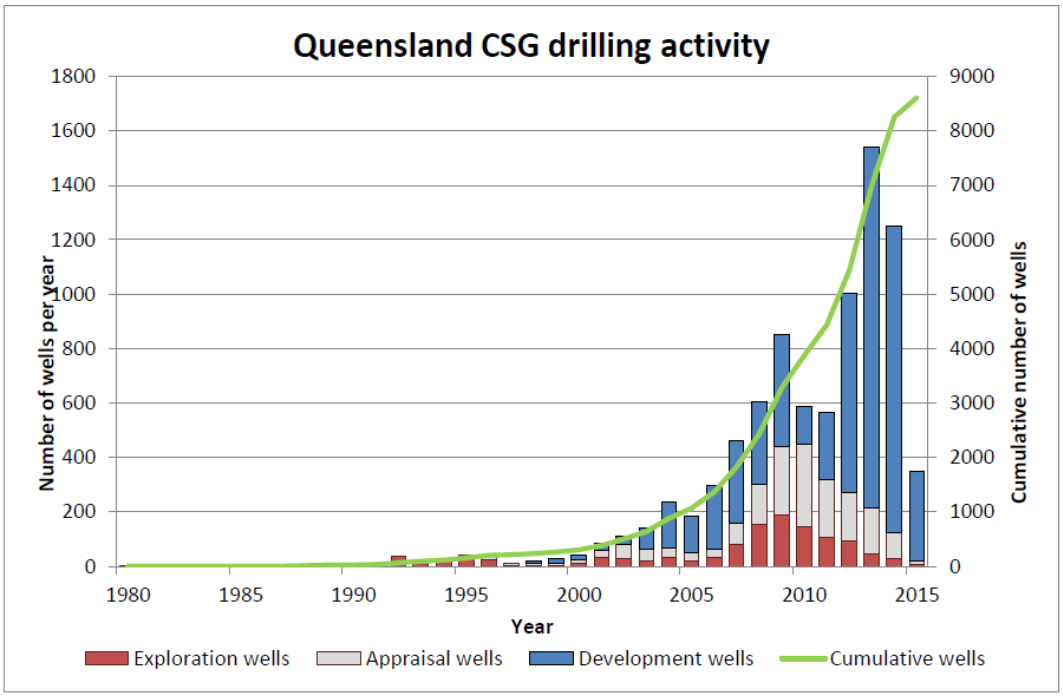
Source: APERC, 2015; p.65

Several other basins in Australia have not been assessed yet and some remain substantially underexplored. This implies that the country has a huge potential for significant additional resources.

The Onshore Hydrocarbons Section at Geoscience Australia, in collaboration with state and territory geological surveys and energy departments, has started to assess the UH potential, both in basins with poor geological knowledge (most of the Australian basins) and in basins where there has already been significant exploration, such as the Cooper Basin, in order to provide a resource assessment on a basin by basin basis.

As far as CSG is considered, reserves have increased markedly from 2007 as drilling accelerated to prove up reserves for the liquefied natural gas (LNG) projects. In Queensland, the drilling activity is increased, and over the last three years, it has focused on development wells (Upstream Petroleum Resources, 2015). This implied a reduction in the number of exploration and appraisal wells, while the number of development wells have substantially increased (Figure 39).

Figure 38. Well drilling rates and cumulative CSG wells drilled



Source: UPR, 2015, p.11

Currently there are only very few wells targeted to shale gas formations drilled in the country. This is due not only to the need of improving the knowledge of resource potential, but also the lack of infrastructures, drilling services and land rigs capable of drilling deeply.

Since 2005, 15 exploration wells have been drilled to search for shale and tight gas resources in Western Australia. Seven of these involved hydraulic fracturing to test the capacity of the reservoir to generate commercial gas flows (Government of Western Australia, 2014). They have been approved by the Department of Mines and Petroleum (DMP), in consultation with the Environmental Protection Authority (EPA), with strict regulatory requirements to ensure they did not have any significant adverse impacts on the environment.

Specifically, the Canning basin, which is considered as having the greatest potential resources in the country (Upstream Petroleum Resources, 2015), has experienced a significant amount of activity in the latest years. Nevertheless, potential challenges to the commercial development in the basin can come from its remote location and lack of existing pipelines, access to roads and water sources. The Northern Perth Basin, on the contrary, is better placed compared to the Canning Basin, because of its close proximity to gas markets, pipeline infrastructure and the Perth city region. Initial results from geological exploration were favourable; in 2012, three shale gas wells were hydraulically fractured in the basin and three prospective formations were identified. It is then more likely that unconventional gas from this basin will reach market first. In the Perth Basin there are also the only tight gas fields currently progressed to the contingent stage of exploration (Government of Western Australia, 2014).

According to the Government of Western Australia, if the current exploration phase proves to be successful, significant commercial production is expected to be five to ten years away.

The greatest potential for commercial development of shale gas in Australia, however, is in the Cooper Basin, where the first two exploration wells were drilled in 2010 and the first, and so far only, commercial shale gas production started in 2012. The initial well flow rate ranged from 1.000 million cubic feet per day (mmcf/d) to 2.600 mmcf/d, in line

with the successful US shale development rates (UCL Australia, 2013). This development has been made possible by processing and transport infrastructure already in place, which allowed the vertical test well to be drilled near existing pipelines and a gas processing plant, even though paved access roads are still lacking.

The availability of existing infrastructure and pipeline network, following decades of conventional oil and gas production in the region, puts the Cooper Basin in a privileged position, as generally other basins do not have infrastructures enabling them to bring the plants online quickly. They will require substantial capital investments to develop the necessary infrastructures, especially remote areas in the north of Western Australia and in the Northern Territory.

A potential risk for commercial development in the Cooper Basins, however, is related to the lacustrine characteristic of the resources, and in particular, their higher clay contents compared to marine shales, which may create difficulties to hydraulic stimulation treatments (see also Section 5.2.3).

In the Northern Territory, the presence of petroleum sources has been identified during drilling and mineral exploration over many years. Some operating companies are actively investigating shale plays in the Beetaloo Sub-basin, where there is evidence of both unconventional and conventional hydrocarbons. The number of wells drilled for unconventional resource exploration passed from two in 2011 to twelve in 2014 (Upstream Petroleum Resources, 2015). At this stage, however, there is no production from unconventional gas resources in the Northern Territory and unconventional gas exploration is still at its early stage. Also in this case, production activities in the area could be made difficult due to basins location; the Beetaloo Sub-basin, for instance, is remote and with very limited access to pipelines and infrastructures.

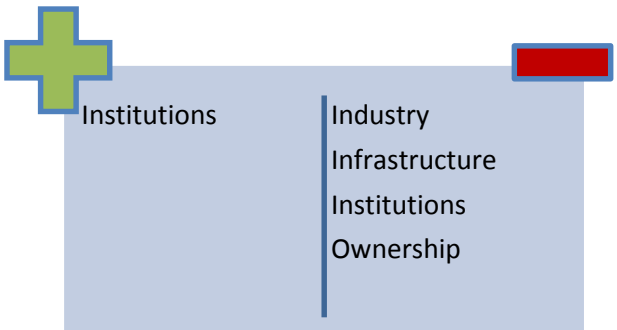
Finally, the Southern Georgina Basin has proven oil potential and a great potential for very large conventional and unconventional gas deposits. Even though it is almost unexplored, some global energy companies have shown interest in the basin, targeting activities primarily towards oil mature source beds and dry gas mature rocks.

5.2 Development of the UH industry in Australia: driving factors and challenges

The UH industry in Australia is still in its infancy. The future development of UH resources activities have to face a series of major challenges, including geological uncertainties related to the characteristics of Australian basins, technology and capital constraints, limited access to gas markets and infrastructure, a service sector not well developed yet.

Driving factors and barriers of the UH industry in Australia are summarized in Figure 39.

Figure 39. Drivers and Barriers of UH Development - Australia



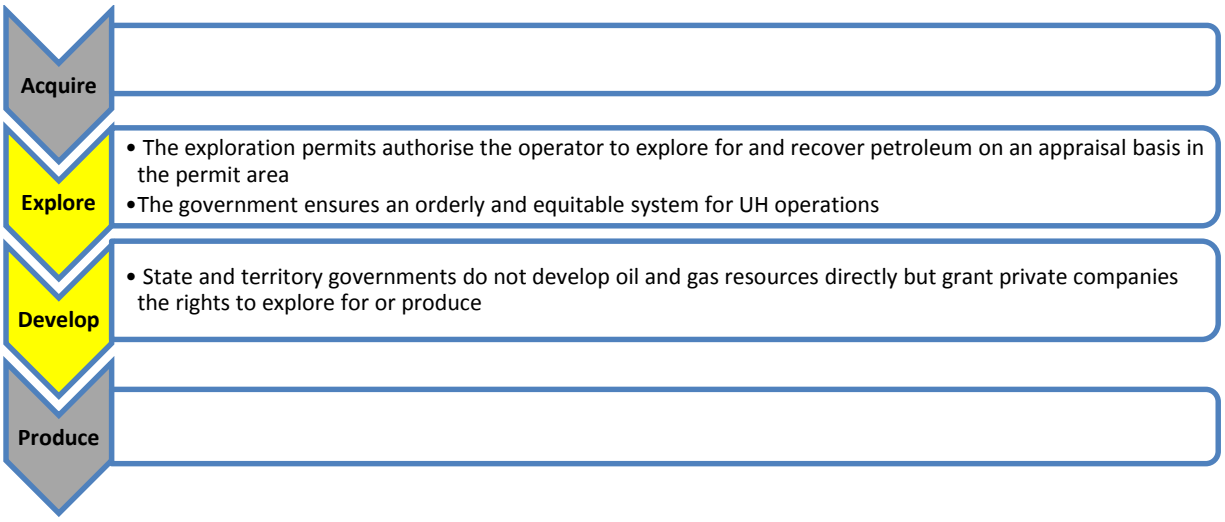
5.2.1. Land and mineral rights ownership framework

In Australia, minerals and petroleum resources are owned by the states, which grant the license to explore and produce and receive a royalty from the production of the resource. Differently from the US, then, local landowners do

not have a right to receive royalty payments from petroleum production, even though in some circumstances some compensation payments are possible. This type of property right system could be a potential constrain to the UH industry development, as already demonstrated by the debate around CSG wells on agricultural land.

The property right system in Australia affects mainly the exploration stage of the supply chain of the UH industry development, as it is shown in Figure 41.

Figure 40. Supply chain phases relevant for land and mineral rights ownership framework



In Australia, the Crown owns all rights to natural resources, including petroleum resources at or below the land surface or the seabed.

The Commonwealth government (i.e. federal government) and state and territory governments do not develop oil and gas resources directly, through state owned companies for instance, but grant private companies the rights to explore for or produce (both conventional and unconventional) resources through a legislative licensing regime. The licenses (commonly referred to as "petroleum titles") distinguishes between the exploratory and production stages; both activities can be carried out only under the authority of an appropriate petroleum title. Some regimes include a third stage (intermediate), allowing retention of an area after the discovery of petroleum until commercial production is possible.

The exploration permits authorise the operator to explore for and recover petroleum on an appraisal basis in the permit area; they have an initial term of five years, with the possibility to renew. Retention leases are similar to exploration permits, but applies when the area contains petroleum but its recovery is not commercially viable, even though it will likely become commercially viable within 15 years. Finally, production licences permit the licensee to recover (and explore for) petroleum in the licence area and are generally granted for life-of-field[31].

Operators can obtain petroleum rights in areas open to exploration and development through a bidding process or a proposal. In most Australian jurisdictions, the holder of an exploration license resulting in a commercial discovery is entitled to receive a production license upon application and is subject to other legal requirements (APERC, 2015).

The property of petroleum, one produced, generally passes from the Crown to the petroleum license holder. Each State and Territory currently imposes royalties relating to

[31] http://www.iclg.co.uk/practice-areas/oil-and-gas-regulation/oil-and-gas-regulation-2016/australia (last accessed: 08/09/2016).

the extraction of petroleum. The government royalty rate for petroleum is between 10 per cent and 12.5 per cent of the value of the wellhead, depending on the jurisdiction.

In cases where a petroleum title coexists with private land, the company can begin operations on the land only after reaching an agreement with the private landowner, generally involving the payment of a compensation. This is the result of the Australian general principle of multiple land use, according to which different parties may have coexisting rights or interests with respect to the same area of land. The types of land interests that may coexist with onshore petroleum titles include private land, leases from the government for pastoral, agricultural or other commercial purposes, mining (i.e. hard rock mineral) tenements, as well as native title rights and interests.

Even though the Australian government does not directly seek to participate in the development of oil or natural gas reserves, it ensures an orderly and equitable system for UH operations. In particular, the government is actively involved in the petroleum sector, by providing a regulatory framework for petroleum operations, the collection and dissemination of geoscientific information with the aim to reducing commercial risk in the exploration stage, and promoting UH industry competitiveness (Norton Rose Fulbright, 2015).

With specific reference to the Cooper Basin, for instance, where the UH industry is currently in an early stage and significantly more exploration activities will be required to improve geological knowledge of the reserves, the Queensland Government is putting in place a number of measures to stimulate investments and to enable the industry development. The government strategy requires the following steps (State of Queensland, 2015):

- attracting new investment in deep gas and oil exploration and associated service industries
- supporting innovative and productive exploration activity
- providing consistent regulatory arrangements
- building the trust and confidence of communities in industry and government regulation
- supporting and accelerating long-term development of the Cooper Basin
- facilitating productive and responsible resource development.

Hence, differently from the US, where oil and gas companies lease the rights to drilling and produce hydrocarbons directly from landowners, in Australia royalty payments are made to the government and can be enjoyed by local populations only indirectly, through the development of public infrastructure, for instance. The system of property rights for minerals and petroleum can challenge the expansion of the UH industry in Australia, reducing the flexibility of operating conditions and the rapidity of access to unconventional resources, two factors that have enabled the shale expansion in the US, as discussed previously. Several cases of litigation and complaints between local landholders/farmers and the government have already emerged in areas characterised by coal seam gas development (de Rijke, 2013). Providing Australian landholders with a greater share of profits from mineral and energy resources and increasing their involvement in negotiation processes have been put forward as a way to ease opposition to CSG, which has frozen exploration and development in Victoria and many areas of New South Wales (Tasker and Chambers, 2013).

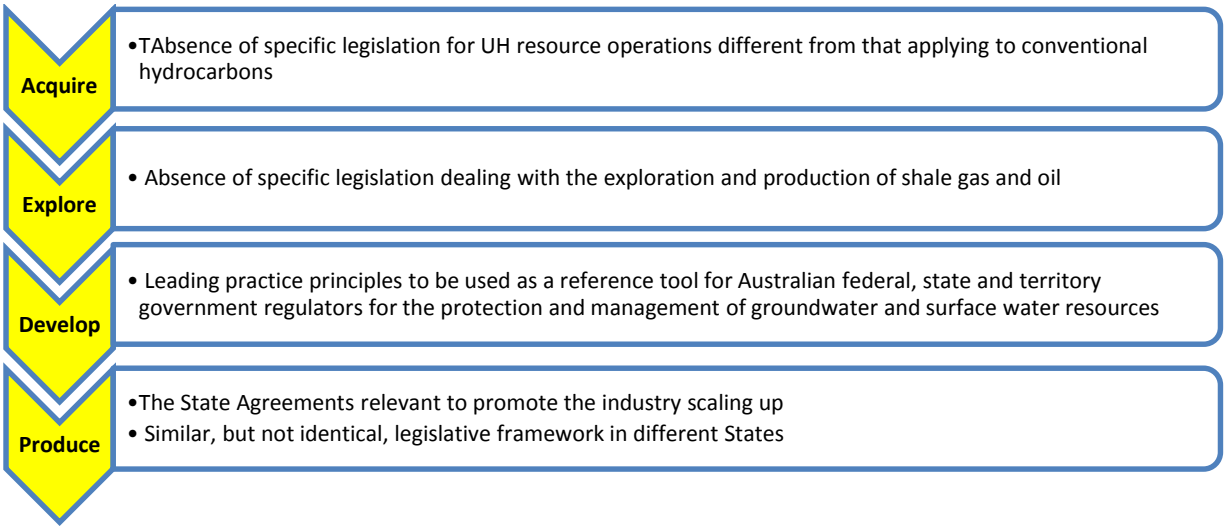
5.2.2. Institutional and regulatory framework

The Australian regulatory framework does not include specific legislation for UH resource operations different from that applying to conventional hydrocarbons. Given the very early stage of UH industry development, regulations (especially environmental regulations) are likely to change rapidly, following the expansion of shale activities. While this can constitute a potential barrier to the UH development (in some states fracking is banned) other aspects of Australian legislation may play as enabling factors. The so-called State Agreements with

major project proponents, for instance, may be a relevant instrument to promote the industry scaling up towards more mature stages of development.

The regulatory framework is expected to have an impact on all phases of the relevant supply chain, as displayed in Figure 42.

Figure 41. Supply chain phases relevant for institutional and regulatory framework



Australia is a federation of six states and two territories. Each state and the Northern Territory has its own legislative power to regulate onshore petroleum exploration and production activities within its boundaries, while offshore petroleum activities are governed under a joint commonwealth–state legislative scheme that provides for a uniform legislative framework (Norton Rose Fulbright, 2015).

As in other countries, legislation relevant to conventional hydrocarbons applies also to the unconventional one, and there is no specific legislation explicitly dealing with the exploration and production of shale gas and oil. In the Petroleum and Geothermal Energy Resources Act (1967) of Western Australia, for example, the definition of petroleum applies to any naturally occurring hydrocarbon or mixture of hydrocarbons. It specifically excludes only oil shale (i.e. hydrocarbons contained in rocks that can only be recovered by mining those rocks as oil shale).

As production of onshore petroleum is primarily a state matter, each state has a similar, but not identical, legislative framework.

In order to guarantee a homogeneous and consistent framework for CSG development across all Australian jurisdictions, and in response to growing concerns about the impact of hydraulic fracturing, the National Harmonised Regulatory Framework (endorsed in 2013) provides a set of leading practice principles to be used as a reference tool for Australian federal, state and territory government regulators. The framework focuses on four key aspects of CSG development (well integrity, water management and monitoring, hydraulic fracturing and chemical use) and represents the government commitment to the protection and management of groundwater and surface water resources.

The framework is directed to regulate CSG production, and explicitly acknowledges that shale gas development entails different geological and hydrological issues[32]. Even though this may imply that the harmonised regulatory framework for CSG will not be extended

[32] The main differences include the fact that unlike CSG, in Australia, where about 10-40% of wells are hydraulically fractured, virtually 100% of shale gas wells would need to be fracked. Further, shale gas wells tend to be deeper than CSG wells and, even though they produce much smaller volumes of produced water, it may be very saline (greater than three times sea water) and the water may contain a range of harmful chemicals, which limit treatment and reuse possibilities (ACOLA, 2013).

to shale gas, it is reasonable to expect that a similar harmonisation process may subsequently be implemented also for the shale gas industry (Norton Rose Fulbright, 2015).

In some states, exploration and extraction for UH resources are banned. In Victoria, for instance, in response to community concerns, a moratorium has been in place since 2012 on approvals of new CSG exploration licences and hydraulic fracturing for all existing mineral and petroleum titles. On 30 August 2016, the Victorian Government announced a permanent ban on onshore unconventional gas extraction, including fracking, and extended the moratorium on onshore conventional gas development until June 2020.

The Government's decision, which is also based on evidence provided by the report released on behalf of the Parliamentary Inquiry into Onshore Unconventional Gas in Victoria (Parliament of Victoria, 2015), aims at preserving the state economy, mainly based on the agricultural sector, which employs more than 190,000 people and exports products for $11.6 billion[33]. At the opposite, activities relating to a potential UH industry are at an early stage in Victoria, where it is not yet known whether reserves of unconventional gas are sufficient to ensure a commercially viable production.

Exemptions to the ban however remain for gas storage, carbon storage research and accessing offshore resources. Exploration and development for offshore gas will also continue.

In Tasmania, the government also introduced a twelve-month moratorium on the use of hydraulic fracturing for the purposes of hydrocarbon resource extraction, to enable a review of its potential impacts (Department of Primary Industries, Parks, Water and Environment, 2015). After the publication of the final report issued by the Department of Primary Industries, Parks, Water and Environment of Tasmania, the moratorium on the use of hydraulic fracturing has been extended to March 2020.

In addition to the petroleum specific legislation, other pieces of government and state legislation apply to petroleum exploration and production activities in order to protect the environment and heritage, native title and Aboriginal heritage as well as to govern the allocation of onshore water rights, industrial relations and workplace health and safety. There are also restriction in conservation reserves, Aboriginal reserves and regional parks. As noted in Section 5.2.1, the access to privately owned land may involve the payment of compensation to the landholder for land surface damage or restrictions on right of way. In some jurisdictions, compensation can be required also for losses related to use of land, earning losses and social disruption (Blake Dawson, 2011).

A feature of Australia's law is the use of direct agreements between a state government and project proponents to facilitate the implementation of large-scale petroleum projects (known as State Agreements). These agreements supplement, and in some cases modify, existing state legislation. The content of state agreements varies from project to project but, generally, they specify the rights, obligations, terms and conditions for the development of a major resource project for a period of up to 50 years. They allow the producer access to land, set out detailed requirements for the development of infrastructure and transport relating to the resource facility, the payment of royalties (including a discounted royalty rate for a period) and set out information requirements (Blake Dawson, 2011).

The Cooper Basin (Ratification) Act 1975, for instance, authorises and ratifies the agreement made by the South Australian government to support the development of a significant gas resource in central Australia. More recently, the Natural Gas (Canning Basin Joint Venture) Agreement Act 2013 ratifies an agreement between the State of Western Australia and some energy companies with the aim of accelerating investment in exploration and evaluation of natural gas resources in the Canning Basin and facilitating

[33] http://www.premier.vic.gov.au/victoria-bans-fracking-to-protect-farmers/ (accessed: 09/09/2016).

the development of pipelines and other infrastructure to deliver gas to the domestic network.

The Agreement, which is for an initial term of 25 years, with a possible extension of 25 years, indicates an overall commitment by the Western Australia government to support the development and exploitation of natural gas resources in the Canning Basin region.

In return, the proponents agree, among other things, that if commercially viable gas is discovered, they have to submit a plan for construction of the domestic gas project, including a 600km pipeline south to Western Australia's existing Pilbara gas network, and that meeting domestic market demand will have the priority over exports. Further, the Agreement provides for the use of local labor and materials as well as the creation and implementation of a community development plan and local industry participation plan[34].

State Agreements appear to be a relevant aspect of the regulatory framework in Australia and an enabling factor for UH industry development in the country: given their relatively long time span, they guarantee long-term certainty to investment projects. Further, they establish a framework for ongoing relations and cooperation between the state and the project proponents.

- Tax policies and economic incentives

Fiscal regimes for upstream projects are different in states and territories; however, they generally are made of a rent-based tax, a corporate income tax and a royalty-based taxation.

The Petroleum Resource Rent Tax is the main tax levied by the Federal Government from all petroleum projects in Australia. It is set at 40% of a project's above normal profits, to avoid discouraging investments. In addition, state governments receive royalties on petroleum produced from on shore projects at the wellhead level; the royalty usually is levied at a rate between 10% and 12.5%. To promote investments, some states use a sliding scale with zero royalties during the first five years of a project, which grows to 6%by year six and afterwards increases 1% annually until reaching a royalty of 10% (APERC, 2015).

Generally, deductible costs are limited to the processing, storage and transport stages of the UH supply chain.

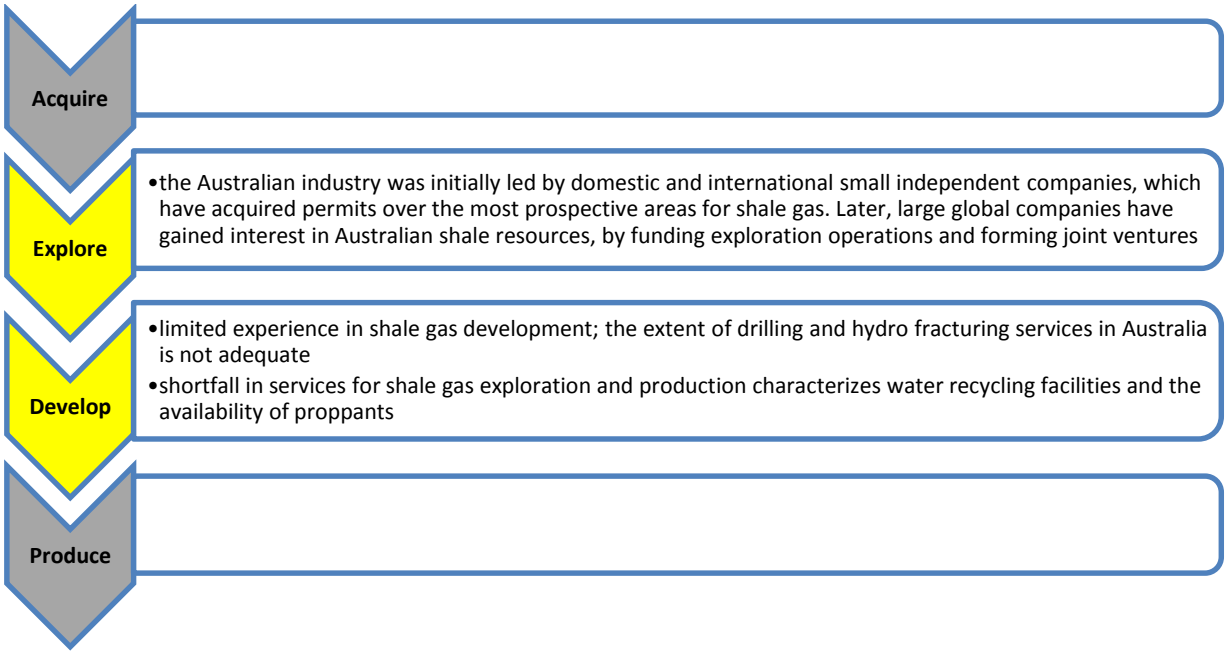
5.2.3. Industry and infrastructure

Relevant challenges to UH resource development in Australia are related to industry characteristics. In particular, given the geological peculiarities of the basins, exploration, drilling and production technologies currently adopted in other contexts (namely the US) should be enhanced and customized for Australian shales. Further, also the expansion of the service industry and improvements in existing infrastructures are essential to the UH industry development.

The weaknesses of the actual industry structure in Australia are likely to affect especially the stages of the supply chain in yellow in Figure 43.

[34] http://www.findlaw.com.au/articles/5183/canning-basin-bill-marks-new-chapter-of-gas-develo.aspx (last accessed: 08/09/2016)

Figure 42. Supply chain phases relevant for industry and infrastructure



Australia has a long history of drilling conventional natural gas and some experience in the production of CSG, but it has still limited experience in shale gas development, and, in particular, in techniques, such as hydraulic fracturing, which has been carried out only moderately in the Cooper Basin.

As in the US, the Australian industry was initially led by domestic and international small independent companies, which have acquired permits over the most prospective areas for shale gas. Later, large global companies have gained interest in Australian shale resources, by funding exploration operations and forming joint ventures. This will be essential to stimulate the scaling up of the industry, as the US case has shown. Nevertheless, one of the main barrier to UH industry development in Australia is related to the geological features of the plays that cast some doubts on the possibility of using the same technologies deployed successfully in other areas as the US.

Australian shale plays are characterised by higher tectonic stresses compared to North American shale formations. The Cooper Basin, in particular, has peculiar geological features that make shale production more complicated. It is lacustrine, and, similarly to the Barnett shale play in Texas, its formations are siltstone, but, differently from Barnett, formations are deeper and have higher clay and CO2 contents, characteristics that reduce the CH4 content of the produced gas and lower the expected economic benefits (UCL, Australia, 2013). Therefore, in these plays, the possibility of adopting technologies already applied successfully in other basins is questionable, and there are no guarantees of long-term success[35].

Fine-tuning of existing technologies and/or innovative technologies then will be essential to unlock the value of UH resources in the country. Further, in order to get the maximum economies of scale and sufficient profits to build infrastructure and initiate the shale gas production, it will be necessary to find the best formations with higher liquid content (UCL, Australia, 2013).

[35]Cook et al. (2013; p.67), for instance, conclude that "with regard to hydraulic fracturing it is not yet clear as to the extent to which the US techno-economic success resulting from the optimal combination of horizontal drilling of deep shale reservoirs and multi-stage transverse vertical fracturing will translate directly to Australian shales".

Besides basins geological characteristics, other aspects related to the lack of services, infrastructures and water availability challenge the UH development.

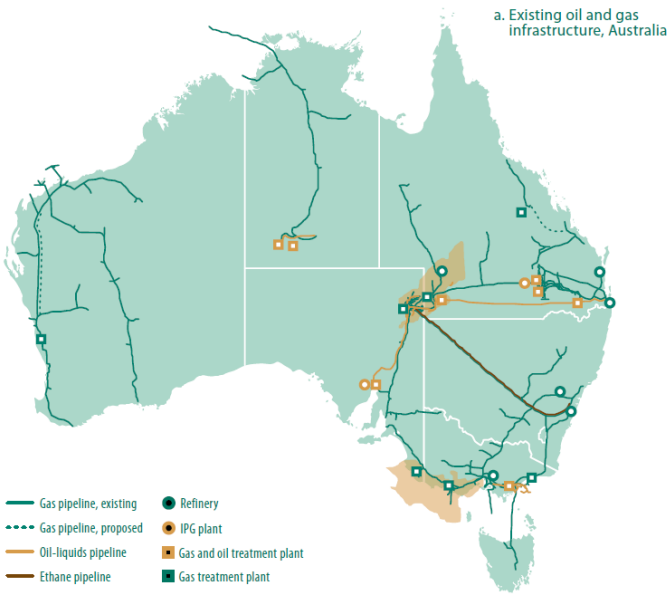
First, the extent of drilling and hydro fracturing services in Australia is not adequate. The drilling technology developed in Australia for CSG (i.e. coil tubing rigs) is not applicable to the deeper shale gas wells, while new hybrid rigs[36] that are currently developed in the US may be more suitable to Australian plays. The existence of only few drilling rigs that can access depths in excess of 3000m inhibits the prospects of industry development, especially by considering that shale gas production requires rapid well replacement procedures and many wells to be fracked simultaneously (UCL, Australia, 2013). For CSG operations also, the lack of service companies implies that most large pieces of equipment have to be imported from overseas. In a context of high demand, waiting lists and long lead times can delay production and lead to cost blowouts (Cook et al., 2013).

In Australia there are currently only very few companies offering hydraulic fracturing services (Halliburton, Baker Hughes and Schlumberger); these should be able to expand significantly their capacity or new companies should enter the market in order to enable the shale development.

A similar shortfall in services for shale gas exploration and production characterizes water recycling facilities and the availability of proppants (ceramic and guar gum) required for deep shale well fracturing, which are currently imported from overseas, mainly from China and India. As a results of these and other factors (such as the lack of skilled personnel, for instance), shale gas drilling and fracking are more than three times as costly as in the US.

A relevant proportion of Australia's shale gas is located in remote areas requiring pipelines to deliver the resources to markets and roads to supply equipment, proppants and water to the plays. Despite some exceptions, such as the Cooper, the Perth and Otway Basins, which are in relatively favourable locations, due to the presence of existing infrastructures that either have incremental capacity or that can be readily expanded, the Australian pipeline network is generally very limited (Figure 44). Basins as Canning and Georgina, for instance, do not have transmission pipelines, and this may be a large barrier for shale gas development in these regions.

Figure 43. Maps of Australian oil and gas infrastructure



Source: Cook et al., 2013; p. 79

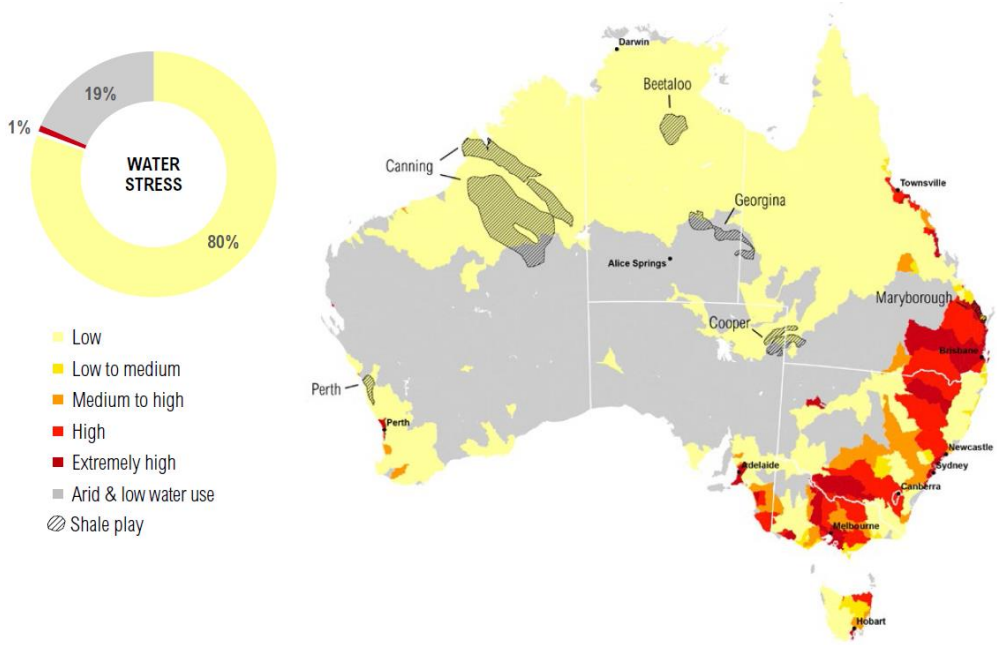
[36]Hybrid rigs "use coil to a set depth then drill to full depth with jointed pipe" (Cook et al. 2013; p.75).

Pipeline access is also constrained by the current regulatory regime of contracted carriage, which restrict access to the market for new entrants in order to ensure the owners to recover pipeline investments costs. Only a limited number of natural gas transmission pipelines have been regulated allowing full third party access (in 2014, 11 of the 32 major transmission pipelines; Australian Government, 2014).

Another potential challenge to future development of UH industry in Australia is represented by its water resource impact. As shale gas production is still in its infancy in the country, the average volume of water required to hydraulically fracture Australian shales is not known, even though it is expected that the required volume could be larger than that of CSG due to greater depths and different geo-mechanical properties of coal and shale (Cook et al., 2013). According to CSIRO (2014) for instance, the water requirements per well of shale gas are on average 20 times fold those of CSG. On the contrary, the volume of produced water is orders of magnitude less than the amount produced over the life of a CSG project.

Australia is the world's second driest continent and both shale and CSG are located in areas of medium to high drought severity and medium to high seasonal variability in water supplies, as displayed in Figure 45. The Cooper Basin, for instance, is located in an arid region with low levels of water use, limited freshwater supplies, and medium to high seasonal variability. The Maryborough play is located in an area of high water stress and relatively high population density compared to the rest of the plays in Australia. Accordingly, UH operations in this area could pose risks to the availability of freshwater, particularly during dry periods, which could drive increased reputational and regulatory risks for companies competing with local agricultural and domestic water user (World Resource Institute, 2014).

Figure 44. Shale Plays and Baseline Water Stress in Australia



Source: World Resource Institute, 2014; p. 50

These considerations suggest that prospects of UH industry development may have significant impacts on local groundwater systems and that they will be strictly linked to the possibility of finding water sources other than groundwater and surface freshwater, including recycled water, saline water, and non-water-based fluids for hydraulic fracturing (APERC, 2015).

6. Stages of UH industry development

The aim of this section is to summarize the main outcomes of our analysis of the drivers and barriers for UH development that can be identified according to existing experiences from outside the EU. In order to provide an informative overview, we will exploit the framework stemming from the literature on the life cycle of industrial sectors.

A good review of the literature on the *industry life cycle* approach is provided, among others, by Peltoniemi (2011).

This allows us to single out the main identified features of the countries we scrutinized, as well as to use the evidence discussed in details in previous sections to provide a tentative identification of the development phase of the UH sector in the analysed countries. The relevance of this analysis stems from the specific features of the sector in itself, but also, as suggested by Wang and Xue (2014), from considering that in the UH industry there is no scope for product innovation and the evolution is driven only by process innovations.

On the basis of these thoughts and of the specific country analyses performed in this chapter, we can summarize the development stage of different countries experiences along the lines described in Figure 45.

As it clearly emerges, there is very little uniformity across scrutinized countries, both in terms of development stages and in terms of (what seem to be) relevant drivers and barriers.

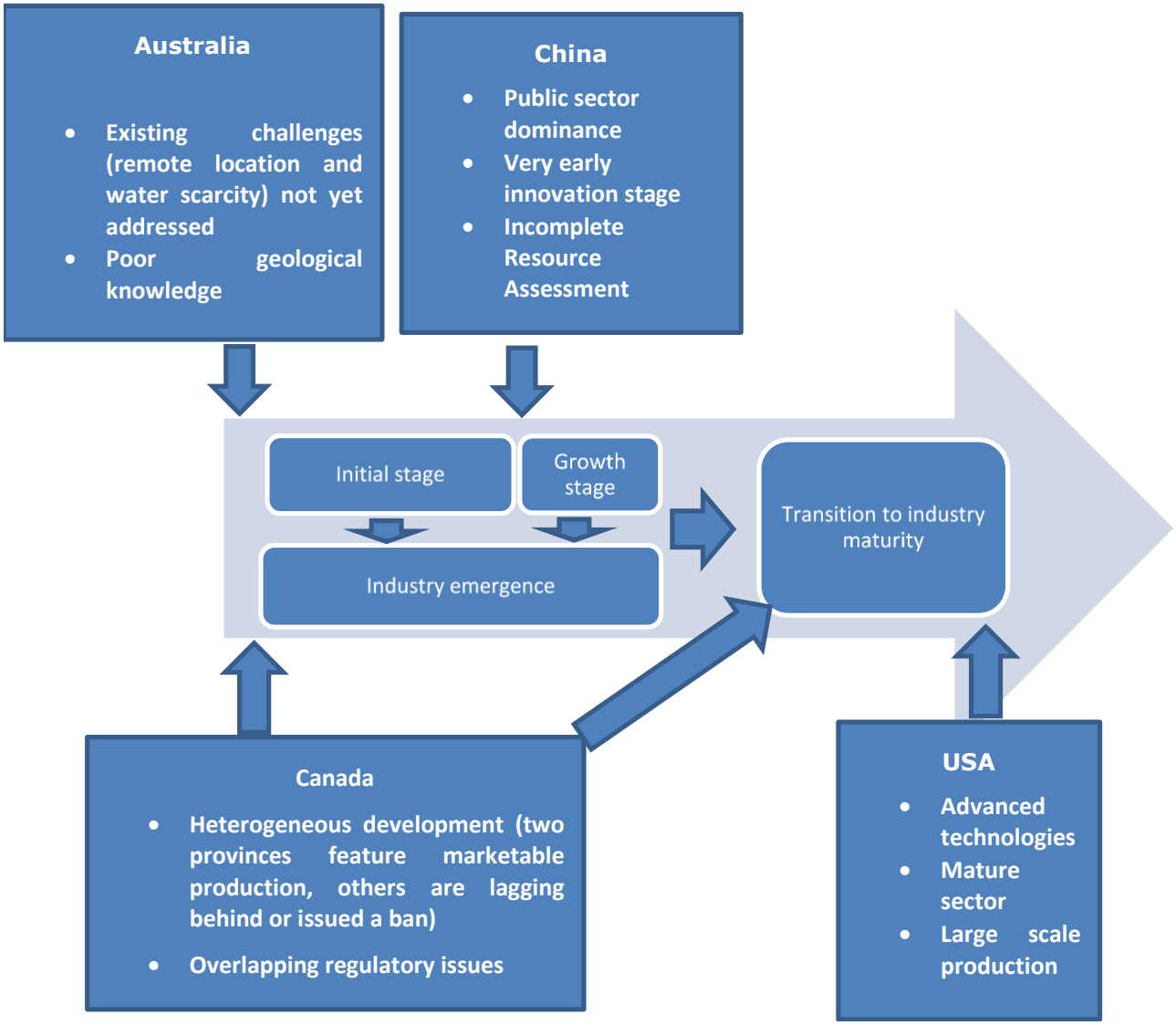
So, for example, while, as expected, US are in a very advanced stage, close to maturity, China and Australia, for different reasons, still lag behind, at an early stage of industrial development. More specifically, the pace of development in China seems to be driven by a relatively slow innovation activity, coupled with institutional features, that may hamper further advancements, and with a resource knowledge that still needs improvements. This latter feature also affects Australia's UH development stage, together with infrastructural and water related issues.

Canada is somewhere in between, with a scattered UH development featuring provinces at an advanced stage and others where a ban has been, or is, in place, resulting also in a heterogeneous evolution of infrastructures and policies.

The overall conclusion of this part of the report goes in the direction of suggesting that country-specific features are likely to affect the potential deployment of UH in contexts different from those analysed here, and that the factors of success in one part of the world do not guarantee the existence of a universal recipe.

This evidence will be useful in addressing the EU case in the upcoming part of the report.

Figure 45. Development stages of UH industry in selected countries.



7. Analysis of the industry value chain potential in Europe and the key aspects of the industrial development process

7.1. Background of the analysis

The UH industry is an evolving industry with increasing participation from mainstream energy industry players (such as Ineos) which now hopes to connect the unconventional gas markets of the United States with that of the UK – including Scotland - starting from shipment of liquefied unconventional hydrocarbons into the UK and with the final aim of exploring and producing unconventional hydrocarbons in the UK; as a result, the level of sophistication is growing. This identifies a unique development stage in Europe, as earlier plays (e.g. in Poland) were examples where such integration was not considered. This is (albeit preliminary) evidence of how European players are improving in sophistication and innovation.

This chapter looks at two important aspects for the prospects for Unconventional Hydrocarbons (UH) in Europe: the emerging opportunities and risks in the UH value chain and the developments around the UH space in technology, economics and finance. Then it also look at the wider industrial development possibilities for UH in Europe.

This part addresses the issues of value chain, its gap analysis, economic and cost structure, as well as industrial development issues, to cover the two thematic areas that comprise this work programme. Quantifying the economic benefits or estimating the jobs creation potential or the likely tax revenues is not the objective of this report and these are topics that are treated in other studies (Godec, M., Spisto (2016)).

While the objective of this effort, at this stage, is not to make recommendations, the findings of these analyses are presented as observations and conclusions.

The remainder of this report, is organised in the following parts:

- An introduction to the European experience
- Industry Value Chain
- Forces at Work in the UH space
- Value Chain Gap Analysis
- Cost Structures and Economics
- Skills Analysis for UH development in the EU
- Industry Development issues
- Emerging Good practices and Management Innovation
- Concluding Observations

By no means is this a conclusive piece of analysis: this chapter attempts to capture a snapshot of an evolving industry; a number of discontinuities that need addressing is also discussed.

7.2 The European experience: an introduction

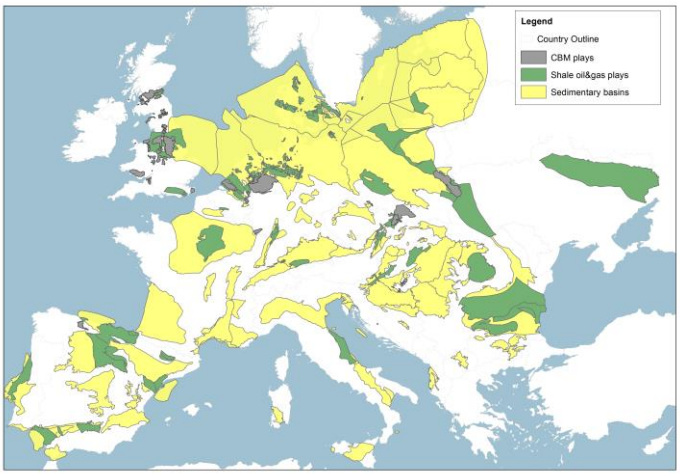
The overview of the literature in the previous sections of the report has identified those factors, which have played the most significant role in enabling the successful development of unconventional hydrocarbon industry in the US and are currently harnessing or facilitating the development in other countries.

As for the countries we have previously examined, the success story of the unconventional hydrocarbon industry in the US has resulted in speculation on whether the so-called "shale revolution" could be replicated in Europe. Several studies agree that the US experience may not be simply duplicated in Europe (see for instance, Spencer et

al., 2014; IEA, 2012; Ernst and Young, 2013; Geny, 2010 among others), due to a number of factors[37], including the poor geological knowledge of current reserves.

However, for the aims of this Section it is worth to note that shale gas resources are present in three major areas in Europe, as displayed in Figure 46. In particular, the largest shale-gas resources can be found in Poland and France, followed by Ukraine, Sweden, Denmark and the United Kingdom, whilst potential coal bed methane resources are significant in Ukraine, the United Kingdom, Germany and Poland. Other data – i.e. gas in place and resource potential for shale gas and oil and CBM – can be found in the Appendix I.

Figure 46. Major unconventional natural gas resources in Europe



Source: The Shale oil and gas polygons and resource assessment are based on the results obtained from the European Commission - EuroGeoSurveys EUOGA project[38]

In a revised assessment of world shale gas resources, EIA (2013) suggests that the potential of shale gas in Europe is relevant (corresponding to 883 Tcf of risked, technically recoverable shale gas resources). However, uncertainties remain regarding the possibility of translating technically recoverable reserves into economically recoverable ones, in the absence of actual exploration and production data (Spencer et al., 2014), especially by considering the limited number of exploration wells drilled in Europe (72 by the end of 2015, of which 25 successfully fracked to release gas) (Inman, 2016).

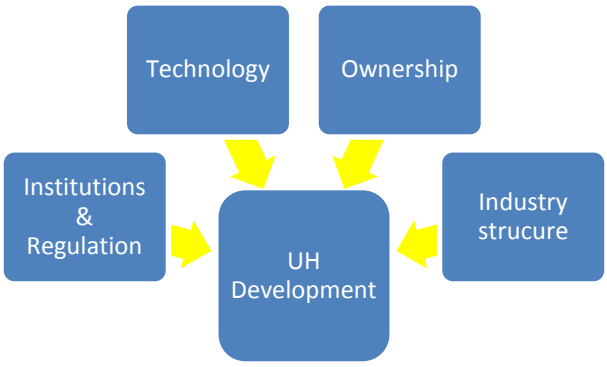
Accordingly, it is particularly interesting to investigate the potential role that elements, previously analyzed for understanding the development of UH industry in non-EU countries, can have in determining whether and how quickly the industry development may take place in Europe.

By following the same framework adopted in the first part of the Report, and still focusing on the upstream part of the shale supply chain, we consider the main factors that have characterized the UH industry development in selected non-EU countries, with the aim of investigating their role in enabling or harnessing the industry development in Europe. We will therefore focus on four main potential drivers, whose links to the UH sector development are summarized in Figure 48. The figure below will then inform the detailed analysis concerning the EU that will be performed in the remaining sections of this report.

[37]The IEA has identified a list of potential challenges to replicating the success of the US shale revolution in other countries, including environmental concerns, fiscal conditions, landowner acceptance, interference from local authorities, pipelines and infrastructure issues, availability of technology, equipment and skilled labor force, and gas players' experience (IEA, 2012).

[38] Contract JRC/PTT/2015/F.3/0027/NC – "Geological Evaluation of Potential Unconventional Oil and Gas Resources in Europe".

Figure 47. Potential drivers/barriers to the development of UH resource in the EU



7.2.1 Technology

As noted in Section 2.2.1, technological innovations have been one of the most relevant factors explaining the UH industry expansion in the US. Technology related factors have played a significant role also in other countries. In China, for example, the reliance on imported technologies, mixed with a not very favourable institutional framework, imply that technology may act either as a driving factor (if innovation activity makes it economically advantageous to start adopting domestically developed technologies and if the institutional setting improves accordingly) or as a harnessing factor (if the sector chooses to keep relying on imported technologies). Together with deep geological knowledge and drilling experience coming from a well-established conventional oil and gas supply chain, in the US huge public and private investments have allowed for major technological breakthroughs, without which the shale boom would not have happened.

Europe could benefit, in principle, from a technology transfer from US companies, where "technology" should be interpreted in a broad view, including not only extraction techniques, but also the logistics and the overall operational model, along with human skills. As noted by Geny (2010; p.69), "the export of drilling, completion and project management techniques and principles from the US is already ongoing. With the US as a proving ground, Europe is gaining years of knowledge-building on the technology side, but it is mostly about the broad principles".

Nevertheless, technologies developed and tailored for US shale basins cannot be simply transposed to European plays, given potential differences and specificities of European shale plays. Even though extensive exploratory drilling is still needed in order to have a better understanding of the geological characteristics of the basins, it is already known that European plays are "smaller, deeper, more highly pressurized (which makes fracturing more difficult) and higher in clay content" (Spencer et al., 2014; p.29). Accordingly, the characteristics of both the basins and the resources make it extremely unlikely the possibility to adopt the same technologies developed for US shale plays. As in the case of Australian shales, then, where the geological peculiarities of the basins require enhancing and customizing US technologies (see Section 5.2.3), the application to EU plays of exploration, drilling and production technologies currently adopted in other contexts will require extensive experimentation and customization at field level. In addition, significant investments in R&D will be needed to adapt completion and fracking techniques to the specific subsurface and regulations of European shales.

To have an idea of the ongoing R&D effort in the EU, we can focus on a specific kind of patents, which are expected to be relevant in relation to the UH sector, namely IPC patent category E21B, which relates to "Earth or Rock Drilling; Obtaining Oil, Gas, Water, Soluble or Meltable Materials or A Slurry Of Minerals From Wells"[39]. In Figure 49, we

[39]For details, see:

report the ratio among the number of patents in EU 28 and the corresponding total number from OECD countries. As it emerges, the innovation activity linked to this specific kind of patents seems to show a slightly decreasing trend in the EU 28 as compared to OECD as a whole. Although not fully conclusive, this evidence seems to suggest that the EU is not performing a significant innovative effort in this kind of drilling technologies, and that additional work is needed in this specific field. Moving to a different technology category, C10G, namely "Cracking Hydrocarbon Oils; Production Of Liquid Hydrocarbon Mixtures, Recovery Of Hydrocarbon Oils From Oil-Shale, Oil-Sand, Or Gases; Refining Mixtures Mainly Consisting Of Hydrocarbons; Reforming Of Naphtha; Mineral Waxes"[40], the corresponding ratio of EU 28 patents over total OECD patents seems to have been recovering from 2008 up to 2012, slowing down in 2013 (Figure 50). However, C10G patents are expected to be a relatively low share of the total innovation activity related to UH development, at least looking at past experiences outside EU (Lee and Sohn, 2014).

Figure 48. Patents, technology code E21B, ratio between EU28 and total OECD patents

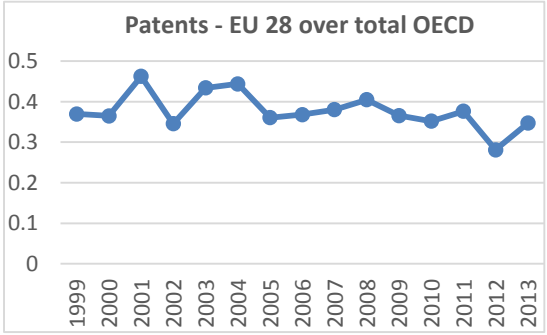
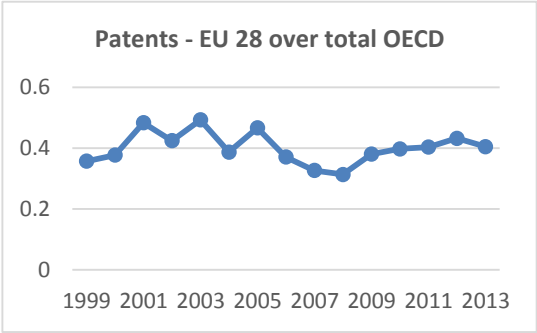


Figure 49. Patents, technology code C10G, ratio between EU28 and total OECD patents



Source: own elaboration on OECD PatStat

Factors related to the need of experiencing a significant technological development, together with the slow evolution of innovation in sectors related to UH exploitation and the physical characteristics of deposits in the EU, are expected to contribute to increase operational costs, reducing the profitability of shales in the EU compared to the experience in the US. As far as drilling costs are concerned, for instance, they tend to increase with the average deposit depth. As reported by Saussy (2015), wells located in the deepest shale deposits, between 12,000 and 13,000 ft on average, are the most expensive. The majority of deposits in the EU are located at this depth: for example, in France the majority of the resources are located between 10,000 and 14,000 ft, in Poland between 10,000 and 12,500 ft and between 11,500 and 14,500 ft in Germany (EIA, 2013). As a result, it can be expected that drilling costs will be on average higher in Europe than in the United States (Saussy, 2015).

As noted by Rogers (2011; p.138), the work needed to exploit profitably shale resources in Europe is likely to be long and "operators are unlikely to commit unlimited resources to such work. If a play cannot be proven to be viable within a given programme budget, work would likely be suspended in a specific location". This is coherent with what has recently happened in Poland, where the major international energy firms, which had previously acquired shale-exploration licences over one-third of the territory, in 2013 and 2014 started to give them up. The decision has been mainly a consequence of

http://www.wipo.int/ipc/itos4ipc/ITSupport_and_download_area/20160101/pdf/scheme/full_ipc/en/e21b.pdf. Clearly, due to data availability, we only refer to the general patent category, so that we cannot be sure that the patents included in our analysis refer explicitly to UH exploitation.

[40]For details, see: http://www.wipo.int/ipc/itos4ipc/ITSupport_and_download_area/20160101/pdf/scheme/full_ipc/en/c10g.pdf. The same *caveats* as in the previous footnote apply here.

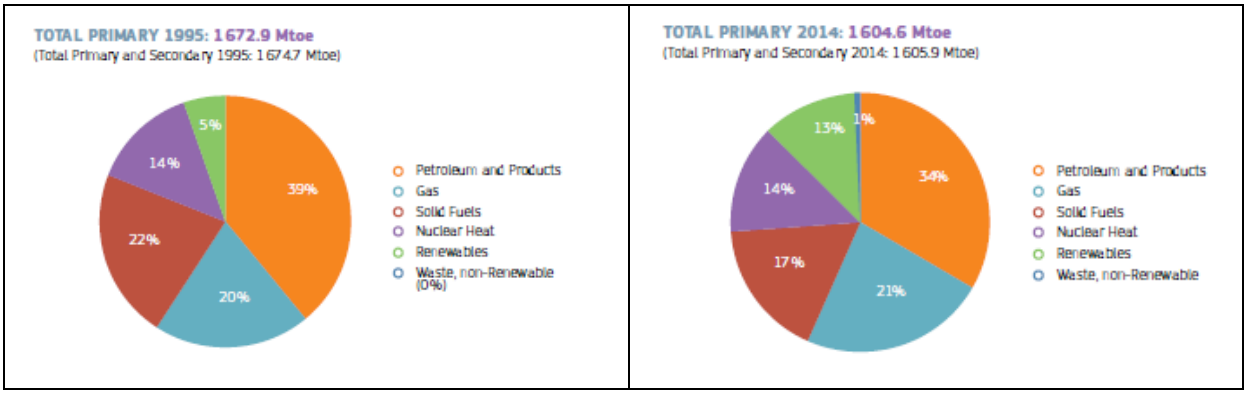
disappointing results and expensive drilling, due to geological features of Polish basins (high clay content, deeper location compared to most successful US plays). This has led to a standstill of drilling activities in Poland (Inman, 2016).

Huge investments could then be required in order to tailor technologies already adopted in other countries, as well as to develop new technologies more suitable to European shale characteristics[41]. Differently from the US experience, however, where government investments provided the foundation for some of the most relevant technology development, the EU Commission does not finance R&D on technologies aimed at extracting fossil fuels. This is considered to be an area for private investment.

7.2.2 Energy market, industry structure and infrastructures

According to IEA (2012), "The European Union is the second-largest regional gas market in the world, with demand amounting to around 550 bcm in 2010, and it is set to become increasingly dependent on imports as indigenous production of conventional gas continues to decline and demand continues to expand". These features of the EU as an interesting case study for UH development are confirmed by the recent evolutions of the energy markets where, according to the latest data (EC, 2016), the quota of gas over total gross inland energy consumption (with reference to primary products only) has been fairly stable between 1995 and 2014; this is worth noticing, especially if we compare the natural gas share to that of other fossil fuels (Figure 50).

Figure 50.Gross Inland Energy Consumption in EU28 – Energy Mix

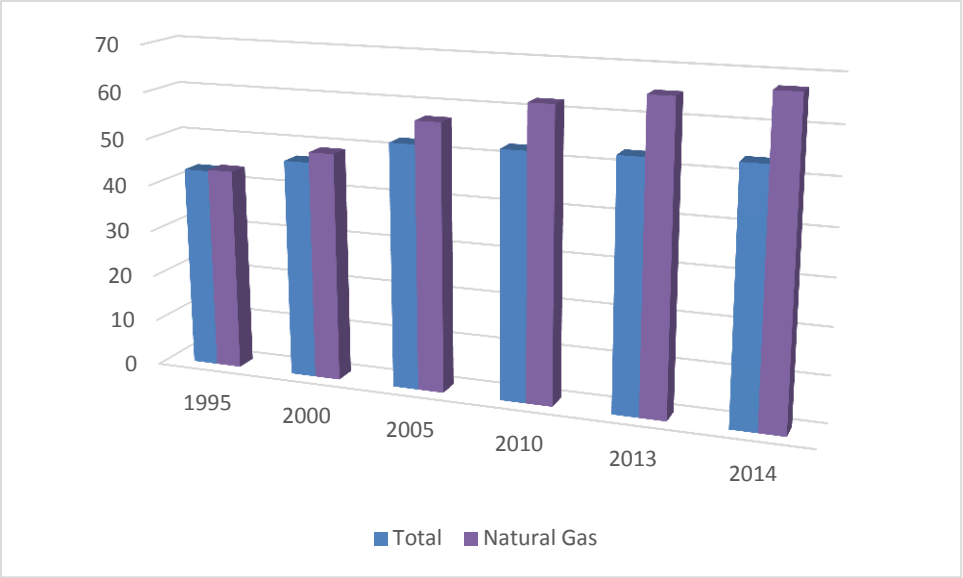


Source: EC, 2016; p.22

Another factor that seems to suggest a relevant potential role for UH development in the EU is related to the high import dependency related to fossil fuels and, in particular, to natural gas. Indeed, the latter has grown far more than the total dependence on fossil fuels (see Figure 51), although petroleum and products still feature the largest import dependency (EC, 2016).

[41]Quite interestingly, for instance, Rex Tillerson, Exxon Mobil Corp.'s chief executive officer, has highlighted the need to develop new methods and tools to tap many of the shale fields, after the company failed in its first two efforts to crack shale gas fields in Poland (see http://business.financialpost.com/news/fracking-failing-to-crack-china-europe-shale?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A%20FP_TopStories%20%28Financial%20Post%20-%20Top%20Stories%29).

Figure 51. EU28 Import dependency



Source: own elaboration on data from EC, 2016

These pieces of evidence may be coupled with the progresses towards a single EU market for energy (gas and electricity). Indeed, as the 2014 Single Market Progress Report underlines[42], energy market integration already delivered benefits in terms of electricity prices reduction and of stable gas prices. Also, improvements are recognized both in terms of competitiveness (as measured by the ability of consumers to choose among several energy suppliers) and in terms of infrastructures. Finally, the report identifies increases of energy trade among EU countries, together with a more efficient use of existing gas infrastructures. This is linked to the improvements in EU energy regulation, mostly related to fair trading and competition enhancements. The identified steps to achieve further progresses include the need for additional investments in electricity related infrastructures, infrastructure rules harmonization, a more active role of consumers in reducing energy consumption and a stricter integration of retail and wholesale markets, effectively translating efficiency gains into lower consumers' prices.

Given these features, and the co-existing issues of reducing energy prices, de-carbonizing the EU economy along the lines of COP 21 agreement in Paris and granting energy security, the assessment of the potential role of UH is a challenging task. More specifically, while the liberalization of the energy markets may play a positive or negative role for UH, depending on their ability to be produced in a way that is competitive with respect to other sources, the de-carbonization of the economy cannot be expected to favour UH deployment. Opposite conclusions are expected when focusing on issues related to energy security, given the above mentioned substantial import dependency that affects the EU.

Among the factors that have driven the shale revolution in the US and that, at the opposite, are limiting its development in other countries, such as Australia, there is the availability of an extended network of pipelines, allowing a quick connection of new fields.

Differently from the US, where pipeline access is based on "common carriage", meaning that gas producers have some access to existing pipelines, in Europe pipeline access is based upon "third part access" principle, implying that, if the pipeline is full, any gas suppliers must build their own pipeline to access markets (Stevens, 2012). In other

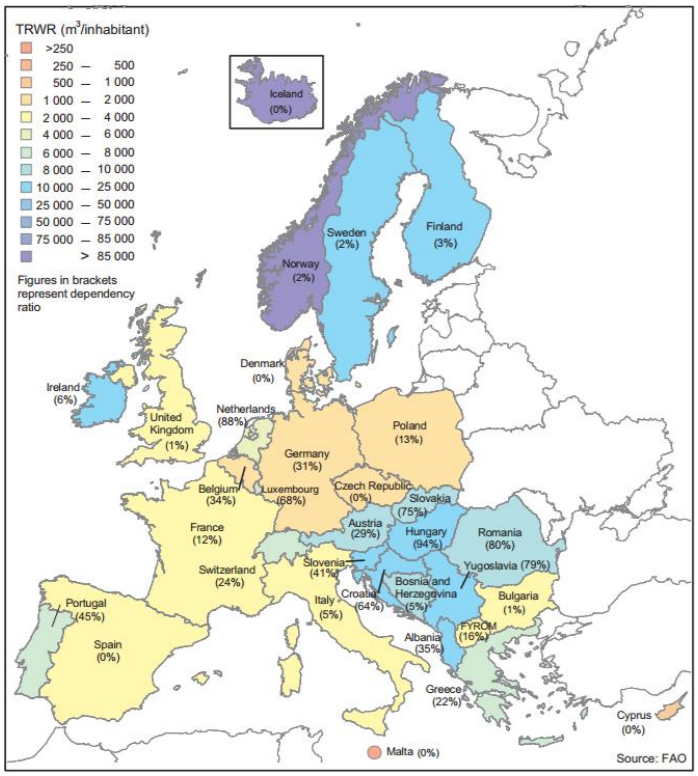
[42] Additional details are available at: https://ec.europa.eu/energy/en/topics/markets-and-consumers/single-market-progress-report.

terms, in Europe, shale gas will need to compete with existing energy sources, and this may be a potential constraint to the development of shale industry in the EU. In Europe, the large national utility companies generally control access to pipelines, which is subject to regulations at national level (Ernst and Young, 2013).

Even though Europe is connected to gas suppliers by pipelines with a total capacity of 530 bcm/year (European Parliament, 2014), significant improvements are required to upgrade the transmission infrastructure, especially in some countries, in order to be able to cope with increased gas flows in the case of successful development of shale plays.

Finally, as we noted for other non-EU countries (e.g. Australia), another serious challenge to the development of UH industry in Europe is represented by water availability. By looking at absolute quantities of renewable water, European countries have abundant freshwater resources, about 2,200 km^3 in an average year (5 percent of the world's water resources) and 4,270.4 m^3/inhabitant/year (FAO, 2003); this is displayed in Figure 52, which shows total availability and dependency ratio.

Figure 52. Total renewable water resources (TRWR) in Western and Central Europe

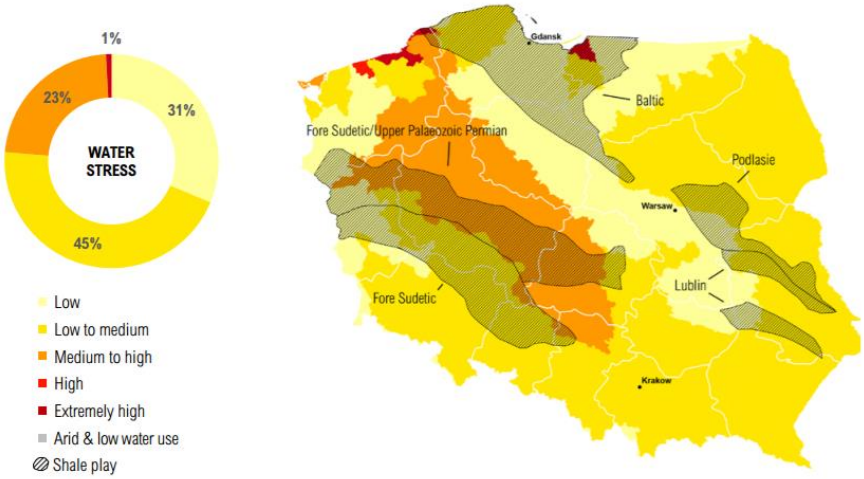


Source: FAO, 2003; p.90

However, water resources are unevenly distributed among countries, especially when population density is taken into account. The point is that the lowest renewable water resources in Europe characterize those countries which appear to have the largest reserves of unconventional hydrocarbon.

Poland, for instance, has the lowest water resources per capita, with only 1,500 cubic meters per year per capita (36% of the European average). Further, high domestic and industrial water uses, together with natural conditions, contribute to increase the water stress, particularly in certain areas in the north of the country. Water availability can then represent a serious challenge to the scaling up of UH industry in Poland; in particular, in the Baltic play, the most prospective one, population density is the highest of all Polish plays and the water stress is extremely high (see Figure 53).

Figure 53. Shale Plays and Baseline Water Stress in Poland



Source: WRI, 2014; p.58

7.2.3 Property rights, institutions and regulatory issues

Differently from the US, where the characteristics of the system of land property rights have played a fundamental role in accelerating the expansion of the UH industry (see Section 2.2.3), access to land surface represents one of the most serious challenges to the development of unconventional resources operations in Europe. As highlighted by Geny (2010), problems related to land access in Europe are twofold: the first issue is linked to the existence of spatial constraints for drilling operations and the construction of infrastructures needed to shale gas exploitation, while the second issue is related to the access to private lands.

In the first case, spatial constraints, due to high population density, high levels of urbanization and the presence of buildings and infrastructures, limit the scope of concessions granted in Europe. Consequently, operators cannot access all the land they were awarded (and they need) to perform exploratory and appraisal drilling activities. This is also due to the existence of stricter regulations concerning safety of local communities and the location of drilling and fracking operations[43]. In particular, several concession areas (especially in Germany, the Netherlands and Poland) are subject to environmental regulations protecting natural reserves (e.g. Natura 2000) and nationally protected sites (such as parks, landscapes, forests, sculptures, lakes, etc.).

The second issue deals with the access to land once operators have been granted the concession to drill by the mining authorities. While in the US the landowner owns also the hydrocarbon resources underneath the property and can thus obtain royalties from production, this does not happen in Europe, where the landowner owns only surface property rights. On the contrary, central governments or monarchs own the mineral property rights and offer licenses to oil and gas companies, allowing them to explore, and eventually, to extract the resources underneath the land. The procedures to obtain licenses are quite standard, even though the terms offered by the governments can be different. However, the pace (and easiness) of the negotiation process in Europe depends on the number of landowners to negotiate with, the degree of support from local administrations and the acceptance of drilling operations by local communities (Geny, 2010).

[43]Geny (2010) as an example of different regulations and public perceptions reports the case of the Barnett Shale Play, in Texas, which is located beneath the fourth largest metropolitan area in the US, and where, despite the very high population density, more than one thousands of wells have been drilled.

An important consequence related to the structure of land property rights in Europe is based on the fact that landowners cannot benefit from revenues generated by exploration and production activities. As a result, they will be generally more reluctant to allow exploratory and drilling activities on their land. Some examples of this reluctance are the local opposition to drilling by Shell in Sweden and public opposition and protests against Chevron in Romania[44].

As for other countries examined in the report, the role of energy policies and regulations will be crucial to enable the development of UH industry in interested Member States. In particular, in Section 2.2.2, we have shown that the combination of fiscal policies, public investments in R&D and a substantial absence of restrictive regulations on permitting and environmental aspects, during the early stages of development, has triggered the rapid and successful expansion of the shale industry in the US. In Europe, policies by interested national governments will be relevant to drive the exploration (and, potentially, the development) of unconventional resources, while respecting existing EU environmental legislation.

A characteristic of energy policies in Europe is that they are defined at both the EU and national level. This may complicate the regulation of shale-related activities, given the different attitudes of national governments. In particular, responses to environmental, health and safety issues could potentially be divergent across Member States, as some countries have been showing strong support to the exploitation of unconventional resources (such as Poland and the UK), while others have vigorously opposed them (such as France).

Different countries attitudes are also reflected at the EU level, where some States advocate energy security/independence arguments, while others put forward environmental consequences. Because of these contrasting positions, the discussion at the EU level is often characterized by ambiguities, with "some hesitancy within the Commission, significant expressions of opposition within the European Parliament and divergent positions in the Council" (McGowan, 2014; p.41).

Complementary to existing EU environmental legislation, the recent EC Recommendation 2014/70 /EU, laying down the basic principles to help those Member States that are interested in exploration and production of unconventional resources in safeguarding public health and the environment, testifies a sort of precautionary attitude at EC level.

This attitude clearly reflects public concerns about potential environmental impacts of shale activities, which suggest the possibility of stricter regulations in the near future. People attention towards the environment and health can be outlined by looking at a 2015 Eurobarometer survey (Flash Eurobarometer 420), aimed at achieving a better understanding of public perception related to shale gas projects in specific areas (where such projects have been permitted or may be planned). As it emerges from Figure 54 and Figure 55, there is substantial heterogeneity across areas both in terms of the perceived potential opportunities and in terms of the related challenges[45]. The same reasoning holds with respect to whether people that have heard, read or seen information concerning shale gas projects feel sufficiently informed (Figure 56), and to the perceived capability to effectively influence the actual UH projects choices (Figure 57). The perception by EU citizens, at least in some areas, of substantial environmental costs, as well as of information and participation problems, may indeed build a consensus in favour of a strict regulation towards UH development.

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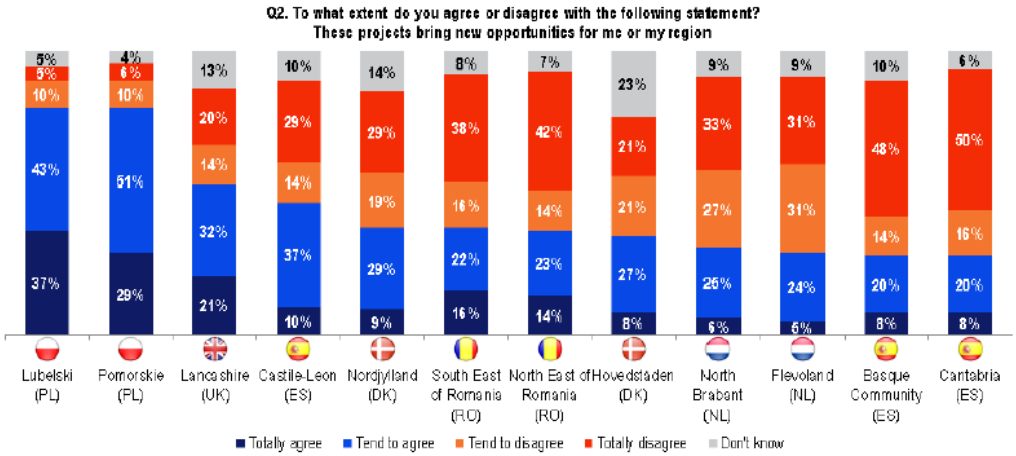
[44] See, for instance, http://energypost.eu/shale-gas-eastern-europe-implications-chevrons-exit-romania/ (last accessed: 01/11/2016).

[45] In particular, perceived opportunities include: local jobs, domestic source of energy, revenues for the local community, attraction of businesses and services, better roads and infrastructures, acquisition of skills. Perceived challenges include: risks to health; pollution of water and air; earth tremors; drop in property values; negative impact on other sectors, such as agriculture or tourism; traffic hazards.

Figure 54. Perceived benefits



Source: EC, Eurobarometer survey 420, 2015

Figure 55. Perceived challenges

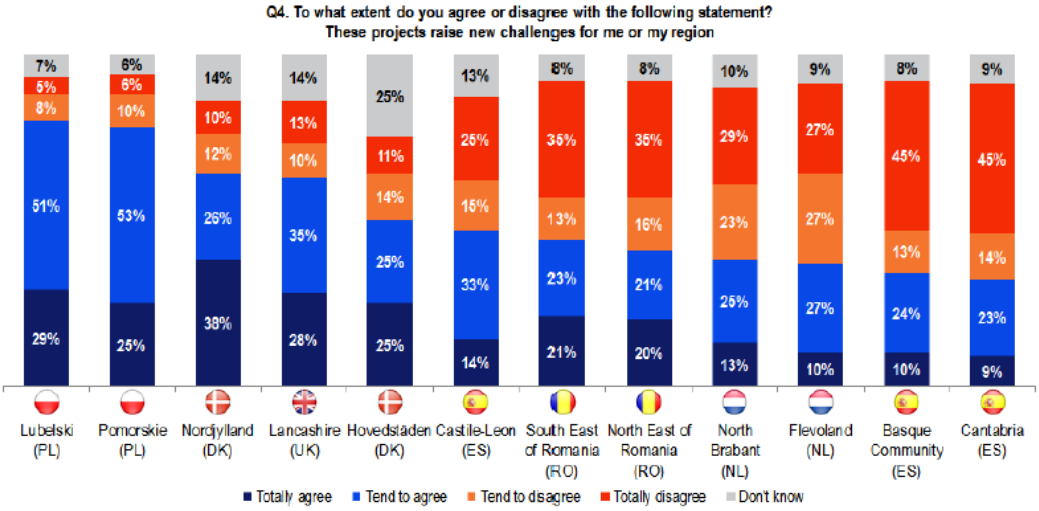
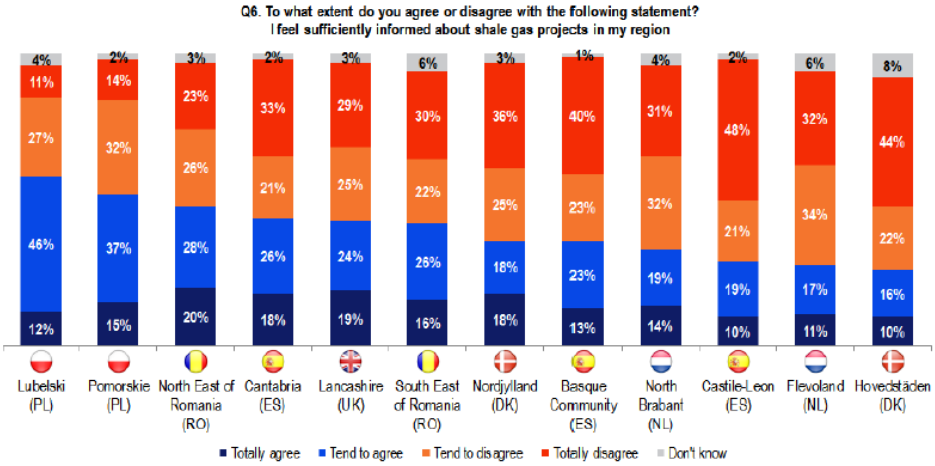


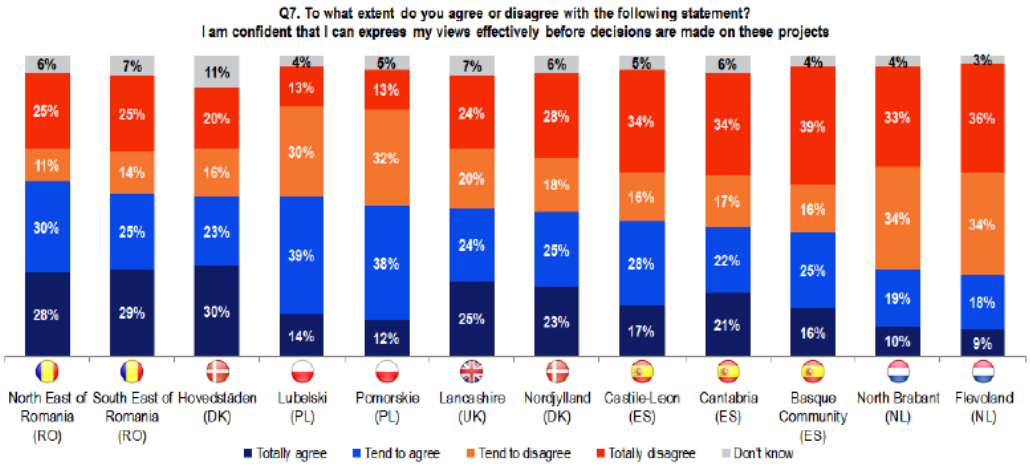
Figure 56. Information

Source: EC, Eurobarometer survey 420, 2015



Source: EC, Eurobarometer survey 420, 2015

Figure 57. Citizens participation effectiveness



Source: EC, Eurobarometer survey 420, 2015

8. The Industry Value Chain in Europe

In this chapter, we will attempt to understand the differences and similarities between the unconventional hydrocarbon value chain elements from the well understood conventional oil and gas value chain. We will then follow this with a macro-economic assessment of the operating environment for the UH industry in Europe, the forces at work and seek to understand how these may affect the value chain elements.

We will use this analyses to identify the specific value chain skill elements that are required to make a successful UH industry, explore which aspects of the value chain that need to be strengthened by conducting a qualitative "gap analysis" and assess the current levels of industrialisation in the EU. Conclude with a qualitative assessment of where we stand today in Europe as regards the maturity of the UH value chain.

The results of this analysis will help us to inform the key elements of possible industrialisation pathways that may be required to be developed.

Table 5 describes the UH industry value chain using the UK as an example.

Table 5. Key upstream-related on-shore activities in UH resources development. Example for UK

Acquire	Explore		Develop	Produce
Obtain environmental and regulatory approval	Conduct geological and geochemical surveys	Design specific well pad requirements	Demobilize drill rig	Confirm viability of well
Acquire surface leasing and permits	Complete site excavation planning and preparation	Mobilize drilling and equipment	Install permanent well head	Install surface facility
	Drilling initial hole	Install infrastructure	Mobilize fracturing equipment	Install piping infrastructure
	Evaluate site using core sampling	Cement intermediate casing go bore	Source and receive fracturing fluids	Prepare site for decommissioning
		Source and receive drilling mud additives	Pump fracturing fluids	
		Drill well before and install production casing	Treat and transport drilling waste and waste water	
			Test for recovery potential	

Source: E&Y 2014. Report for the UK

The UH industry, like conventional Oil and Gas consists mainly of traditional Upstream, Mid-Stream and Down Stream elements and like the conventional O&G industry the "upstream" relates to exploration and production- in other words "supply" the "mid-stream" relates to bulk transport and processing- in other words "refining" and the "downstream" elements refer to distribution and marketing in other words "transportation & distribution". The element of "trading" permeates at all levels of the chin in one form or the other once the hydrocarbon has been "produced" which is the point of intersection between upstream and midstream.

Table 5 provides two major messages:

- the upstream element of UH value chain contains activities that are specific to the UH space but once produced the mid-stream and downstream elements are exactly identical. This means that once "produced" UH hydrocarbons can- with suitable modifications e.g. liquefaction in the case of LNG- enter the conventional hydrocarbon asset systems. This means once the gas is produced it can be liquefied and transported large distances- as has been the case with US Shale-to-LNG projects in the US or can be introduced into the gas pipeline transportation system for distribution and supply.

- the individual elements of the upstream activities are exactly where the main differences in the methods of exploration and production lie. This is the space that has been enabled by the combination of hydraulic fracturing and horizontal.

Let us now turn to the specifics of the Upstream component of the value chain:

Site Acquisition: Upstream permits for E&P activities and their allocation by auction or other competitive means is the standard in this industry. This is no different in the UH case. Sites have to be identified and allocated. In the US, this is largely open competitive activity carried out with landowners (as mineral rights are private) whereas in other parts of the world the allocation happens in other ways, i.e. by the Governments.

Explore: Unlike conventional hydrocarbons where exploration is a high risk activity, due to the nature of UH formations- where the gas initially in place (GIIP) estimates are a function of permeability and ToC, both of which can be known in advance, the risks relate not to the success or failure of test wells but to further detailed studies that need to be carried out before drilling can start.

Develop: This is the element that is very unique to the UH space and best described as getting the various elements of the hydraulic fracturing and directional drilling into place, identifying drill points, 3-D imaging, well pad preparation etc.

Produce: Involves the actual process of fracking and ensuring the well pad performs to expected performance specifications and that all aspects of the contingency planning are in a state of readiness.

The main difference vis-a-vis conventional hydrocarbons lies in the E&P or the upstream end of the business- this is largely due to the processes of hydraulic fracturing and horizontal drilling.

The key differences with conventional hydrocarbons are in elements of development and production, shown as 3.0 and 4.0 in the figure above. The drilling infrastructure required, the casing integrity and well cementing and completion practices vary significantly as do the requirements of hydraulic fracturing and importantly the preparatory work required for directional (horizontal) drilling.

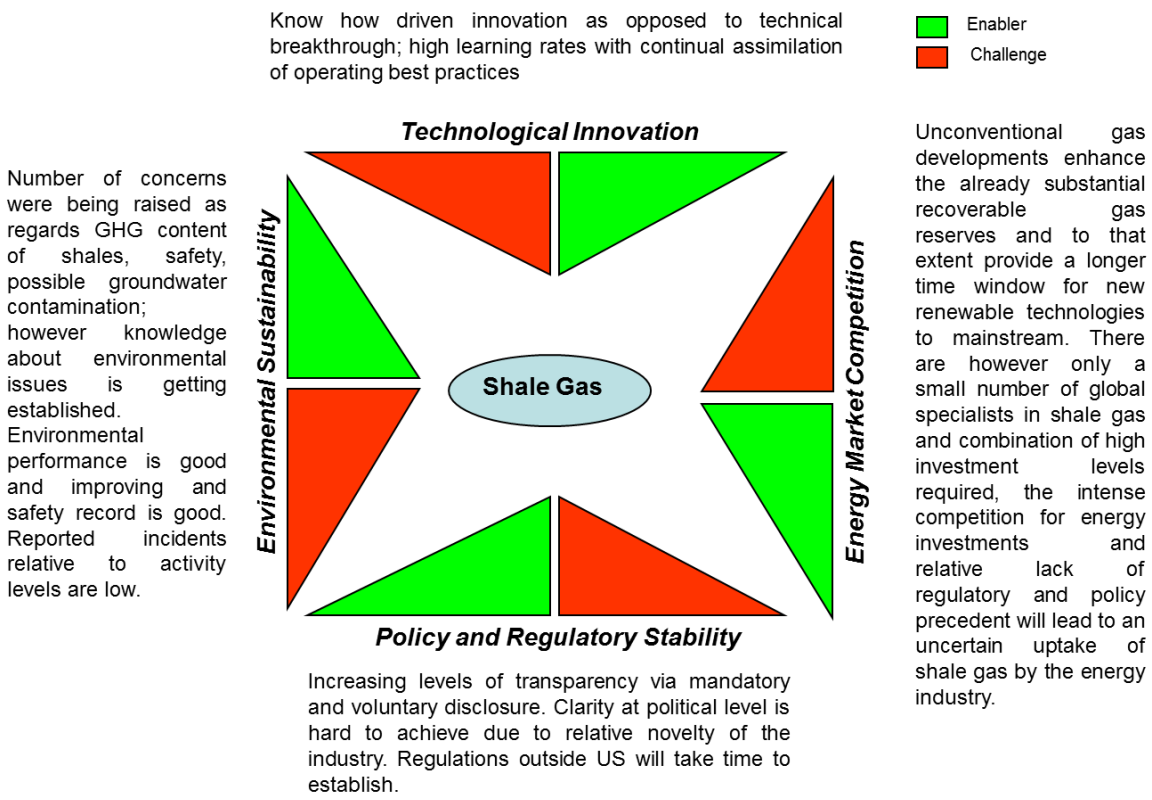
Let is now turn our attention to answer the question, what are the macro-economic forces at work in the UH industry? And how do these forces interact to shape the outcomes of this industry that is beginning to take shape?

9. The Forces at Work in UH

Figure 58 Figure 58 captures the forces at work in the unconventional hydrocarbon space that we group in: policy and regulation, barriers to entry and the intensity of market competition, the role of technology and innovation that is at play and the environmental issues that bound the scope for growth in any industry. With this figure we want to show that within the UH space there are enabling and counter forces at play within the same category of forces. It is in this space that the main controversies around the potential of unconventional hydrocarbon resources development arise. One reason is to be attributed to the poor availability of data an research around relevant issues, as for the case of green house gas emissions intensity of shale gas activities. E.g. all through 2010-11 there emerged conflicting reports about the green house gas (GHG) intensity of shale gas. In 2012 the IEA published a study (IEA 2012) dedicated to unconventional hydrocarbons – "The Golden Rules for the Golden Age of Gas. World energy outlook on

unconventional gas" - where GHG intensity of shale gas was addressed. The agency determined that the carbon dioxide intensity of shale gas development was at 8% more than that of Natural gas. Other more recent studies state that indeed, carbon dioxide emissions from fossil fuel use are lower than in the case of other conventional resources, i.e. coal (Chang 2015) and that " carbon dioxide emissions from fossil fuel use in the USA declined to some extent between 2009 and 2013 […] in part due to replacement of coal by natural gas (*also from shale gas*). However, significant quantities of methane are emitted into the atmosphere from shale gas development: an estimated 12% of total production considered over the full life cycle from well to delivery to consumers, based on recent satellite data" (Robert W Howarth 2015). Lack of complete information around the GHGs intensity of this resources and the comparison with other competing fossil fuel play an important role at the decision making level.

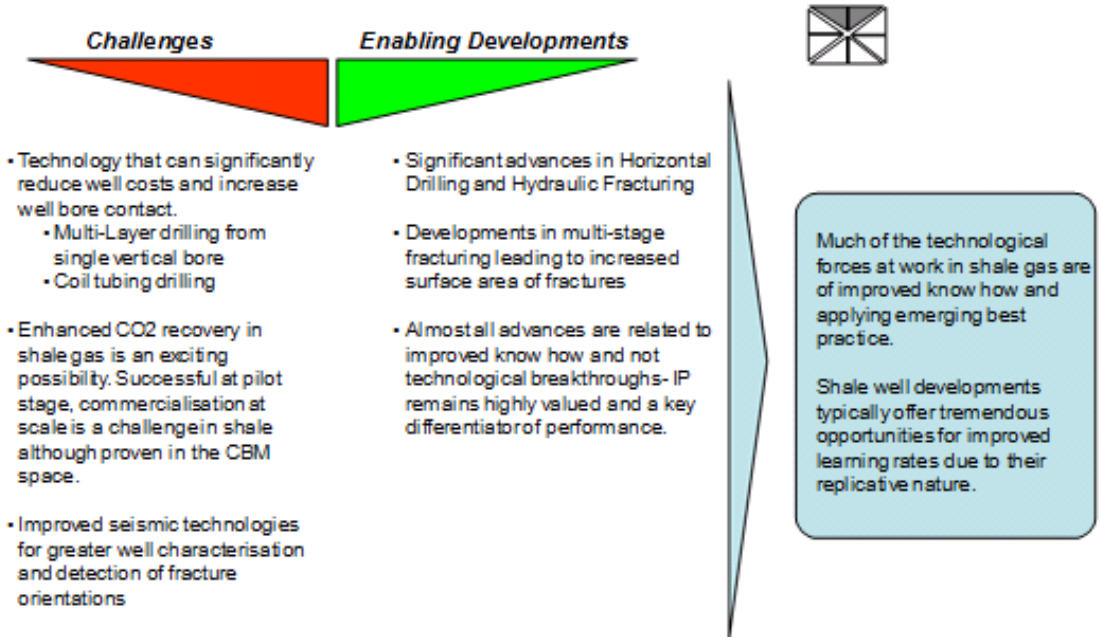
Figure 58. Counterbalancing forces at work in unconventional hydrocarbons development. Enablers and challenges



Source: EnerStrat Consulting analysis

As can be seen, the forces at work could be seen to exerting both enabling and resistive pressures; the remainder of this section seeks to disaggregate them to help us understand the state of play. Figure below highlights the importance of the concept of "management innovation" that continues to play a shaping role in the future evolution of the UH space.

Figure 59. Synopsis of technological development issues



Source: EnerStrat Consulting

This was an example of corporate managements conceiving and developing an elegant technological innovative solution that unlocked the UH production by combining two different sets of technologies. The enabling forces at work in the technology area continue to advance the frontier even today not by any further technological innovation but the improvements have come through continuous incremental improvements that reflect the management culture of the organisations that operate in the US.

Yet, at the same time a number of challenging technological forces prevail too- Figure 59 captures which the companies operating in the UH space need to continually track. As an example, improvements in 3-D seismic well characterisation that improve the recovery rates in tight wells are not exclusive to the UH space but prevail all across the Oil and Gas industry- it thus becomes a technology management and innovation challenge for companies operating in the UH space as to how they keep track of these developments, how they are incorporated in their drilling programmes etc. This continuing demand to stay on top of these developments requires companies in this space to think creatively about managing this innovation process.

On the whole though, the forces of technology and innovation have largely played a positive role in the UH industry, esp the management innovation- described above- in the US that made it possible and continue to unlock greater UH potential.

As we have already seen, none of these technologies could have individually unlocked such industry potential and hence it has to be recognised that the unlocking of the unconventional resources has been a unique culmination of management innovation.

This opens the issue of scalability of such innovation globally. The uptake of these innovations has not been uniform and the most relevant question in the force of technology therefore is not the issue of learning rates or breakthrough technology but rather that "what, if any, are the (EU) region specific features (which may or may not be different to the ones observed in the US) that are important drivers and barriers to understanding the UH potential development?" Given that it is widely acknowledged that it is virtually impossible to recreate enabling operating environment, the force of technology does face some headwinds when it comes to being globally prevalent- management innovation does not travel as fast as a breakthrough technology- because as we have seen in the case of the US, the highly competitive nature of the oil and gas development industry is what spurred innovation in this industry in the first place.

On the regulatory front, the forces have so far been largely of an enabling nature for UH production. There have been concerns raised about transparency of drilling operations, especially on the use of fracturing chemicals being used. The industry responded positively in to regulators and policy makers and new standards and disclosure norms continue to being developed. The uncertainties in the policy space have now shifted to the stance national governments have taken towards UH. These are gradually being addressed as more experiences are being shared in this space.

We shall see in the subsequent chapters how these are being addressed along dimensions of economics and cost competitiveness, economic value creation potential and the outlook for new jobs.

Also, in order to be able to analyse the likely impacts, it is worthwhile to understand the issues of skills available within the EU along the value chain, our assessment and analysis of the emerging gaps. Now that the value chain elements and the forces at work that are shaping the UH space are better understood, we move to the value chain gap analysis which helps us calibrate how well prepared the EU as a region is to start building an industrial ecosystem for UH.

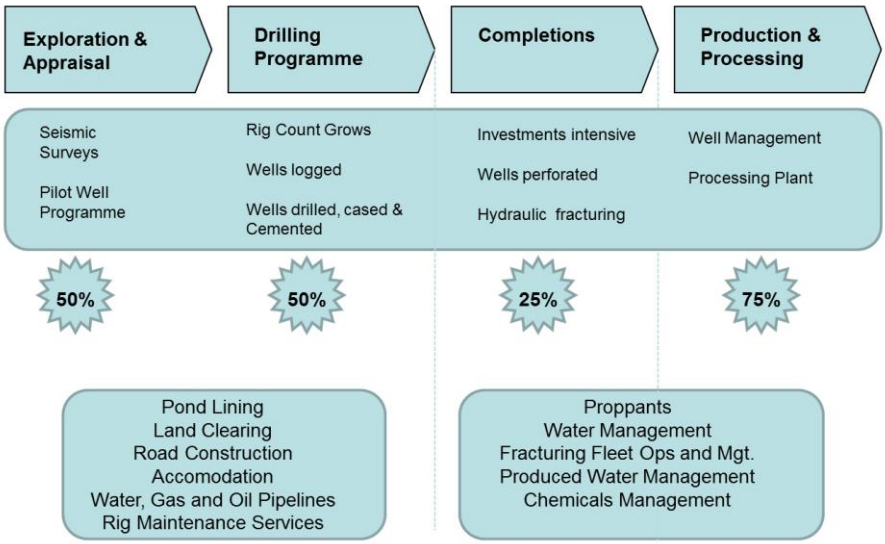
10. Value Chain Gap Analysis

The value chain chapter clarified that the upstream element of the value chain is distinctly different from the upstream elements of other conventional oil and gas chains. This chapter takes a deeper dive within this upstream element first and then touches upon the two other industry chains where UH has the potential to mainstream into: 1) the global LNG chain, as we already have seen how shale-to-LNG integration has resulted in the US based UH industry impact the global gas markets and 2) the integration of UH into the existing European oil and gas industry- the so called mid-stream and downstream elements of the UH value chain.

Figure 60 discusses the four key distinctive upstream elements of unconventional hydrocarbons: Exploration and Appraisal, Drilling Programme, Well Completions and Production Processing. It identifies the key activities that need to be carried out that make a difference in the success of a UH programme and provides a qualitative assessment of "preparedness" in Europe of the industry along these evaluated value chain elements.

The two boxes at the bottom of the figure include specific areas of improvements required to be able to advance further in terms of value chain maturity.

Figure 60. EU supply chain capability VS key activities/characteristics of a typical UH supply chain

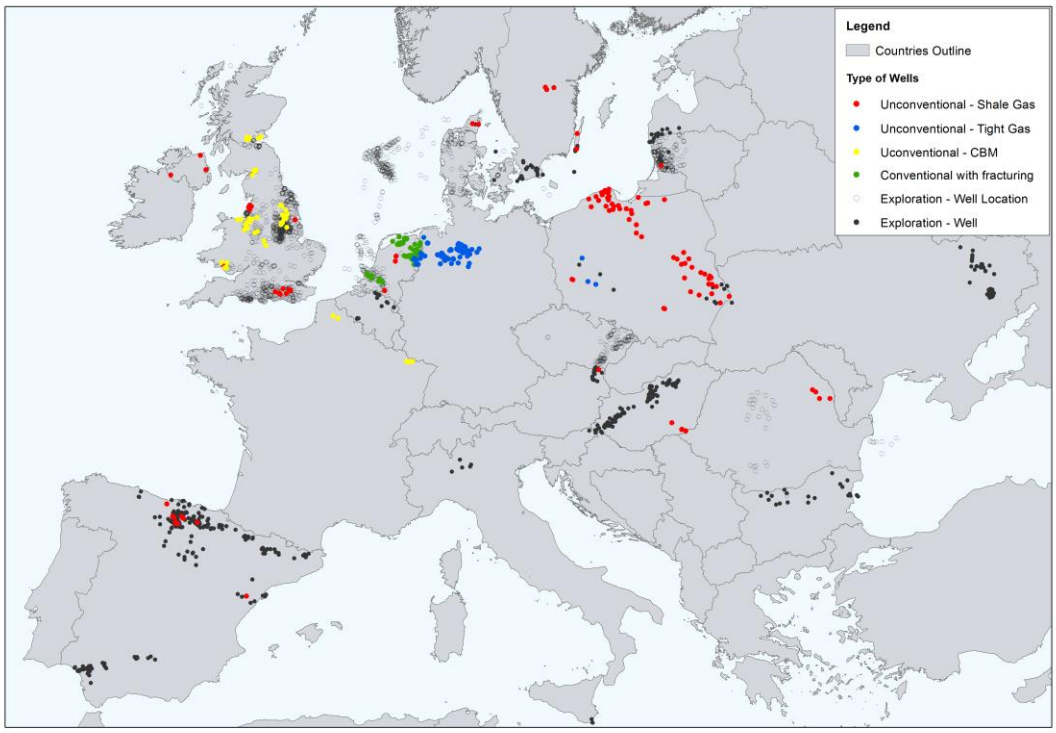


Source: EnerStrat Consulting Analysis

Let us now examine each of these aspects in a little more detail to unpack the capability score (percentage in the figure above) that we have awarded for the individual elements of the upstream value chain gaps.

Exploration & Appraisal: This area deals with the ability and skills of firms with experience in conducting studies relating to seismic, well prospectivity and reservoir modelling, important collateral services to the resource exploitation. A number of EU based companies have built a good reputation in this space and a number of EU firms in this space have a global footprint e.g. Schlumberger. A number of US based firms e.g. Baker Hughes also have offices in various EU capitals. Moreover the technology intensity-driven nature of this business means that this is a highly mobile element of the industry. What drives the score down to 50% is the relatively small number of pilot test wells that have been tapped in the EU within the UH space. This will grow with experience and the skills sets required can be relatively easily deployed. Figure 61 shale gas, tight gas, CBM exploration activities and conventional exploration activities with fracking in Europe.

Figure 61. Shale gas, tight gas, CBM exploration activities and conventional exploration activities with fracking in Europe



Source: The Shale oil and gas polygons and resource assessment are based on the results obtained from Commission - EuroGeoSurveys EUOGA project (Contract JRC/PTT/2015/F.3/0027/NC – Geological Evaluation of Potential Unconventional Oil and Gas Resources in Europe) and JRC UH Database

Drilling Programme: Currently except for the UK, Poland and Germany, there is extremely limited experience of UH drilling and Hydraulic fracturing in Europe. There is however a body of experience of well logging and well cementing in the region. One enabling factor in favour of Europe is the possibility of either building or importing drilling rigs. The engineering experience in the rig space in Europe is quite mature and hence helps to drive the score up to 50%.

Well Completions: is a specialised function where our assessment is that the EU capability is the weakest; this is the area where expertise in well perforation and hydraulic fracturing counts. Especially directional horizontal drilling and well perforation activities need to be well synchronised- this is very much experience and know how driven. This is also an area of highly localised skills within the US industry system. E.g.

when the shale gas drilling programme was announced, this was an area of expertise that was almost entirely secured from professionals moving from the United States. We assess the capability here to be 25%

Production and Processing: This is a functional area which involves maintaining production levels, conducting asset management and making sure the established processes run smoothly. Many of the skills from the conventional hydrocarbons can be transplanted in this space. This is thus an area where the supply chain capability can be built up from the existing conventional oil and gas ecosystem. We therefore assess the capability to be at 75% levels.

The box items mentioned in the fig 6 are some of the important specialised functions that contribute to safe/secure operations of UH programmes. Some of these activities may appear to be only peripherally connected to core UH activities e.g. road construction or accommodation or land clearing. These however have emerged as activity areas which were crucial to smooth operations of UH programmes. They have been identified on the basis of our previous engagements in the UH space in North America.[8]

As seen from the gap assessment above, while there are a number of areas of improvement identified, these are all areas that can build the required maturity with greater experience. It will be important to understand how these gaps can be closed as UH activity builds up in the EU in future. We have discussed some ideas in the subsequent chapters in skills analyses and industry development issues in the later part of this report. We now turn our attention to the cost structure and economics of UH projects- our objective is to understand at a more granular levels the principal expenditure heads in a UH programme.

It also needs to be understood that even in a rapid build up programme like the one evidenced in the US, there have been periods of supply chain constraints. In the period 2010-12, the US shale gas industry faced a range of supply chain related constraints. These constraints need to be better appreciated and are an important source of learning for regions like the EU.

While some constraints can be relatively quickly resolved by procuring from the open market e.g fracking consumables like guar gum used as propppant was relatively easy to procure when a shortage was faced- it did cause a rapid ramp up in guar gum prices for a short period- other constraints especially relating to high end capital equipment such as fracking pumps or infrastructure related bottlenecks such as rail road capacity for transportation are long lead items that are not easily resolved.[9] Figure 62 below lists the various heads of supply chain constraints that were evidenced in the US in the high ramp up period 2010-12.

Figure 62. Services involved in the UH resources development

Source: Government of South Australia, Office of Manufacturing Innovation, Dr Paul Goiak

11. Cost Structure and Economics

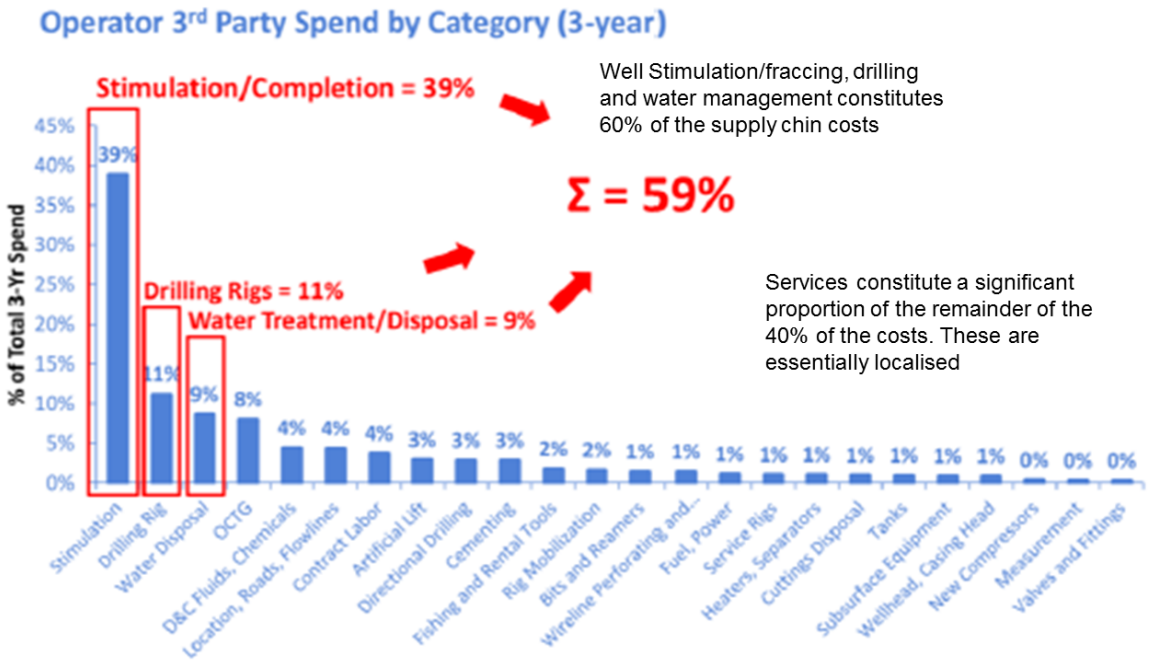
In this chapter we explore the cost structure of UH projects based on observed data for UH project spend; our aim is to identify individual elements of UH project spend to make a high level assessment of the extent of supply chain elements that can be locally procured. This chapter does not aim to make any profitability or economic value add assessment nor does it seek to link the developments in the external energy pricing environment e.g. crude oil prices to make a viability case for UH.

This is important to highlight as UH project profitability is highly localised and resource specific. E.g. there has been immense speculation in the international media about the viability of the US shale gas industry profitability especially in the light of rapidly declining wholesale price of gas domestically in the US- The Henry Hub price.

It is anticipated that individual project sponsors will address the economics and financing of UH projects on their individual case by case basis. We are taking a macro-view in this chapter to understand: "what parts of the UH supply chain can be served domestically within the EU? What are the various services that are required in UH project development activities? What proportion of the overall spend do services make up as compared to capital equipment?" etc.

Figure 63 provides a percentage wise breakdown of project expenditure for UH operators over a 3 year period 2010-2013, which was published by the US DoE in 2014 and cited in a South Australian Government paper, presented in 2015.

Figure 63. Understanding operator supply chain spends and costs structure: United States example



As can be seen from the US example given above the following principal conclusions can be drawn:

- Well stimulation and hydraulic fracturing constitutes the main element of the cost structure with three cost heads of well stimulation, drill rigs and water treatment making up a bulk 60% of the costs
- The remainder of the 40% are spread widely across a range of "services"

- Of the three main expenditure elements Well Stimulation and Completions represent a combination of capital equipment supply (for both stimulation and completion) as well as a range of specialized services.
- These services also form the core of the package of export services in UH that is being offered by the US DoE in its technical assistance packages e.g. this was the case in the UH programme in Poland, recently and was being discussed for a UH programme proposed for Ukraine.

What is significant is that:

1. The wide ranging services that make 40% of the costs are by and large already present in Europe and are highly localized, representing a potential opportunity for EU players.
2. EU based companies- especially in water and waste water management services have been doing well in securing participation in the UH programme underway in the US and therefore would appear to be in a position to offer similar services in the EU. Some like Veolia Water Management have even developed bespoke solutions that are being well appreciated in the UH programme in the US.
3. The potential surplus of drill rigs that might emerge in the United States represent a trade opportunity for the EU- this is now a possibility as the advances in directional drilling in the US imply that fewer rigs are now required than envisaged earlier for the UH programme in the US- in addition to the possibility of EU companies expanding their manufacturing base for drill rigs or securing trans-Atlantic partnership in this space.
4. US well stimulation and hydraulic fracturing players seeking to grow represent a skill base that EU could attract to help build its industrial supply chain base. This has been the case in Poland recently.

In addition the early experience of the UK and the available analysis from the UK onshore oil and gas operators group (UKOOG) appears to suggest that 1) the spend breakdown numbers are substantial and consistent with what has been observed in the US and shown in (**Error! Reference source not found.**) and 2) with the possibility of the scale that EU as a region could offer, even the 40% of procured services, which can potentially be offered by EU companies, the domestic services revenue potential can be quite substantial.

Figure 64. UK shale gas industry spending 2016-2032

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Note: Assumes 100 well pads, each with 10 vertical and 40 lateral wells (low case) implies a single well spend of £ 333 Million, with peak well activity at 2014; 50 high Tonnage Drill Rigs required at peak year activity.

The EU companies could also explore the opportunity to develop service hubs for the UH industry with localised skills- which could improve the prospects of an EU industrial base for UH. The questions raised in the right hand side of **Error! Reference source not found.** remain open questions that remain to be addressed to better understand the scale economies that could be created by a UH industrial base in the EU.

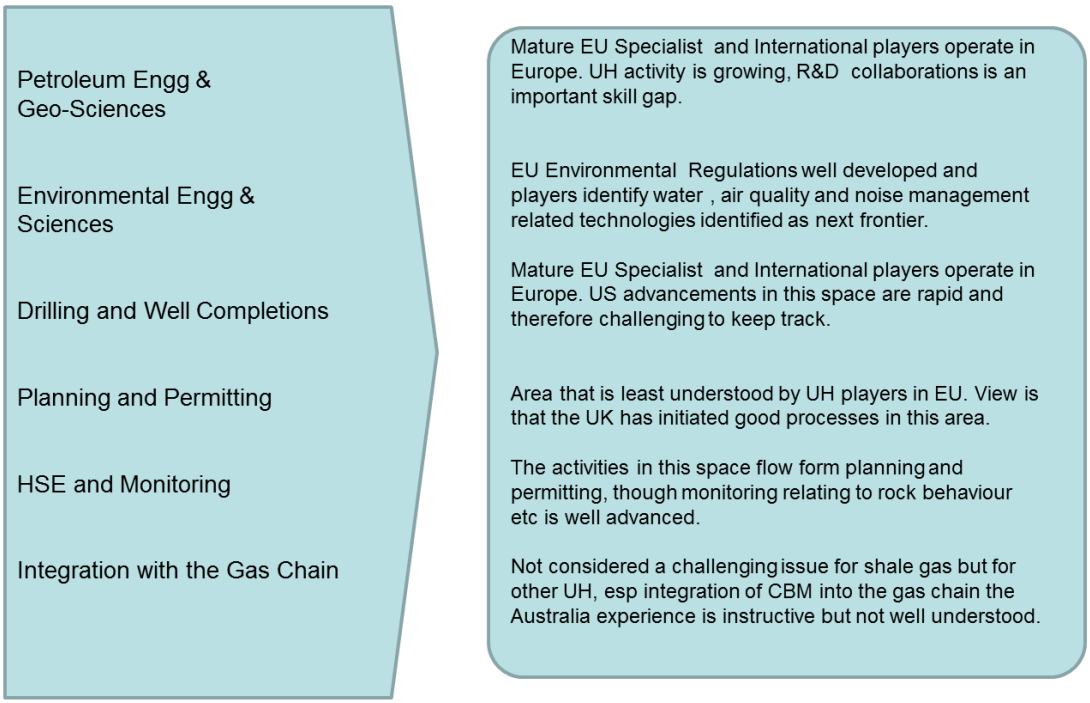
12. Skills Analysis for UH Developments in the EU

In this chapter, we assess the skill sets required across the industry and its stakeholders to be able to successfully deliver an industrials and professional services base for a EU based UH industry.

A high level synthesis of the required skills base is described in Figure 65 this has been derived from the observations and conclusions drawn from the previous chapters of value chain and its gaps, economics and the supply chain constraints.

Predictably, except for the last two: HSE and Monitoring and Integration with the Gas Chain the top 4 relate to the upstream part of the industry value chain.

Figure 65. Key Upstream skills analysis for EU member States



As can be seen from the Figure 65, the assessment is on the basis of the supply chain constraints and the gap analysis. The comments on the right hand side in the figure are a summary of observed evidence in Europe. This synthesis is borne out from our previous studies on the subject and has also been reflected in our recent interviews with participants in the UH programme in Poland and the UK. The first activities in Poland UH programme started in 2011, soon after a similar initiative was announced in the UK.

The first reserves mapping efforts were started in 2010 and activities in Poland and the UK meant that a number of US players started to focus in the European markets and a healthy domestic skill base from the UK based companies began to emerge.

It has already been mentioned that the UK had some experience of hydraulic fracturing to begin with from its North sea activities in the late 60s and the well-established oil field services infrastructure and skill base in Aberdeen ensured that some of the required skills were ramped up quickly.

The establishment of well-developed regulation and best practices in sectors such as water and waste water management, and the long standing industry verticals of produced water services for the oil and gas industry also meant that a base of UK/European players existed that could learn from the US shale gas experience quite quickly.

As a result, we find that there are a number of international UH players that already operate in Europe and secondly the skills that EU players have in the conventional space have to some extent already been applied in the US context e.g. in Water Management, Veolia Water Management has developed a bespoke solution of the overall water services including data management and real time monitoring that has already been appreciated in the US. The Veolia - Anterro Resources partnership for the Dodderidge County project in West Virginia for comprehensive water services for UH development is one such case in point.

We will consider later on in the report additional such examples that help us to draw some observations of the possibility of developing a UH industrial base in the EU.

Let us now consider some of the skill analyses findings in detail:

Petroleum Engineering and GeoSciences: This is a high end skill set that helps in the planning and coordination stage of a UH project. This involves reservoir modelling, understanding of the sub-surface, interpretation of 3D seismic surveys and well planning issues. The educational and research base is well established in this area with a number of reputed technological universities imparting education and training in this area. Mobility of professionals is also well developed. We assess this to be a positive development for EU in its aspirations for a UH industrial base.

Environmental Engineering and Sciences: Similar to Petroleum Engg this area is well developed in the EU and a steady supply of professionals is possible to meet the requirements for the UH industrial base creation.

Drilling and Well Completions: This is an area of rapid technological advances and is a function of an existing critical mass of projects in development. The challenge even in advanced markets such as the US is the ability to keep up with advancing good practices. This can pose a challenge in the EU and some expertise sharing on an ongoing basis would be a useful step.

Planning and Permitting: This is an area that is least well understood in the EU and an area where US good practices do not help much. This is due to the fact that mineral development rights are privately owned whereas elsewhere in the world the mineral rights remain with the State. Planning and permitting processes vary from country to country. It would help to explore if a common framework for UH projects planning and permitting can be evolved in the EU.

HSE and Monitoring: these flow from the planning and permitting rules and hence would vary from country to country, region to region.

Integration with the Gas Chain: This has already been attempted successfully in the case of CBM in Australia and now Shale-to-LNG gas deliveries to markets in Japan and UK are already a reality. The EU LNG industry is well-developed globally connected and there are already a number of transactions where Shale to LNG activity is picking up in the EU. Additionally, integration with the EU gas pipeline system is also not considered to be serious challenge as the treated gas can flow into the EU pipeline systems as long as standard gas quality harmonisation has been done.

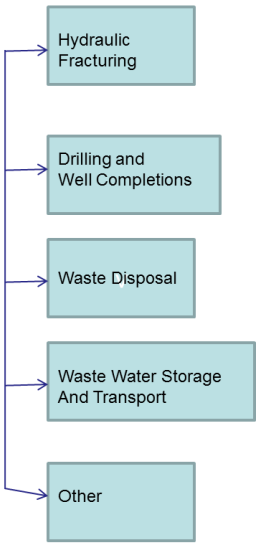
Beyond the UH related upstream skills, other example of cross sector skills that could be exploited is in the area of water treatment, conservation and management. This has been possible due to the high levels of sophistication already existent in the European water, waste water management industry and the technological advancements at play in Europe, driven in large part by the highly developed regulation and performance standards in the water industry.

Water management is a highly sensitive subject for the industry as has been evidenced in the active UH industry in North America- European players have managed to capture a significant share of this market in North America. One example cited here is that of the Veolia Water Management in West Virginia and there are possibly others too. These will require more considered study, consultation with the EU players who already have a foot print in the UH industry in North America.

In the remainder of this chapter we focus on the "high value added" components of the UH project spend. Having established that the activities relating to Hydraulic Fracturing/Well Stimulation, Well Completions, Water management inclusive waste water management and waste disposal constitute not only top share of the project spend but are also critical elements of the projects that "need to be got right" if the projects are to succeed.

Figure 66 highlights the strategic importance of these activities for building a UH industrial base in the EU and the column on the far right provides evidence seen so far within the EU member states.

Figure 66. Analysing the capital, skills and standards requirements



Strategic Importance to the EU	Current Status and Skill Sourcing
Key component of the programme. High end skill that would initially be imported.	Part of tier-1supplier category.
Potential for upskilling. High quality drilling and completions expertise is available in Europe.	UK, Germany, Norway, Denmark, France, Spain and Italy have well developed firms. Many have international collaborations.
EU capability is well developed. EU players have North American exprience.	Mainly France/ UK Experience
Evolving practice- expertise sharing with the US will be key. Sensitive economics.	EU Environment standards would provide the benchmark- this is well understood part of the sector.
Large part of the "others" include services which have strong localisation component. This can be challenging for EU wide deployment.	This should be explored carefully. Significant parts of the system already well developed?

Source: EnerStrat Consulting Analysis

In addition, we provide the following three examples of EU companies participating successfully in the US shale gas programme. This is still only indicative evidence, a more detailed study of successful case studies may be helpful in building a more comprehensive picture of the full extent of the advantage it might provide to EU players if a UH industrial base is established as an aim going forward:

- StatOil is already one of the major players in the US shale gas industry, what is now significant is that StatOil has successfully delivered a new pilot in its Bakken asset in North Dakota where it has successfully managed to re-inject 100% of the flow back water for hydraulic fracturing in its Williams County project. This innovation will dramatically reduce overall water usage whilst ensuring that all flow back water is safely handled throughout the lifecycle of the project.
- As already mentioned, Veolia Water Technologies in partnership with Anterro Resources in West Virginia has developed a bespoke total water management solution which is now seen as best practice
- Vallourec of France, a specialist provider of seamless tubular solutions for industrial processes has developed seamless tubular solutions for high integrity casings and tubings that are seen to be advancing the state of play in shale formations in the US.

These three examples- though not a fully comprehensive list- give an indication of the potential contribution that might be possible in the EU were the EU to start considering building an industrial base for UH.

In summary, our view on the skills assessment is that this is an important area for the EU to address if an industrial base for UH is sought to be developed. The right set of ingredients appear to be in place though this area needs to be monitored further.

13. Industrial Development Issues

It is widely recognised now that the circumstances that led to the rapid development of the UH industry in the US were in a sense unique; it is also acknowledged that these conditions would be very hard if not impossible to replicate elsewhere in the world. In fact the private mineral right of citizens is a feature that is unique to the United States.

We therefore address the issue of a UH industrial base from a EU perspective where unlike the US, mineral rights are not privately owned, a fully unbundled and highly competitive upstream industry devoid of national oil companies or national champions is not the reality, where member states are attempting a seamless flow of energy to be facilitated by regulation and underpinned by well-developed infrastructure and where a single market price for gas or electricity is not yet a reality.

It has to be recognised that a future UH industry would thus have to find accommodation with the rest of the European energy industry in a continuing state of transition.

We have thus far developed an understanding of the UH industry value chain, its gaps, its economics and macro-financial issues and we have painted a fair picture of the state of play in its supply chains. We have also identified a handful of European players who have distinguished themselves in the rapidly evolving UH industry in the US. In this chapter we articulate the various external factors that are required to build the industrial ecosystem.

The first requirement is a set of desirable geological formations, these may not be uniform across the EU but a well-informed bottom up assessment, possibly conducted by national geological surveys of the individual member states is possibly a requirement. Only a joined up picture of these mapped resources can inform the EU of the true extent of the resource potential and the required industrial capacity to deliver such a programme.

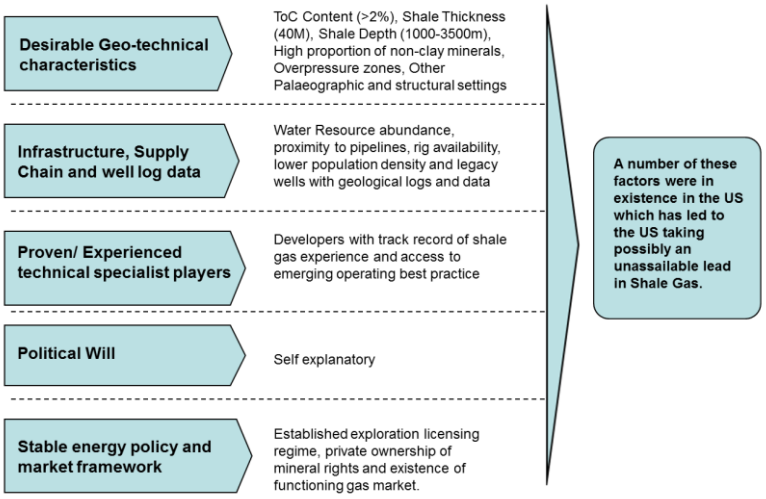
The second requirement is adequate infrastructure, a well-developed supply chain and the information infrastructure of well log data, core samples and a good understanding of how to interpret the data.

Thirdly, an environment where developers with good track record feel attracted to operate in. This is an area difficult to get exactly right. A domestic industry that shares the vision of its policy makers is an essential first step in creating this environment. The guidelines for operators are required to be transparent, easily understood and policy makers have to remain open to receive inputs/feedback from experienced international operators whilst the initial policy ground is being prepared.

As already described in the beginning of this chapter, UH industry will have to find accommodation with the rest of the evolving energy system- this implies that a stable energy policy and market framework that can attract the UH industry players is essential.

To be able to create this operating environment, what is absolutely required is policy clarity, which is difficult to achieve in the absence of political will to build an industrial base for UH. Figure 67 captures these requirements.

Figure 67. What really matters in UH developments. A summary of drivers



Source:EnerStrat Consulting Analysis

We identified three key aspects that could play a role in building the industrial base for UH in Europe:

Firstly, jobs creation. Companies are more likely to recruit and train new people in order to grow and meet increased demand for their products and services driven by the growth in the unconventional space. A realistic understanding of likely new jobs is required at the EU wide level.

Secondly, cost. For onshore oil and gas production to be commercially viable, the market design for price formation needs to be transparent, well costs structures well understood. To that extent we have built a good understanding of the cost structures and note that a competitive gas market is evolving in the EU.

Thirdly, tax revenues. This is self-explanatory, industry players would contribute to tax revenues that a new industry can generate.

14. Assessment Of Capability/Preparedness of EU Member States. Some examples

In this section, we assess the current capability or future preparedness of a set of EU member states that have the resource potential and have made pronouncements relating to UH. This is an indicative selection based also on how active and vocal the member states or the civil societies and other stakeholders have been of late. These member states therefore represent the most likely candidates for any future UH developments. It has to be reiterated here that there is almost non-existence of any real project specific data anymore in these member states that would lend itself to any realistic analysis of either the cost structures, economics or industrial supply chain competitiveness, this section is therefore a qualitative analysis of the set of member states which provide some indication of a desire to move forward in UH developments in the near term (up to 2020/21). One common feature of all these so called "emergent UH" EU member states is that they have had either an unofficial or official moratorium on UH activities, especially hydraulic fracturing. This was a trend observed in all these countries starting from 2011.

There was a widespread movement of environmental activism especially relating to possibility of ground water contamination that started in 2010/11 coinciding with the emergence of early entry of US based shale gas companies in Poland. This aspect has been covered in earlier EU publications and hence the objective here is not to revisit the issue but only to highlight/reference it. The key member states that have been considered in this analysis include Netherlands, Bulgaria, Germany, Poland, Hungary, Czech Republic and Romania. Each of these represent a case of a composite nature of

drivers that include concerns around environment sustainability/air quality, water contamination, energy security and energy price competitiveness that were at work which led to either an official or an unofficial moratorium on UH activity, especially shale gas exploration using hydraulic fracturing. Different combinations of drivers have been at play in these countries e.g. in the Visegrad Countries- Bulgaria, Czech Republic, Hungary and Romania the moratorium has been unofficial. Importantly at the point of the moratorium being considered, each of these countries represented a positive or neutral outlook towards shale gas exploration.

Similarly, Poland and Germany today represent countries where there is an existing, albeit very limited, early evidence of domestic industrial activity/capability. Concerns here have been more to do with environmental perceptions. Indeed as we shall see, Germany today represents the case of a country that appears to be "willing to be persuaded" about the viability of UH, especially shale gas exploration using hydraulic fracturing techniques. The Netherlands is yet another example where a "desire to retain leadership/market share of EU gas" appears to be driving to an inevitable conclusion that UH, especially shale gas exploration using hydraulic fracturing will "most probably" have to be considered to achieve the stated objectives by 2030. Figure 68 captures a high level summary of the state of play in EU member states as regards capability/preparedness for UH activity going forward.

Figure 68. Our assessment on capacity/capability in selected EU Member States

	Exploration	Drilling	Completion	Production
Bulgaria	Chevron active until 2014	No evidence	No evidence	No evidence
Czech Republic	No evidence	No evidence	No evidence	No evidence
Denmark	No evidence	No evidence	No evidence	No evidence
Germany	Some evidence of CBM	Capacity for CBM	No evidence	Capacity for CBM
Hungary	One project by TXM	No evidence	No evidence	No evidence
Netherlands	Capacity exists	Capability exists	No evidence	Capacity exists
Poland	capapcity exists	Limited capapcity	Limited capapcity	Some capapcity
Romania	No evidence	No evidence	No evidence	No evidence
Sweden	No evidence	No evidence	No evidence	No evidence
UK	capapcity exists	No evidence	No evidence	No evidence

Source:EnerStrat Consulting Analysis

As can be seen, the area of least preparedness in these countries is "Well Completions" – this is understandable as this is the part of the value chain that is highly reliant on "knowhow" and is simply a function of having experience of UH well completion practices.

The member states discussed in this chapter demonstrate one additional quality: each of these states whilst having a moratorium have kept up with the emerging developments by conduction their own studies and thereby keeping an open mind to future UH developments- this is an encouraging development. We now consider each of these countries in some detail.

14.1 Bulgaria

The Risks of building a programme around one single large investor

Bulgaria along with other countries, has had a positive/neutral view towards exploitation of shale gas to diversify gas supply till it issued a ban on hydraulic fracturing in January 2012. The ban was in response to heightened environmental activism that questioned the environmental integrity of hydraulic fracturing in particular the issue of possible ground water contamination. The ban was an "unofficial" ban according to local experts who opined that neither was a formal consultation launched prior to the ban nor was the ban supported by any act of Parliament; Bulgaria also cancelled the shale gas permit issued to Chevron later in 2012.

In 2014, there was a call for the ban to be lifted by the Bulgarian Chamber of Mines and Geology but at the time of writing, the ban remains in place. Chevron is reported to have quit its development work in Bulgaria. In our view, it is very unclear whether the opposition to shale gas that emerged in Bulgaria truly reflected the stated concerns on environmental integrity or whether there were wider geo-political forces at work. PM Borisov is quoted by a leading public affairs agency just before the decision to revoke the Chevron license: *"It was a mistake that the necessary broad public debate on this topic, to explain to the people what fracking means, has not happened".*

In our assessment, Bulgaria appears to have recognised the importance of a fair and open public consultation, appears to have recognised that the issues relating to one foreign company may have gotten mixed with genuine environmental threat perceptions and there appears to be an effort underway to keep an open mind in relation to future development of UH. At the moment, there is little evidence of on the ground capability to make it happen, even f the resources appear to be in place.

Figure 69. Companies active in shale gas exploration activities in Bulgaria

Operators (nationality)	Geological province	Year of activities*	Nr. of concessions	Total depth, ft	Results
LNG Energy	Moesian Platform	2011	1	10,466	Numerous shows s C1 – C3
TransAtlantic Petroleum	Moesian Platform	2011	1	N/R	N/R

Source: EMD 2016
Note: *Recent activities

14.2 Czech Republic

No UH prospects

In the Czech Republic, a de-facto ban on UH (shale gas from hydraulic fracturing) was issued in September 2012 and expected to remain till June 2014- this however remains in place to date. In June 2014, the Geology Law that was amended kept the role for UH open in theory but the Energy Strategy for the Czech Republic published in 2015 appears

to have a bias for LNG within the gas/hydrocarbon space and for nuclear power in electricity.

There is no evidence of any UH activity in the Czech Republic and our assessment is that the situation is unlikely to change in the near future.

14.3 Denmark

Figure 70. Companies active in shale gas exploration activities in Denmark

Operators (nationality)	Geological province	Year of activities*	Nr. of concessions	Total depth, ft	Results
Total	Fennoscandian Border Zone	2015	1	N/R	N/R

Source: EMD 2016
Note: *Recent activities

14.4 Germany

Calibrated advance towards regulated UH development

On 22nd June 2016, the German government passed a bill on allowing hydraulic fracturing for shale gas development following many months of protracted consultations, risk studies undertaken by regional governments, an extensive stakeholder dialogue including an extensive consultation with environmental lobby groups in the country. This bill paves the way for UH development in Germany. The new law allows for drilling depths greater than 3000m including hydraulic fracturing. For depths less than 3000m the law now allows for a six person expert panel to be created to grant approvals.

Our assessment of the German UH debate that we have followed ever since it began in 2011 is that this new law represents a fact based, pragmatic outcome that recognises the need to safely exploit UH resources beyond 2020. The ban on hydraulic fracturing was initially issued for 7 years (upto 2021) in 2014; it is as yet, unclear what the legal status of this ban is. In theory UH development can start now in 2017 although it needs to be recognised that the formation of the stipulated six member committees (applicable only for depths less than 3000M) may require some time.

Germany already has licensing regime for Coal Bed Methane and some 7500 sq m of area has been offered for exploitation but for shale gas exploitation using hydraulic fracturing the evidence so far is just one test drilling in Lower Saxony in 2008. Germany has extensive experience of fracturing for conventional hydrocarbons and even at depths greater than 5000M – some more than 300 fracturing jobs have been carried out in tight gas reservoirs. Germany also has around 160MW of power generation capacity fuelled by CBM (called locally in Germany as Coal Mine Methane).

Hence we conclude with our assessment for Germany that UH development beyond 2020 and possibly as early as 2017 is now a distinct possibility.

Figure 71. Companies active in shale gas exploration activities in Germany

Operators (nationality)	Geological province	Year of activities*	Nr. of concessions	Total depth, ft (min/max)	Results
ExxonMobil	North East German Basin	2008 2009; 2011	8	3,394 - 10,950	N/R

Source: EMD 2016
Note: *Recent activities

14.5 Hungary

Test Drilling allowed, but not commercial UH production.

Despite the issuing of permits to allow exploratory drilling for UH (in particular shale gas) being in place since December 2013, an effective ban on hydraulic fracturing is in place in Hungary.

The government statement implies that that the permits remain in place for research and testing but hydraulic fracturing based commercial production is so far not allowed.

Hungary represents a case of a positive/neutral policy view towards UH being offset by the political compulsions of domestic public opinion. Case in point being the amendment of the mining law at the end of 2014 which allows existing licence holders to carry out test drilling programmes. So far, TMX, a subsidiary of Falcon Oil and Gas remains the only player in the country engaged in UH activity.

Falcon started operations in Hungary in 2005 starting with its subsidiary TXM hlding a 35 year production licence for the Mako Trough, an area covering around 245,750 acres (around 1000 sq km)

Falcon TMX has so far drilled 6wells with each of the test wells flowing hydrocarbons. The company has carried out two vertical test stimulations and no horizontal or drills so far.

Our assessment is that Hungary appears to be unlikely/unable to address the status-quo in its UH development programme despite the stated desire by the government in many public fora so far.

14.6 Poland

Exit of the first movers

Poland represents an instructive case for dependency on external resources assessment to kick start a development programme. The basic facts of the Polish shale gas story are well known- US EIA estimates of 5.5TCM in 2011 were challenged by the Polish Geological Institute which assessed that the reserves were not expected to exceed 768BCM; Still a very substantial figure and not a cause for abandonment of projects, which we now see.

A total of 70 exploration wells have been drilled in Poland so far, 54 vertical and 16 directional/horizontal wells. From the initial list of companies active in Polish UH space, the US players have now all left and only two companies; the state owned PGNiG and Orlen Upstream remain active. The last to pull out of Poland was ConocoPhillips, one of the most active companies that drilled 7 out of the 70 wells. The Polish Geological Institute, which is preparing a new report on recoverable UH (mainly shale gas) potential suggests that atleast 100 additional wells are required to be drilled to get an adequate view on the resource potential. Domestic companies PGNiG and Orlen are carrying out the next stage of the drilling programme.

Our assessment for Poland therefore suggests that this early experience appears to have been instructive for the authorities and stakeholders in Poland. PGNiG appears to be dominating along the supply chain as there appear to be no public mentions of independent drilling contracts being offered.

Within this group of seven countries shown in Figure 72, the Polish experience is clearly the most mature (in terms of actual activity on the ground) and the presence of a domestic gas company poised for taking a leading role is an encouraging development.

Exploration activates generally last one or two months, and only in few cases up to 5 or 6 months for the same concession.

Figure 72. Companies active in shale gas (white area) and shale liquids (grey shaded area) exploration activities in in Poland

Operators (nationality)	Geological province	Year of activities*	Nr. of concessions	Total dept, ft (min/max)	Results
Indiana investment (BNK)	Baltic Depression	2012, 2014	3	14,100 – 17,700	Muted/mjnor/ high gas show s
Saponis investments	Baltic Depression	2010, 201	3	11,560 – 11,780	Significant gas show s : C1 – C3
Lane Energy (3Legs)	Baltic Depression	2010, 2011, 2012, 2013, 2014	8	9,250 – 14,688	Gas/gas show s
Talisman Energy Polska	Baltic Depression, Danish-Polish Marginal Trough	2011, 2012	2	11,800 – 14,930	C1 + small C2-C5/ C1-C3
Eni Polska	Baltic Depression	2011, 2012	3	N/R	N/R
PGNiG	Baltic Depression Danish-Polish Marginal Trough	2010, 2012, 2013, 2014	17	10,00 – 13,255	Primising gas flow/ No H2S and low N2/ havier hydrocabons/ flow ed gas
Chevron Polska	Danish-Polish Marginal Trough	2011, 2012, 2013	4	N/R	N/R
ExxonMibil E&P Poland	Danish-Polish Marginal Trough, East European Platform Margin	2010, 2011	2	12,490	N/R
Orlen Upstream	Danish-Polish Marginal Trough, East European Platform Margin	2011, 2012, 2013, 2014	12	8,573 – 13,830	N/R
Marathon Oil Poland	Danish-Polish Marginal Trough, East European Platform Margin	2011, 2012	6	N/R	N/R
Gora Energy (San Leon)	Fore-Sudetic Monocline	2011	1	11,550	C1 – C3
Wisent Oil & Gas	Baltic Depression	2011, 2012, 2014	3	5,075 – 9,160	N/R
Talisman Energy Polska	Baltic Depression	2011	1	9,147	C1-nC8

Source: EMD 2016
Note: *Recent activities

14.7 Romania

"It looks like we don't have shale gas, we fought very hard for something we do not have. I cannot tell you more than this, but i don't think we fought for something that existed" PM Ponta to TV channel Antena-3 reported by Reuters in 2014.

Unlike the other Visegrad countries, Romania did not announce an official moratorium but had effectively banned hydraulic fracturing till December 2012; in June 2012, the Senate rejected the ban on hydraulic fracturing and Chevron continued to pursue development in its wholly owned and operated 3 concessions in the South East of Romania and the Barland Shale formation in North East Romania.

In early 2015, Chevron relinquished its concessions in Romania and pulled out. There is currently no evidence of activity in Romania.

Our assessment is that this situation is unlikely to change in the near future.

Concluding Comment on the "Emergent Seven"

Netherlands and Germany appear to be countries with the greatest prospects towards real activity in the UH space, followed by Poland where the efforts of the two domestic companies are already continuing.

Overall, we believe that the initial concerns raised about the environmental integrity of UH drilling programmes is slowly reducing as new facts come to light. This situation will take time to clarify. The issue of wider energy geo-politics also plays its part in the progress towards UH development. This space will require to be continually monitored.

Figure 73. Companies active in shale gas exploration activities in Romania

Operators (nationality)	Geological province	Year of activities*	Nr. of concessions	Total dept, ft	Results
Chevron Romania E&P	South Carpathian Basin	2015	1	9,850	N/R

Source: EMD 2016
Note: *Recent activities

14.8 Sweden

Figure 74. Companies active in shale gas exploration activities in Sweden

Operators (nationality)	Geological province	Year of activities*	Nr. of concessions	Total depth, ft	Results
Aura Energy	Ostergötland Lower Paleozoic	2011	1	N/R	
Gripen Energy	Ostergötland Lower Paleozoic	2012, 2013, 2015	13	282 – 366	Weak flow of flammable gas/1 Mscfd In 2-hour flow (97.5% CH4)/strong gas flow/ intermittent gas flow/ 3.1 Mscfd after 30 minutes/ flow ed gas
AB Igrene	Siljan Ring Depression	2009, 2010, 2011, 2013, 2015	7	1,450 – 2300	N/R
Shell	Fennoscandian Border Zone	N/R	3	2,448 – 3,134	N/R

Source: EMD 2016
Note: *Recent activities

14.9 The Netherlands

No UH before 2020 but high probability of UH before 2030

Netherlands is large producer and consumer of natural gas since the 60-s and hosts the EU's largest swing field, The Groningen field. The country has highly advanced conventional HC capability with significant geotechnical, appraisal, testing and E&P expertise. This is useful and an advantageous starting point.

Dutch gas production is now in decline and the country has plans in place to substitute the lost volumes from new smaller fields and deployment of advanced technologies. UH exploration is currently not allowed, an official ban on shale gas exploration using hydraulic fracturing is in place till the year 2020.

Netherlands ban has been based upon the issue of environmental integrity of hydraulic fracturing and in response it has launched two specific investigations conducted by the TNO in collaboration with Universities: M4Shale Gas Initiative that explores the issues surrounding Measuring, Monitoring, Mitigating and Managing the environmental impact of shale gas. A second initiative called "Structured Vison Shale Gas" is currently underway which seeks to explore the strategy for exploring UH beyond 2020. The results of the study are not yet announced though there is evidence from the TNO- The Dutch National Organisation for Applied Scientific Research- that suggests that *"in order for the ambition of 30BCM of production to be achieved by 2030, it will require large investment into under-explored areas, new technologies, and also, most probably, the development of challenging reservoirs such as shale gas"*

14.10 The United Kingdom

Figure 75. Companies active in shale gas (white area) and shale liquids (grey shaded area) exploration activities in the UK

Operators (nationality)	Geological province	Year of activities*	Nr. of concessions	Total depth, ft	Results
Viking UK Gas	Anglo-Dutch Basin	2013	1	10,000	N/R
Rathiln Energy (UK)	Anglo-Dutch Basin	2013	2	9,000 – 10,420	N/R
IGas	Cheshire Basin	2011, 2014	4	5,174 – 7,004	Gas indication/ significant gas indication
Cuadrilla	East Irish Sea Basin	2010, 2011	6	2,000 – 10,775	Substantial gas flow/ junked and abandoned
Composite Energy	Midland Valley of Scotland	2005, 2007	3	N/R	N/R
UK Methane	South Wales Carboniferous	2011, 2012	2	N/R	N/R
Cuadrilla Resources	Anglo-Paris Basin	2014	2	2,700	Hydrocarbon liquids
Horse Hill Development	Anglo-Paris Basin	2013	1	8,770	Hydrocarbon liquids

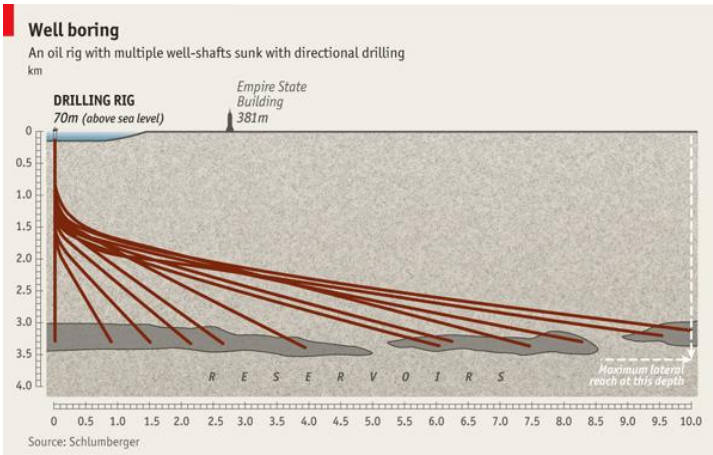
Source: EMD 2016
Note: *Recent activities

15 Emerging Good Practice Examples

In this chapter, we capture the emerging good practices that could help inform policy makers in the EU to calibrate the UH activity within other member states. This is not an exhaustive list of good practices but the aim of highlighting these practices is to advance the debate on issues which have been part of the public commentary on UH in the recent past. In particular, it is important how e.g. the technology advances we are now seeing in the US might help us re-examine a popular notion that given the levels of urbanisation

in the EU and due to higher population density, UH deployment might be difficult in the EU member states or another frequently quoted difference between the private nature of mineral rights in the US and the fact that no other country encourages private mineral rights; or how e.g. early UH movers in the EU such as the UK plan to develop the skill base that could be deployed in the UH industry s it begins to take shape in the country.

Figure 76. Technology Advances: Greater Depths, Greater Distances and More Data



Source: The Economist 21st July 2012, accessed August 2016.

As of 2016, this scope of horizontal drilling activities has expanded. Directional horizontal drills of distances greater than 10 km at even greater depths are now in evidence. UH resources are now being developed in urban settings and built environments- e.g. 10 km long directional drilling undertaken at the University of Texas, Austin campus. Future UH sites could well be urban formations and these will have to be carefully considered given the traditional view that EU being a population dense region compared to the US UH developments might be slow/difficult. The foot print of the average well pad is shrinking rapidly with advancements in technology. The issue in Europe would be how these advances in technology might traditionally held views of UH development.

Now, importantly, new advancements in sensors, advanced electronics and high pressure- high temperature engineering mean that instruments in the "drill-string" are able to transmit dozens of additional measurements: of the radioactivity of the surrounding rock, its resistivity to electromagnetic waves, and so on. This means a much richer understanding of unconventional formations; with more sensor data more precise estimates of GIIP, its composition etc. will be possible.

16 Advances in Public Policy Engagement: Direct benefit to communities in the UK Example

The UK announced its shale gas programme in 2007 with the launch of a resource assessment and planning applications for shale gas drilling activity. In 2011 following evidence of minor seismic activity the drilling programme was suspended. Following a detailed public consultation the moratorium was lifted a year later in 2012. One of the issues that local communities highlighted in the public stakeholder consultations was the issue of benefit schemes for directly affected communities.

In January 2013, The Prime Minister announced that councils could keep 100 per cent of business rates they collect from shale gas sites – double the prevailing 50% figure.

This commitment was estimated to be worth up to £1.7 million a year for a typical site is to be directly funded by the Government.

Community benefits for local people were also strengthened. In the previous year, the industry had announced that local communities would receive £100,000 when a test well was fracked – and a further 1 per cent of revenues if shale gas was discovered.

The industry then confirmed that it would further consult on how this money could best be shared with the local community, with options including direct cash payments to people living near the site, plus the setting up of local funds directly managed by local communities.

In most parts of the world where mineral rights are not privately owned, the issue of benefits to the community directly affected by the drilling activity is expected to crop up. While the idea of drilling for UH resources continues to be debated publicly in the UK and opposition from local communities continues, the revenue sharing model with direct benefit to the communities and the communities in charge of the utilization of the benefits has emerged as best practice.

The UK shale gas consultation is still by no means over, although results to date indicate that the public acceptance to UH activity is now growing and plans now appear to be in place for UH activity to begin by April 2017, the public consultation model followed in the UK for UH activity is beginning to be viewed as an example of emerging best practice in a European country.

16.1 UH Education: UK Example

The UK Government, in anticipation of the proposed developments on shale gas developments going ahead (whilst the public enquires relating to the opposition to fracturing continued in parallel) announced the creation of new centres of excellence for unconventional hydrocarbons to train the next generation of onshore oil and gas specialists with the aim to capture the economic opportunities offered by natural shale gas.

The proposed "National College for Onshore Oil and Gas" is to be headquartered in Blackpool and linked to colleges in Chester, Redcar and Cleveland, Glasgow and Portsmouth.

The Government is providing £750,000 of development funding which will be matched by industry bodies and education providers to develop the College. Further capital funding will be available from the National College programme to support the college on an industry-matched investment basis. The National College will:

- Provide high level specialist skills needed by the industry from 'A' level equivalents right through to postgraduate degree level, and train teachers and regulators.
- Accredit relevant training and academic courses run by other institutions.
- Carry out research and development for improved equipment, materials and processes that will increase the efficiency and reduce the environmental impact of operations.
- Work with schools to encourage children to consider careers in the industry, and to help them make the right subject choices early on.

Blackpool and the Fylde College's Lancashire Energy HQ will deliver a comprehensive range of qualifications up to postgraduate level, with facilities including a drill simulator and emergency control simulator.

The University of Chester's Faculty of Science and Engineering at Thornton Science Park will deliver a number of undergraduate and postgraduate degree courses as well as specialist masters, MRes and PhD programmes, and has recently been awarded funding to construct an Energy Systems Demonstrator.

Portsmouth's, Highbury College's Centre of Excellence in Construction, Energy & Sustainable Technologies provides a comprehensive range of accredited and bespoke courses to support entry to and progression in the onshore energy industry. The College

is also developing strong links with the Southern Alberta Institute of Technology, located in Calgary, Canada's hub for oil and gas operations

Redcar and Cleveland College's Teesside Oil and Gas Academy have already started to deliver a range of accredited and specialist bespoke courses in 2014-15, including Drilling and Petroleum Engineering, Geology and Geophysics, Quality management systems, and Piping and Pipeline Engineering.

The Weir Advanced Research Centre, based at the University of Strathclyde in Glasgow, will accelerate the development of high pressure pumping, hydraulic fracturing and other above ground hardware together with the training of highly skilled employees to operate the equipment.

Industry group, the United Kingdom Onshore Oil and Gas (UKOOG), led the bid to set up the college. Oversight by the industry will ensure that these colleges ensure students achieving the high level specialized training to meet the current and future needs of the industry, and keeps the UK ahead of the competition in drilling, hydraulic fracturing, site development and environmental management.

17 Conclusions

In this study, we provide an introductory overview, based on existing literature and on industry knowledge, on the key factors that have influenced the development of the unconventional hydrocarbon industry in selected countries, namely US, China, Australia and Canada. The analytical framework used in this work connects the facts and variables that have shaped each country's experience to relevant segments of the supply chain.

The same approach is then used to understand the potential of an industrial development of the unconventional hydrocarbon sector in Europe, by analysing the existing technology, know how, and the features of correlated sectors that could support the emergence of this type of industry in Europe.

The focus of this analysis was centred on the upstream components of the unconventional hydrocarbon value chain, namely the supply chain - which is quite different and highly specialised with respect to conventional hydrocarbon development activities. Similarities between the conventional and unconventional hydrocarbon sector are shared mainly in the mid-stream and downstream components of the hydrocarbon value chain.

The other focus of this analysis touched upon the services aspects of the UH project expenditure elements. In this respect we know that a number of European companies have successfully entered the relatively well developed North American market thanks to their strong and solid experience on hydrocarbon sector development. These elements play a relevant role in the assessment of the potential development of the UH sector in Europe.

As it emerges from the analysis of the experiences in countries outside Europe, drivers and barriers to the industrial development change according to the economic culture in each region, the infrastructure endowment of the gas and oil sector, the availability of related industries and services in support of the unconventional resources exploitation, and the financial support or constraints from the public and private sectors.

The analysis for Europe aimed at assessing the conditions for the potential development of an unconventional hydrocarbon industry by analysing the features of the sector, not only in those European countries with an estimated resource potential but also in other countries, which, for example, may have an advantage in the provision of correlated services in specialized sectors.

The evidence we provide for this last point is only indicative as the unconventional hydrocarbon industry is still at an emergent stage in some countries of Europe where some - though modest! - exploration activities have been carried out between 2011 and 2013 (i.e. Poland, UK) showing disappointing results and a separate detailed assessment might be required at a later stage.

As the figure below indicates, a number of open issues exist in relation to the development of an unconventional hydrocarbons industry in Europe e.g. the skill building strategy for EU Member States; development of institutions for imparting education in this thematic area; deep dive analyses of key regions from the resource potential stand point; value chains and the service industry skills up-gradation agenda etc.

An important consideration is also to be made regarding what the delivery model for this industrial development could be? E.g. how centralised does it ought to be? What regional specialisations based on existing infrastructure and skills base can be developed?

It is perhaps appropriate to conclude that our assessment of the UH value chain elements, cost structure and economics and the assessment of the required skills to develop an industrial base suggests that the areas in which more knowledge should be produced include, amongst others:

- A more detailed study to understand the success of EU players in the US Unconventional Industry and to explore potential models for engagement.

- A synthesis study of the assessments made by member state geological surveys to assess the UH potentially independently
- A cross functional study to determine what is the nature of accommodation that the UH industry if launched could hope to find in an evolving EU energy system.

Figure 77. Industrial supply chain development strategic issues

Key Insights	Issues to address
3 Activities of Industrial Well Stimulation, Drilling Rigs and Water Treatment/Management constitute 60% of the operator spend. A large number of industrial items/sub assemblies Already being made in the EU can be absorbed in the UH supply chain with marginal technical upgrades. A considerable part of the 40% of the spend is in providing services	1. How to facilitate the strategic sourcing partnerships? 2. Buy versus Build decisions for Rigs? Strategic investment in a central rig venture? 3. How to capture/incorporate new/best practices in 4. water treatment and management? What R&D/Commercialisation support or Innovation Programme can be developed to up-skill existing Industries? Can the JRC launch/facilitate a co-investment fund model to kick start venture activity in the services industry?

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List of abbreviations and definitions

UH: Unconventional Hydrocarbons

EU: European Union

JRC: Joint Research Centre

CBM: Coal Bed Methane

ToC: Total Organic Content

DECC: Department of Energy and Climate Change (UK)

E&P: Exploration and Production

GIIP: Gas Initially In Place

US DoE: United States Department of Energy

R&D: Research and Development

GHG: Green House Gas(es)

IEA: International Energy Agency

HSE: Health Safety and Environment

UKOOG: United Kingdom Onshore Oil and Gas Group

BCF: Billion Cubic Feet

3D: Three Dimensional

LNG: Liquefied Natural Gas

IoD: Institute of Directors

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Annexes

Annex I. Unconventional hydrocarbon resources in Europe

Figure 78. Shale gas resources in Europe (cbm)

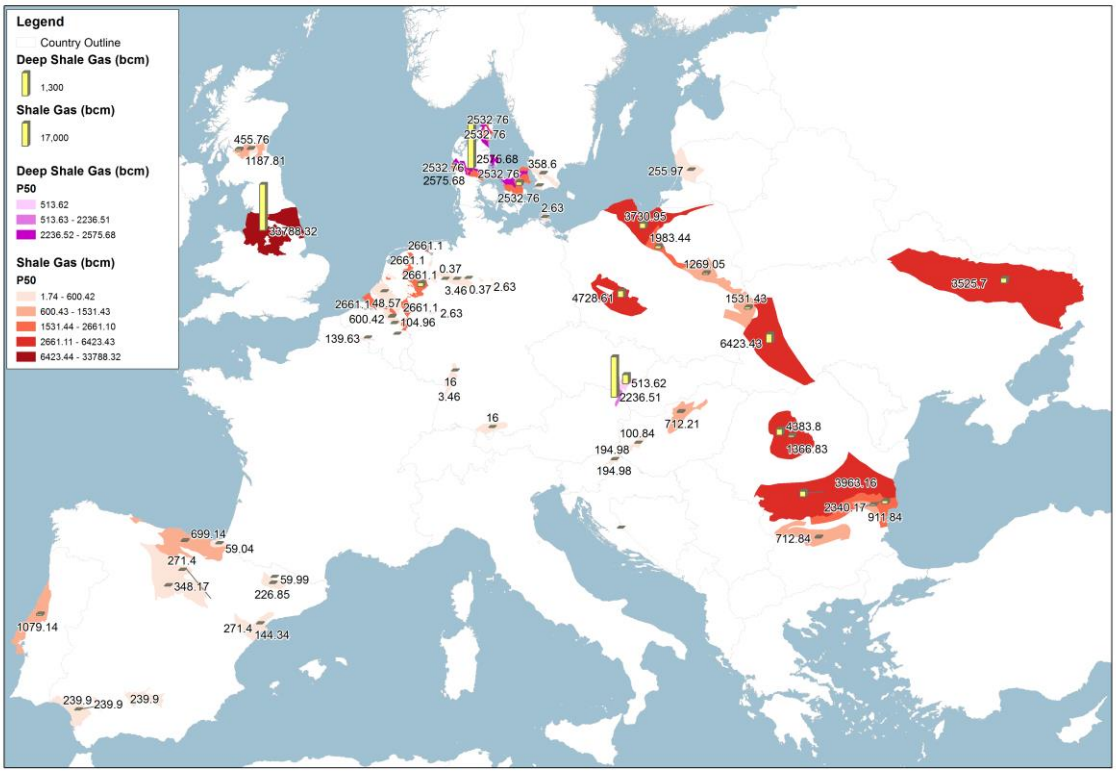
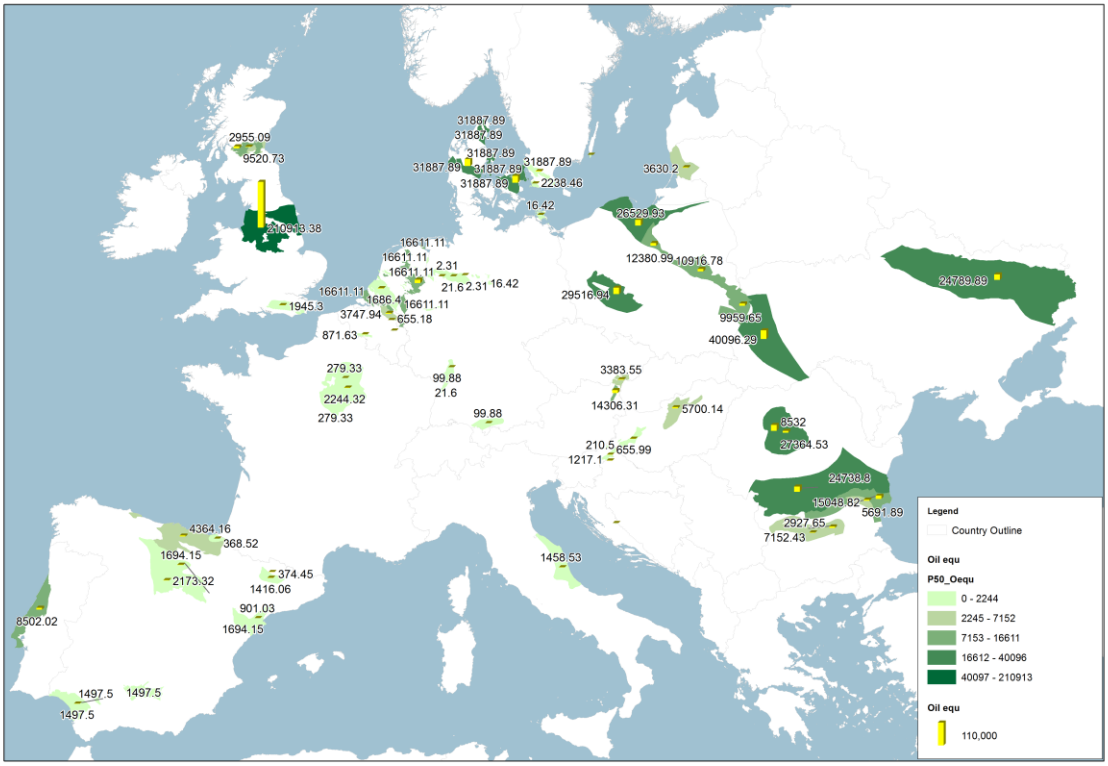
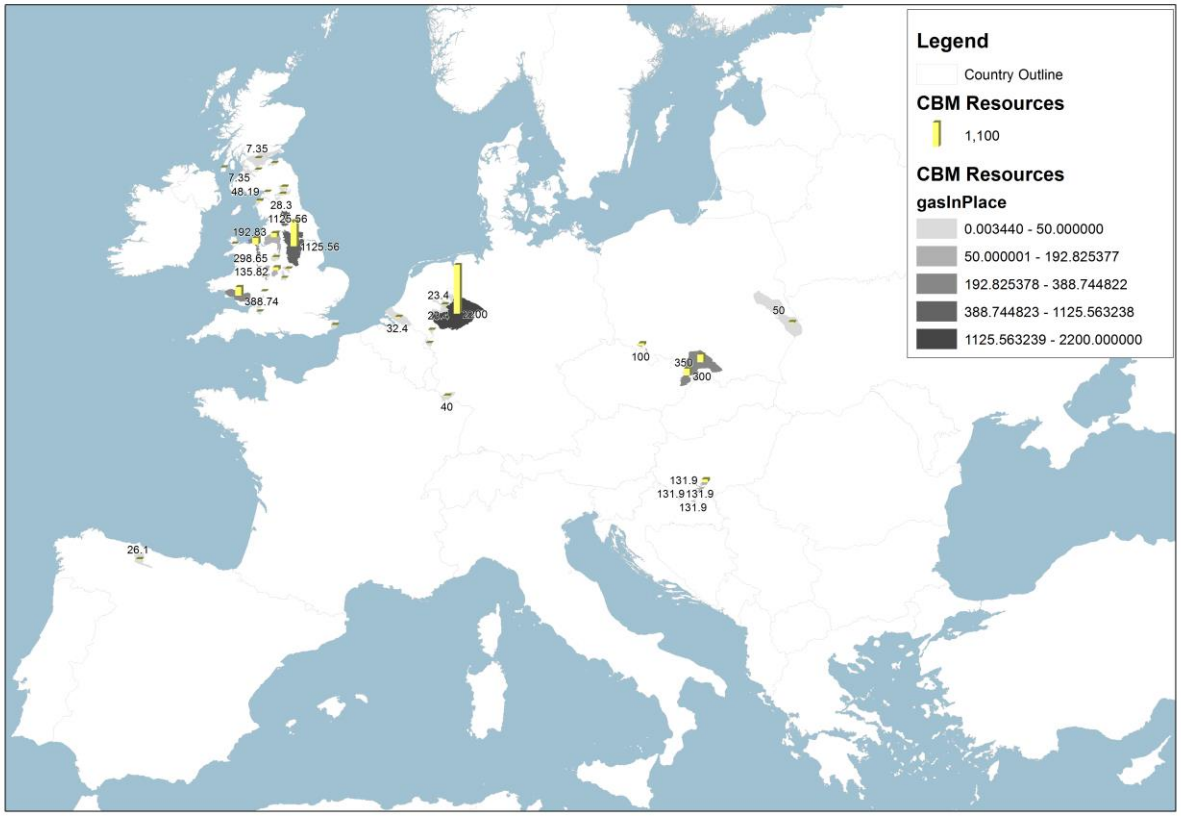


Figure 79. Shale oil resources in Europe (barrel of oil equivalent (BOE))



Source (Figure 78 and Figure 79): The Shale oil and gas polygons and resource assessment are based on the results obtained from European Commission - EuroGeoSurveys EUOGA project 2015 (Contract JRC/PTT/2015/F.3/0027/NC – Geological Evaluation of Potential Unconventional Oil and Gas Resources in Europe)



Source: JRC UH Database

Figure 80. CBM resources in Europe (gas in place (GIP))

Annex II. Unconventional energy supply chain sectors and main activities

Below we report 2 different categorizations of the key activities of each segment of the UH supply chain.

The following categorization has been taken from NAICS code in IHS ECONOMICS, 2014.

a) MANUFACTURING OF CAPITAL GOODS

1. Manufacturing of agricultural, construction and mining machinery.
2. Manufacturing of Motor vehicles and Motor vehicle parts.
3. Manufacturing of wholesale machinery and equipment.
4. Manufacturing of Power Boilers and Heat exchangers.
5. Manufacturing of heavy gauge metal tanks.
6. Manufacturing of Lawn and garden tractors and garden equipment.
7. Manufacturing of cutting tools and machinery tool accessories.
8. Manufacturing of turbine and turbine generator set units.
9. Manufacturing of speed changer, high-speed drive and gear.
10. Manufacturing of power transmission equipment.
11. Manufacturing of other engine equipment.
12. Manufacturing of pumps and pumping equipment.
13. Manufacturing of air & gas compressors.
14. Manufacturing of conveyors and conveying equipment.
15. Manufacturing of power-driven hand tools.
16. Manufacturing of electronic components
17. Manufacturing of automatic environmental controls for residential, commercial and appliance use.
18. Manufacturing of instruments for measuring, displaying and controlling industrial process variables.
19. Manufacturing of fluid metering tools and counting devices.
20. Manufacturing of analytical laboratory instruments.
21. Manufacturing of other measuring and controlling devices.
22. Manufacturing of heavy-duty trucks.
23. Manufacturing of light-duty trucks and utility vehicles.
24. Manufacturing of railroad rolling stock.

b) LOGISTICS

25. Water transportation
26. Rail transportation
27. Freight trucking
28 Pipeline transportation

c) MATERIALS

29. Retail building material and garden supply.
30. Manufacturing of Steel products.
31. Lumber and construction materials.
32. Metal and mineral materials.
33. Electrical goods
34. Hardware, plumbing and heating.
35. Chemical and allied products.
36. Mining of construction sand and gravel.
37. Manufacturing of industrial gases.
38. Manufacturing of basic inorganic chemicals.
39. Manufacturing of cement.
40. Manufacturing of ready-mix concrete.
41. Manufacturing of concrete blocks and bricks.
42. Manufacturing of iron and steel mills and ferroalloys.
43. Manufacturing of aluminium sheet, plate and foil
44. Manufacturing of fabricated pipe and pipe-fitting.

d) PROFESSIONAL AND OTHER SERVICES

45. Water, sewage and other systems.
46. Warehousing and storage.

47. Insurance Carriers
48. Architectural, engineering and related services.
49. Scientific and technical services
50. Rental and leasing of construction, mining and forestry machinery.
51. Non-hazardous waste treatment and disposal.
52. Repair and maintenance of commercial and industrial machinery and equipment.
53. Repair and maintenance of automotive and electronic equipment.

e) CONSTRUCTION AND WELL SERVICES

54. Construction of pipelines, rail, marine structures, storage facilities, LNG export facilities and manufacturing structures.
55. Construction of upstream facilities and structures.
56. Drilling oil and gas wells.
57. Support activities for oil and gas operations.

This categorization is given by Ernst & Young, UK report. We used this framework for the analysis in this report.

a) Acquisition

1) Obtain environmental and regulatory approvals.
2) Acquire surface leasing and permits.

b) Exploration

1) Conduct geophysical and geochemical surveys.
2) Complete site excavation planning and preparation.
3) Drill initial hole.
4) Evaluate site using core sampling.

c) Development

1) Design specific well pad requirements.
2) Mobilise drill rig and equipment.
3) Install infrastructure.
4) Cement intermediate casing into borehole.
5) Source and receive drilling mud additives.
6) Drill borehole and install production casing.
7) Demobilise drill rig.
8) Install permanent well head.
9) Mobilise fracturing equipment.
10) Source and receive fracturing fluids.
11) Pump fracturing fluids.
12) Treat and transport drilling waste and waste water.
13) Test for recovery potential.

d) Production

1) Confirm viability of well.
2) Install surface facilities.
3) Install piping infrastructure.
4) Prepare site of decommissioning.

Annex III. Industry analysis for unconventional hydrocarbon resource providers

The growth potential of UH-related firms is significant in Europe. In fact, there are few competitors. A shale gas well to ~3 km depth may cost 8-9 million US$ in the US, but ~18 million US$ in Europe. The reason given by the experts is that, in Europe, there is no significant drilling market. So, for example, a drilling rig that, after mobilisation, may drill 5-6 wells back-to-back in the US, in Europe it may drill just on well and demobilise. When companies moved to Poland to explore for shale gas, they used local drilling firms. San Leon, a company that remained in Poland for a considerable time after almost everyone else had left - included ENI SpA who was retreating from its three Polish exploration concessions because "the geology was much more unfavourable than had been earlier thought" (Financial Times 2014) - partnered with a local drilling firm, in order to complete its drilling schedule. In these types of agreements, the drilling company carries out the drilling operations at the exchange of a percentage of a possible discovery. Before ENI SpA also ExxonMobil, Marathon Oil and Talisman Energy have pulled out, leaving Chevron as one of the few big companies still hunting for gas.

The UH industry providers may be divided into several sub-sections, related to the various stages of the supply chain (Figure 1; see also ANNEX III) of UH resource development, such as:

(a) chemical companies
(b) metallurgy companies;
(c) integrated oil & gas firms;
(d) goods manufacturers;
(e) building contractors
(f) pipeline operators
(g) electricity producers;
(i) wastewater treatment companies etc.

In the HIS 2014 report, the authors insist, also, on the existence of "rolling stock manufacturers" (in effect "rail locomotive manufacturers") to promote UH projects. Some of these firms are very large conglomerates that have been operating for years throughout Europe and in the rest of the World (e.g. ENI, MOL, Engie, TOTAL etc.). Other companies are much smaller and can only provide services locally. Even though in Europe there is no significant drilling market, most of the large European countries already have the majority of the services needed for UH E&P. When all relevant companies in the EU countries are studied, it is revealed that there are three sectors that every EU country, independent of size, has:

(i) building construction companies, consultants and material providers;

(ii) wastewater treatment and environment services;

(iii) steel providers.

It remains clear that the European countries willing to explore and produce UH resources will have to "borrow" from abroad for each phase of the supply chain, and especially in the first years of activity, services, human capital, capital goods and technology (Godec and Spisto (2016) give a detailed indication of the skilled force by value chain segment and during each the phases of UH resource development). At present, a handful of US-based firms dominate the UH E&P market (e.g. Schlumberger, Halliburton, Baker-Hughes). Over time, however, several European companies (Fugro, Engie etc.) may enter the European UH market, if exploration shows some good results.

Porter's Five Forces method

Industry rivalry (degree of competition among existing firms): HIGH. There are several companies that provide the same service on a country level. In some areas, such as waste-water treatment, there is already (2016) a strong competition to provide the best solution for cleaning the flowback/production water. The same may occur in building, pipeline, telecommunications and IT industries, where several companies may compete

for the same UH project. On the other hand, there are few large companies that can operate throughout Europe. Most companies will compete on a country level.

Threat of substitutes (products, or services): MEDIUM. On a country level, there will be several substitutes for each service/product. The particularity in Europe is that there are countries, where a local UH industry will be readily available and there are countries that may have to import all products & services. In the capital goods industry (Construction & Utility equipment; Machine & cutting tools; Material handling equipment & cranes; Engines & power systems; Trucks & truck equipment) several companies will provide substitute products. The same may occur at the construction & well services industry (Well services & drilling support; Well pad access & gathering infrastructure; Pipeline infrastructure; Processing, refining & export infrastructure; Roads & other public infrastructu-re), as well as at the Logistic support industry (Pipeline shipment ; Rail shipment). There will be no competition/substitutes for slickwater/proppant (hydraulic fracturing) preparation, as the materials needed for this operation are very specialised and may be provided by specific, large, US-based firms only. According to the model, availability of substitute products will limit the ability of firms to raise prices.

Bargaining power of buyers: LOW. In effect, the UH providers can operate in a "captive" market. The countries and operators that wish to carry out UH projects in Europe have few providers, if they wish to keep costs down and not employ US firms. According to the model, powerful buyers have a significant impact on prices.

Bargaining power of suppliers: HIGH. For reasons discussed above, although there are several alternative providers for UH-related goods and services and a strong competition, if the government and operators wish to keep costs low they may use local suppliers, preferentially. In this case, operators may finally save money and increase profits, although they may pay a high prices to European suppliers that may be cheaper than the US providers. According to the model, powerful suppliers can demand premium prices and limit the firm's profit.

Barriers to entry (Threat of new entrants): HIGH. The cost of converting a business into a UH-related supplier may be prohibiting. UH upstream projects are very new in Europe and several companies may feel unsafe to convert to such operation, if they already have a good business. The political will and the public reaction in Europe against UH projects, may keep firms away from entering the UH field. According to the model, barriers may act as a deterrent against new competitors.

Methodology

The various UH supply chain sectors were taken from the IHS 2014 Study, which used the U.S. NAICS Code. IHS give particular importance to the existence of an industry that supplied "rolling stock" material and, more specifically, train locomotives, wagons and lorries. Hence, a special section on "rolling stock" suppliers is added in each country. Other industries included are: "wastewater treatment", "industrial building construction", "metallurgy", "drilling services", "electricity providers", "chemicals, "oil & gas producers and suppliers", "capital goods suppliers" etc. The "electricity providers" are the buyers of any domestically-produced energy. "Metallurgy" and "drilling services" are the suppliers of steel pipes and drilling material and consultancy. "Capital Goods" and "Chemicals" will provide all material for hydraulic fracturing and wastewater treatment.

In the US, the few industrial sections that profited between 2001-2012 (Kelsey et al, 2016) in terms of employment were: oil & gas extraction companies; drilling oil & gas wells; support activities for oil & gas operations; oil & gas pipeline construction; manufacturing of oil & gas field machinery; and, geophysical surveying and mapping. These industries are directly linked to UH E & P in the US and it is possible that this trend will be repeated in Europe. The definition of "job" is different, however, in the US and Europe.

In the US (Kelsey et al, 2016), employment in UH depended on the phase of E & P: 18% of UH employment in Pennsylvania (2011) was associated with the pre-drilling phase;

80% with the drilling and infrastructure phase; and 2% with the production phase. It is seen, therefore, that most of the budget is spent during the drilling, hydraulic fracturing and completion phase, an observation seen in the UK, as well.

In the Ernst & Young 2014 report, extra industries include the services that will deal with land acquisition, environmental licensing, as well as with geological & geophysical data acquisition and interpretation. In my experience, these services are, generally, provided by personnel already employed by the petroleum company and do not include external help.

The *companies* mentioned in each country are taken from various websites and are, only, *indicative*. They are meant to be examples of the existence of a particular industry in a specific country.

The amounts shown for UH investment in some countries were calculated as follows:

The volume of calculated (by some agency, often EIA) shale gas resource in a country was multiplied by the average price of domestic and industrial gas, assuming that all shale gas income will by re-invested. This is a big assumption, but experience has shown

that it happens, at least, in the first few years of UH exploitation.

The sums calculated, were, subsequently, apportioned using the ratios of the Ernst & Young UK report for each of the major UH drilling expenses. As can be seen, the largest expense is hydraulic fracturing (61.5%). In total, the drilling cost (61.5+24.65% = 86.15%) represents the main cost of UH projects. Expenses, not predicted in the Ernst & Young report, include all expenses tied to ESIAs (Environmental and Social Impact Assessments) and all expenses towards legal advice.

As a general comment, it can be said that all EU countries, independent of size, have strong "building construction" industry, "metallurgy" and "wastewater treatment" sectors. It seems that there is no shortage of engineers in the EU. Most of the relevant companies, however, are small/medium and can only provide services locally. Some EU countries possess large companies that may act in a pan-European field. Some companies have, also, international experience (e.g. Total, Shell, BP, Lundin, ArcelorMittal, Siemens, BASF and others) and can provide services and goods in large-scale operations. The main problem of UH projects in the EU, though, remains: the price of drilling a UH well is, at least, twice the price of a well onshore U.S. According to U.S. companies operating in Europe, this difference in cost is due (i) to the non-repeatability of business; and (ii) to the lack of infrastructure in the EU. Apart from the obvious shale gas/shale oil opportunities in the EU, other UHs include Coal Bed Methane and Tight Sandstone Gas (leaving aside the vast resources of oil shales, which are not included in the study). "Goods" in the results refer to *capital* goods.

It has to be noted that most EU countries have not had any estimate of their UH prospectivity. I believe it is important for each EU country to have a widely-accepted and published estimate of all its UH prospectivity.

A summary of the information detailed by country is given in table Table 6.

Table 6. UH potential industry development: Technical support

Country	Construction & utility equipment	Machine & cutting tools	Material handing equipment & cranes	Engines & power systems	Trucks & truck equipment	Well services & drilling support	Well pads	Micro-seismic monitoring
Austria	√	√	√	√	√	√	√	√
Belgium	√	√	√	√	√	√	√	n/a
Bulgaria	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Croatia	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cyprus	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Czech Republic	√	√	√	√	√	n/a	n/a	n/a
Denmark	√	√	√	√	√	√	√	√
Estonia	√	√	√	√	√	√	n/a	n/a
Finland	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
France	√	√	√	√	√	√	√	√
Germany	√	√	√	√	√	√	√	√
Greece	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Hungary	√	√	√	√	√	n/a	n/a	n/a
Ireland	√	√	√	√	√	√	√	n/a
Italy	√	√	√	√	√	√	√	√
Latvia	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Lithuania	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Luxembourg	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Malta	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Netherlands	√	√	√	√	√	√	√	√
Poland	√	√	√	√	√	√	√	√
Portugal	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Romania	√	√	√	√	√	√	√	√
Slovakia	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Slovenia	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Spain	√	√	√	√	√	√	√	√
Sweden	√	√	√	√	√	√	√	√
United Kingdom	√	√	√	√	√	√	√	√

n/a: non-available service
√: available service

Table 6 9continued). UH potential industry development *According to Phaal et al. (2011) approach

Country	Working conditions					Development sequence				
	Lad topography	**Water resources**	**Pipeline network**	**Roads**	**Water treatment services**	**UH type**	**Production increase**	**Commercial tests**	**Tech. research**	**Stage of development of UH industry***
Austria	foothills	sufficient	developed	available	available	TSG/SG/SO	none	yes	very deep wells	embryonic
Belgium	plain	insufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Bulgaria	plain	sufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Croatia	foothills	insufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Cyprus	on an island	insufficient	developed	available	available	n/a	none	no	none	precursor
Czech Republic	plain	insufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Denmark	plain	sufficient	developed	available	available	TSG/SG/SO	none	yes	none	precursor
Estonia	plain	insufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Finland	plain	sufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
France	plain	sufficient	developed	available	available	TSG/SG/SO	none	yes	geochemistry	precursor
Germany	plain	sufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Greece	within mountains	insufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Hungary	plain	sufficient	developed	available	available	TSG/SG/SO	none	yes	none	precursor
Ireland	coastal	insufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Italy	within mountains	insufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Latvia	plain	sufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Lithuania	plain	sufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Luxembourg	plain	insufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Malta	on an island	insufficient	developed	available	available	n/a	none	no	none	precursor
Netherlands	plain	sufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Poland	plain	sufficient	developed	available	available	TSG/SG/SO	none	no	none	embryonic
Portugal	coastal	insufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Romania	foothills	sufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Slovakia	plain	sufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Slovenia	plain	insufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Spain	foothills	insufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
Sweden	plain	sufficient	developed	available	available	TSG/SG/SO	none	no	none	precursor
United Kingdom	plain	insufficient	developed	available	available	TSG/SG/SO/ CBM	none	yes	seismic activity	embryonic

Annex IV. Unconventional energy supply chain sectors

Table 7. Unconventional energy supply chain sectors

MANUFACTURING OF CAPITAL GOODS		LOGISTICS	MATERIALS		PROFESSIONAL AND OTHER SERVICES	CONSTRUCTION AND WELL SERVICES
Agricultural, construction and mining machinery	Automatic environmental controls for appliance use	Water transportation	Retail building material and garden supply	Basic inorganic chemicals	Water, sewage and other systems	Support activities for oil and gas operations
Motor vehicles and Motor vehicle parts	Instruments for measuring, displaying and controlling industrial process variables	Rail transportation	Steel products	Cement	Warehousing and storage	Upstream facilities and structures
Wholesale machinery and equipment	Fluid metering tools and counting devices	Freight trucking	Lumber and construction materials	Ready-mix concrete	Insurance Carriers	Drilling oil and gas wells
Power Boilers and Heat exchangers.	Analytical laboratory instruments	Pipeline transportation	Metal and mineral materials	Concrete blocks and bricks	Architectural, engineering and related services	Pipelines, rail, marine structures, storage facilities, LNG export facilities and manufacturing structures
Heavy gauge metal tanks	Other measuring and controlling devices		Electrical goods	Iron and steel mills and ferroalloys	Scientific and technical services	
Lawn and garden tractors and garden equipment	Heavy-duty trucks		Hardware, plumbing and heating	Industrial gases	Rental and leasing of construction, mining and forestry machinery	
Cutting tools and machinery tool accessories	Light-duty trucks and utility vehicles		Chemical and allied products	Construction sand and gravel	Non-hazardous waste treatment and disposal	
Speed changer, high-speed drive and gear	Railroad rolling stock				Repair and maintenance of commercial and industrial machinery and equipment	
Power transmission equipment	Conveyors and conveying equipment				Repair and maintenance of automotive and electronic equipment	
Manufacturing of electronic components	Power-driven hand tools					
Pumps and pumping equipment	Air & gas compressors					

Source: NAICS code, IHS ECONOMICS, 2014

Annex V. Country Profiles

AUSTRIA

Statistics: Population: 8.6 million (Aug 2016). Population density (Aug 2016) is 102.1 people per km^2 .Workforce: 4.4 million (2016) 5.5%, agriculture, 26% industry, 68.5% services). No specific data for petroleum employment. Unemployment: 9.4% (Aug 2016). Corruption index, 2015: 16th (in 169). (EC Staff Working document 2016. Country report Austria).

Geological information the UH potential of Austria lies mostly in shale gas and shale oil from the Upper Jurassic Mikulov marls in the Vienna Basin. An additional source of UH are the Oligo-Miocene Schöneck shales, which can be exploited for their oil & gas potential. Tight sandstone gas may, also, be explored within the various sandstone units. The Mikulov marls, due to their high calcite content are favourably compared with the shale oil Eagleford rock in Texas. The University of Leoben has carried out important research of the Tertiary shale gas potential of the Styrian Basin in south-eastern Austria, near the border with Hungary and Slovenia (part of the large Pannonian Basin) (Fig. 1.1).

Drilling activity: In 1985, OMV drilled a very deep (8.5 km) well (Zistersdorf) in the Vienna Basin to establish a viable deep petroleum system. The well discovered gas shows and a good petroleum source rock, but, it also proved an extremely complicated tectonic picture. Following this activity, in the beginning of 2010s, OMV, drilled shale gas wells into the Mikulov marls. Failing to prove commercial shale gas, OMV, in the autumn of 2012, abandoned plans for shale gas exploration in Austria, after having citing increased expenditures that make the project uneconomic. According to OMV, pursuing shale gas in Austria in 2012 made "no economic sense", as the pending introduction of a law in Austria that would require companies to undertake a detailed environmental inspection before each planned project had negative economic consequences. OMV had planned to drill two shale gas exploration wells in Lower Austria at a cost of 130 million euros, as geological studies had shown the potential for large shale gas reserves in this region, which could cover Ausria's domestic requirements for 30 years. However, plans for drilling in the Mistelbach district were met with protests from environmental and community groups, resulting in the company placing a temporary halt to plans in March 2012. Since 2014, IEA has been urging Austria to explore for shale gas.

Oil imported: 1.14 MMBbl / oil products import: 0.85 MMBbl / natural gas imported: 1.21 MMBOE / imported coal in 2007: 3.5 million tons / imported electricity in 2013: 21.15 MMtoe / wind energy capacity (2012): 1.4 MW / domestically-produced energy comes mostly from biomass and hydroelectricity (Figure 1.2).

Austrian industries that may be involved in the energy sector:

ELECTRICITY PROVIDERS; OIL & GAS COMPANIES; CONSTRUCTION; GAS TRANSPORTATION; NATURAL GAS PROVIDERS; CHEMICALS; GOODS MANUFACTURE AND SERVICES; WASTE-WATER SERVICES; DRILLING SERVICES; ROLLING STOCK MANUFACTURERS; METALLURGY; SERVICES

Cross-linked sectors to the hydrocarbon sector: Given an oil price higher than US$50/Bbl and a positive political climate, OMV will restart drilling for shale gas/shale oil. The cost of an EIA (Environmental Impact Assessment) is insignificant, compared to the overall cost of a well. OMV calculated 425 TCF of shale gas in Austria, a very high amount of gas. The Vienna Basin, which is the focus of OMV's exploration, is geologically very complicated and the target formation (Mikulov marls) are very deep. Hence, exploration may occur in the Molasse Basin (for the Schöneck shales). RAG (Shell & German companies) will participate in UH exploration. Any discovered gas may be bought by the Austrian state, domestic electricity producers and domestic chemical companies as feedstock. The gas may also be exported by the Baumgarten gas terminal (Central European Gas Hub). Gas Connect may be involved in transportation. Its pipeline network (Fig. 1.5) covers sufficiently all the sedimentary basin of Austria. The various goods

manufacturers and the metallurgy firms in Austria can provide the required services and products. Waste-water disposal services are, also, available.

Austria's unemployment is high but the corruption is low. The workforce is mostly employed in services, but ¼ is working in industry. Most of the oil, refined products and natural gas are imported, as well as all the coal. Austria does not export any liquid hydrocarbons. Austria produces a significant amount of bio-waste and hydro-electric energy (Figure 1.2).

Figure 1.1: Sedimentary basins of Austria. (Yalçın M.N., Littke R. & Sachsenhofer R., 1997. Thermal History of Sedimentary Basins. P. Springer-Verlag, p. 71-167)

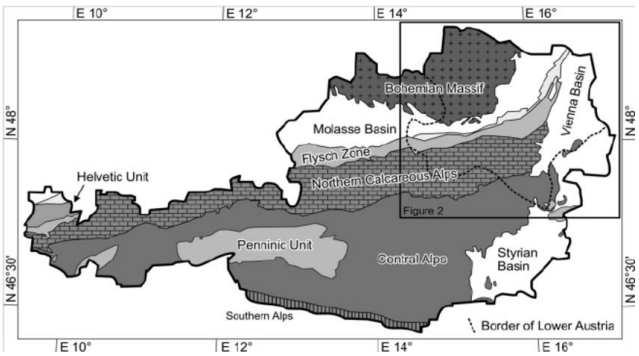
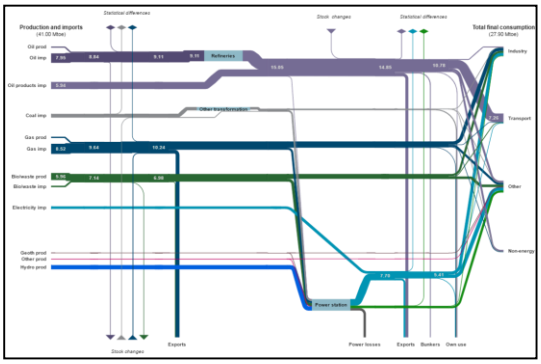


Figure 1.2: Sankey diagram for Austria, IEA 2013 (unit: Mtoe= Millions of tons of oil equivalent).



The upstream Supply Chain for Austria would include seismic acquisition, drilling, production facilities and water treatment for unconventional petroleum projects. OMV has already tried to drill very deep exploration wells for shale gas in the Vienna Basin, but without success. The Baumgarten Central Europe Gas Hub (Fig. 1.4) is an important import-export gas point for Austria and its neighbouring countries.

Figure 1.3: Italy, Switzerland and Austria Pipelines map (CIA)

Figure 1.4. The Schwechat Refinery (OMV, Schwechat)

<u>Barriers and drivers to the development of UH industry</u>:

- Barriers: negative public opinion / complicated geology (Alpine tectonics)

- Drivers: long-term experience in petroleum E & P (OMV and RAG) / active university (Leoben) research on petroleum issues / extensive pipeline network - Gas pipelines exist

mostly in the northern and southern parts of the country (Figs 1.5a-1.5d), linking Austria with gas mostly coming from Russia. Russia's desire is to supply Italy via Austria (Figs 1.3-1.5) / availability of UH-related products and services.

Figure 1.5a: The TAG pipeline System (TAG GmbH)

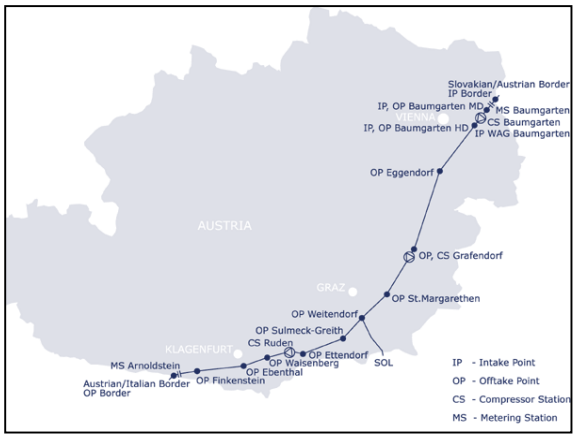


Figure 1.5b: Gas Connect gas pipelines (Gas Connect GmbH, 2011)

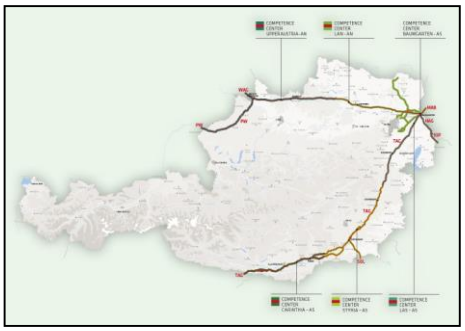


Figure 1.5c: Natural gas grid and storage facilities in Austria (greengasgrids.eu)

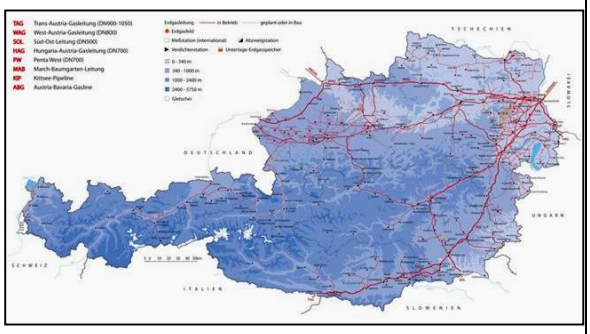
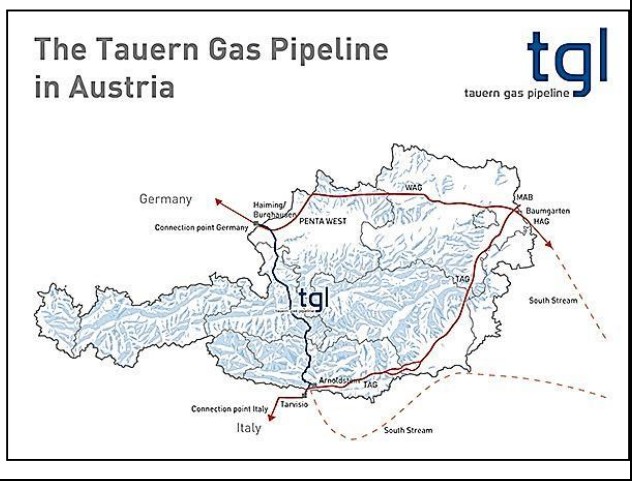


Figure 1.5d: The Tauern Gas Pipeline in Austria (Hydrocarbons Technology



Stage of development of the UH industry according to Phaal *et al*. (2011) approach: According to the Phaal model, the upstream UH supply chain of Austria is in the Embryonic Stage. The transition science to technology took place, when OMV drilled for shale gas in the Vienna Basin

Budget for UH expenses

Table 8. Budget for UH expenses – Austria

Hydraulic fracturing	drilling and completion expenditure	Waste management	transportation	other expenses
0.080 million €	0.032 million €	0.011 million €	0.005 million €	0.002 million €

Source: Ernst & Young study for UK (2014)

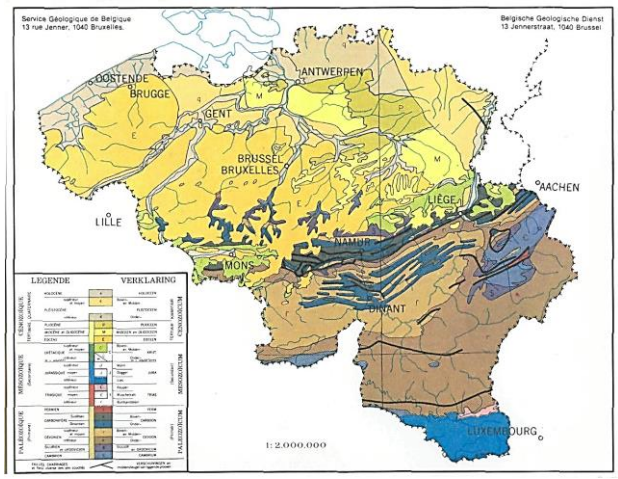
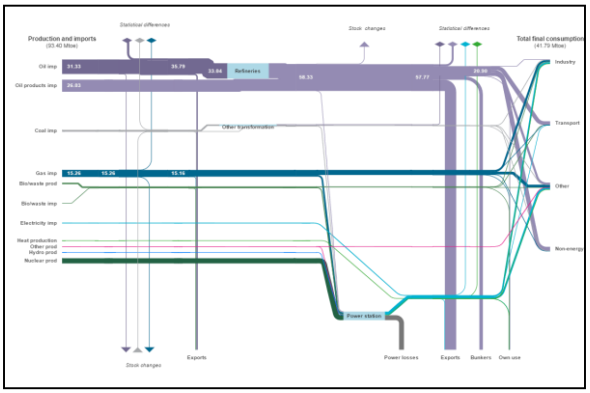
BELGIUM

Statistics *Population:* 11.4 million (Sept 2016). *Workforce*: 5.15 million (2013), of which 2% in agriculture, 25% in industry, 73% in services. The workforce in Belgium is highly skilled**,** trained and productive. About ¾ of it is, however, employed in services. Belgium is ranked as the first most productive country in Europe and the Belgian workforce is ranked as being the 5th most productive in the world (OECD). This is, largely, due to the importance on education, always encouraged by the Belgian government**.** Belgian employees are the happiest employees in the world**.** *Unemployment:* 8.3% (July 2016). *Corruption Index, 2015:* 15th (in 169). (EC Staff Working document 2016. Country report Belgium).

Geological information Belgium possesses two major sedimentary basins (Figs 2.1 and 2.2): (i) the Upper Devonian-Lower Carboniferous Namur-Dinant Basin; and, (ii) the Lower Cretaceous Mons Basin. Possible UH targets could be the Carboniferous shales and the various Carboniferous coal beds for CBM extraction in the first basin. The second basin contains shales (Weald) of good quality.

Fossil fuel activity in Belgium Belgium is the 5th coal producing country in the world. In Belgium, the last coal mine was closed in 1993. The coal mines may become targets for CBM production. Most of the oil and gas of Belgium are imported (Fig. 2.2). Most of the oil is used in transport and most of the gas in other energy needs. There is nuclear electricity production. Almost all refined oil products are exported, although, Belgium imports a large amount of refined petrol, mostly used in transport. In early 2013, it was published that Belgium has potential shale reserves in Lower Namurian shales under Limburg, Liège and Campine, without announcing volumes. *Oil imported in 2013:* 1.14 MMBbl / *oil products imported in 2013*: 0.85 MMBbl / *natural gas imported in 2013*: 1.21 MMBOE / *imported coal in 2007*: 3.5 million tons / *imported electricity in 2013*: 21.15 MMtoe / *wind energy capacity in 2012*: 1.4 MW / domestically produced energy comes mostly from biomass and hydroelectricity.

De Morgen reported that there may be up to 250 BCF of coal bed methane beneath Limburg (Fig. 2.1). If the unconventional gases are extractable and the extraction can be done in a safe and cost-effective manner, shale gas and coal bed methane would provide a more reliable source of energy than Belgium's renewable resources. Additionally, as Belgium is phasing out nuclear power by 2025, domestic production of shale gas would be a way of guaranteeing security of supply for the country's industry. At 8.3%, the unemployment in Belgium is not insignificant.

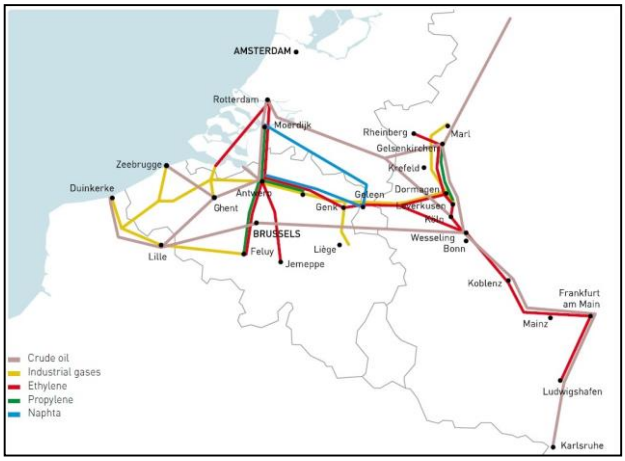
Figure 2.1:Geological Map of Belgium (Service Géologique de Belgique; Bruxelles) Figure 2.2: UH Prospective areas of Belgium-Limburg	Figure 2.2: Sankey diagram for Belgium, IEA 2013
	

Cross-linked sectors to the hydrocarbon sector: Belgium possesses all industry needed for commercial exploration and production of UH. Cross-links exist at all levels and in all market sectors (ELECTRICITY PROVIDERS; GOODS MANUFACTURERS; METALLURGY; PETROLEUM DISTRIBUTION; WASTEWATER TREATMENT AND ENVIRONMENT; DRILLING SERVICES; CONSTRUCTION SERVICES; CHEMICAL COMPANIES; ROLLING STOCK MANUFACTURERS).

Barriers and drivers to the development of UH industry in Belgium.

- Barriers: No experience in petroleum E & P.

- Drivers: active research on petroleum issues and geology / extensive pipeline network that covers all prospective areas (Figs 2.4 and 2.5) / possible shale and coal targets.

Figure 2.4: Pipelines of Belgium (Countries of the World)	Figure 2.5. Pipelines of Belgium (essencia)
	

Stage of development of the UH industry according to the Phaal *et al*. (2011) approach: Belgium is in the "precursor" phase. The S(cience) to T(echnology) step has not, yet, taken place (no shale gas wells).

Budget for UH expenses: not available.

BULGARIA

Statistics *Population*: 7.1 million (2016). *Workforce*: 2.55 million (2009): 7.3% agriculture, 35.2% industry, 57.5% services. *Unemployment* (March 2016): 9.88%. *Corruption index, 2015*: 69th (in 169). (EC Staff Working document 2016. Country report Bulgaria).

Geological information Bulgaria possesses four major sedimentary basins (Fig. 3.1): (i) the Rhodope Basin; (ii) the Srednogorie Zone; (iii) the Balkanides Basin and, (iv) the Moesian Plateau. Main shale gas/oil targets are the Etropole Jurassic shales and the Tertiary Oligo-Miocene shales.

Petroleum activity in Bulgaria According to IEA (2013) gas accounts for 12% of Bulgaria's gross inland energy consumption. The country produces a small amount of natural gas (Fig. 3.2) and depends on Russia to cover most of its natural gas needs. Most of the oil is imported. Refined products are used for transport, or re-exported. Domestic coal and nuclear production is used for electricity generation. Imported gas is used for electricity generation and for industry needs. The country shows a very small production of hydroelectricity.

Figure 3.1: Main structural elements of Bulgaria. (Georgiev G. & Botoucharov N., 2007)

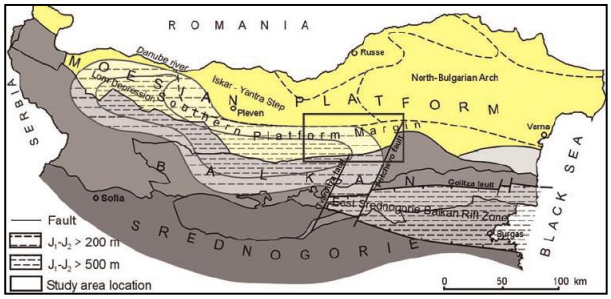
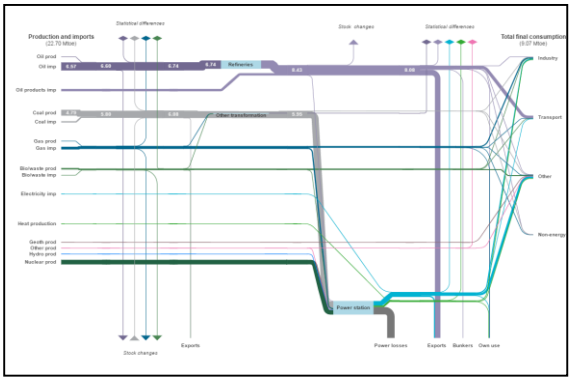


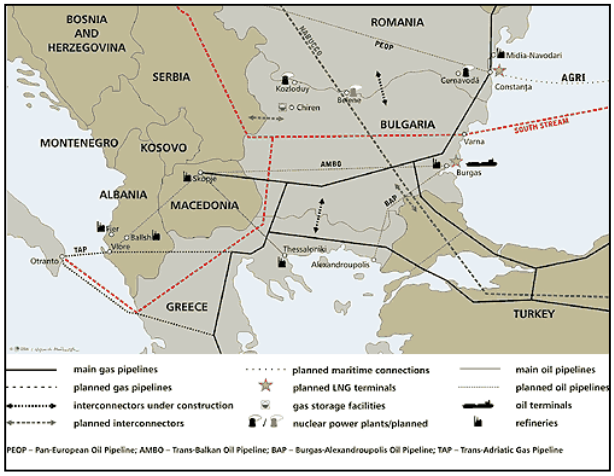
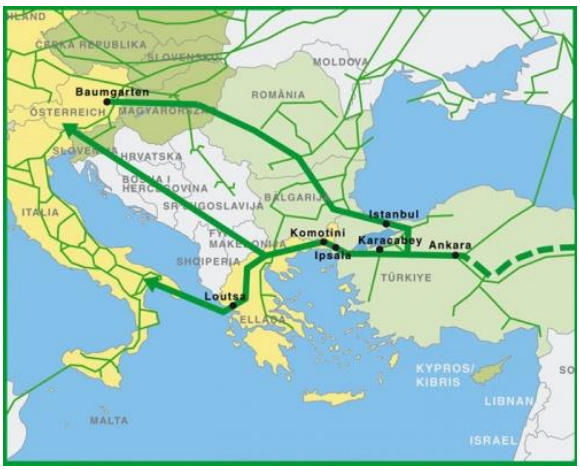
Figure 3.2: Sankey diagram for Bulgaria, IEA 2013.



Cross-linked sectors to the hydrocarbon sector: Bulgaria possesses all industries necessary for UH projects (PETROLEUM DISTRIBUTION; PETROLEUM COMPANIES; ELECTRICITY PRODUCTION & SUPPLY METAL LIGHT BUILDING CONSTRUCTION; CHEMICALS; DRILLING; GOODS SUPPLIERS; METALLURGY ; CONSTRUCTION), apart from Rolling Stock manufacturing, which is on the contrary present in the nearby Romania.

Barriers and drivers to the development of UH industry specific to Bulgaria. - Barriers: negative public opinion / Law against any UH E & P .

- Drivers: active research on petroleum issues and geology by the Sofia University; extensive pipeline network for Russian gas (Figs 3.3-3.5).

Figure 3.3a: Pipelines in Bulgaria (Ośrodek Studiów Wschodnich)	Figure 3.3b: Pipelines in Bulgaria (Sofia News Agency, 2010)
	

<u>Stage of development of the UH industry according to Phaal *et al*. (2011) approach</u>: Bulgaria is in the "precursor" phase of Phaal *et al*. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no shale gas wells). In Bulgaria, the University of Sofia is carrying out activities to support the scientific findings, potential is stimulated and investment may follow. Bulgaria still needs proper evaluation of the UH prospectivity.

Figure 81. Budget for UH expenses – Bulgaria

Hydraulic fracturing	drilling and completion expenditure	Waste management	transportation	other expenses
90.4 million €	36.2 million €	12.4 million €	5.7 million €	2.2 million €

Source: Ernst & Young study for UK (2014)

CROATIA

Statistics *Population*: 4.2 million (2016). *Labour force*: 1.7 million (2012), 2% agriculture, 29% industry, 69% services. *Unemployment* (March 2016): 17.2%. *Corruption Index, 2015*: 50th (in 169) (EC Staff Working document 2016. Country report Croatia).

Geological information Croatia possesses four major sedimentary basins (Fig. 4.1.), all overlain by existing pipelines (Figs 4.2). The main UH target are the Tertiary shales in the Pannonian Basin, shared by several central European countries.

Figure 4.1: Onshore sedimentary troughs of Croatia (Croatian Hydrocarbon Agency).

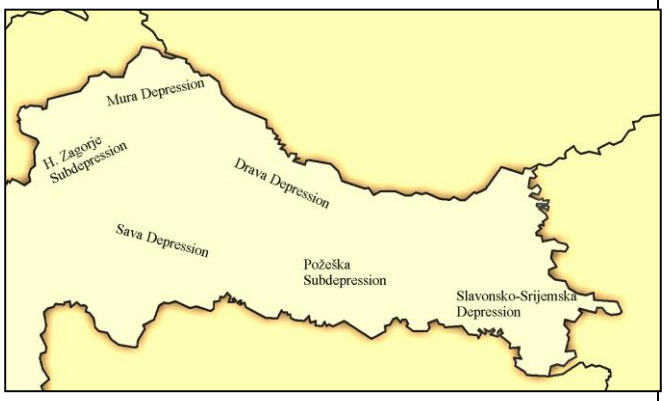
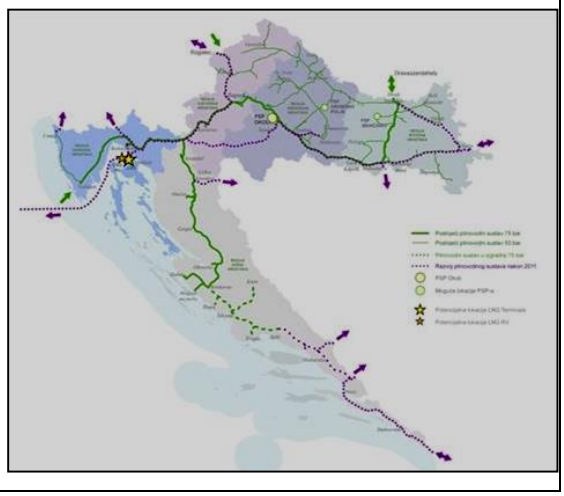


Figure 4.2: Natural gas grid and storage facilities in Croatia (Green Gas Grids)



UH activity in Croatia None, at present. INA is the state oil company, potential candidate to engage in petroleum E & P, of all kinds.

Cross-linked sectors to the hydrocarbon sector: Croatia possesses all industry needed for immediate UH E & P (PETROLEUM DISTRIBUTION; ELECTRICITY PROVIDERS; OIL COMPANIES; DRILLING CONTRACTORS; WASTEWATER AND ENVIRONMENT; GOODS MANUFACTURERS; ROLLING STOCK MANUFACTURERS; CHEMICAL INDUSTRY; METALLURGY; CONSTRUCTION).

Barriers and drivers to the development of UH industry specific to the country.

Drivers: active research on petroleum issues and geology / extensive pipeline network (Fig. 4.4).

Figure 4.3: Sankey diagram for Croatia, IEA 2013.

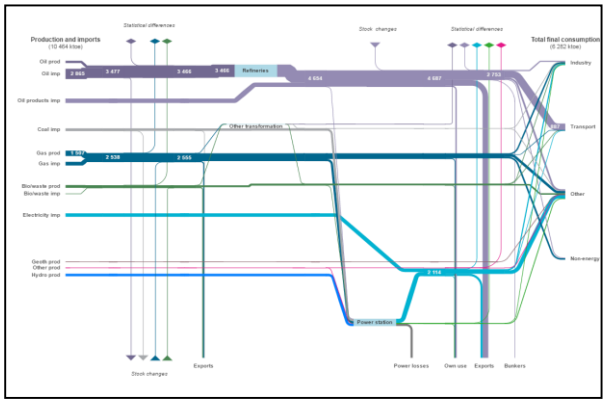
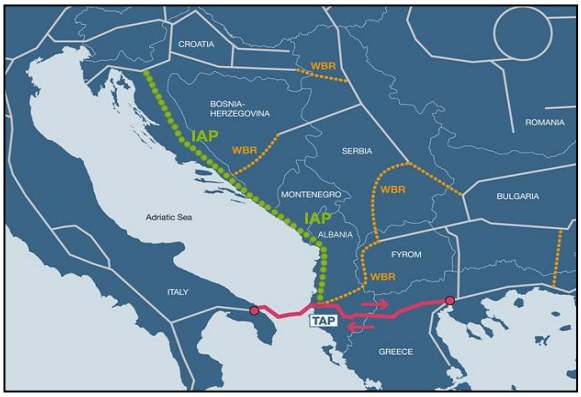


Figure 4.4: Trans-Adriatic & Ionian-Adriatic Pipelines (Legislative & Policy Journal, 2013).



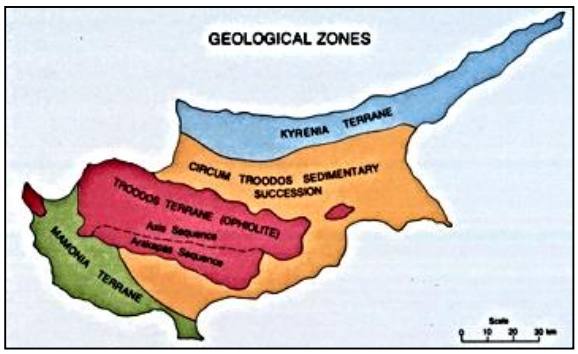
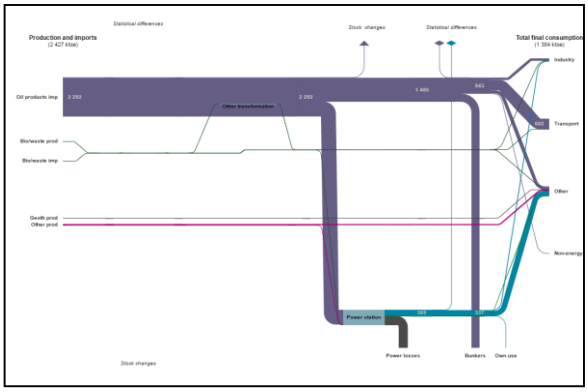
Stage of development of the UH industry according to Phaal *et al*. (2011) approach: Croatia is in the "precursor" phase. The S(cience) to T(echnology) step has not, yet, taken place (no shale gas wells). In Croatia, INA wishes to support the scientific findings, stimulate potential and investment, by exploring in the Pannonian Basin

Budget for UH expenses: not available.

CYPRUS

Statistics: *Population*: 1.2 million (Aug 2016). *Labour force*: 400 000 (2006): 8.5% agriculture, 20.5% industry, 71% services. *Unemployment* (March 2016): 12.1%. *Corruption Index, 2015*: 32nd (in 169) (EC Staff Working document 2016. Country report Cyprus).

Geological information. The main sedimentary basins of Cyprus are all offshore (Fig. 5.1). In 2014, Nobel Petroleum discovered the large "Aphrodite" offshore gas field in the EEZ of Cyprus. Cyprus possesses large asbestos reserves at the Troodos Mountain (not currently produced). No proven UH target rock.

Figure 5.1: Geological zones of Cyprus (Cyprus Geological Survey)	Figure 5.2: Sankey diagram for Cyprus, IEA 2013
	

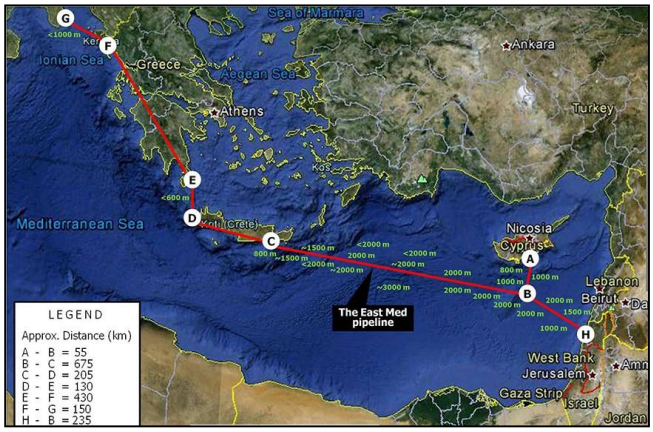
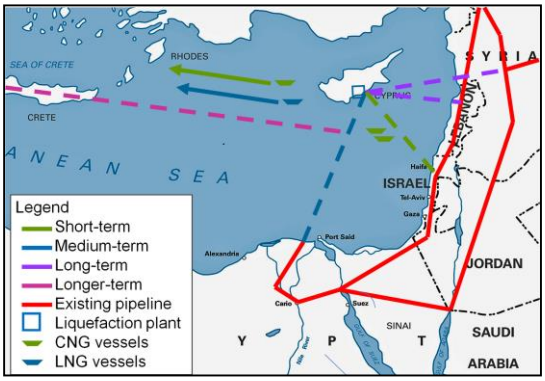
Petroleum activity in Cyprus None, at present. Cyprus is a small country with high unemployment is high. At present all the available resources are employed in the development of the conventional "Aphrodite" field.

Cross-linked sectors to the hydrocarbon sector: all industry sectors are present, apart from rolling stock manufacturing (PETROLEUM PRODUCTION AND MARKETING; ELECTRICITY AND NATURAL GAS SUPPLIERS; GOODS SUPPLIERS; CONSTRUCTION INDUSTRY; WASTEWATER TREATMENT AND ENVIRONMENT; No rolling stock manufacturing. There is no railway in Cyprus; CHEMICAL COMPANIES; METALLURGY; INDUSTRIAL BUILDIND CONSTRUCTION).

Barriers and drivers to the development of UH industry specific to Cyprus.

- Barriers: No experience in petroleum E & P/ no onshore pipeline network.

- Drivers: research on petroleum issues and geology / possible development of the pipeline infrastructure with the Mediterranean countries (Figure 5.3) / possible links with Israeli gas (Figure 5.4).

Figure 5.3: Proposed pipelines in Cyprus (New English Review, 2015)	Figure 5.4: Pipelines in Eastern Mediterranean. (The Cypriot Puzzle, 2014)
	

<u>Stage of development of the UH industry</u> according to Phaal *et al*. (2011) approach: Cyprus is in the "precursor" phase of Phaal *et al*. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no shale gas wells). In Cyprus, there are no activities to support the scientific findings.

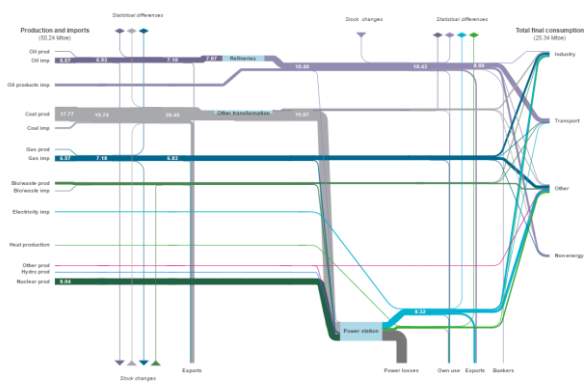
<u>Budget for UH expenses</u>: no data

CZECH REPUBLIC

Statistics: *Population*: 10.6 million (2016). *Labour force*: 5.3 million (2012): 2.6% agriculture, 37.4% industry, 60% services. *Unemployment* (March 2016): 5.7%. *Corruption Index, 2015*: 37th (in 169). (EC Staff Working document 2016. Country report Czech Republic).

Geological information. The Czech Republic possesses several sedimentary basins (Fig. 6.1), all prospective for UH E & P. Main targets will be the Tertiary shales, the Silurian shales near Prague and several tight sandstone gas units.

Petroleum activity in Czech Republic None, at present. In the Czech Republic most of the oil, gas and refined products are imported and used in transport (Fig. 6.2). All produced coal, together with nuclear power, is used in electricity production. The electricity is used for domestic and industrial use and there are severe electricity losses. The country depends on Russian.

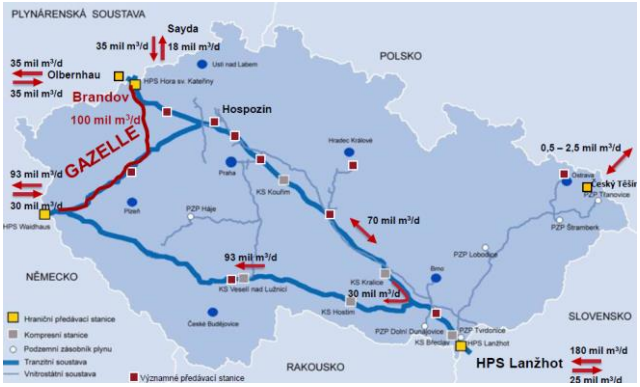
Figure 6.1: The main sedimentary basins in the Czech Republic (McCann, 2008)	Figure 6.2: Sankey diagram for Czech Republic, IEA 2013
	

Cross-linked sectors to the hydrocarbon sector: all industry sectors are present for immediate start of UH projects (ELECTRICITY PROVIDERS; PETROLEUM REFINING & DISTRIBUTION; DRILLING OPERATIONS; GOODS MANUFACTURERS AND PROVIDERS; PETROLEUM DRILLING; METALLURGY; CHEMICALS; ROLLING STOCK MANUFACTURING (Very little, at present); CONSTRUCTION; WASTEWATER AND ENVIRONMENT).

Barriers and drivers to the development of UH industry specific to Czech Republic.

- Barriers: No experience in petroleum E & P

- Drivers: research on petroleum issues and geology / extensive pipeline network (Figures 6.3 and 6.4).

Figure 6.3: Germany, Netherlands and Czech Republic Pipelines map	Figure 6.4 Pipelines in the Czech Republic (NET4GAS, 2013)
	

<u>Stage of development of the UH industry</u> according to Phaal et al. (2011) approach: Czech Republic is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). In Czech Republic, there are no activities to support the scientific findings.

<u>Budget for UH expenses</u>: no data.

DENMARK

Statistics: *Population*: 5.7 million (Sept 2016). *Labour force*: 2.8 million (2011): 4.4% agriculture, 22.6% industry, 73% services. *Unemployment* (March 2016): 4.2%. *Corruption Index, 2015*: 1st (in 169). (EC Staff Working document 2016. Country report Denmark).

Geological information Denmark shares in the south the Lower Saxony Basin with Germany that has UH prospectivity in the Lower Jurassic and Lower Carboniferous shales. In addition, in the north, it shares with Sweden (Fig. 7.1) the Danish Basin that contains the high-quality Alum Shale, explored in 2013 by Shell. While the main UH target in Denmark will be shale gas and shale oil from Jurassic and Carboniferous shales, tight sandstone gas will also be explored.

Figure 7.1: Geological basins of Denmark (GEUS)

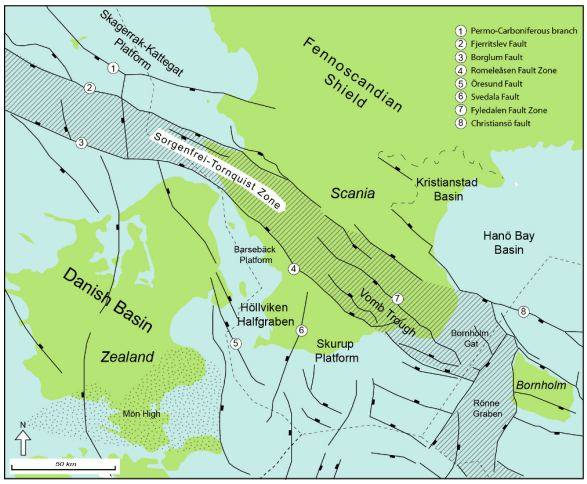
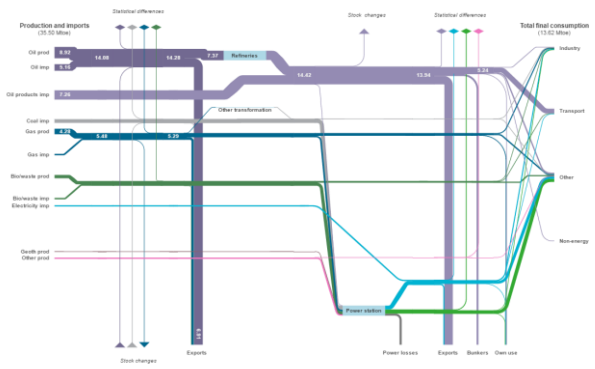


Figure 7.2: Sankey diagram for Denmark, IEA 2013



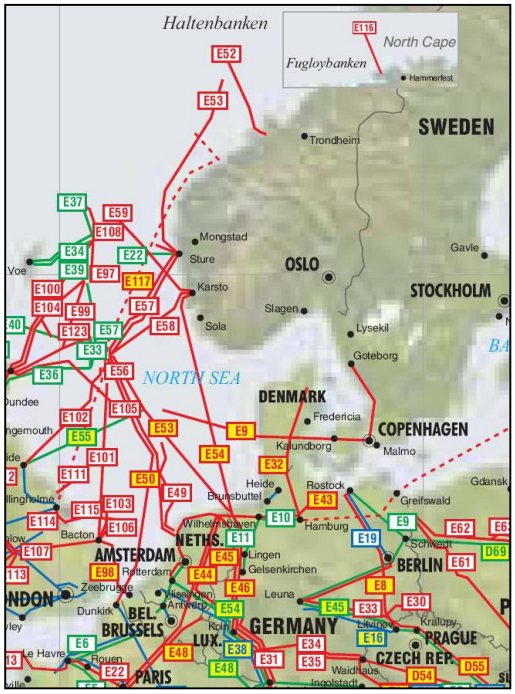
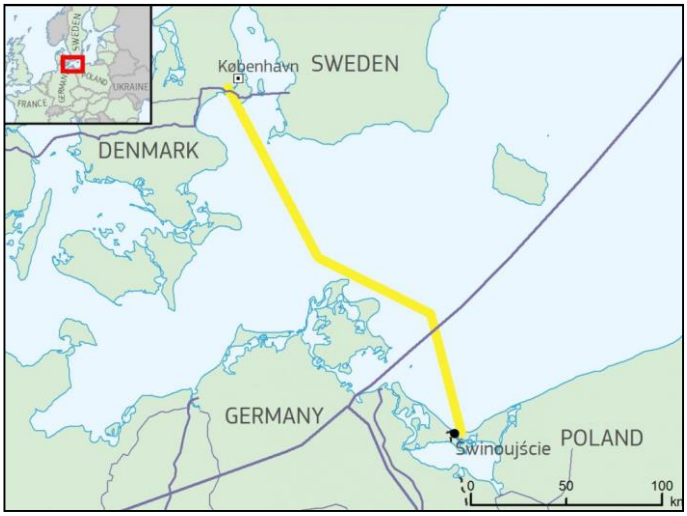
Petroleum activity in Denmark For many years, Denmark has explored exclusively the offshore area of the country, especially conventional oil from the Upper Cretaceous chalks. The Danish oil companies (Dong and Maersk) are experts in drilling and producing from hard and "tight" rocks like chalk. At present, there has been no UH drilling in Denmark. Denmark produces a lot of domestic oil, which is refined and exported, or used in transport (Fig. 7.2). All domestic and imported gas, coal and bio-waste fuels are used in electricity production. At the same time, Denmark is the largest supplier of offshore wind farms and produces, also, a lot of bio-waste electricity.

Cross-linked sectors to the hydrocarbon sector: all industry sectors are present for immediate start of UH projects (OIL COMPANIES; GAS AND ELECTRICITY TRANSMISSION; WASTEWATER TREATMENT; GOODS SUPPLIERS AND CONGLOMERATES; PETROLEUM DRILLING; METALLURGY; CHEMICAL COMPANIES; CONSTRUCTION; ROLLING STOCK MANUFACTURERS).

Barriers and drivers to the development of UH industry specific to Denmark.

- Barriers: negative public opinion / already producing conventional oil.

- Drivers: research on petroleum issues and geology / extensive pipeline network (Figs 7.3 and 7.4) / no perceived corruption.

Figure 7.3. Norway, Sweden and Denmark Pipelines map (Countries of the World).	Figure 7.4: Poland - Denmark interconnector "Baltic Pipe" INEA-EU
	

<u>Stage of development of the UH industry according to Phaal *et al*. (2011) approach</u>: Denmark is in the "precursor" phase of Phaal *et al*. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). In Denmark, there are no activities to support the scientific findings

<u>Budget for UH expenses</u>:

Figure 82. Budget for UH expenses - Denmark

Hydraulic fracturing	drilling and completion expenditure	Waste management	transportation	other expenses
162.4 million €	65.1 million €	22.3 million €	10.3 million €	4 million €

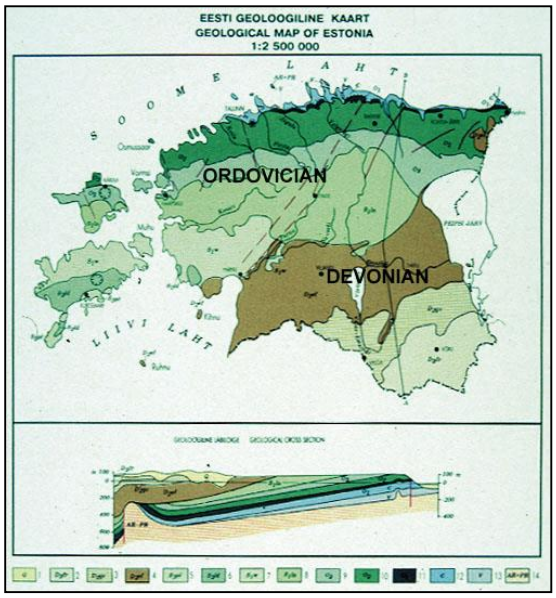
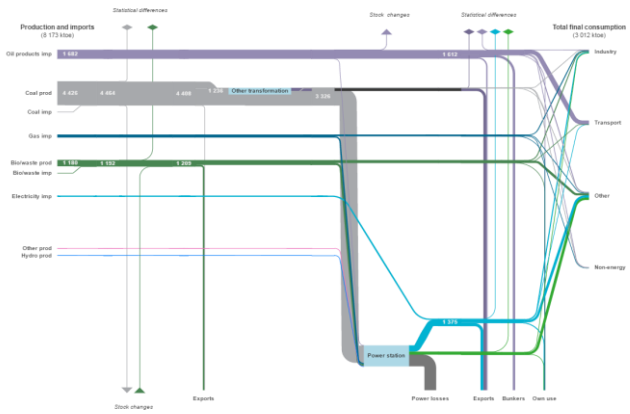
Source: Ernst & Young study for UK (2014)

ESTONIA

Statistics: *Population*: 1.3 million (Jan 2016). *Labour force*: 700 000 (2010): 4.2% agriculture, 20.2% industry, 75.6% services. *Unemployment* (March 2016): 6.5%. *Corruption Index, 2015*: 23rd (in 169). (EC Staff Working document 2016. Country report Estonia).

Geological information Estonia contains only one sedimentary basin, of Lower Paleozoic age (Fig. 8.1). The outcropping Ordovician shale ("kukersite") has been exploited heavily as an oil shale and provides 85% of Estonia's electricity. Shale oil and gas is expected to be targeted in the Ordovician rocks.

Petroleum activity in Estonia none, at present. Only the oil shale production is active. Estonia's Eesti is the only company that may have a pan-European UH presence. Eesti has a lot of experience in E & P of oil shale and bids for oil shales projects all around the world. Oil is imported mainly from Russia and used in transport (Fig. 8.2). Domestic coal is used to produce electricity, or is used in homes. There is severe electricity loss. The unemployment is not very high and any UH E & P activity will compete with oil shales. Estonia is expected to support any petroleum activities that may provide domestic energy.

Figure 8.1 : Geological map of Estonia (Estonia Geological Survey)	Figure 8.2 : Sankey diagram for Estonia, IEA 2013
	

Cross-linked sectors to the hydrocarbon sector: all industry sectors are present for potential UH projects development, apart from rolling stock, which has to be imported (ENERGY PRODUCERS AND SUPPLIERS; CHEMICAL INDUSTRY; METALLURGY AND LIGHT METAL CONSTRUCTION; GOODS AND DRILLING SUPPLIERS; CONSTRUCTION; WASTEWATER TREATMENT AND ENVIRONMENT; There is no rolling stock industry in Estonia).

Barriers and drivers to the development of UH industry specific to Estonia.

- Barriers: negative public opinion / already producing oil from oil;

- Drivers: research on petroleum shales and geology / existing pipeline network (Figures 8.3- 8.5) / industrial tradition.

Figure 8.3: Russia - FSU Pipelines map (Countries of the world)	Figure 8.4 : Gas pipelines (FreeNews, 2015)
	

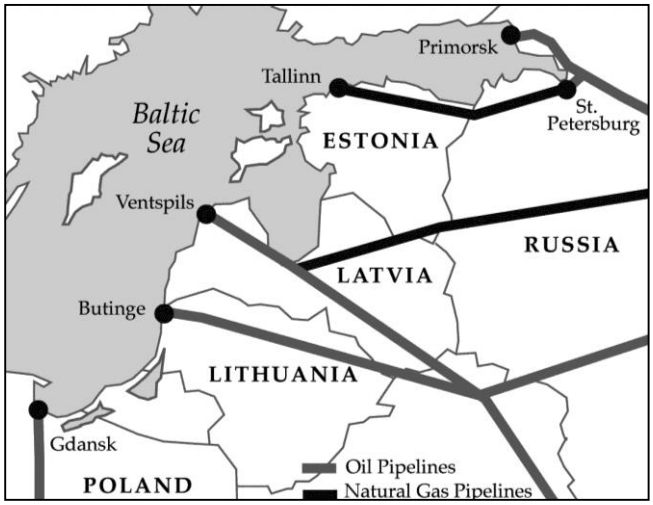


Figure 8.5: Major crude oil pipelines and ports in the Baltic Sea Region (Lithuanian quarterly journal of Arts and Sciences, v. 53, 2007)

Stage of development of the UH industry according to Phaal *et al*. (2011) approach: Estonia is in the "precursor" phase of Phaal *et al*. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). In Estonia, there are no activities to support the scientific findings, apart from oil shale studies.

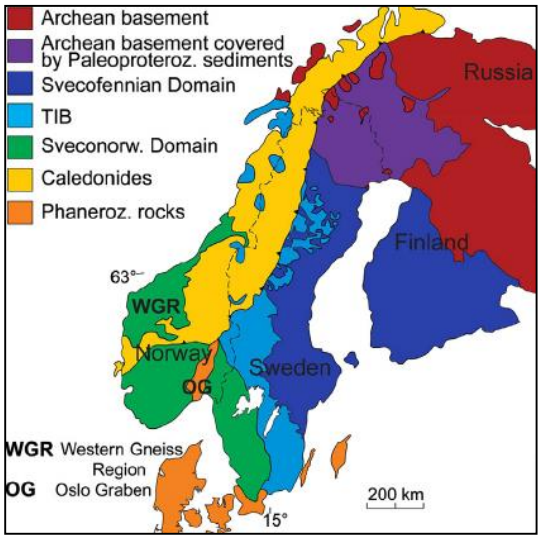
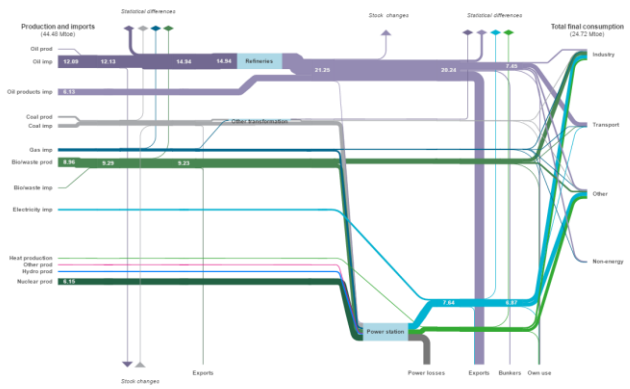
Budget for UH expenses: not available

FINLAND

Statistics *Population*: 5.5 million (Sept 2016). *Labour force*: 2.7 million (2011): 4.4% agriculture, 22.6% industry, 73% services. *Unemployment (March 2016):* 10.1%. *Corruption Index, 2015*: 2nd (in 169). (EC Staff Working document 2016. Country report Finland).

Geological information Finland does not possess sedimentary basins (Fig. 9.1), as most of its territory is occupied by Proterozoic metamorphic rocks. The only small basins will be offshore the southern part of the country. No target rock for UH exploration has ever been proposed.

Petroleum activity in Finland: none, at present. Finland does not possess the right geology to carry out UH exploration. A proper geological study may reveal "hidden" targets. Almost all oil is imported and used in transport (Fig. 9.2), or as fodder to refineries. Oil products are exported. Bio-waste is producing a lot of energy and, along with coal and nuclear fuels it is used directly in industry and in electricity production.The biogas market covers more than half of the current use of natural gas.

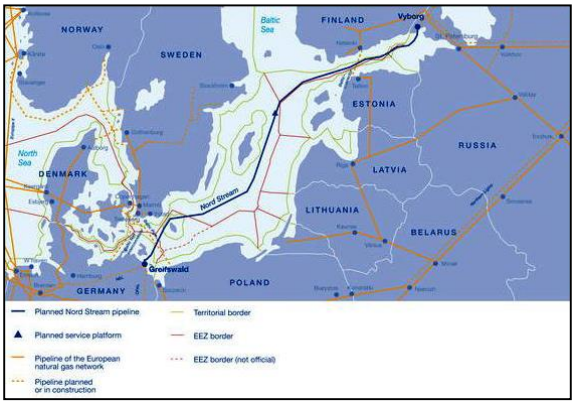
Figure 9.1 Simplified tectonic map of the Baltic Shield. (Pedersen H. A., Debayle E., & Maupin V. (2013): Earth & Planet. Sci. Letters)	Figure 9.2: Sankey diagram for Finland, IEA 2013.
	

Cross-linked sectors to the hydrocarbon sector: Finland possesses all industries necessary for UH projects (ENERGY PRODUCTION, DISTRIBUTION AND TRADE; ELECTRICITY SUPPLIERS; GOODS MANUFACTURERS AND SUPPLIERS; DRILLING PROVIDERS; CHEMICAL INDUSTRY; METALLURGY; ROLLING STOCK MANUFACTURERS; CONSTRUCTION; WASTEWATER TREATMENT AND ENVIRONMENT)

Barriers and drivers to the development of UH industry specific to Finland.

- Barriers: negative public opinion / Lack of geological targets.

- Drivers: active research on petroleum issues and geology / extensive pipeline network in the south (Figs 9.3 and 9.4).

Figure 9.3: Finland's Natural Gas Pipelines (Fossil Energy International, 2003)	Figure 9.4: The Nord Stream pipeline (Business Insider, 2010)
	

<u>Stage of development of the UH industry</u> according to Phaal *et al*. (2011) approach: Finland is in the "precursor" phase of Phaal *et al*. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no shale gas wells). Finland still needs proper evaluation of the UH prospectivity.

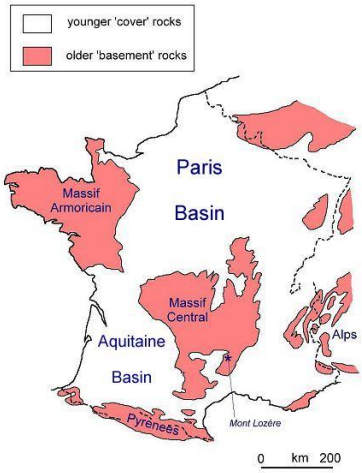
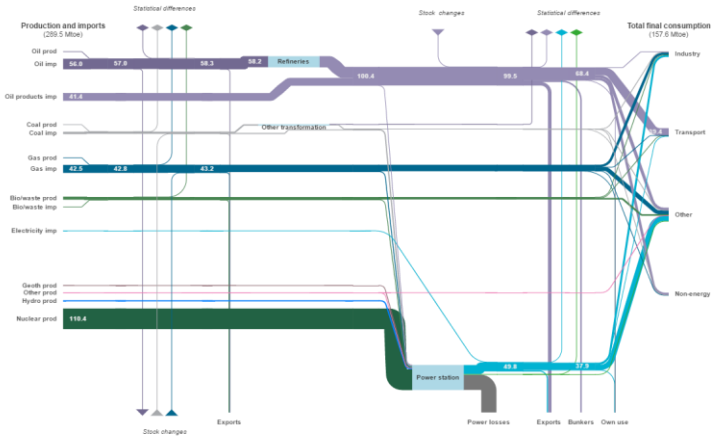
<u>I.</u> <u>budget for UH expenses</u>: not available.

FRANCE

Statistics *Population*: 65 million (Sept 2016). *Labour force*: 30 million (2012): 3% agriculture, 20.6% industry, 76.4% services. *Unemployment (March 2016):* 10.2%. *Corruption Index,* 2015: 23rd (in 169). Main EU document: Country Report - France (2016).

Geological information France possesses several sedimentary basins (Fig. 10.1), all of which are prospective for UH E & P. Targets include the Lower Jurassic Schistes carton (shale gas/shale oil), Paleozoic shales (shale gas), Carboniferous coals (CBM) and various sandstone rock (tight sandstone gas).

Drilling activity: There has been intense drilling activity in the 1960s onshore in France for conventional petroleum, when in the Aquitaine Basin (Fig. 10.1) has been particularly targeted. In the mid-2000s there was an intense interest in shale gas/shale oil and the Bakken play. Several companies were awarded exploration blocks. All the licenses were, however, abrogated in 2011, when the French government banned by law any hydraulic fracturing. At present, most of the electricity comes from nuclear power (Fig. 10.2) and is used in the household sector and in the industry. Most of the oil, gas and refined products are imported and used in transport. Little coal is imported and used for electricity production. Biogas is domestically produced and used at homes.

Figure 10.1: Tectonic basins of France (Virtual Geology)	Figure 10.2: Sankey diagram for France, IEA 2013.
	

Cross-linked sectors to the hydrocarbon sector: France possesses all industries necessary for UH projects. In the Companies Listing website there are 62.000 French companies. The largest ones, involved in Energy, are: Areva, Engie *(formerly Gdf-Suez)*, Total S.A., Technip S.A., Électricité de France S.A. (EDF), Alstom GRTgaz

Barriers and drivers to the development of UH industry specific to France.

Barriers: high production of electricity from nuclear fuels that may compete with the higher costs of production of UH resources.

Drivers: active research on petroleum issues and geology / extensive pipeline network covering all basins (Figigures 10.3-10.4 – 10.5).

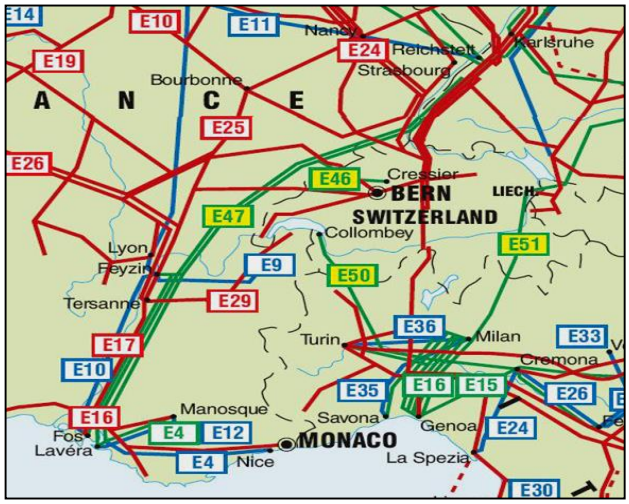
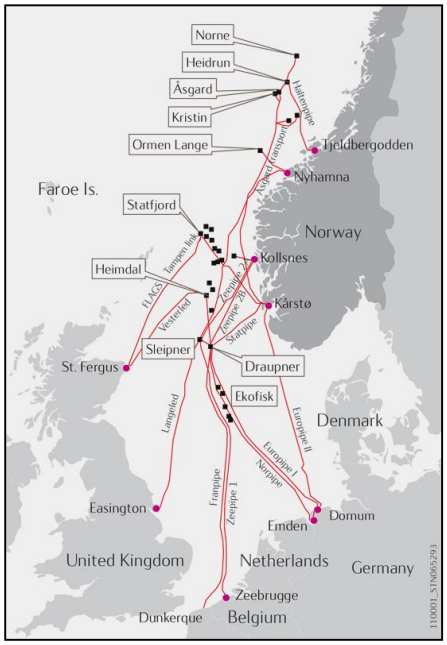
Figure 10.3. Pipelines of France (Countries of the World)	Figure 10.4. The South European Pipeline E47 (also known as *Lavéra–Karlsruhe pipeline* (Countries of the World)
	

Figure 10.5. The Franpipe (Statoil, 2011)



<u>Stage of development of the UH industry</u> <u>according to Phaal *et al*. (2011) approach</u>: France is in the "precursor" phase of Phaal *et al*. (2011). The S(cience) to T(echnology) step has not, taken place (no shale gas wells).

<u>Budget for UH expenses</u>

Figure 83. Budget for UH expenses – Franc

Hydraulic fracturing	drilling and completion expenditure	Waste management	transportation	other expenses
701 million €	281 million €	96.3 million €	44.5 million €	17 million €

Source: Ernst & Young study for UK (2014)

e

GERMANY

J. Statistics *Population*: 80.7 million (2016). *Labour force*: 44.2 million (2011): 1.6% agriculture, 24.6% industry, 73.7% services. *Unemployment (March 2016):* 4.2%. *Corruption Index, 2015:* 10th (in 169). (EC Staff Working document 2016. Country report Germany).

Geological information: There are several large deep sedimentary basins in Germany (Fig. 11.1), in the southern, central and northern parts of the country. Targets for UH exploration include the Lower Carboniferous, Permian and Lower Jurassic shales (for shale gas/shale oil) and the Upper Carboniferous coals (for CBM). The German government gives away areas for UH exploration, but under very strict regulations. The Federal Mining Law governs all UH E & P activities.

Petroleum activity: No UH onshore drilling at present. ExxonMobil is waiting for the German government to allow UH activities in depths less than 3 km, in order to expand its activities. Gaz de France will, also, be active in Germany. There is drilling activity for conventional petroleum in the Lower Saxony Basin. Most of the oil, gas and refined products are imported and used in transport (Fig. 11.2). All the coal, produced and imported is used in electricity production. The electricity comes from nuclear fuels (imported mostly from France) and is used at homes and in the industry. Half of coal was imported and used for electricity production. Small bio-gas and small nuclear power is used at homes and in the industry. There were severe electricity losses.

Figure 11.1: Deep sedimentary basins (purple) in Germany (Global CCS Institute).

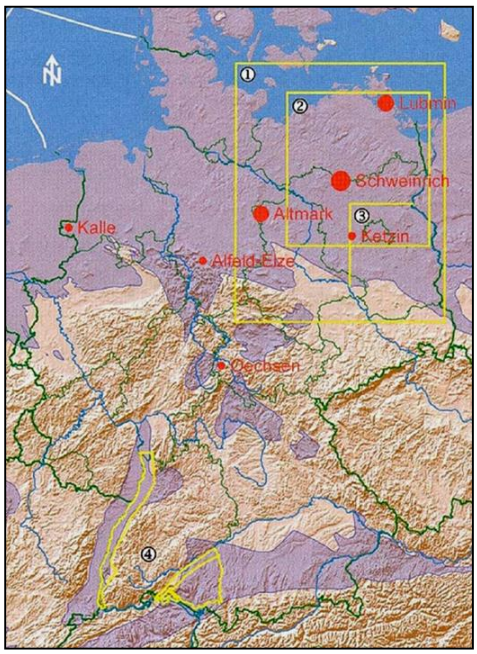
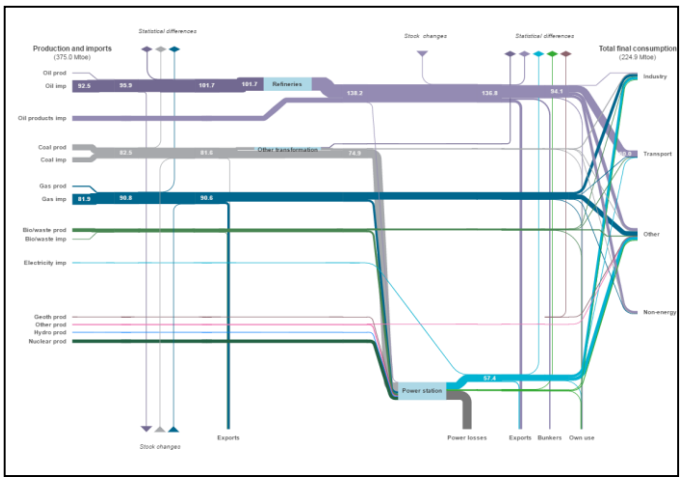


Figure 11.2: Sankey diagram for Germany, IEA 2014



Cross-linked sectors to the hydrocarbon sector: Germany possesses all industries necessary for UH projects (OIL AND GAS COMPANIES; GAS & ELECTRICITY SUPPLIERS; GOODS AND SERVICES SUPPLIERS; METALLURGY; DRILLING SERVICES SUPPLIERS; CONSTRUCTION; ROLLING STOCK MANUFACTURERS; WASTEWATER TREATMENT AND ENVIRONMENT).

Barriers and drivers to the development of UH industry, specific to Germany.

Barriers: negative public opinion / most workforce employed in services.

Drivers: available information on onshore geology / low perceived corruption / dense pipeline network (Figs 11.3 and Figure 11.4 that represents the exclusive pipeline (Nordstream) to import gas from Russia) / several geological basins and target rocks.

Figure 11.3: Pipelines of Germany (Countries of the World)	Figure 11.4: Nord Stream pipeline (Deutsche Welle, 2011)
	

<u>Stage of development of the UH industry according to Phaal et al. (2011) approach</u>: Germany is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells).

<u>Budget for UH expenses</u>

Figure 84. Budget for UH expenses – Germany

Hydraulic fracturing	drilling and completion expenditure	Waste management	transportation	other expenses
90.4 million €	36.2 million €	12.4 million €	5.7 million €	2.2 million €

Source: Ernst & Young study for UK (2014)

GREECE

Statistics *Population*: 11 million (Sept 2016). *Labour force* (=people aged 15 and older,who meet the definition of the International Labour Organization for the economically active population - *all people who supply labour for the production of goods and services during a specified period*. It includes *both the employed and the unemployed*): 5 million (2013). 12.5% agriculture, 22.4% industry, 65.1% services (2005). *Unemployment (March 2016):* 24.2% (highest in the EU). *Corruption Index, 2015*: 58th (in 169). (EC Staff Working document 2016. Country report Greece).

Geological information Greece possesses several offshore sedimentary basins (Fig. 12.1), but its onshore prospective area is rather limited, due to the existence of high mountains. There is, also, a moratorium in drilling at the Aegean area, between Greece & Turkey. Possible targets for shale gas/shale oil projects are, certainly, the Jurassic Posidonia Shales. There may be other targets, but there is no geological knowledge available.

Petroleum activity in Greece: None, at present. In the late 1990s, two companies drilled unsuccessfully for conventional oil onshore western Greece. The Greek governments have actively pursued conventional petroleum projects during the last 10 years, but few international companies participate.

At present, Greece totally depends for its energy needs on lignite mining and on gas from Russia and central Asia. Most of the oil, gas and refined products were imported (Fig. 12.2) and used in transport. Most coal is domestically produced (lignite) and used in electricity production. All gas is used for electricity production. Some bio-waste production was used directly by homes. There were severe power losses. Several Greek companies have opened offices in the surrounding Balkan countries.

Figure 12.1: Sedimentary Basins of Greece. (Tourloukis V. & Karkanas P, 2012. Quaternary Science Reviews, v. 43, p.1-15)

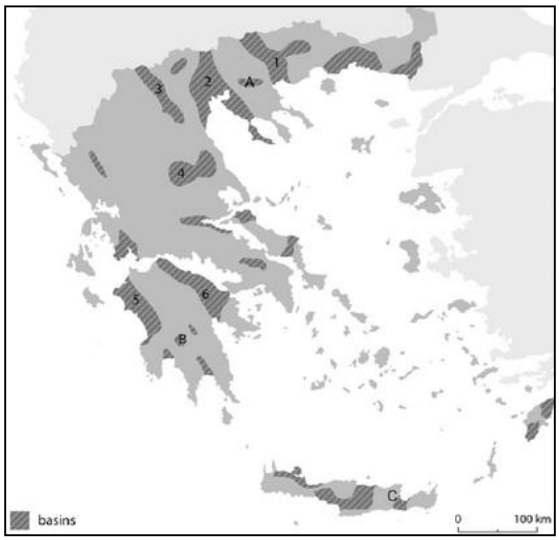
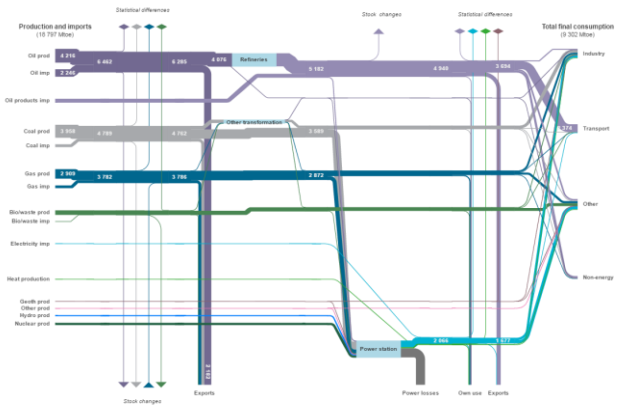


Figure 12.2. Sankey diagram for Greece, IEA 2013.



Cross-linked sectors to the hydrocarbon sector: Greece possesses all industries necessary for UH projects (HOLDINGS AND INVESTMENT CONGLOMERATES; PETROLEUM AND ENERGY TRANSMISSION; OIL & GAS EXPLORATION AND PRODUCTION; GAS AND ELECTRICITY PRODUCTION; CEMENT AND BUILDING MATERIALS; METALLURGY; CHEMICAL COMPANIES; ROLLING STOCK MANUFACTURERS; WASTEWATER TREATMENT AND ENVIRONMENT; DRILLING SERVICES).

Barriers and drivers to the development of UH industry specific to Greece.

- Barriers: severe economic crises / lack of appropriate geological evaluation;

- Drivers: research on petroleum issues and geology / pipeline network for export (Figs 12.3-12.5).

Figure 12.3: Balkan Area - Southeast Europe pipelines (Countries of the World, 2008)	Figure 12.4: The Southern Gas Corridor (BP).
	

<u>Stage of development of the UH industry</u> according to Phaal *et al*. (2011) approach: Greece is in the "precursor" phase of Phaal *et al*. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no shale gas wells). Greece still needs proper evaluation of its UH prospectivity.

<u>Budget for UH expenses</u>: not available

HUNGARY

Statistics *Population*: 9.9 million (Sept 2016). *Labour force*: 4.3 million (2011). 7.1% agriculture, 29.7% industry, 63.2% services (2011). *Unemployment (March 2016)*: 6%. *Corruption Index, 2015*: 50th (in 169). Main EU document: Country Report - Hungary (2016)

Geological information Hungary possesses several onshore sedimentary basins (Fig. 13.1). The only basin that has been extensively researched for UH is the Makó Trough, in which ExxonMobil explored unsuccessfully for tight sandstone gas around 2010. Targets for shale gas/shale oil include the Tertiary shales. Several sandstone formation are expected to contain tight gas and could be targeted.

Petroleum activity in Hungary: None, at present. After ExxonMobil left, Hungary, via its oil company MOL, has shown a lot of interest in promoting UH projects in the country and elsewhere, with little success, at present. ExxonMobil explored for UH tight sandstone gas and reported a very large shale gas resource. It was not materialised, thought. At present, Hungary depends for its gas needs on Russia. Most of the oil, gas and refined products are imported and used in transport and at homes (Figure 13.2). Some coal is domestically produced and used in electricity production. All domestic nuclear power is used in electricity production. Some electricity is imported and used at homes and in the industry. There are severe power losses.

Figure 13.1: Sedimentary basins of Hungary. (Corver M.P., Doust H., Diederik van Wees J. & Cloetingh S. (2009) *In*: "Classification of rifted sedimentary basins of the Pannonian Basin System according to structural genesis, evolutionary history and hydrocarbon maturation zones", Marine & Petroleum Geology).

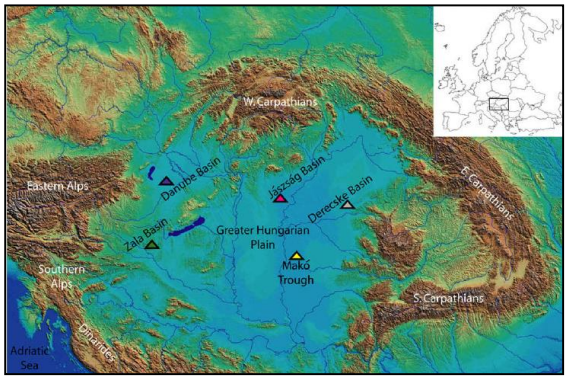
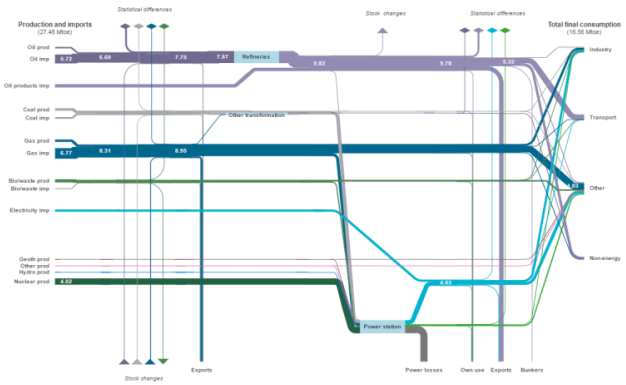


Figure 13.2: Sankey diagram for Hungary, IEA 2013.



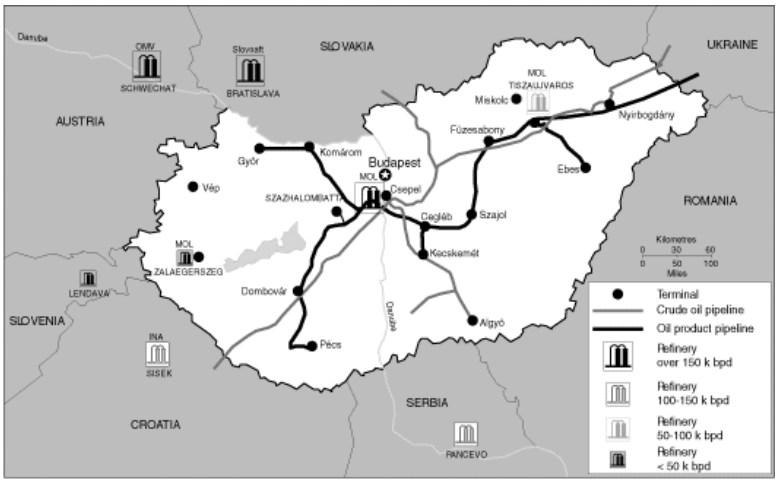
Cross-linked sectors to the hydrocarbon sector: Hungary possesses all industries necessary for UH projects (PETROLEUM AND ELECTRICITY MARKET; METALLURGY **;** GOODS MANUFACTURERS; CHEMICAL INDUSTRY; CONSTRUCTION; WASTEWATER TREATMENT AND ENVIROMENT; DRILLING SUPPLIERS; at present, no rolling stock manufacturing).

Barriers and drivers to the development of UH industry specific to Hungary.

- Barriers: negative public opinion / uncertain political climate / lack of appropriate geological evaluation

- Drivers: research on petroleum issues and geology / pipeline network for export (Figs 13.3).

Figure 13.3: Pipelines of Hungary (Fossil Energy International)



<u>Stage of development of the UH industry</u> <u>according to Phaal *et al*. (2011) approach</u>: Hungary is in the "precursor" phase of Phaal *et al*. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no shale gas wells). Hungary still needs proper evaluation of its UH prospectivity.

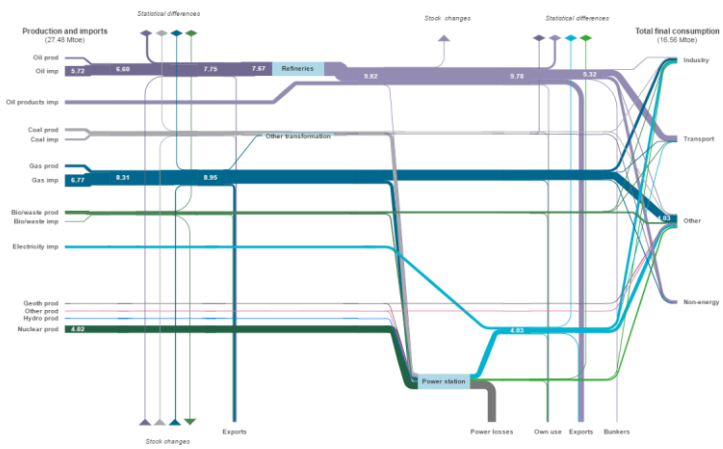
<u>Budget for UH expenses</u>: not available.

IRELAND

Statistics *Population: 4.7 million (Sept 2016). Labour force: 2.2 million (2011). 5% agriculture, 19% industry, 76% services (2011). Unemployment (March 2016): 8.4%. Corruption Index, 2015: 18th (in 169).* (EC Staff Working document 2016. Country report Ireland).

Geological information: There are few onshore sedimentary basins in Ireland (Fig 14.1). The geology is assumed to be the same as in Scotland. The Clare Shale is overmature for conventional petroleum, but may be fine for UH projects. Ireland has focussed on its offshore prospectivity for many years and, hence, its onshore prospectivity has been neglected.

Petroleum activity in Ireland: None at present. After the Corrib-Shell incident in 2013, there is no onshore drilling activity. Almost all oil, gas and refined products were imported and used in transport (Fig 14.2). Some refined products are exported. Some coal was domestically produced and used in electricity production. There were power losses. All domestic nuclear power was used in electricity production. All electricity is used at homes and in the industry. A small bio-waste production is used for power generation. The Irish public is negatively influenced against petroleum E & P in the country, after the Corrib incident in 2013.

Figure 14.1: Namurian Paleogeography (Society for Sedimentary Geology, 2016)	Figure 14.2: Sankey diagram for Ireland, IEA 2013
	

Cross-linked sectors to the hydrocarbon sector: *Ireland possesses all industries necessary for UH projects (*ENERGY E & P, PRODUCTION AND DISTRIBUTION; WASTEWATER SERVICES; PIPELINE SERVICES; CHEMICAL COMPANIES; GOODS MANUFACTURERS AND SERVICES; ROLLING STOCK MANUFACTURERS; CONSTRUCTION; METALLURGY*).*

Barriers and drivers to the development of UH industry specific to Ireland.

- Barriers: negative public opinion / lack of appropriate geological evaluation

- Drivers: available pipeline network for export (Figures 14.3 - 14.5).

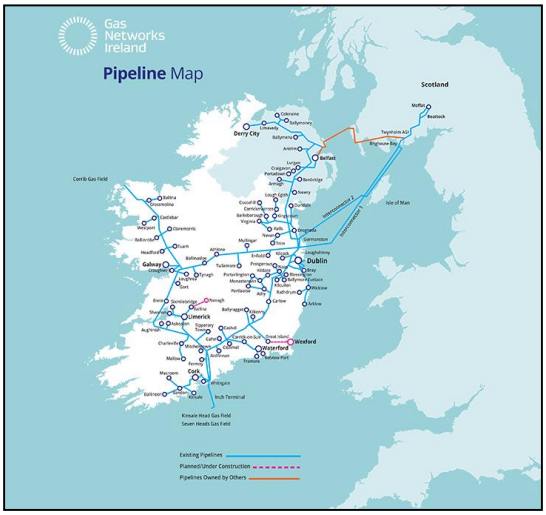
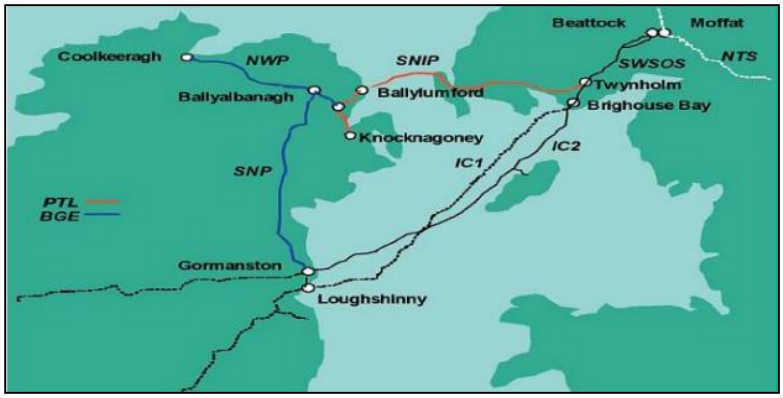
Figure 14.3: Ireland Pipelines (Countries of the world)	Figure 14.4: On- and offshore pipeline map of Ireland (Gas Networks Ireland)
	

Figure 14.5: Pipelines from Northern Ireland to Eire (Market Consultation for Physical Reverse Flows on South-North Pipeline, 2012)



<u>Stage of development of the UH industry</u> according to Phaal et al. (2011) approach: Ireland is in the "precursor" phase of Phaal et *al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no shale gas wells). Ireland still needs proper evaluation of its UH prospectivity.*

<u>Budget for UH expenses</u>: not available.

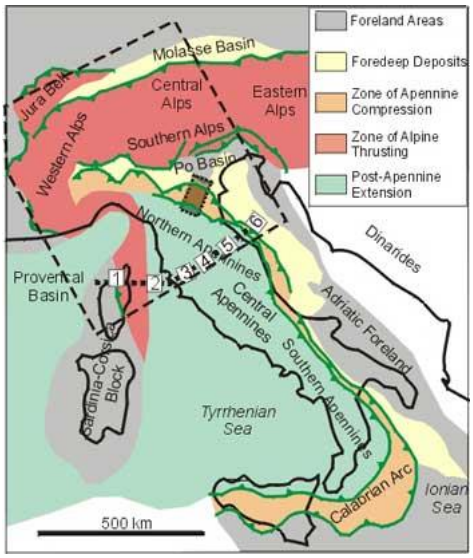
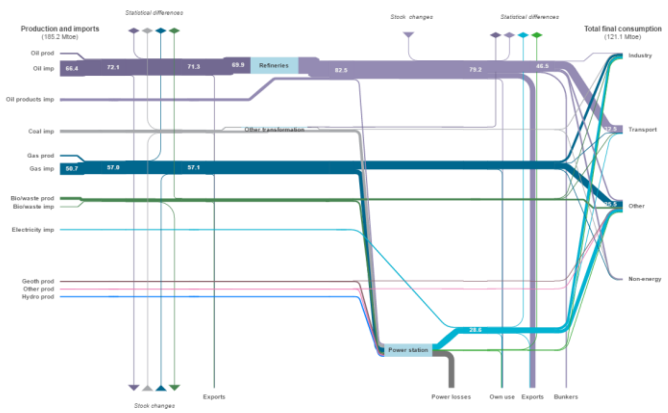
ITALY

Statistics *Population*: 60 million (Sept 2016). *Labour force*: 25.7 million (2011). 3.9% agriculture, 28.3% industry, 67.8% services (2011). *Unemployment (March 2016)*: 11.4%. Corruption Index, 2015: 61st (in 169). (EC Staff Working document 2016. Country report Italy).

Geological information: Italy does not possess large onshore sedimentary basins (Fig. 15.1). The largest ones are located on the Appenines mountain belt and in the southern part of the country. No UH targets have been identified. It is expected that the Jurassic Posidonia shales may constitute a target.

Petroleum activity in Italy: None, at present. ENI is exploring elsewhere.

Italy has high unemployment. Almost all coal, gas and refined products are imported and used in transport and power production (Fig. 15.3). Some refined products are exported. There are power losses. All domestic nuclear power is used in electricity production. All electricity is used at homes and in the industry. Small bio-waste production is used for power generation. ENI is a major company that can act in a pan-European level.

Figure 15.1. Tectonic areas of Italy (Groome W., 2007. The Po Basin (northern Italy): An example of a Piggyback Basin)	Figure 15.3. Sankey diagram for Italy, IEA 2013.
	

Cross-linked sectors to the hydrocarbon sector: Italy possesses all industries necessary for UH projects (ELECTRICITY PROVIDERS; OIL AND GAS E & P COMPANIES; CHEMICAL COMPANIES; ROLLING STOCK MANUFACTURERS; METALLURGY; CONSTRUCTION; WASTEWATER TREATMENT AND ENVIROMENT)

Barriers and drivers to the development of UH industry specific to Italy.

- Barriers: negative public opinion / lack of large sedimentary basins / high perceived corruption;

- Drivers: available pipeline network for export (Figs 15.4-15.7) / ENI experience in E & P projects;.

Figure 15.4: Italy Pipelines (Countries of the world)

Figure 15.5: Italy Pipeline Grid (BRS Resources, 2013)

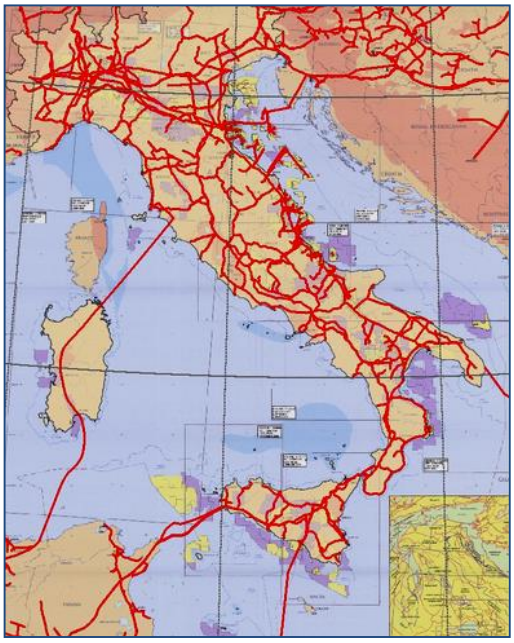
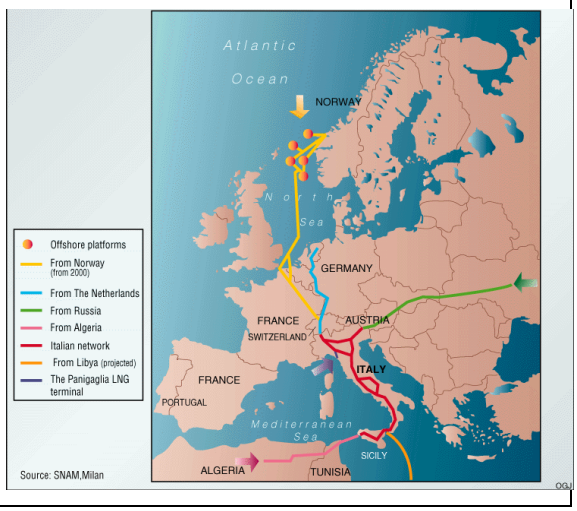


Figure 15.6: Trans-Mediterranean Gas Pipeline (Pipeline & Gas Journal, 2015)

Figure 15.7: Gas supply routes to Italy (Oil & Gas Journal, 1998)



<u>Stage of development of the UH industry</u> according to Phaal et al. (2011) approach: Italy is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no shale gas wells). Italy still needs proper evaluation of its UH prospectivity.

<u>Budget for UH expenses</u>: not available

LATVIA

Statistics **Population**: *2 million (Sept 2016).* Labour force*: 1 million (2013). 8.8% agriculture, 24% industry, 67.2% services (2010).* Unemployment *(March 2016): 9.8%.* Corruption Index, 2015*: 40th (in 169). Main EU document: Country Report - Latvia (2016).*

Geological information: Latvia possesses only one onshore sedimentary basin, the Baltic Syneclise (Fig. 16.1). The basin contains Paleozoic sediments and has some production (Fig. 16.2) from Lower Paleozoic sandstones.

Figure 16.1: Geological structure of Latvia. (Latvian Environment, Geology and Meteorology Centre, 2010)

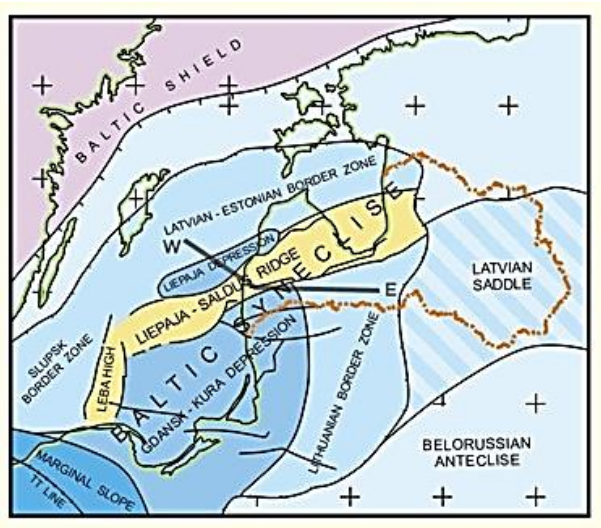
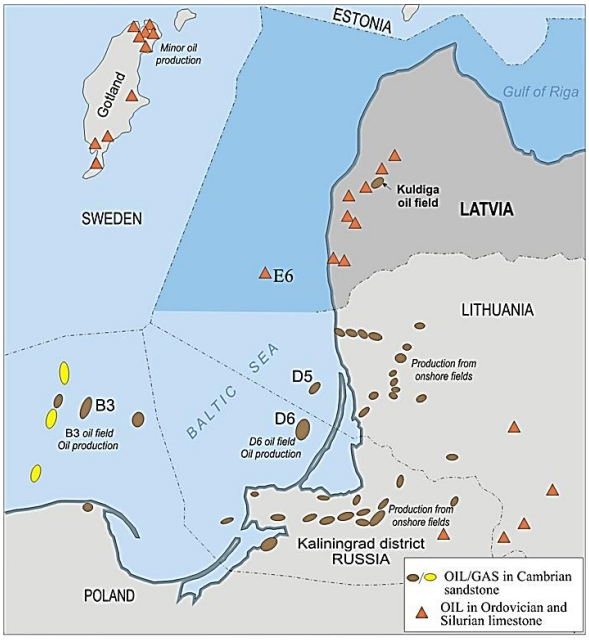


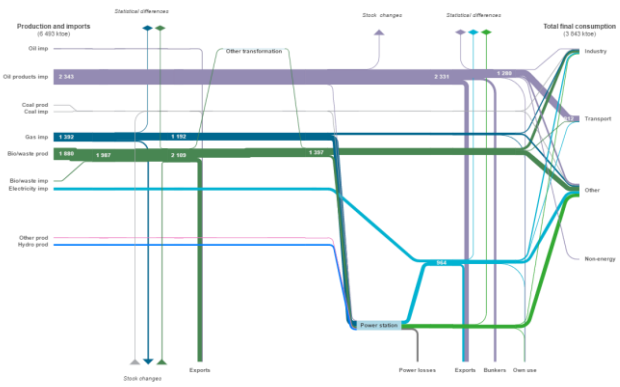
Figure 16.2 Petroleum accumulations and oil production in the Baltic Region. (Latvian Environment, Geology and Meteorology Centre, 2010)



HC accumulations and oil production in Baltic Region

Petroleum activity in Latvia: None, at present. All refined products are imported and used in transport and export (Fig. 16.3). Important bio-waste energy is produced domestically and is used in electricity production, homes, industry and for export. Very small power losses. Some electricity was imported. All electricity is used at homes. Industry is powered by bio-waste. No coal use. Latvia's energy depends on Russia, a link that the Latvian government is trying to cease, by producing some domestic energy.

Figure 16.3: Sankey diagram for Latvia, IEA 2013

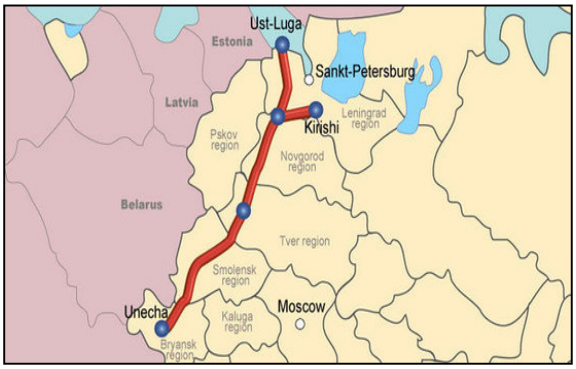


Cross-linked sectors to the hydrocarbon sector: Latvia possesses all industries necessary for UH projects (ENERGY SUPPLIERS AND PRODUCERS; CHEMICAL COMPANIES; METALLURGY**;** GOODS SUPPLIERS AND MANUFACTURERS**;** WASTEWATER AND ENVIRONMENT; CONSTRUCTION; DRILLING SERVICES At present, there are no rolling stock manufacturers in Latvia).

Barriers and drivers to the development of UH industry *specific to Latvia.*

- Barriers: lack of sedimentary basins / high perceived corruption

- D rivers: available pipeline network for export (Figs 16.4 and 16.5)

Figure 16.4: Russia - FSU Pipelines map (Countries of the world)	Figure 16.5: The Baltic Pipeline System-II (America Pink)
	

Stage of development of the UH industry according to Phaal *et al*. (2011) approach: *Latvia is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no shale gas wells). Latvia still needs proper evaluation of its UH prospectivity*.

Budget for UH expenses*: not available*

LITHUANIA

Statistics *Population*: 2.85 million (Sept 2016). *Labour force*: 1.5 million (2012). 7.9% agriculture, 19.6% industry, 72.5% services (2012). *Unemployment (March 2016):* 8.3%. *Corruption Index*, 2015: 32nd (in 169). (EC Staff Working document 2016. Country report Lithuania). .

Geological information: Lithuania possesses only one onshore sedimentary basin, the Baltic Syneclise (Fig. 17.1). The basin contains Paleozoic sediments and has some production (Fig. 17.2) from Lower Paleozoic sandstones.

Figure 17.1. Geological structure of Lithuania. (Latvian Environment, Geology and Meteorology Centre, 2010)

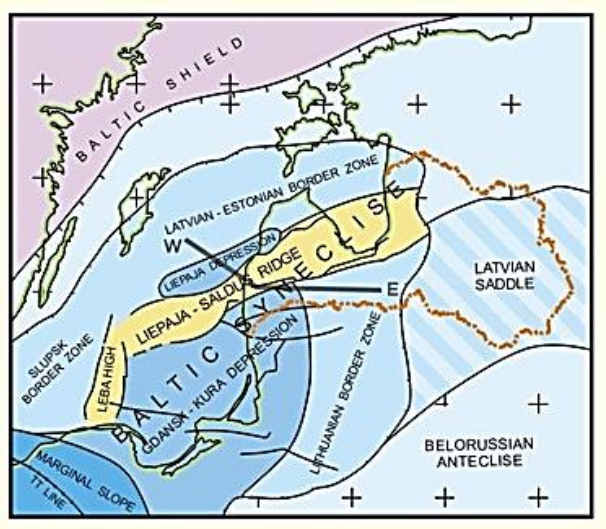
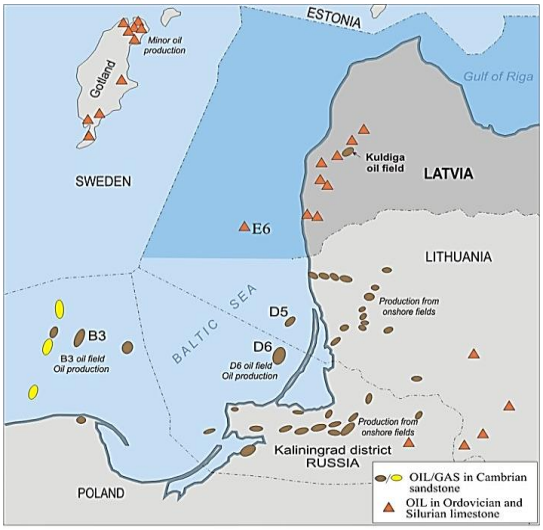


Figure 17.2. Petroleum accumulations and oil production in the Baltic Region. (Latvian Environment, Geology and Meteorology Centre, 2010)



Petroleum activity in Lithuania: None, at present.

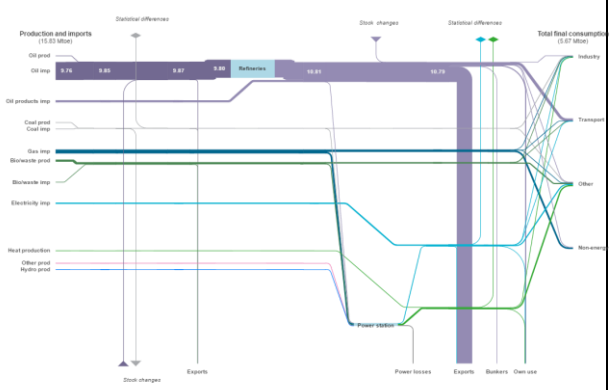
All refined products are imported and used in transport and export (Fig. 17.3). Important bio-waste energy is domestically produced and used in electricity production, homes, industry and for export. Very small power losses. Some electricity is imported. All electricity is used at homes. Industry is powered by bio-waste. No coal use. Lithuania's energy depends on Russia, a link that the Lithuanian government is trying to cease, by producing some domestic energy.

Cross-linked sectors to the hydrocarbon sector*: Lithuania possesses all industries necessary for UH projects, apart from Rolling Stock manufacturing (*ENERGY PRODUCERS AND SUPPLIERS; ROAD TRANSPORT; CONSTRUCTION; CHEMICAL COMPANIES***;** METALLURGY). At present, Lithuania does not have rolling stock manufacturers. They import rolling stock from Poland, Russia and the Czech Republic.

Barriers and drivers *to the development of UH industry specific to Lithuania.*

- Barriers: lack of sedimentary basins;

- Drivers: available pipeline network for export (Figs 17.4).

Figure 17.3: Sankey diagram for Lithuania, IEA 2013.	Figure 17.4: Pipeline network in Lithuania (ORLEN, 2007)
	

Stage of development of the UH industry according to Phaal et al. (2011) approach: Lithuania is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no *shale gas wells). Lithuania still needs proper evaluation of its UH prospectivity.*

Budget for UH expenses: *not available*

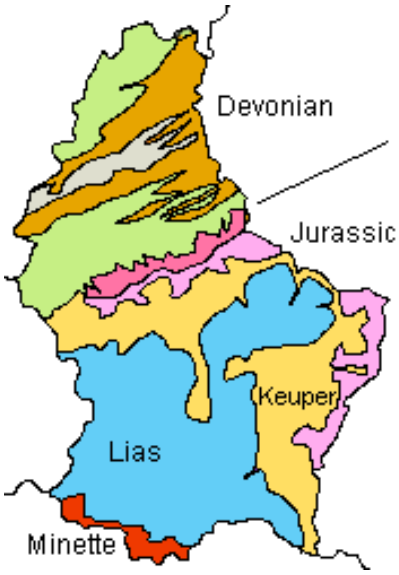
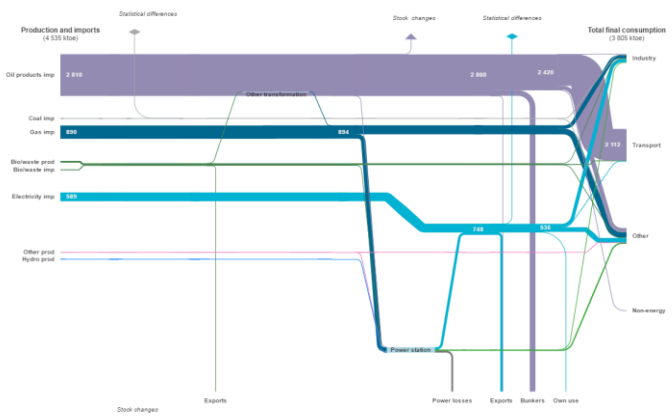
LUXEMBOURG

Statistics Population: 600 000 (2016). Labour force: 200 000 (2012). 1.2% agriculture, 19.4% industry, 79.4% services (2012). Unemployment (March 2016): 6.5%. Corruption Index, 2015: 10th (in 169). Main EU document: Country Report - Luxembourg (2016).

Geological information: Luxembourg does not possess any major sedimentary basins (Fig. 18.1). It shares a basin with Germany and the large Paris Basin with France. The latter basin contain the Jurassic Schistes carton rock that can become a target for shale gas/shale oil E & P.

Petroleum activity in Luxembourg: None, at present.

All refined products are imported and used in transport and bunkering (Fig. 18.2). Very small power losses. Some electricity is imported. All gas is imported and used at homes, the industry and power production. No coal use. Electricity is produced by imported gas. No coal use. Luxembourg is supplied with natural gas by interconnected gas networks, mostly from Russia and Norway. Luxembourg will welcome UH projects, but it will follow France.

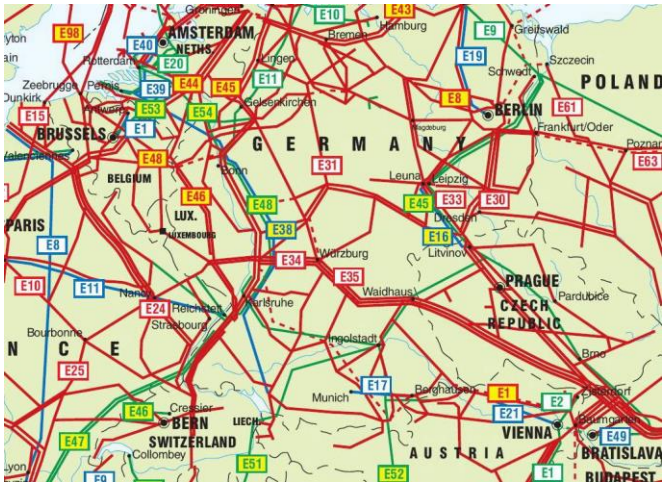
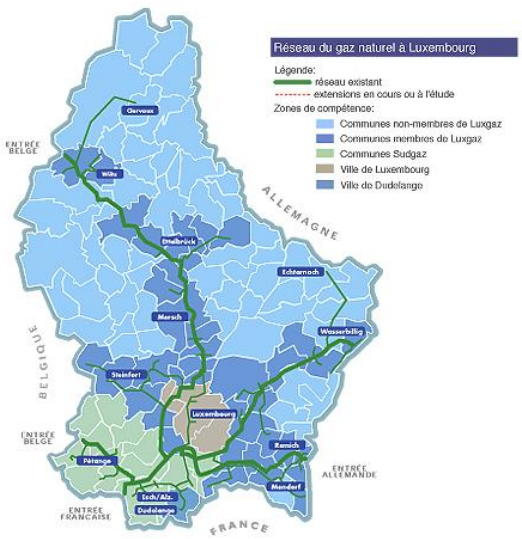
Figure 18.1: Structural map of Luxembourg.	Figure 18.2: Sankey diagram for Luxembourg, IEA 2013
	

Cross-linked sectors to the hydrocarbon sector: Luxembourg possesses all industries necessary for UH projects (GENERATION AND DISTRIBUTION OF ENERGY; CHEMICAL; WASTEWATER TREATMENT; METALLURGY; ROLLING STOCK MANUFACTURERS; CONSTRUCTION; GOODS MANUFACTURERS AND PROVIDERS).

Barriers and drivers to the development of UH industry specific to Luxembourg.

- Barriers: lack of sedimentary basins / no experience in petroleum projects

- Drivers: available pipeline network for export (Figs 18.3 and 18.4) / Very low perceived corruption.

Figure 18.3: Pipelines through Luxembourg (Countries of the World)	Figure 18.4: The gas pipeline network of Luxembourg (ErdGas)
	

<u>Stage of development of the UH industry</u> according to Phaal et al. (2011) approach: Luxembourg is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). Luxembourg still needs proper evaluation of its UH prospectivity.

<u>Budget for UH expenses</u>: not available .

MALTA

Statistics Population: 420 000 (Sept 2016). Labour force: 200 000 (2013). 1.4% agriculture, 22.2% industry, 76.4% services (2013). Unemployment (March 2016): 5.2%. Corruption Index, 2015: 37th (in 169). Main EU document: Country Report - Malta (2016).

Geological information: Very little is known about the petroleum prospectivity of Malta. The geology (Fig. 19.1) seems to be the same as in Tunisia. There are no major onshore sedimentary basins.

Petroleum activity in Malta: None, at present.

All crude oil and refined products are imported and used, mostly in bunkering. Other uses of imported oil include transport and electricity production. Some of these products are re-exported. Important power losses. The electricity is, mostly, used for home consumption (Fig. 19.2). Some electricity is imported. All gas is imported and used at homes, the industry and power production. Electricity is produced by imported gas. Malta is connected to the European gas network via Italy at Gela, using a gas pipeline, floating LNG storage and a re-gasification unit.

Figure 19.1: Geological map of Malta. (everything is electric, 2009)

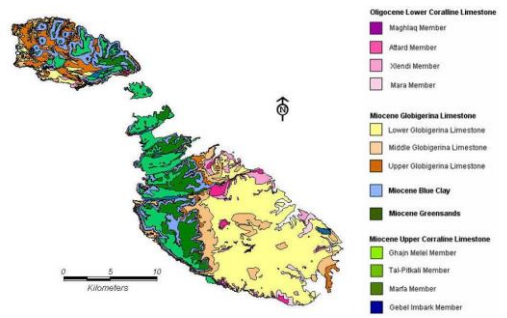
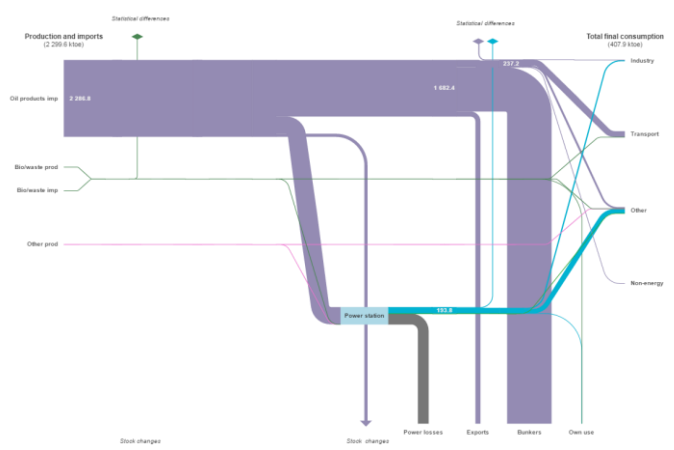


Figure 19.2: Sankey diagram for Malta, IEA 2013

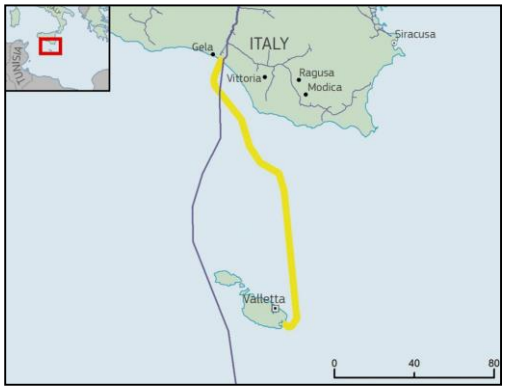
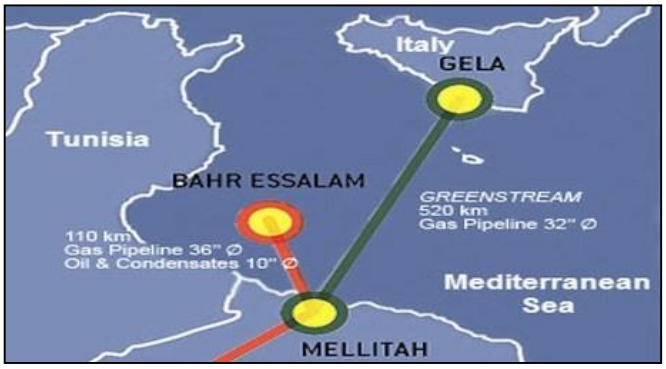


Cross-linked sectors to the hydrocarbon sector: Malta possesses all industries necessary for UH projects, apart from rolling stock manufacturing. Malta will need to import rolling stock from Italy (ENERGY COMPANIES; WASTEWATER TREATMENT AND ENVIRONMENT; GOODS MANUFACTURERS & PROVIDERS; METALLURGY; CONSTRUCTION; CHEMICAL COMPANIES; at present, there is no rolling stock manufacturing in Malta).

Barriers and drivers to the development of UH industry, specific to Malta

- Barriers: lack of sedimentary basins / no experience in petroleum projects.

- Drivers: available pipeline network for export (Figs 19.3 and 19.4).

Figure 19.3: The Greenstream pipeline (INEA-EU, 2016)	Figure 19.4: Libya-Malta-Sicily pipeline (maltastar)
	

<u>Stage of development of the UH industry</u> according to Phaal et al. (2011) approach: Malta is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). Malta still needs proper evaluation of its petroleum geology and UH prospectivity.

<u>Budget for UH expenses</u>: not available.

NETHERLANDS

Statistics *Population*: 17 million (Sept 2016). *Labour force*: 7.9 million (2013). 2.3% agriculture, 18.8% industry, 78.9% services (2013). *Unemployment (March 2016):* 6.4%. *Corruption Index, 2015*: 5th (in 169). Main EU document: Country Report - The Netherlands (2016).

Geological information: The Netherlands onshore share sedimentary basins with

neighbouring countries (Fig. 20.1). The country was a major coal producer and user until the 1960's when the giant Groningen gas field was discovered and developed, followed by many other smaller gas fields (Fig. 20.2). Main UH targets include the Lower Jurassic shales (for shale gas/shale oil), Carboniferous coals (for CBM) of abandoned mines and several tight sandstones (for tight sandstone gas). Peat and coal were mined in Limburg. During 1965–75 all coal mines were closed.

Figure 20.1: Structural map of the Netherlands. Carboniferous rocks outcrop in the south-eastern province of Limburg (Lower Rhine-Roer Valley Graben). The Lower Jurassicm Posidonia Shale is well developed (jgs.lyellcollection.org)

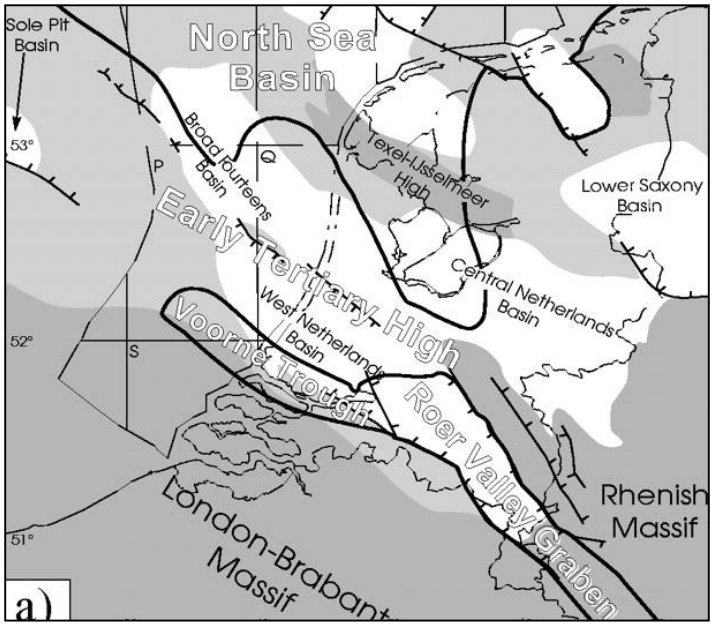
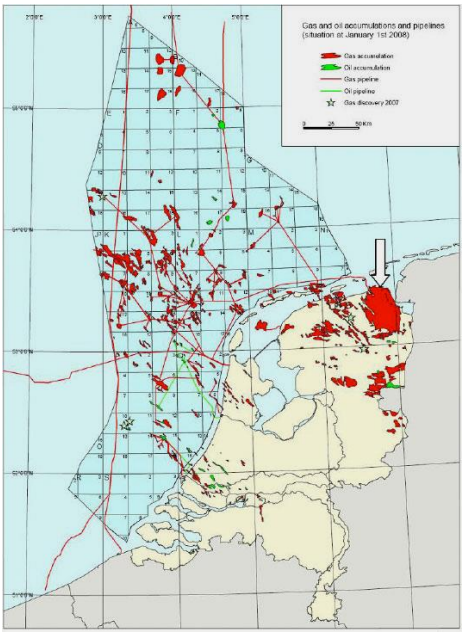
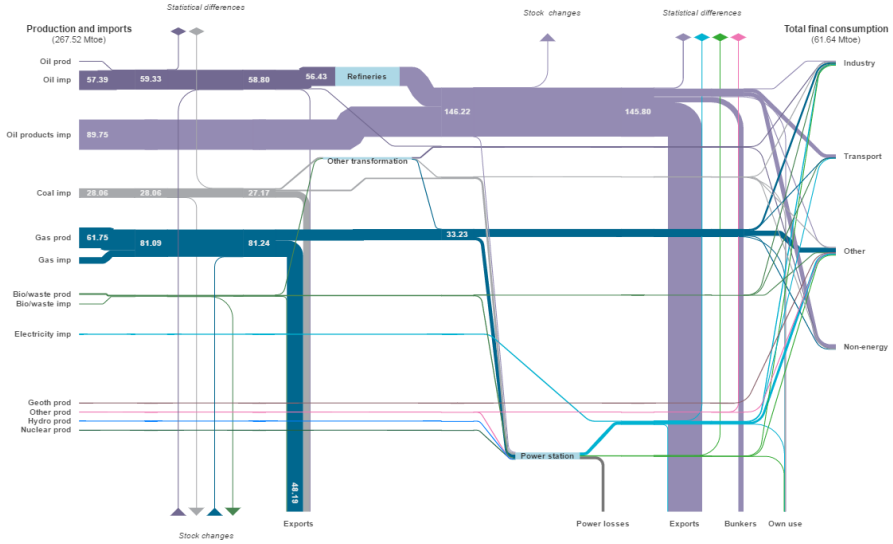


Figure 20.2: Gas and oil accumulations and pipelines in the Netherlands. The Groningen gas field is indicated with the white arrow (AAPG, 2008)



Petroleum activity in The Netherlands: Onshore, none, at present. The Netherlands pursue a very active offshore exploration activity. All oil and oil-refined products are imported and, mostly, re-exported (Fig.20.3). Other uses of imported oil include transport and bunkering. Minor power losses. Most of the gas is domestically produced and exported. Some gas is imported and used for power production and home use. The electricity is used, mostly, for home and industry consumption. Coal is imported and re-exported.

Figure 20.3: Sankey diagram for the Netherlands, IEA 2013.



<u>Cross-linked sectors to the hydrocarbon sector</u>: The Netherlands possesses all industries necessary for UH projects, apart from rolling stock (OIL & GAS COMPANIES**;** DRILLING AND ENERGY CONTRACTORS; ENERGY PROVIDERS; CHEMICAL INDUSTRY; METALLURGY; CONSTRUCTION; WASTEWATER TREATMENT; GOODS MANUFACTURERS; no rolling stock manufacturing).

<u>Barriers and drivers</u> to the development of UH industry, specific to the Netherlands.

Barriers: no barriers founded according to the analysis done in this report.

Drivers: available pipeline network for export (Figs 20.4 and 20.5) / experience in petroleum projects **/** several geological studies**.**

Figure 20.4: Netherlands Pipelines (Countries of the World)	Figure 20.5: Pipelines in The Netherlands (Rotterdam-Rijn Pijpleiding)
	

Stage of development of the UH industry according to Phaal et al. (2011) approach: The Netherlands is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). The Netherlands still needs proper evaluation of its UH prospectivity.

Budget for UH expenses:

Figure 85. Budget for UH expenses – The Netherlands

Hydraulic fracturing	drilling and completion expenditure	Waste management	transportation	other expenses
126 million €	50.5 million €	17.3 million €	8 million €	3.1 million €

Source: Ernst & Young study for UK (2014)

POLAND

Statistics *Population*: 38.6 million (Sept 2016). *Labour force*: 18.2 million (2013). 12.9% agriculture, 30.1% industry, 57% services (2013). *Unemployment (March 2016)*: 9.6%. *Corruption Index, 2015:* 30th (in 169). (EC Staff Working document 2016. Country report Poland).

Geological information. Poland possesses three large sedimentary basins (Fig 21.1). Since the beginning of 2000s there has been extensive exploration for shale gas in these basins (all of which are serviced by gas pipelines, Fig. 21.3), prompted by the high shale gas reserves published by USGS, targeting unsuccessfully the Silurian, Ordovician and Cambrian shales for shale gas. Poland, also, possesses well-known conventional targets, such as the Permian Rotliegend desert sandstones, which are very gas productive. The UH prospectivity of Poland needs to be re-oriented.

Petroleum activity in Poland: The main UH basin of Poland is the large onshore Baltic Basin, where there has been a lot of shale gas drilling, since the beginning of the 2000s. After failure to have even one discovery, the operators deepened some wells to test the Ordovician shales below. These proved to be thin and still not productive. Following this second failure, the operators drilled deeper to test the Cambrian Alum shales (tested unsuccessfully for shale gas by Shell in southern Sweden). Still no success, as the shales were found over mature. At this point in time, after more than 70 wells were drilled, most companies left the country.

In Poland most of the oil and oil-refined products are imported and, mostly, used for transport (Fig. 21.2). Some oil is re-exported. All coal is domestically produced and used for electricity generation. Some coal is exported and a small amount is used at homes. There are significant power losses. There is some small domestic bio-waste energy production used at homes. Most of the gas is imported from Russia and used in the industry. The electricity is used for home and industry consumption. Approximately 300,000 people are employed in the fuel and energy sector in Poland (125,000 are employed in the coal mining industry and, nearly, 150,000 in supply of electricity and gas). Earnings in the energy sector are distinctly higher than average earnings in the Polish economy, making it one of the best-paid sectors.

Figure 21.1: Sedimentary basins of Poland (Vinsons & Elkins, 2011).

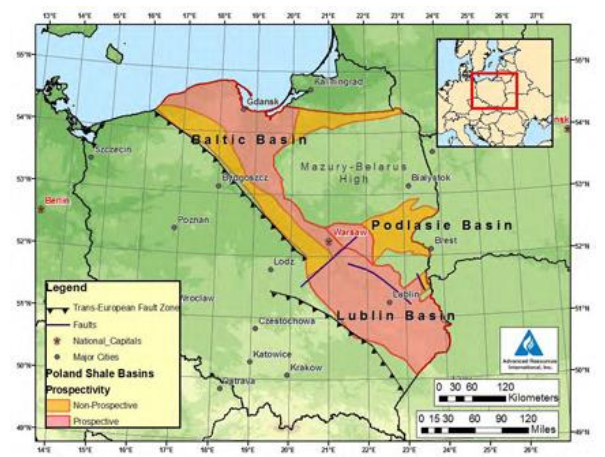
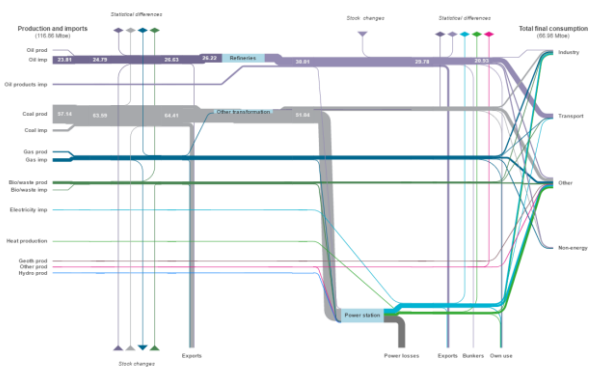


Figure 21.2: Sankey diagram for Poland, IEA 2013

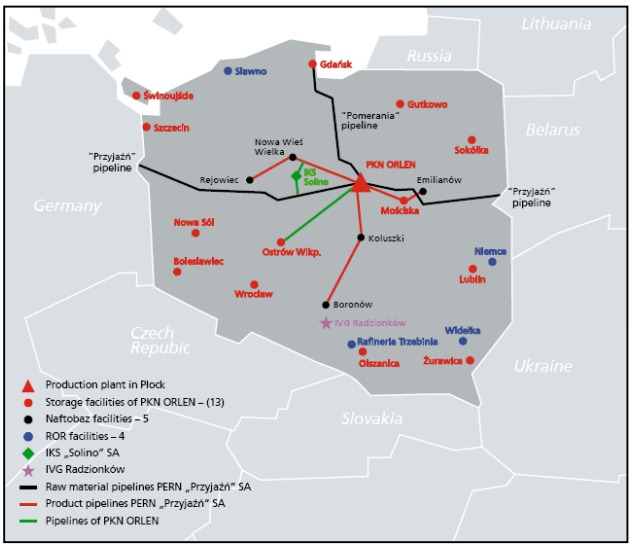


Cross-linked sectors to the hydrocarbon sector: Poland possesses all industries necessary for UH projects (OIL & GAS COMPANIES; ELECTRICITY PROVIDERS; ROLLING STOCK MANUFACTURERS; CHEMICAL INDUSTRY; METALLURGY; GOODS MANUFACTURERS AND SUPPLIERS; CONSTRUCTION; WASTEWATER TREATMENT AND ENVIRONMENT).

Barriers and drivers to the development of UH industry, specific to Poland.

Drivers: available pipeline network for export (Figs 20.4 and 20.5) and a quite developed internal gas infrastructure (Figure 21.3)/experience in petroleum projects **/** several geological studies**.**

Figure 21.3. Pipelines of Poland. (ORLEN, 2014)



<u>Stage of development of the UH industry</u> according to Phaal et al. (2011) approach: Poland is in the "embryonic" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has, taken place (many shale gas wells), but, without success. Poland still needs proper evaluation of its UH prospectivity.

<u>Budget for UH expenses</u>:

Figure 86. Budget for UH expenses – Poland

Hydraulic fracturing	drilling and completion expenditure	Waste management	transportation	other expenses
757.5 million €	303.6 million €	104 million €	48 million €	18.5 million €

Source: Ernst & Young study for UK (2014)

PORTUGAL

Statistics *Population*: 10.3 million (Sept 2016). *Labour force*: 5.4 million (2009). 11.7% agriculture, 28,5% industry, 59.8% services. *Unemployment (March 2016):* 12.4%. *Corruption Index, 2015*: 28^{h} (in 169). (EC Staff Working document 2016. Country report Portugal).

Geological information. The main onshore sedimentary basin in Portugal is the Lusitanian Basin (Fig. 22.1). The basin contains Lower Jurassic shales and is, currently, being explored for shale gas. Portugal possesses several other basins, but they are located offshore (Fig. 22.1)

Petroleum activity in Portugal: Currently, the only UH onshore activity is the exploration for shale gas in the Lusitanian Basin.

All the oil, oil-refined products and gas are imported and, mostly, used in electricity production and transport (Fig. 22.2). Some oil is re-exported, or used in bunkering. All coal was imported and used for electricity generation. Some, domestically produced bio-waste energy is used in power generation, in the industry and at homes. Small power losses. All electricity is used for home & industry consumption. Portugal suffers from high unemployment and will profit from UH projects. A positive factor is that over ¼ of the workforce is employed in the industry.

Figure 22.1: Sedimentary basins of Portugal. (Taylor A.M *et al,* 2014, Geological Journal)

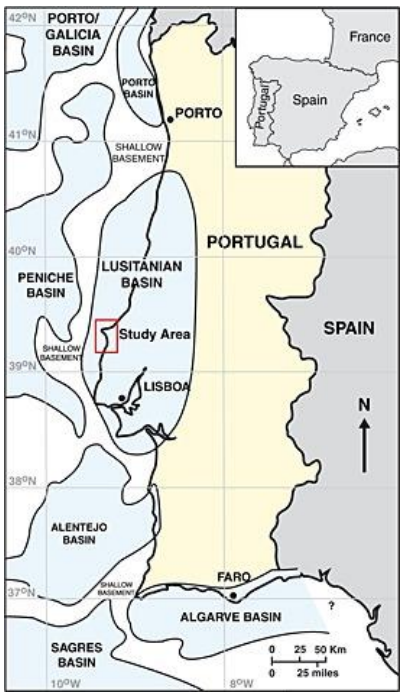
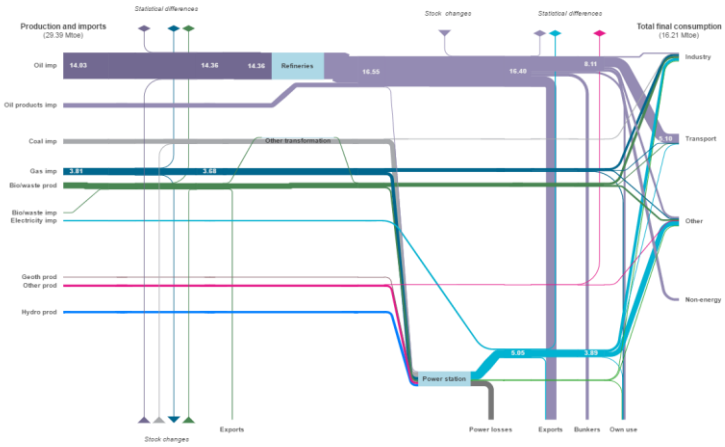


Figure 22.2: Sankey diagram for Portugal, IEA 2013



Cross-linked sectors to the hydrocarbon sector: Portugal possesses all industries necessary for UH projects (UTILITY SUPPLIERS; OIL & GAS COMPANIES; CHEMICALS; METALLURGY AND DRILLING PIPES; CONSTRUCTION INDUSTRY; GOODS MANUFACTURERS; WASTEWATER TREATMENT; No manufacturing of locomotives).

Barriers and drivers to the development of UH industry, specific to Portugal.

- Barriers: negative public opinion / no experience in petroleum projects / little information on onshore geology;

- Drivers: available pipeline network for export (Figs 22.3 and 22.4) / Low perceived corruption.

Figure 22.3: Pipelines in Portugal (Countries of the World)	Figure 22.4a: Gas Pipelines in Portugal (Oil & Gas Journal, 1998)	Figure 22.4b: Maghreb-Europe Gas Pipeline (GME) (Oil & Gas Journal, 1996)
		

<u>Stage of development of the UH</u> industry according to Phaal et al. (2011) approach: Portugal is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). Portugal still needs proper evaluation of its UH prospectivity.

<u>Budget for UH expenses</u>: no data.

ROMANIA

Statistics *Population*: 19.3 million (Sept 2016). *Labour force*: 9.45 million (2013). 29% agriculture, 28,6% industry, 42.4% services. *Unemployment (March 2016):* 6.4%. *Corruption Index, 2015*: 58^{h} (in 169). (EC Staff Working document 2016. Country report Romania).

Geological information: Romania is a traditional oil producing country, with several sedimentary basins (Fig. 23.1), all of which are overlain by pipelines (Figs. 23.3. and 23.4). Each basin in Romania may be targeted for UH projects. The Transylvania Basin (Fig. 23.1) currently produces biogenic gas. Possible UH targets include the Tertiary shales and several sandstone beds (for tight sandstone gas).

Petroleum activity in Romania: The conventional drilling activity in Romania has always been very intense, especially after the two main oil companies of Romania (Petrom & Rompetrol) were taken over by OMV and KazMunayGas. Some companies (both US and Balkan), showed interest in these kind of projects, but no continued action occurred. The Canadian Transatlantic Petroleum carries out development drilling.

Some oil and oil-refined products are imported and, mostly, used in transport (Fig. 23.2). Little oil is exported. All gas & coal are produced domestically and used for electricity generation. A little nuclear energy and bio-waste fuel is used for power generation, in industry and at homes. Small power losses. All electricity is used for home & industry consumption.

Figure 23.1: Geologic map of Romania (Knapp J.H, Knapp C.C., Raileanu V. & Dinu C., 2005, Tectonophysics)

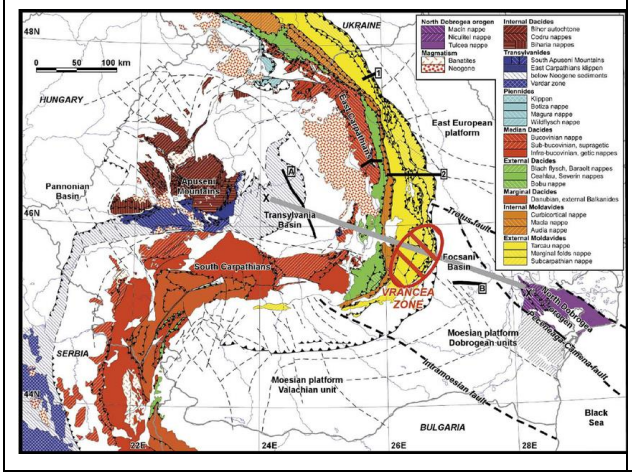
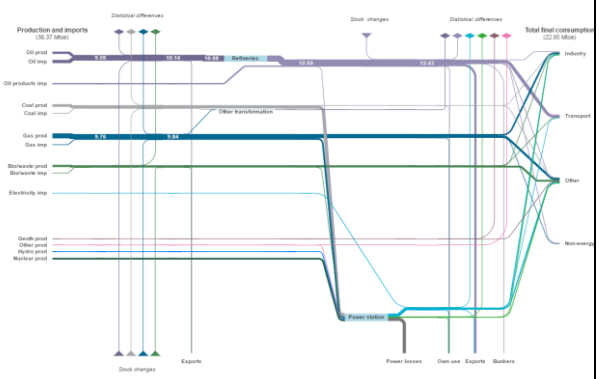


Figure 23.2: Sankey diagram for Romania, IEA 2013.



Cross-linked sectors to the hydrocarbon sector: Romania possesses all industries necessary for UH projects (OIL & GAS PRODUCERS AND SUPPLIERS; PETROLEUM DRILLING SERVICES; CHEMICALS; METALLURGY; CONSTRUCTION; ROLLING STOCK MANUFACTURERS; WASTEWATER TREATMENT, GOODS MANUFACTURERS).

Barriers and drivers to the development of UH industry, specific to Romania.

Barriers: no investment from foreign companies;

- Drivers: available pipeline network for export (Figs 23.3 and 23.4) / experience in petroleum projects / available information on onshore geology.

Figure 23.3: Pipelines of Romania (Countries of the World)	Figure 23.4: The AGRI pipeline. (1) Pipeline transport of gas from Azerbaijan to Georgian Coast; (2) Liquefaction of gas into LNG at new terminal on Georgian Coast; (3) Ship transport of LNG from Georgia to Romania by two LNG carriers of 140 000 m^3 capacity; (4) Re-gasification of LNG to gas at new regasification terminal on Romanian Coast (Costanţa), with storage of 160,000 m^3; (5) Pipeline transport of gas from regasification terminal to Romania, Hungary and other potential gas markets. (AGRILNG).
	

<u>Stage of development of the UH industry</u> <u>according to Phaal et al. (2011) approach</u>: Romania is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). Romania still needs proper evaluation of its UH prospectivity.

<u>Budget for UH expenses</u>:

Figure 87. Budget for UH expenses – Romania

Hydraulic fracturing	drilling and completion expenditure	Waste management	transportation	other expenses
252.5 million €	101.2 million €	34.7 million €	16 million €	6.2 million €

Source: Ernst & Young study for UK (2014)

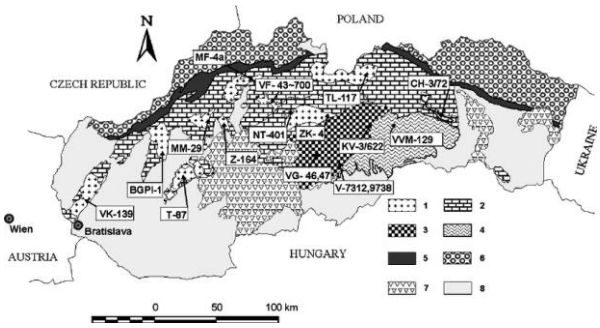
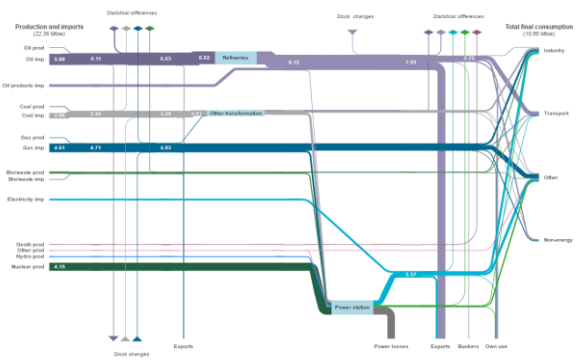
SLOVAKIA

Statistics *Population*: 5.4 million (Sept 2016). *Labour force*: 2.7 million (2013). 3.5% agriculture, 27% industry, 69.5% services. *Unemployment (March 2016):* 9.9%. *Corruption Index, 2015*: 50^{h} (in 169). (EC Staff Working document 2016. Country report Slovakia).

Geological information: Slovakia is divided geologically in two regimes (Fig. 24.1): (i) the Bohemian Massif in the west and, (ii) the Western Carpathians in the east. Both areas are overlain by pipelines (Fig. 24.3) and may contain targets for UH projects. The southern part of the country (Fig. 24.1) may contain the Tertiary Schöneck shales, prospective for shale gas & shale oil. Abandoned coal mines in the country may become targets for CBM production.

B. Petroleum activity in Slovakia: no current onshore drilling for oil & gas.

All oil is imported and used in transport, or re-exported (Fig. 24.2). All gas is imported and used for electricity generation, industry and at homes. All nuclear energy was used in power generation. Severe power losses. All electricity (some is imported) was used for home & industry consumption. Currently, Slovakia is depended on Russian oil and gas imports, via the Druzhba pipeline.

Figure 24.1: Tectonic-geological map of Slovakia. (Kohút M., Kovach V.P, Kotov A.B. & Savatenkov V.M., 1999, Geologica Carpathica)	Figure 24.2: Sankey diagram for Slovakia, IEA 2013
	

Cross-linked sectors to the hydrocarbon sector: Slovakia possesses all industries necessary for UH projects (OIL & GAS REFINING, SUPPLY AND DISTRIBUTION; DRILLING SERVICES; ELECTRICITY; CONSTRUCTION INDUSTRY; ROLLING STOCK MANUFACTURERS; METALLURGY; CHEMICAL INDUSTRY; WASTEWATER TREATMENT AND ENVIRONMENT; GOODS PROVIDERS).

Barriers and drivers to the development of UH industry, specific to Slovakia.

- Barriers: no investment from foreign companies / High perceived corruption;

- Drivers: available pipeline network for export (Fig. 24.3) / experience in petroleum projects / available information on onshore geology.

Figure 24.3: Pipelines in Slovakia (slovakrating)

Stage of development of the UH industry according to Phaal et al. (2011) approach: Slovakia is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). Slovakia needs proper evaluation of its UH prospectivity.

Budget for UH expenses: no data.

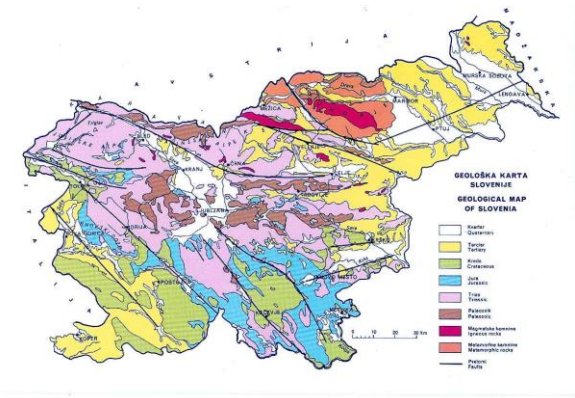
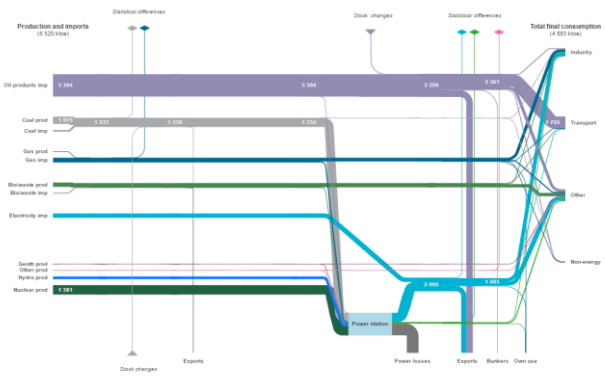
SLOVENIA

Statistics Population: 2 million (Sept 2016). Labour force: 900 000 (2013). 2.2% agriculture, 35% industry, 62.8% services. Unemployment (March 2016): 12%. Corruption Index, 2015: 35^{h} (in 169). (EC Staff Working document 2016. Country report Slovienia).

Geological information: Slovenia contains a part of the large Pannonian Basin, at its south-western region (Fig. 25.1), which possesses significant UH prospectivity, in Tertiary shales and tight sandstones.

B. Petroleum activity in Slovenia: no current onshore drilling for oil & gas.

All oil products are imported and used in transport, or re-exported (Fig. 25.2). All domestic coal production is used in electricity production. All gas is imported and used in the industry. There is some bio-waste energy production used at homes. All nuclear energy is used in power generation. There are severe power losses. All electricity is used for export, home & industry consumption. Slovenia suffers from high unemployment and depends for its energy on Russia.

Figure 25.1: Geological map of Slovenia (The Fossil Forum, 2013)	Figure 25.2: Sankey diagram for Slovenia, IEA 2013
	

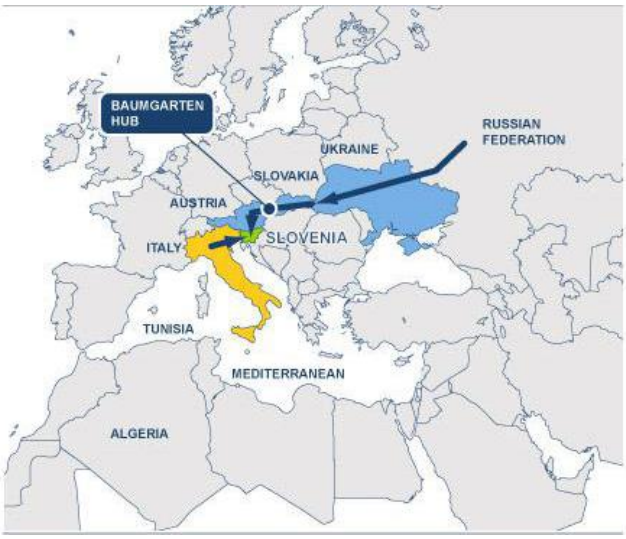
D. Cross-linked sectors to the hydrocarbon sector: Slovenia possesses all industries necessary for UH projects (OIL, GAS PROVIDERS AND DRILLING; CHEMICALS; ROLLING STOCK MANUFACTURERS; METALLURGY AND HARDWARE; GOODS SUPPLIERS; WASTEWATER SERVICES AND ENVIRONMENT; CONSTRUCTION).

Barriers and drivers to the development of UH industry, specific to Slovenia.

- Barriers: possible negative public opinion / no investment from foreign companies / High perceived corruption;

- Drivers: available pipeline network for export (Fig. 25.3) / experience in petroleum projects / available information on onshore geology.

Figure 25.3: Natural Gas sources and transmission routes to Slovenia (Geoplin)



Stage of development of the UH industry according to Phaal et al. (2011) approach: Slovenia is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). Slovenia needs proper evaluation of its UH prospectivity.

Budget for UH expenses: no data.

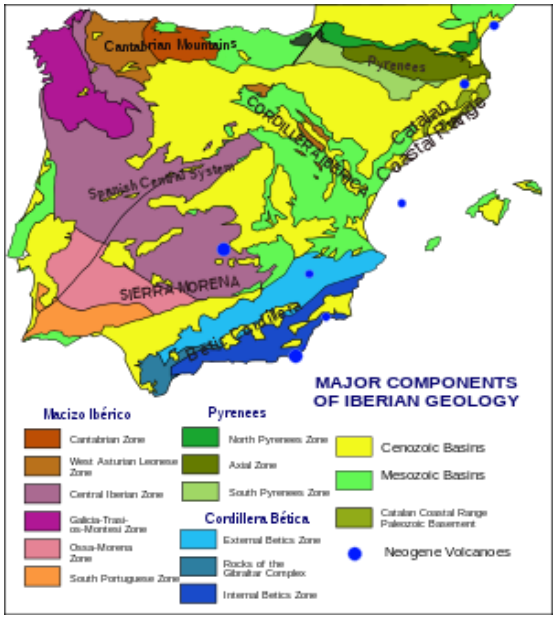
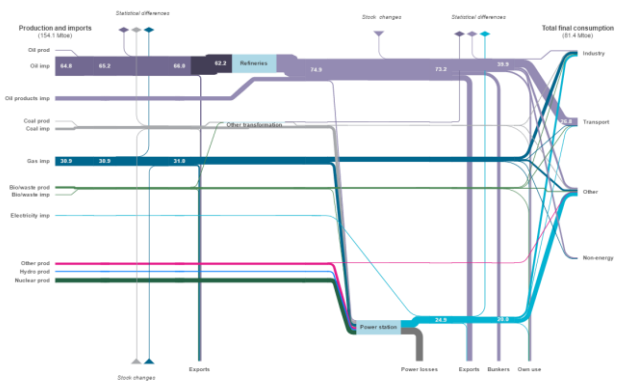
SPAIN

Statistics *Population*: 46 million (Sept 2016). *Labour force*: 23.2 million (2013). 4.3% agriculture, 24% industry, 71.7% services (2013). *Unemployment (March 2016)*: 21%. *Corruption Index, 2015*: 30th (in 169). Main EU document: Country Report - Spain (2016).

Geological information: Spain is a mountainous country, with few sedimentary basins (Fig. 26.1). UH activity is concentrated in the deep basin at the southern side of the Pyrenees. The basins contain proven Lower Jurassic shales and Silurian shales that can become targets for UH exploration. The abandoned coal mines in the Asturias and in Galicia may produce coal bed methane.

B. Petroleum activity in Spain: no current onshore drilling for oil & gas.

All oil is imported and used for transport, re-export and bunkering (Fig. 26.2). All coal is imported and used for electricity generation. There are significant power losses. All domestic nuclear capacity is used for electricity production. All gas is imported and used in the industry and power production. The electricity is used for home and industry consumption. Some small bio-waste power production is for home use. Spain imports ~ 80% of its energy. In January 2014, Repsol decided to cancel its oil drilling project near the Canary Islands, after a decade conducting tests with disappointing results. The plan to drill near the Canary Islands sparked angry protests from locals and environmentalists. The local government fiercely opposed any drilling, over fears that it would spoil the islands' tourism industry. Several Spanish provinces have resisted UH projects, with Cantabria and La Rioja having passed bans on hydraulic fracturing. However, the Spanish Constitutional Court declared these actions unconstitutional.

Figure 26.1: Geological map of Spain. (The Geology of Spain, 2002)	Figure 26.2: Sankey diagram for Spain, IEA 2013
	

Cross-linked sectors to the hydrocarbon sector: Spain possesses all industries necessary for UH projects (UTILITIES SUPPLIERS; PETROLEUM INDUSTRY; GOODS SUPPLIERS AND MANUFACTURERS; WASTEWATER TREATMENT AND ENVIRONMENT; ROLLING STOCK MANUFACTURERS; CONSTRUCTION INDUSTRY; METALLURGY; DRILLING SERVICES).

Barriers and drivers to the development of UH industry, specific to Spain.

- Barriers: negative public opinion / no investment from foreign companies / high perceived corruption / no experience in petroleum projects / lack of extensive basins]

- Drivers: available pipeline network for export (Fig. 26.3) / available information on onshore geology.

Figure 26.3: Spain and Portugal Pipelines (Countries of the World)

<u>Stage of development of the UH industry</u> according to Phaal et al. (2011) approach: Spain is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). Spain needs proper evaluation of its UH prospectivity.

<u>Budget for UH expenses</u>

Figure 88. Budget for UH expenses – Spain

Hydraulic fracturing	drilling and completion expenditure	Waste management	transportation	other expenses
36.1 million €	14.5 million €	5 million €	2.3 million €	0.9 million €

Source: Ernst & Young study for UK (2014)

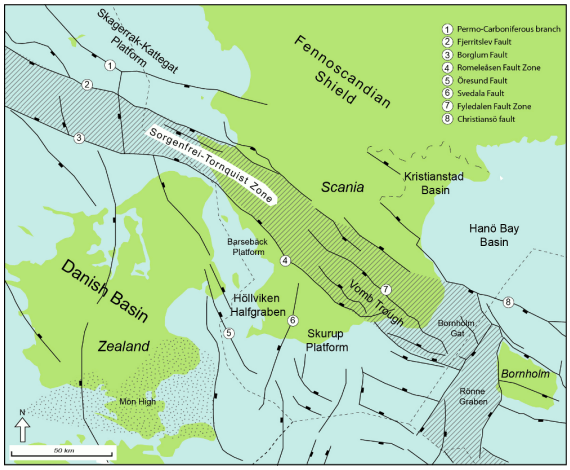
SWEDEN

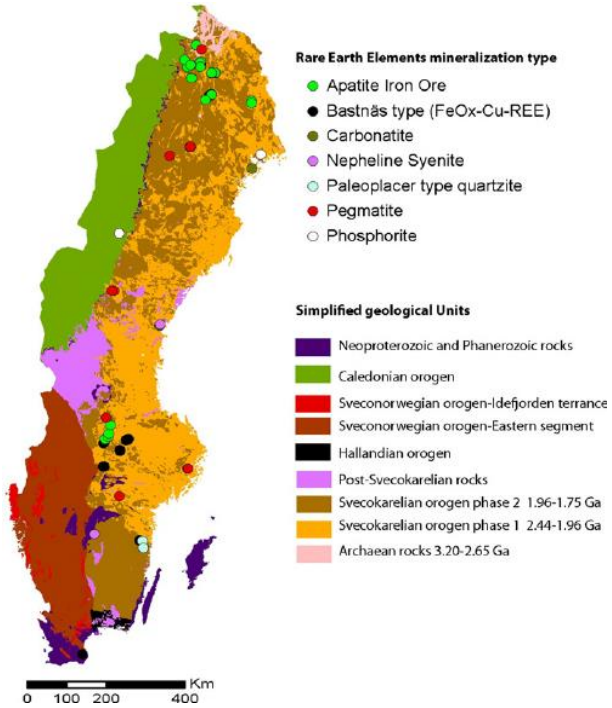
Statistics *Population*: 9.9 million (Sept 2016). *Labour force:* 5.1 million (2013). 1.1% agriculture, 28.2% industry, 70.7% services (2013). *Unemployment (March 2016):* 7.5%. *Corruption Index, 2015:* 3rd (in 169). Main EU document: Country Report - Sweden (2016).

Geological information: Sweden does not possess onshore sedimentary basins (Figs 27.1 and 27.2). It has only one pipeline in the Skåne province. The only UH target are the Lower Paleozoic Alum Shales that contain a lot of uranium.

Figure 27.1: Structural map of Sweden. (Geological Survey of Denmark and Greenland)

Figure 27.2: Simplified geological map of Sweden (Sadeghi M., Morris G.A., Carranza E.J.M. & Andersson M., 2013, Journal of Geochemical Exploration)





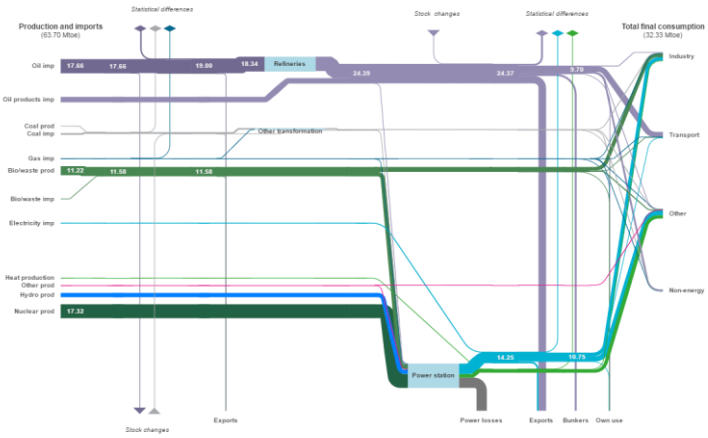
Petroleum activity in Sweden: no current onshore drilling for oil & gas. Shell drilled in 2010 three unsuccessful shallow shale gas wells in southern Sweden to test the Cambrian Alum Shales.

Cross-linked sectors to the hydrocarbon sector: Sweden possesses all industries necessary for UH projects (OIL AND GAS COMPANIES; ELECTRICITY SUPPLIERS; GOODS SUPPLIERS; DRILLING SERVICES; METALLURGY; CONSTRUCTION; ROLLING STOCK MANUFACTURERS; WASTEWATER TREATMENT AND ENVIRONMENT; CHEMICALS).

Barriers and drivers to the development of UH industry, specific to Sweden.

- Barriers: no investment from foreign companies / no experience in petroleum projects / lack of basins / no pipeline network (Fig. 27.4)

- Drivers: available information on onshore geology / very low perceived corruption / Sweden is 2nd in EU for industrial innovation (Bloomberg Innovation Index).

Figure 27.3: Sankey diagram for Sweden, IEA 2013.	Figure 27.4: Pipelines map (Countries of the World, 2008)
	

<u>Stage of development of the UH industry</u> according to Phaal et al. (2011) approach: Sweden is in the "precursor" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has not, yet, taken place (no UH wells). Sweden needs proper evaluation of its UH prospectivity.

<u>Budget for UH expenses</u>

Figure 89. Budget for UH expenses – Sweden

Hydraulic fracturing	drilling and completion expenditure	Waste management	transportation	other expenses
54.1 million €	21.7 million €	7.4 million €	3.4million €	1.3 million €

Source: Ernst & Young study for UK (2014)

UNITED KINGDOM

Statistics *Population*: 65.2 million (Sept 2016). *Labour force*: 30.15 million (2013). 1.4% agriculture, 18.2% industry, 80.5% services (2013). The latest UKOOA estimate (1999) was that 270 000 jobs were supported by the offshore oil & gas industry. Around 44% of these jobs were in Scotland, but oil related jobs exist in almost every part of the UK. Previous studies, in 1997, estimated that the offshore oil & gas industry supported a total of some 210,000 jobs. *Unemployment (March 2016):* 5.1%. *Corruption Index, 2015*: 10th (in 169). Main EU document: Country Report – United Kingdom (2016).

Geological information: The UK possess several onshore sedimentary basins (Fig 28.1), all serviced by pipelines (Fig. 28.3). It also contains a large number of abandoned coal mines with Upper Carboniferous coal beds that can be exploited for CBM. Target shales (for shale gas/shale oil) are mostly in Jurassic rocks, in the south and northern part of England. Scotland possesses a very high-quality shale near Edinburgh.

Petroleum activity in the UK: Two UH wells were drilled by Cuadrila, at the Cumbria region (Preese Hall-1) and in southern England (Balcombe-2). Economic interest from the private sector is shown for exploit CBM in Scotland.

Oil & gas is imported, or produced and is used for transport and export (Fig. 28.2). Some oil is re-exported. Most coal is imported and used in power generation. There are power losses. All nuclear capacity is used for electricity production. All bio-waste energy is domestically produced and used in the industry and electricity production. The electricity is used for home and industry consumption. After several years (2010-2014) of deliberation, the UK government gave the "green light" to companies for UH E & P in Britain, by organising the 14th onshore licensing round. Several UK, US and French companies got blocks onshore Britain for UH activities (for more details on UK see chapter 14. Assessment Of Capability/Preparedness of EU Member States. Some examples).

Figure 28.1: Sedimentary Basins in the United Kingdom (Department of Trade & Industry)

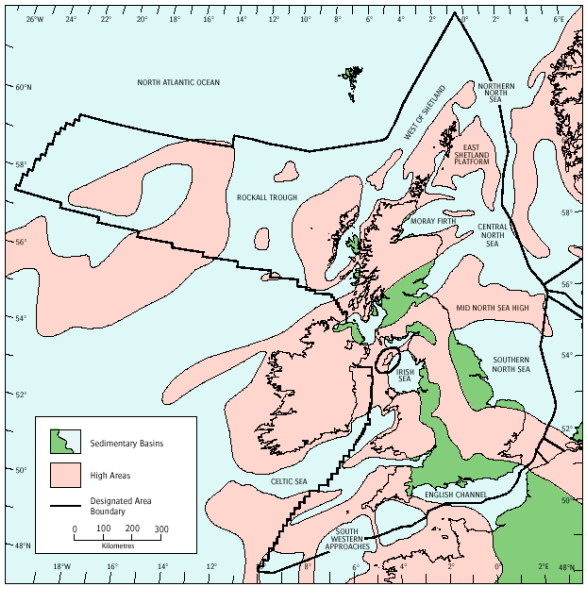
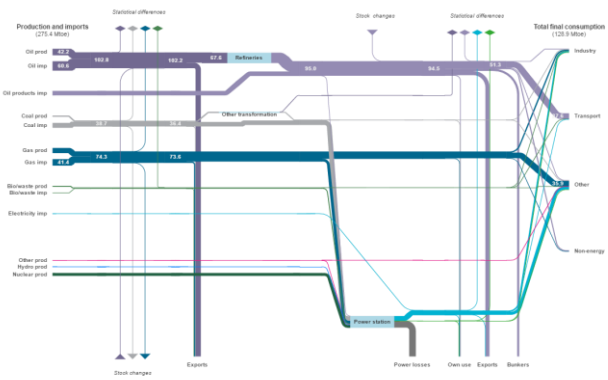


Figure 28.2: Sankey diagram for UK, IEA 2013.



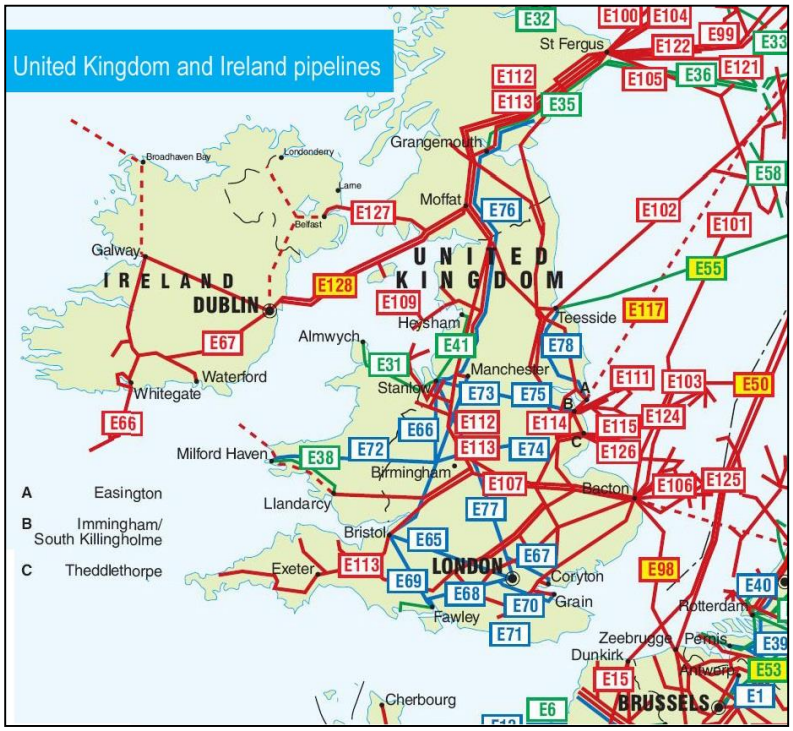
Cross-linked sectors to the hydrocarbon sector: The UK possesses all industries necessary for UH projects (ENERGY (OIL & GAS, COAL, ELECTRICITY) COMPANIES; DRILLING SERVICES; ROLLING STOCK MANUFACTURERS; GOODS PROVIDERS; WASTEWATER TREATMENT; CONSTRUCTION COMPANIES; METALLURGY; CHEMICALS.)

Barriers and drivers to the development of UH industry, specific to the UK.

- Barriers:

- Drivers: available information on onshore geology / dense pipeline network (Figure 28.3) / several geological basins and target rocks.

Figure 28.3: Pipelines in the UK (Countries of the World)



<u>Stage of development of the UH industry</u> according to Phaal et al. (2011) approach: The UK is in the "embryonic" phase of Phaal et al. (2011). The S(cience) to T(echnology) step has taken place (existing UH wells). At present, only the BGS report exists for UH evaluation in the UK.

<u>Budget for UH expenses</u>

<u>Budget for UH expenses</u>

Figure 90. Budget for UH expenses – UK

Hydraulic fracturing	drilling and completion expenditure	Waste management	transportation	other expenses
126.1 million €	50.5 million €	17.3 million €	8 million €	3.1 million €

Source: Ernst & Young study for UK (2014)

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