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Shale Gas for Europe – Main Environmental and Social Considerations

A Literature Review

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IMPORTANT EXPLANATORY REMARKS

The purpose of this study is to provide an overview of shale gas development in the USA and to assess the implications of findings with regard to the prospects for shale gas development in the EU by 2020-2030. Particular emphasis is placed on the environmental and social aspects of market-scale extraction of shale gas. Any purely technological, techno-economic and regulatory aspects of shale gas exploitation are beyond the scope of this study. Other European Commission services, such as DG for Energy (ENER), DG for the Environment (ENV), DG for Climate Action (CLIMA), and the Joint Research Centre itself have already performed or are currently undertaking in-depth analyses of those aspects of shale gas.

The analysis is based on a critical review of a number of literature sources, complemented by the authors' analysis. Bibliographical references for literature, or other sources where more information can be found on a given subject, are shown in square brackets []. For the sake of simplicity, these references are numbered, although the data and information sources themselves are listed in alphabetical order.

Most of the background data and information were collected from publicly available sources during the period June-November 2011. The study was finalised in January 2012. Input to the report was provided by the European Integration & Regional Competitiveness Foundation, Sofia, Bulgaria under Fee-Paid Contract No. P2011017990KAVA / 14.09.2011.

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EU – European Union

GDP – Gross Domestic Product

GECF – Gas Exporting Countries Forum

LNG – Liquefied natural gas

MBtu – Million British Thermal Units

Tcf – Trillion cubic feet

US – United States of America

EXECUTIVE SUMMARY

The growing geopolitical concentration of conventional reserves of oil and gas in the hands of a small number of countries has heightened concerns about the security, reliability and affordability of energy supply worldwide. The risk of the Gas Exporting Countries Forum becoming a gas cartel, with a largely overlapping membership with the oil cartel, OPEC, has further spurred the search for alternative unconventional gas deposits. Amongst the different forms of unconventional gas, the greatest progress to date has been made on shale gas, thanks to major techno-economic breakthroughs in the US and the potential for exploitation elsewhere.

The impetus for and rapid development of the US shale gas industry is attributable to a suite of factors, including: 1) Good geological knowledge, which saved on costs; 2) Long experience with shale gas exploration and exploitation, which led to a step change in extraction technologies and economics; 3) Relatively low population densities that allowed for intensive drilling across vast areas; 4) Private property status of underground resources, which encouraged landowners to support shale gas; 5) A diversified and highly competitive energy sector accommodating a number of smaller and independent venture companies that continuously refined shale gas technology, along with a large number of service companies; 6) Various regulatory and tax incentives; and 7) A liberalised gas market, where every developer had access to pipeline capacity to sell its gas. Growing security and diversity of supply concerns and rising gas prices were also instrumental.

The rapid expansion of the US shale gas sector has spurred interest for shale gas development in other regions possessing shale deposits, including the EU. At the same time, concerns regarding the broader economic, environmental and social implications of developing a domestic shale gas industry have come to the fore.

Many of the factors for success in the US may be drawbacks in Europe. The key disadvantages appear to be the high population densities, the scarcity of innovative smaller players in the EU energy sector and the shortage of drilling equipment and trained staff. The geological knowledge at EU level is fragmented, and the geology itself seems to present more of a challenge than in the US. Experience of shale gas exploitation is very limited. As underground resources are the exclusive property of national governments, private initiatives are discouraged. The EU gas market and pipeline infrastructure is still largely monopolised by large companies that dominate the EU energy sector. EU gas imports are becoming increasingly diversified in a situation of lower gas prices. The shale gas potential in the EU is generally estimated as moderate, possibly compensating for declining indigenous conventional production. EU shale gas will also be more expensive than US shale gas as well as other feasible alternatives for the import of conventional and unconventional gas supply (e.g. from Arctic deposits).

The potential environmental externalities of current extraction technologies for shale gas are often viewed as the main threat to the future of the shale gas industry. The most important environmental concerns regarding shale gas production appear to be associated with water. They are the following: 1) Large freshwater demand. Although the absolute pressure of shale gas extraction on total water resources may be modest, it could become severe in regions that are already experiencing water deficits. This is particularly important for the EU, where water availability per capita is relatively low; 2) Contamination of freshwater, mostly by methane and fine particles; 3) Underground and surface pollution by hazardous chemicals, which are used as fracturing agents, and/or with heavy metals and radioactive elements mobilized by fracturing water; 4) Wastewater handling, treatment and disposal. The sustainable management of freshwater resources and wastewater streams requires an excellent knowledge of geology, prudent exploitation of shale gas deposits, full and complete disclosure of the chemical components that are employed, cautious land-use planning, stringent building and operational standards, and strict governmental control over operational safety and security.

Apart from water, other potential environmental conflicts of industrial exploitation of shale gas include: 1) Visual landscape disturbance; 2) Impacts on biodiversity and natural conservation, particularly potential conflicts with Natura 2000; 3) Higher noise levels; 4) Worsened local air quality; and 5) Seismic concerns.

The greenhouse gas performance of shale gas is generally poorer than that of conventional gas, but may be better than that of coal in favourable circumstances. This is largely due to fugitive methane emissions. There are cost-efficient techniques, such as flaring and capturing (better), which can significantly reduce fugitive emissions. Maintaining high building, operational and post-operational conservation standards is crucial, not only for cutting greenhouse gas emissions, but also for limiting and eliminating other environmental externalities of shale gas exploration and exploitation.

The application of state-of-the-art technologies or alternative shale gas extraction technologies, such as using liquefied petroleum gas or liquefied carbon dioxide and nitrogen instead of water as a fracturing method, may mitigate some, but not all of these environmental challenges. However, these novel technologies are still at the very early stages of development, and may bring other challenges, such as serious safety and security hazards or a worsening in greenhouse gas performance. In any event, given the typical long lead times for new technologies (e.g. it took approximately 40 years for shale gas to commercialise), these new technologies may not reach industrial-scale application by 2030 – which is the time horizon of this study - at least in the EU.

The socio-economic impacts of shale gas development, such as job creation, should always be the subject of a comprehensive cost-benefit analysis on a case-by-case basis, taking all direct and indirect consequences into account, whether they be positive or negative. Since there is no industrial-scale production of shale gas in the EU at present, drawing up quantitative projections about their related potential socio-economic impacts is extremely challenging. Direct extrapolation of the North American experience does not appear to be trustworthy, because of the large differences in geological, economic, social and regulatory conditions. Finally, not many genuinely independent and reliable analyses on the social consequences of shale gas exploitation were encountered in the course of the study.

Although the prospects for large-scale indigenous production of shale gas in the EU are uncertain, the EU can still benefit from shale gas. The EU is already benefiting from the shale gas boom in the US through the increased supply of liquefied natural gas, which was originally destined for the US, and improved contractual conditions for pipeline imports. A new generation of technologies for shale gas exploitation at lower costs and with smaller environmental footprints could also make indigenous shale gas deposits in the EU attractive in the longer term, beyond 2030. European energy companies may also wish to investigate options for prospective shale gas acquisitions outside Europe.

From the research point of view, the priority issues that need to be addressed in the EU in the short-to-medium term include improved mapping of shale gas resources across Europe and determination of: the extent to which the application of best available technologies and practices can mitigate key environmental concerns with hydraulic fracturing, in particular with regard to water use and pollution; potential social and economic costs and benefits of shale gas development; and the overall economic feasibility of shale gas development when using best available technologies.

1. BACKGROUND: WHY SHALE GAS BECAME A TOPICAL ISSUE

The highly volatile world oil and gas prices over the past few years have reawakened concerns about the security, reliability and affordability of energy supply worldwide. Global energy markets have gradually become extremely sensitive to events that sometimes have little to do with the energy sector. The supply of core energy products (oil, gas, coal) is becoming concentrated in the hands of a very limited number of countries. A large number of major energy-supplying countries are experiencing levels of political instability and varying degrees of unpredictability.

The geopolitical situation regarding gas supply is becoming particularly complicated. Although gas is more geographically dispersed than oil, the concentration of gas reserves is higher. While Saudi Arabia, Venezuela and Iran – the "top three" in the world in terms of oil reserves – account for 44% of global oil reserves, Russia, Iran and Qatar (the top three in gas reserves) actually control 53% of global gas reserves [6]. Iran is amongst the leaders in terms of both oil and gas reserves, with 10% and 16% of global reserves respectively. Given recent trends, Russia, Iran and Qatar might be the only large suppliers of gas worldwide by 2030. The geopolitical implications of such a scenario could be extremely challenging, especially in the light of the Fukushima nuclear disaster and the ongoing reconsideration of nuclear power in Europe and worldwide.

The market situation for gas was further complicated by the creation in 2001 of the Gas Exporting Countries Forum (GECF), which has grown stronger over time. Although the GECF is deliberately making efforts to distance itself from the image of a gas cartel, there are striking parallels with the OPEC oil cartel [71, 90]. Eight members of OPEC (out of a total of 13[1]) are also GECF members (out of a total of 14). In fact, OPEC already influences gas markets in two ways. First, in some regions of the world, particularly in Europe, the gas price under long-term supply contracts is indexed to the price of oil. As OPEC (still) has some control over oil prices, it therefore also exercises some control over gas prices. Second, technologically, oil recovery is accompanied by some degree of gas recovery (associated gas). Hence, OPEC can directly contribute to gas supply [62]. At present, a large portion of associated gas is wasted (flared). The oil producing countries flare approximately 150 billion m^3 of gas per year, which is equivalent to more than 5% of world gas production, 30% of EU gas demand and 75% of Russian gas exports [3, 120]. Capturing and selling this gas is liable to have a tremendous impact on the world gas market, especially in view of the very large amounts of gas being flared in key oil and gas producing countries [3]. Russia alone accounts for almost one third of all flared gas worldwide [3].

The GECF could potentially have an extremely firm grip on the market. The GECF controls 73% of world gas reserves and 42% of world gas production [3] – equivalent to OPEC's share of world oil production [6]. The greatest risk comes from the GECF's extended control – amounting to 85% - over the global flexible gas trade in liquefied natural gas (LNG) [3]. The large overlap between GECF members and top flaring countries [3] indicates that there is additional potential to boost their combined supply power. Russia is a member of the GECF, despite the fact that historically it has abstained from OPEC membership.

Faced with such a prospect, the industrialised countries that possess modest gas reserves have begun to look for alternative ways to secure their energy supply and economic growth. Owing to progress in technologies, it has become cost-efficient to exploit deeper and less abundant deposits of gas that are generally more

[1] Indonesia is still considered to be an OPEC member, although the country announced in 2008 that it would leave the cartel.

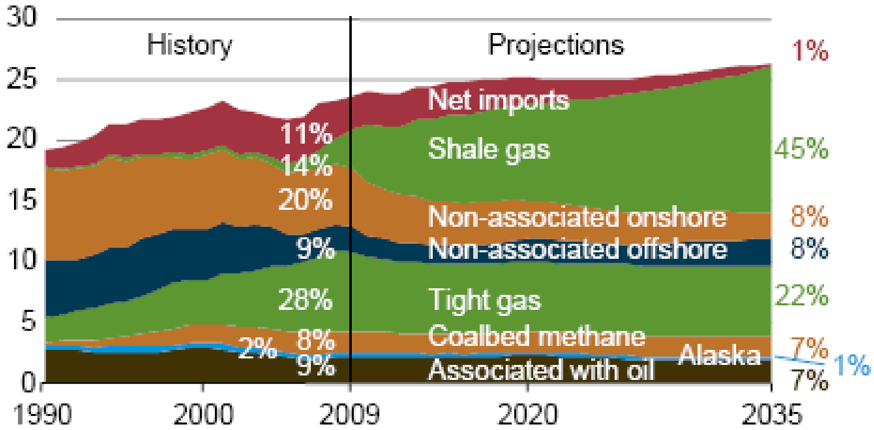
challenging to extract – so-called "unconventional gas". Of all the types of unconventional gas, shale gas in particular has attracted attention. The rapid expansion of the US shale gas sector has spurred interest for shale gas development in other regions possessing shale deposits, including the EU. At the same time, concerns regarding the broader potential economic, environmental and social implications (including potential impacts to human health) of developing a domestic shale gas industry have come to the fore.

2. DEVELOPMENT OF THE US SHALE GAS INDUSTRY AND COMPARISON WITH EU CONDITIONS

The following analysis lists the main factors that have influenced the development of shale gas deposits in the US and the likelihood of this being replicated in the EU.

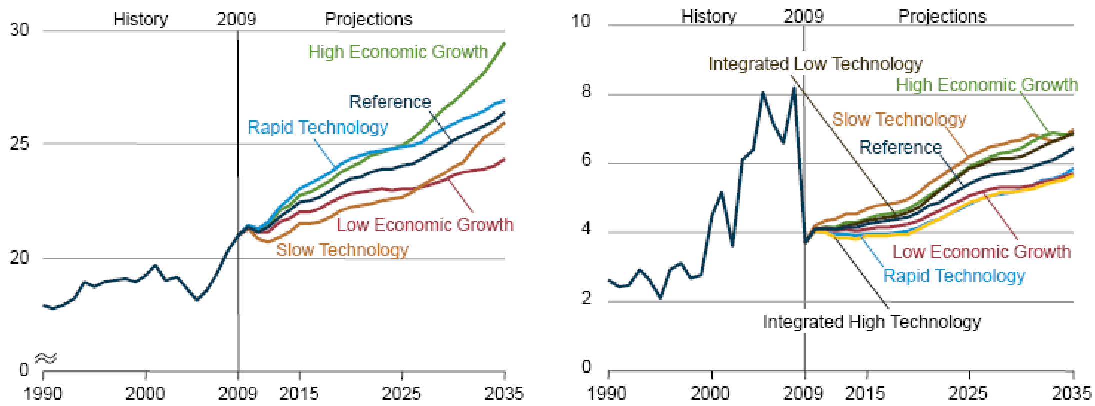
Security of supply: As the largest consumer of natural gas in the world, the US is responsible for almost 22% of world gas demand [6]. Prior to the development of the US shale gas industry, domestic production of gas was declining (***Figure 1***), with imports making up the difference in the widening gap between production and demand. The US shale gas revolution has done much to reverse this trend - ***Figure 1***.

Figure 1: *US gas supply 1990-2035 (trillion cubic feet / year) [99]*



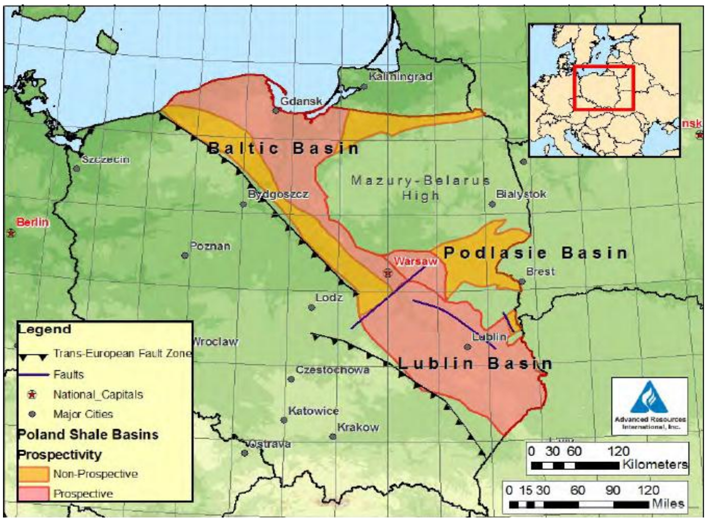
Recent US reference case projections estimate a steady growth in shale gas production. It is forecast that shale gas will account for 47% of total US gas production by 2035, compared to 16% in 2009, and less than 2% in 2000 [100]. However, production and prices may vary significantly, depending on the pace of technological development, the size of technically recoverable shale gas reserves, economic growth and trends in world supply/demand balance - ***Figure 2***.

Figure 2: *Left: Total US gas production under five scenarios (trillion cubic feet); Right: Annual average prices for gas in seven scenarios (US dollars per thousand cubic feet), 1990-2035 [100]*



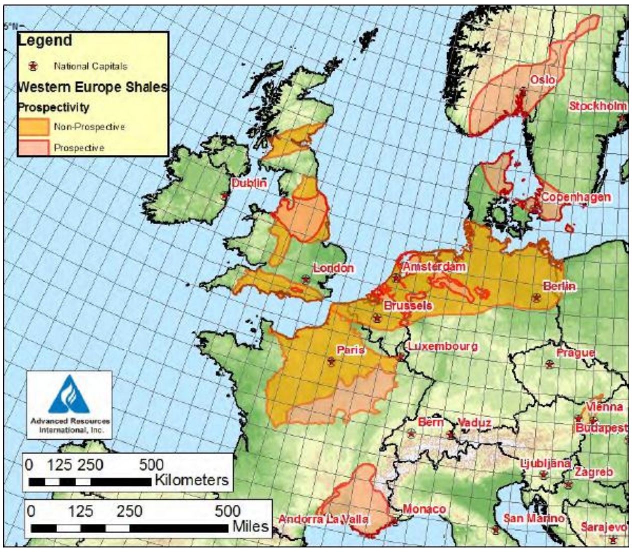
The EU accounts for roughly 1% of global conventional gas reserves [6]. Although gas accounts for one quarter of gross domestic energy consumption [26], EU gas production is declining, even as consumption continues to rise [6]. Shale gas is being considered as an option to increase indigenous gas production, but it is not yet developed on an industrial scale. Among the EU Member States, Poland appears to be most optimistic about developing domestic shale gas resources. According to US estimates [102], Poland holds the largest reserves of shale gas in the EU. These are distributed beneath a large area (***Figure 3***), with the majority deemed to be "prospective". Roughly one hundred concessions have been granted, mainly to US companies including ExxonMobile, Chevron, ConocoPhilips, and Marathon Oil [45, 150, 153]. The first shale gas exploration project in Poland commenced in 2010. Exploratory drilling is expected to yield better estimates of shale gas potential within 4-5 years, while large-scale production may be feasible within 10-15 years [114].

Figure 3: *Proven (darker fields) and potential (lighter fields) shale gas deposits in Poland [102]*



Besides Poland, a number of other EU Member States are deemed to have shale gas deposits that may be economically exploitable – ***Figure 4***. However, the reserves in all these countries are noticeably smaller than in Poland. This fact makes the large-scale industrial production of shale gas uncertain in these countries by 2030 – which is the time horizon of this study.

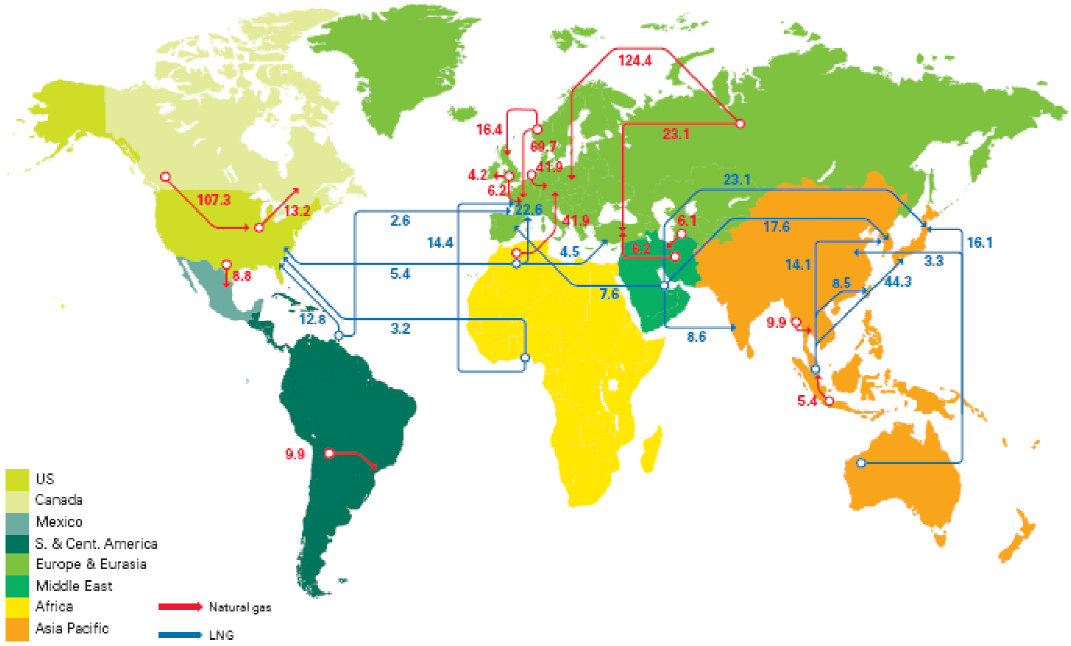
Figure 4: *Shale Gas Basins of Western Europe[2] [102]*



[2] Shale gas basins in the Eastern part of the EU (except Poland) are far less promising. The only basins that have been assessed as having some exploitation prospects are in the Baltic States. Romania and Bulgaria may also have potential basins (not yet assessed). Significant availability is forecast in Ukraine [102].

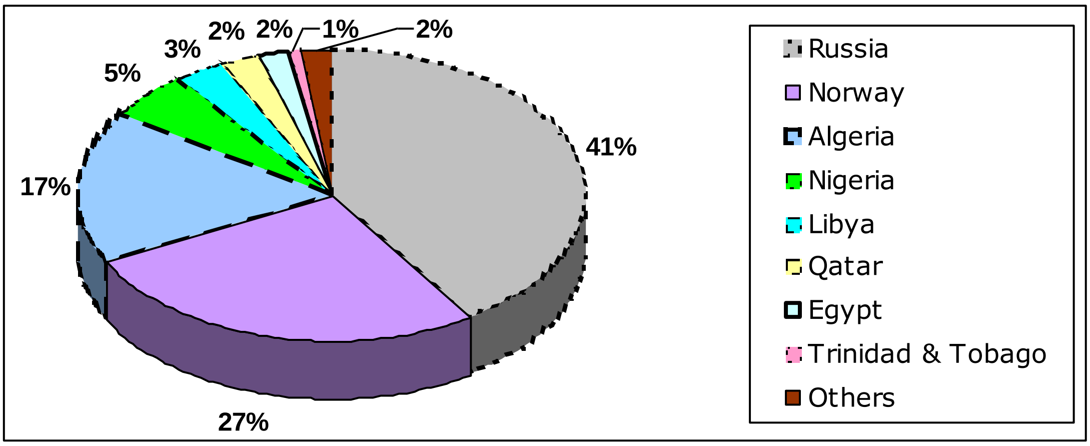
Diversity of supply: Due to the physical properties of gas, its transportation and handling are more restricted compared to oil. For this reason, the import options available to the US are very limited. Apart from pipeline imports from Canada, the only feasible alternative is liquefied natural gas (LNG) - ***Figure 5***. With the GECF's increasing power and its tight grip on the world LNG trade, such a growing dependence on a potentially cartel-like supplier could have serious economic and geopolitical implications. These concerns are likely to have speeded up the development of the US shale gas sector.

Figure 5: *Major gas trade movements the world in 2007[3] (billion m^3) [5]*



The EU is heavily dependent on gas imports, which currently account for 60% of domestic consumption [35]. However, over the years, the EU has managed to diversify its gas supplies to a considerable extent, although it still imports around 40% of all its gas from Russia – ***Figure 6***.

Figure 6: Breakdown of EU natural gas imports by origin in 2007 (%) [49]



Currently, the EU imports its gas through pipelines from Russia, Norway, Algeria and Libya, whereas LNG is shipped to Europe from Norway, Nigeria, Algeria, Libya, Egypt, Qatar and Trinidad & Tobago. The EU is considering a number of additional

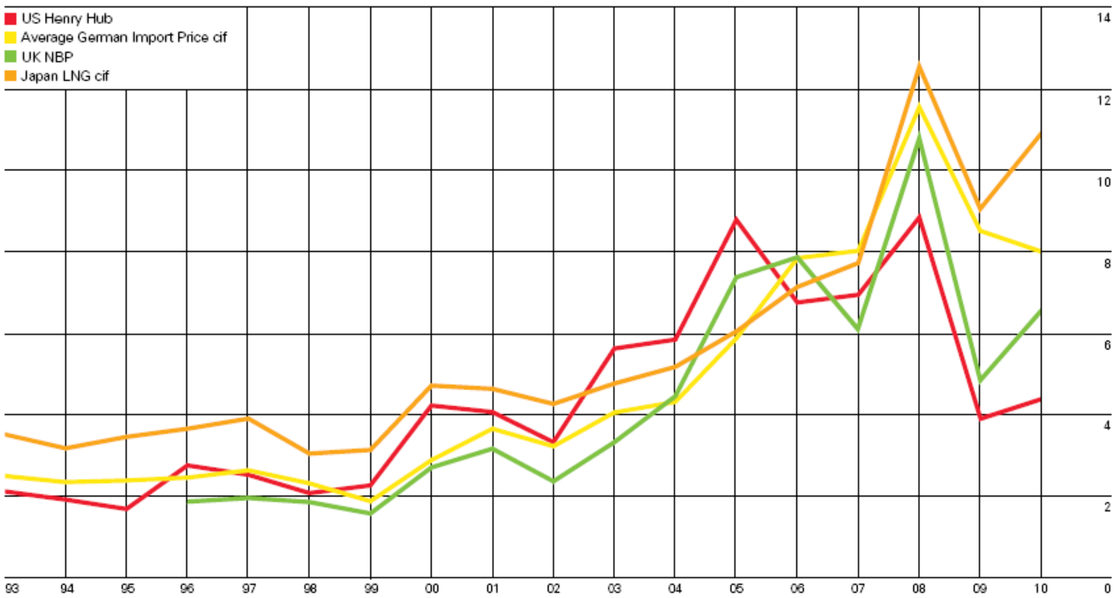
[3] 2007 marks the peak in US LNG imports.

pipeline supply routes and LNG receiving terminals. Concerns about the diversity of supply in the EU compared to the US may, therefore, not provide a strong enough impetus for the development of shale gas at EU level. However, the potential impact of shale gas on import dependence may vary from one EU Member State to another. According to some analysts, under a high gas demand scenario shale gas could reduce France's dependence on gas imports by 40% by 2050, while Poland could become self-sufficient in gas [17].

One indication of the changing structure of EU gas imports was the first ever importation – albeit small – of LNG from the US in 2010. US exports have been made possible owing to the expansion of shale gas and the resulting oversupply in the US market in particular. With the projected growth in US indigenous gas output, there will be a steady drop in US gas import needs (***Figure 1***) and the US may become a (major) LNG exporter [48]. Increasing numbers of LNG supply facilities, originally built to cater for the US market, will most likely be available in the future to other gas users around the world. The drastically reduced import needs in the US have already led to the shift of considerable volumes of LNG, originally destined for the US, to the European market [43, 74, 87]. The increase in LNG supply has also affected alternative pipeline supplies and contracts, making them more flexible [68, 75, 101, 121], to the benefit of gas buyers. For example, Russia has had to lower gas prices for the European market and to allow a fraction of its sales to be indexed to spot gas market or regional market hubs, rather than to oil prices [79, 101]. Depending on the availability of LNG, the tendency to actually make gas contracts fairer may become more pronounced in the future. The EU is often quoted as being one of the main winners in such a scenario [43, 68, 74, 78, 79, 87]. To sum up, the EU is already benefiting significantly, although indirectly, from the US shale gas boom.

Gas prices: Natural gas production from shale deposits is typically more costly than conventional gas production. The accelerated development of shale gas in the US coincided with - and was indeed triggered by - a period of rising (and generally high) gas prices worldwide [74]. Between 1998 and 2005, US gas prices quadrupled – see ***Figure 7***. Besides making gas projects more attractive, high gas prices partially compensated for the initial capital-intensive mistakes made due to lack of experience (learning-by-doing) in the early stages of development of the US shale gas industry [74].

Figure 7*: Average annual gas prices in different markets (US dollars per million Btu, MBtu) between 1993 and 2010 [6]*



In theory, the price of energy goes down in times of financial and economic crisis. However, this phenomenon was not so pronounced or has even been absent in the past few years, mainly for geopolitical reasons. World energy markets are likely to become increasingly unpredictable [52, 90]. In a situation of financial and economic uncertainty, it would be challenging to commit substantial and sustained investment to less proven undertakings such as shale gas [74]. Conventional natural gas production is generally a more mature technology than shale gas production. The major gas suppliers – the GECF and Russia – may be in a position to supply gas to Europe, at least until 2030, at such (low) price levels so as to hold back the development of indigenous EU reserves of shale gas [18, 75].

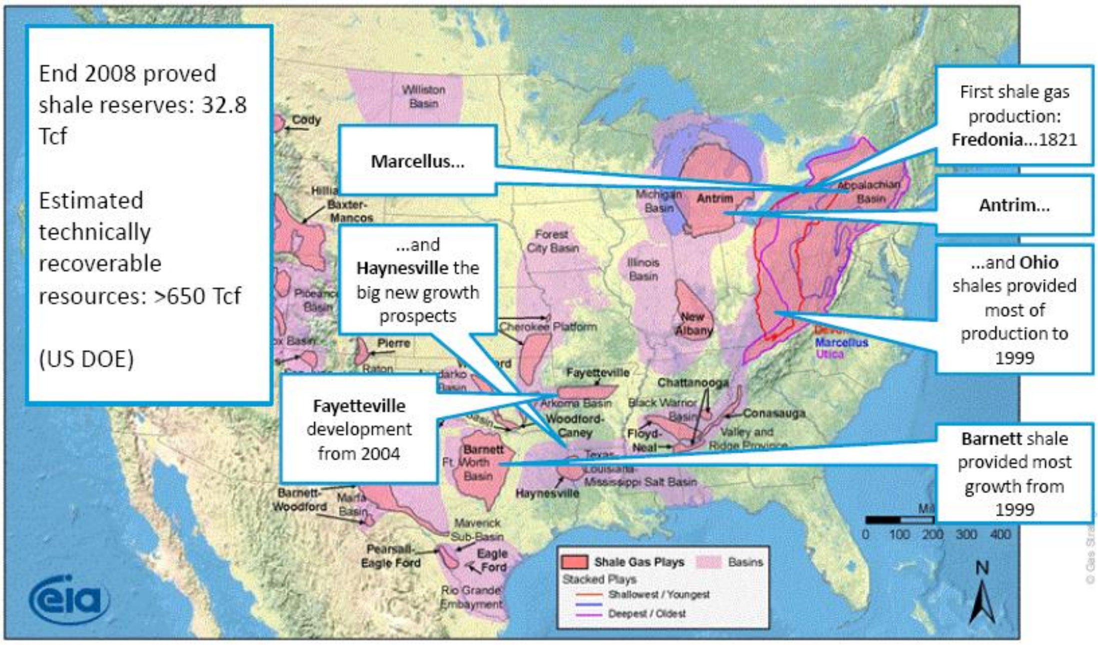
Geological knowledge of shale deposits: The US Geological Survey (USGS, www.usgs.gov), a specialised scientific agency of the US Department of the Interior, is a reference centre for high-quality geological data, information and analysis for the US and the rest of the world. Within the USGS, the Energy Resources Program undertakes "to understand the processes critical to the formation, accumulation, occurrence and alteration of geologically based energy resources; to conduct scientifically robust assessments of those resources; and to study the impact of energy resource occurrence and/or production and use on both environmental and human health" [109]. The contribution of the USGS to the thorough understanding of shale gas geology in the US has been critical to the success of the shale gas industry [126]. In particular, it has been crucial for reducing extraction costs by facilitating targeted exploration activities.

Shale gas deposits in the EU are spread across large areas, often beneath several Member States. The extent of geological knowledge at EU level is less advanced than in the US [41, 44, 59, 74, 75]. There is no comparable, consistent and comprehensive EU geological repository, although Member States do have their own geological services. In addition, EU geology in general seems to be more complex [40, 59, 74, 76, 90, 117] – shale gas deposits tend to be smaller and deeper [18]. The situation may differ considerably across the EU – in some areas, shale gas might be more easily extracted than in other areas. The main research priorities in this regard are to derive detailed information on the geological characteristics of EU shale gas deposits and how they influence the economic feasibility of recovery.

Experience with shale gas exploration and exploitation: Although the US shale gas revolution only spans the past decade, the very first attempts to develop shale gas deposits in the US date back to the nineteenth century – ***Figure 8***. Industrial-scale exploitation of shale gas formations began almost 40 years ago, triggered by the First Oil Shock (1973). Technologies were being continuously developed and refined. This sustained and consistent process led to a step change in the techno-economics of shale gas recovery in the 2000's - ***Figure 1***. Underpinned by the high world gas prices (***Figure 7***), this technological breakthrough resulted in a massive increase in gas supply from shale deposits – ***Figure 1*** [59, 76, 87, 98, 103].

By contrast, shale gas exploration and exploitation are in the very early stages of development in the EU. Both experience and infrastructure are scarce. Experimental drillings have been conducted in several Member States, including the UK, Poland, Germany and France. A major hurdle to EU shale gas exploration is the insufficient availability of equipment (drilling rigs, in particular) and trained staff, which is mainly due to the far smaller number of mid-stream services and service companies than in the US. In theory, this shortage could be overcome, but in any event the catching-up process would be costly and time consuming. From the energy industry perspective, the scarcity of equipment and personnel is quoted as a major, if not the most important, bottleneck for shale gas development in the EU in the foreseeable future [18, 19, 21, 41, 51, 59, 74, 86, 90, 95, 121].

Figure 8: *Shale gas development in the US (lower 48 states) [21]*

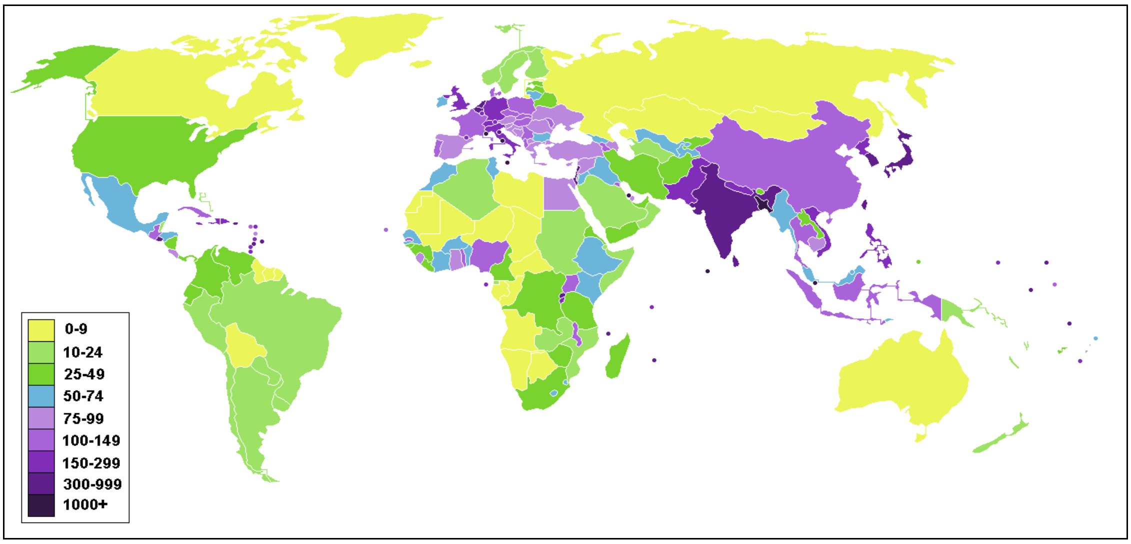


<u>*Population density*</u>: Shale gas deposits are typically less concentrated and are distributed across larger areas than is the case with conventional gas deposits. Shale gas exploitation therefore requires higher density drilling over correspondingly greater surface areas [21] compared to conventional gas extraction. For example, almost 4 000 vertical and 7 000 horizontal wells were drilled in the Barnett shale gas field between 1990 and 2008 [82]. Shale gas wells also tend to become exhausted more quickly than conventional gas wells [21]. The productivity of horizontal wells declines particularly rapidly, i.e. by almost 50% from the first to the third year of operation [66]. The technological requirement for more intensive drilling to extract shale gas compared to conventional gas involves the increased likelihood of conflicts with alternative land uses.

As ***Figure 9*** shows, the US has a relatively low average population density – namely 32 inhabitants per km^2 [26]. To date, most US shale gas production has occurred in the Barnett shale gas field in Texas, where population density is only slightly higher than the US average – at 38 inhabitants per km^2. Competition for surface access or social opposition in this particular region has not significantly affected the development of the industry. As production continues to expand into far more densely populated areas, such as the Marcellus Shale gas field in the North-East US, it remains to be seen what socio-economic impacts such competition may have and how these can be resolved.

Europe is far more densely populated than the US, with 113 inhabitants per km^2 [26], although population densities vary both between and within Member States. Given the intensive drilling over a large surface area and the substantial support infrastructure required for exploiting shale gas, high population densities may present a major barrier to the large-scale development of shale gas extraction in many parts of the EU [40, 41, 75, 111, 117, 121] due to the increased likelihood of conflict with other land users. For example, the US Barnett shale gas field in northern Texas consists of roughly 8 000 wells spread over a total area that is comparable to the combined area of Benelux (Belgium, the Netherlands and Luxembourg) [114]. <u>It should therefore be a priority research objective to map shale gas reserves versus population densities and alternative uses of land in order to identify areas of potential conflict.</u>

__Figure 9__: World population density map (inhabitants per km^2)



Source: http://urbancongress.wordpress.com/

Legal status of underground resources: Under US legislation, the property rights to underground resources, including shale gas deposits, belong to landowners. US landowners therefore have an economic interest in the development of shale gas resources underlying their property via lease payments. In the case of the Barnett field, shale gas often represents a key opportunity, if not the only economic opportunity, for landowners to earn a reasonable return on property [59, 89, 113].

The property rights to underground resources in the EU are state-owned and regulated at Member State level. Shale gas exploration and exploitation may therefore go against landowners' interests and hence may encounter strong opposition. It is difficult to predict the extent to which the interests of property owners may present an obstacle to potential shale gas projects. Major issues arise as to the kind of compensation schemes that might be envisaged to facilitate acceptance of shale gas development by the public, and at what cost in terms of money and time [41, 51, 59, 90, 117, 121].

Energy sector structure: Historically, in the US, major energy companies have concentrated their efforts on exploiting conventional gas reserves, whereas the development of unconventional deposits was largely beyond their core sphere of interest [21]. A number of smaller, more flexible and innovative independent energy companies filled this gap. Their continuous and consistent research and development of extraction techniques, assisted by rising gas prices (***Figure 7***) has done much to facilitate the advent of the large-scale commercial exploitation of shale gas resources in the US [59, 79, 90].

Unlike the US energy sector, where there are many large and small players, the EU energy sector is dominated by a few large companies. Their investment portfolios sometimes include shale gas, but only as a minor component in their overall diversification strategies. There are practically no smaller venture companies in the EU that appear keen to pursue sustained and consistent investment in shale gas technologies and deposits. On the other hand, the potential involvement of big EU energy companies in future shale gas exploration and exploitation could speed up progress, due to their large capital availability and greater capacity to hedge market risks in the more regulated EU markets, as the next paragraph explains [18, 21, 87, 95].

Ownership/operation of pipelines and access to pipeline capacity: Every gas producer in the US, regardless of size, can place competitive bids for pipeline throughput capacity in a free market situation. The transport capacity is not exclusively reserved for the pipeline owner or for a few short-listed large producers. Such a market structure ensures that smaller, independent shale gas developers have a secured access to the gas market, thereby guaranteeing a channel to reimburse their upstream investment. Without such a liberalised market structure, the US shale gas boom would have been significantly impeded [59, 79, 90].

The EU gas market is currently far less liberal than that of the US. There are still a number of limitations as far as access to transport capacity is concerned. Although the physical infrastructure may be in place, it is not accessible to all operators [21, 59]. The EU's Third Gas Package [31, 33, 34] aims to eliminate the remaining restrictions in order to create a truly liberalised single market for gas. However, not enough progress has yet been achieved at Member State level. Eighteen of the twenty-seven EU Member States face court proceedings for non-compliance with EU internal energy market regulations [25]. Such market imperfections may discourage investments in the development of shale gas by stakeholders - regardless of their size - who do not possess pre-booked or guaranteed transport capacity [90, 95, 121].

Regulatory framework for the exploration and exploitation of shale gas: The US shale gas industry is exempt from many federal regulations, leaving most of the oversight to state governments [24, 61, 92, 103], which have at times been hard pressed to keep up with the rapid growth of the industry. US state authorities have generally been favourably disposed towards shale gas development as a means of promoting economic development [37, 92, 113]. Support also included favourable tax incentives for the upstream sector[4] [59]. This preferential tax treatment has encouraged smaller and innovative independent companies to pursue shale gas exploration and development [79, 90].

The current legislative framework in the EU was largely drafted for the exploration and exploitation of conventional gas deposits. As observed by Geny [59], its components, such as definitions, concepts and permit procedures, may sometimes not correspond to the specifics of unconventional gas, including shale gas. For example, the exploration and exploitation of a single shale gas field in Europe may involve obtaining several permits through several different regulatory procedures if the field is located beneath several (neighbouring) countries. These countries may have quite different regulatory regimes, which can complicate and delay exploration and exploitation. Furthermore, the exploration licences are typically granted for strictly pre-defined blocks. Such a procedure may impede the quick and efficient continuous search for layers that are rich in shale-gas, and make it even harder for developers to obtain licences for blocks [59].

Concerns about the security and diversity of energy supply, on the other hand, are putting growing pressure on the EU. In view of these concerns, the European Commission has stated in its vision for 2020 that "the potential for further development of EU indigenous fossil fuel resources, including unconventional[5] gas, exists and the role they will play must be assessed in all objectivity" [124]. In keeping with the subsidiarity principle, the Commission has not earmarked any specific form of unconventional gas, because the choice of fuel mix remains the

[4] The Intangible Drilling Cost (IDC) Expense Rule has had a particularly strong positive impact on shale gas pioneers. IDCs which are incurred during drilling and initiating production (such as wages, supplies, contractor services, etc.) and for which there is no salvage value, account for 70% of total well development costs. According to the IDC Expense Rule, if IDC are expensed, they are deducted against tax liability in the year in which they are incurred instead of being distributed across future years. In this way, smaller companies secure enough cash to re-invest into shale gas development [79].

[5] Authors' underlining

sovereign domain of the EU Member States. The European Council has further developed the Commission's proposal and called for an assessment of Europe's potential for sustainable extraction and use of conventional and unconventional (shale gas and oil shale) fossil fuel resources [27]. The Transport, Telecommunications and Energy Council later re-affirmed the European Council's position, but added that "in order to further enhance its security of supply, the EU's potential for sustainable extraction and use of conventional and unconventional (e.g. shale gas, oil shale) fossil fuel resources should be assessed, in accordance with existing legislation on environment protection" [14]. In this context, various European Commission services, such as the DG Energy (ENER), DG Environment (ENV), DG Climate Action (CLIMA) and DG Joint Research Centre (JRC), are currently conducting comprehensive analyses to ascertain the extent to which current legislation in the EU is conducive to the development of shale gas resources, and what modifications might be necessary in order to ensure that any such development is sustainable. Nevertheless, to date there is no dedicated legislative framework for shale gas development at EU level. Concurrently, the EU has put forward ambitious alternative energy goals for renewable energy sources [30] and energy efficiency.

The above analysis suggests that the role of indigenous shale gas in the future energy mix of the EU may not be so decisive for European and world gas markets compared to the role of US shale gas. Such a hypothesis is underpinned by various independent estimates (***Figure 10*** and ***Figure 11***), which come to rather similar conclusions that shale gas deposits in the EU are much smaller than US deposits. The EU's share of the assumed global shale gas reserves ranges between 4% [***Figure 10***] and 11% [102], which is larger than the corresponding EU share of 1% of world conventional gas reserves. However, it does not appear large enough to evolve into a gas game-changer for the EU as it did for the US [86, 117], unless very high gas prices (above 8.0-9.0 USD/MBtu [19, 75, 121]) continue for a long period of time [18]. Moderating the impact of indigenous shale gas exploitation for the EU as a whole would be a minor consideration [29, 17]. However, the potential contributions of shale gas may differ considerably from one Member State to another [161]. Some recent scenarios predict that shale gas might contribute 5% of EU production and 2-3% of EU consumption in the coming decades [29]. Other countries in the world, such as Canada and China [41, 49, 68, 82, 87, 90], may be better positioned than the EU for shale gas exploitation.

Figure 10: *Regional distribution of tight sand and shale gas resources [3]*

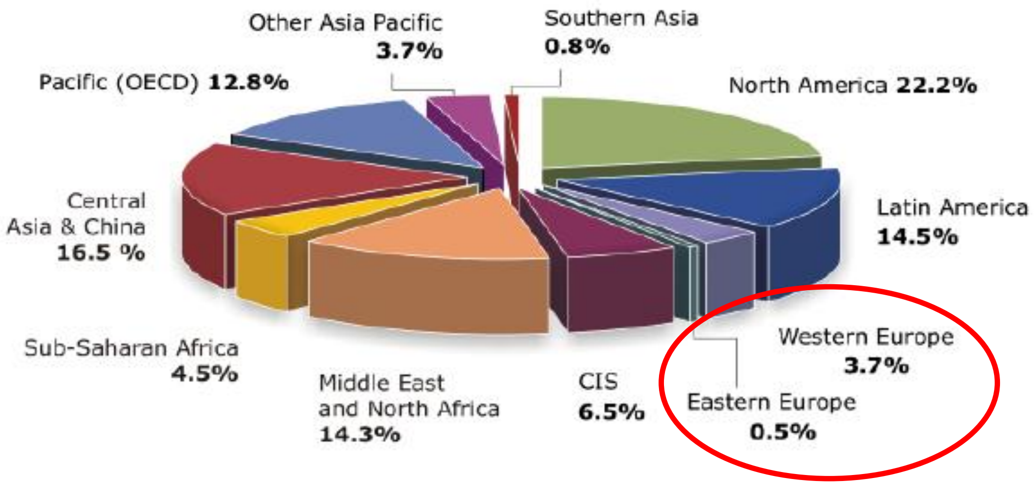
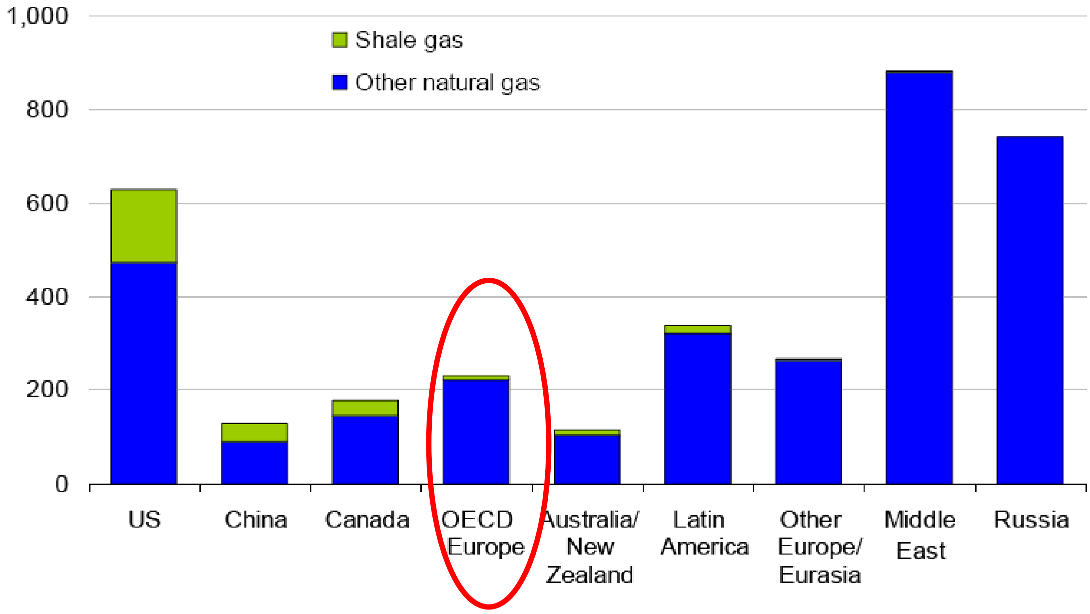


Figure 11: *Projected total global natural gas production, including shale gas production, in 2030, in billion m³ [82]*



Summary: The impetus for and rapid development of the US shale gas industry is attributable to a suite of factors, including: 1) Good geological knowledge that helped reduce costs; 2) Long experience with shale gas exploration and exploitation, which led to a step change in extraction technologies and economics; 3) Relatively low population densities that enabled intensive drilling across large areas; 4) Private property status of underground resources, which motivated landowners to support shale gas; 5) Diversified and highly competitive energy sector which accommodates a number of smaller and independent venture companies that continuously refined shale gas technology, along with a large number of service companies; 6) Various regulatory and tax preferences, which helped to rapidly kick-start the shale gas industry; 7) A liberalised gas market, where every shale gas developer had access to pipeline capacity to sell its gas. The growth of the US shale gas industry has also been facilitated by the growing security and diversity of supply concerns and rising gas prices.

Many of the factors for success in the US are likely to be experienced as drawbacks in Europe. The key disadvantages in Europe appear to be the high population densities, the lack of innovative smaller players in the EU energy sector and the shortage of drilling equipment and trained staff. The geological knowledge at EU level is fragmented and the geology itself seems to be more challenging than in the US. There is very little experience of shale gas exploitation. Underground resources are the exclusive property of national governments, with the result that private initiatives are discouraged. The EU gas market and pipeline infrastructure is still largely monopolised by big companies that dominate the EU energy sector. EU gas imports are becoming increasingly diversified against a backdrop of lower gas prices. The shale gas potential in the EU is generally estimated to be modest. EU shale gas will also be more expensive than US shale gas.

3. ENVIRONMENTAL DIMENSIONS OF SHALE GAS EXPLOITATION

Until recently, the environmental implications of shale gas exploration and exploitation received little consideration. With the accelerated development of shale gas production, these externalities are starting to attract greater attention. Concerns about the safety and environmental compliance of shale gas production were, in part, triggered by the 2010 British Petroleum's Deepwater Horizon oil platform incident in the Gulf of Mexico [74, 89]. The US Department of Energy has ordered a comprehensive assessment of challenges, including the environmental challenges, of extended shale gas development [88, 104]. The US Environmental Protection Agency is also investigating the issue. All of these initiatives are driven by the growing realisation that shale gas development may be hampered by environmental concerns in the future [44, 45, 47, 54, 59, 75, 76, 89, 90, 92].

The assessment of environmental risks is even more relevant to the EU, where sensitivity about the environment is generally greater than in the US [86, 87]. Several studies have been carried out or are underway on this matter. A recent report by the Oxford Institute of Energy Studies [59] provides a general overview of the EU regulatory framework and contains a regulatory analysis for several EU Member States (the Netherlands, Germany, Poland). A study, produced at the request of the European Parliament [29], provides a brief overview of potential environmental issues related to shale gas development within the current EU regulatory framework. Amongst its conclusions, the study identifies serious gaps in the existing EU legislative frameworks that could potentially apply to shale gas development. In particular, the study has noted that the threshold for the Environmental Impact Assessment of gas projects is currently set at 500 000 m^3 of gas extraction per day, which is well above any feasible industrial yield of shale gas in Europe. The European Environment Agency has also discussed the potential environmental implications of shale gas, in particular as far as contamination of ground and surface water is concerned [28]. Other relevant studies include reports from the Tyndall Centre for Climate Change Research and the European Centre for Energy and Resource Security [96, 75]. Various European Commission services, in particular DG Environment (ENV) and DG Climate Action (CLIMA), are also carrying out detailed studies on the environmental and regulatory implications of potential large-scale shale gas extraction in the EU. The following analysis aims to summarise the likely environmental concerns of shale gas exploitation in the EU from a broader sustainability perspective.

Freshwater consumption: Consumption of freshwater for high-volume hydraulic fracturing is often cited as a primary drawback of current shale gas extraction technologies [21, 68, 77, 86, 87, 92, 98, 121]. The US Environmental Protection Agency (EPA), mandated by Congress, has launched a comprehensive study of the freshwater footprint of shale gas production [108]. The final results of this study are expected by 2014 [81].

The North American experience suggests that there may be wide variations in the use of freshwater – ranging from 1 500 to 45 000 cubic metres per well [29]. These variations depend on the particular geology and structure of the field in question [112]. Wells may also require re-fracturing during their lifetime in order to improve production rates [29, 96]. Some wells may be re-fractured up to ten times [29].

Current estimates of the scale of water use for shale gas exploitation are contradictory. For example, according to one source, water use for shale gas exploitation in the Barnett shale gas field accounts for roughly 25% of the total water demand for Texas county[6] [29], while another source suggests that water usage accounts for only 0.1-0.8% of total water use across US shale gas regions - ***Figure 12*** [16, 103].

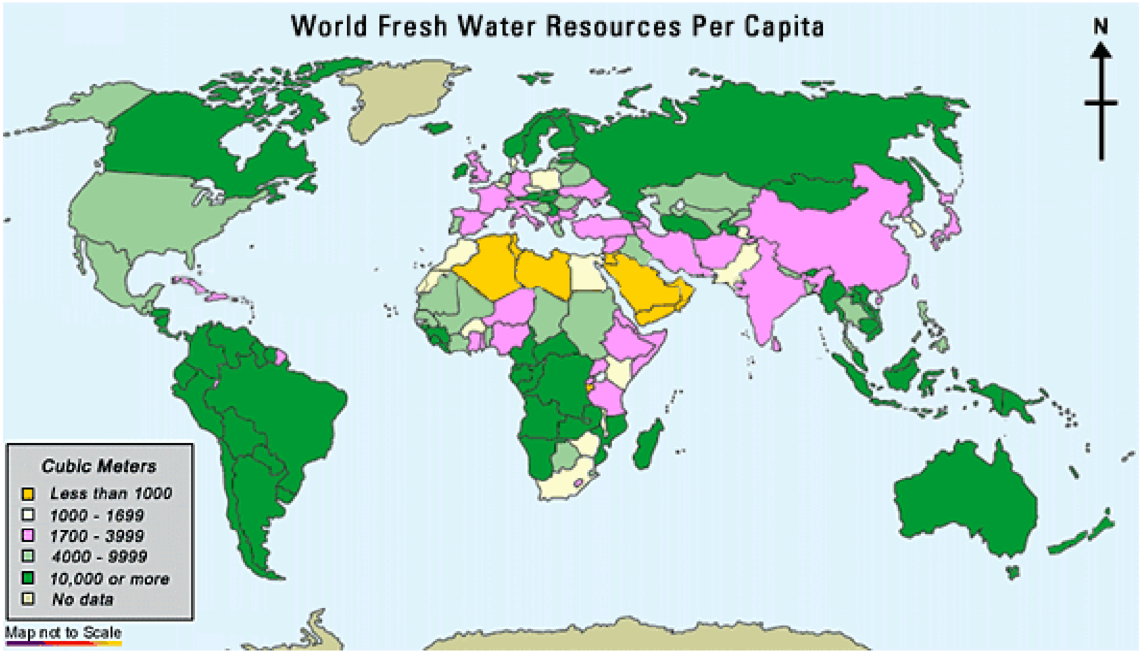
Figure 12: *Comparative water usage in major shale plays [77]*

Shale gas plays	Public supply	Industrial / Mining	Irrigation	Livestock	Shale gas
Barnett, TX	82.7%	3.7%	6.3%	2.3%	**0.4%**
Fayetteville, AR	2.3%	33.3%	62.9%	0.3%	**0.1%**
Haynesville, LA/TX	45.9%	13.5%	8.5%	4.0%	**0.8%**
Marcellus, NY/PA/WV	12.0%	71.7%	0.1%	<0.1%	**<0.1%**

Currently, there are no reliable comparisons of the water footprint of shale gas versus other energy sources. Some estimates of average life cycle water use (m^3/GJ) for conventional energy sources calculate the following figures: 0.164 for coal, 0.086 for uranium, 1.058 for crude oil, and 1.090 for natural gas [60]. While the water footprint of shale gas will clearly be higher than that of conventional natural gas, it will be necessary to conduct similar thorough and comprehensive research on water consumption in order to ascertain its performance relative to coal and oil, for example. In particular, such research should consider the relative importance of removals of water from the hydrological cycle due to the deep-well injection of wastewater against comparable removals for other energy technologies.

The overall pressure of shale gas extraction on freshwater availability at the level of EU Member States is difficult to predict. So far, there is no industrial-scale production of shale gas in the EU. As already stated, the shale gas geology in Europe appears to be far more complex than in North America, and may require denser, deeper and more sophisticated drilling. Simple logic suggests that the water consumption in the EU may be greater than in the US. In any event, the availability of freshwater in the EU is generally lower than in North America (**Figure 13**).

Figure 13: *Freshwater resources per capita in the world*

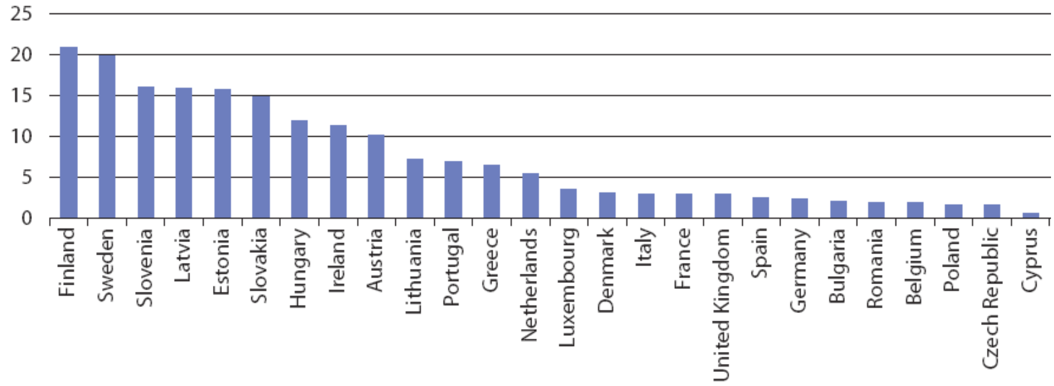


Source: http://www.printablemapstore.com/

[6] 17 billion litres for shale gas out of a total of 67 billion litres of total water use [29]

Only nine EU Member States possess larger freshwater resources per capita than the US, which has 9 344 m^3 per capita per year [119] – ***Figure 14***. The environmental (and social) implications of water use for shale gas exploitation needs to be assessed carefully, on a case-by-case basis. While the overall water footprint of shale gas production might be negligible in terms of national per capita water resources, on a local scale the production of shale gas could have a substantial impact on freshwater supply. If exploitation occurs in areas where local populations are already experiencing water deficits, the incremental pressure on available water resources could be severe [59, 77, 96, 98, 103]. Seasonal variations in water supply should also be taken into account [16].

Figure 14: *Freshwater resources per capita in EU Member States based on a 20-year average (1 000 cubic metres) [62]*



Note: Luxembourg – estimate; Malta - not available

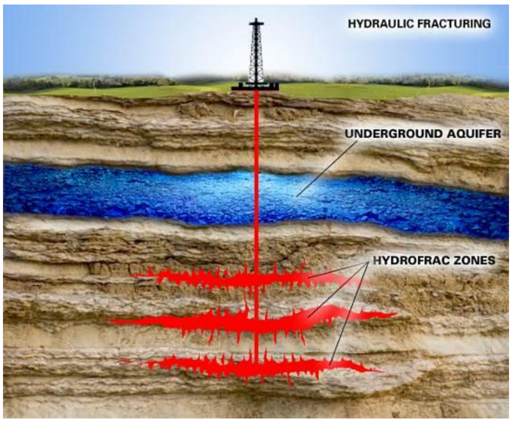
Freshwater pollution: Another environmental concern associated with current shale gas technologies that is being widely discussed is the potential pollution of freshwater resources [21, 50, 51, 68, 87, 88, 92, 96, 98]. The majority of all the incidents reported as a result of drilling shale gas wells in the US from 2005-2009 are related to contamination of ground and surface waters (***Figure 15***). The extent to which the risks of such pollution are manageable is a matter of ongoing debate. Potential risk mitigation measures include excellent geological knowledge, strict compliance with safety and security prescriptions, and the application of state-of-the-art technologies (seismic, drilling, fracturing, gas capturing, etc.) that are properly run by well-trained and experienced technical and managerial staff [22, 77, 87, 103, 121].

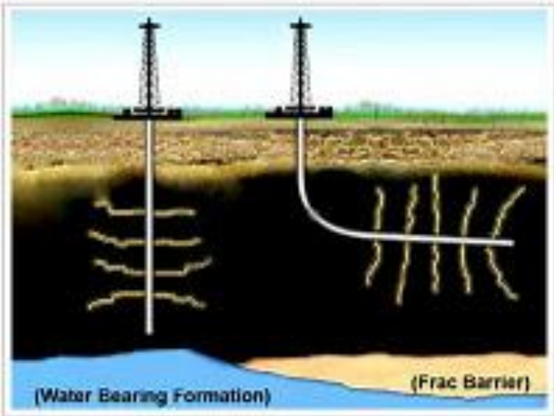
Figure 15: *Widely reported incidents involving shale gas well drilling in the US, 2005-2009* [77]

Type of Incident	Number	% of total
Groundwater contamination by natural gas or drilling fluid	20	47
On-site surface spills	14	33
Off-site disposal issues	4	9
Water withdrawal issues	2	5
Blowouts	2	5
Air quality	1	2

An excellent knowledge of geology is the major prerequisite in order to avoid groundwater contamination when exploring and exploiting shale gas fields. This is mainly required to map the location of shale gas layers in relation to underground aquifers. In by far the majority of cases to date, the shale gas layer was located beneath underground aquifers [9, 20, 77] – **Figure 16** (left). However, it is possible to have shale gas layers that are above (**Figure 16**, right), or even at the same level (including bordering) as underground aquifers.

Figure 16*: Shale gas formations located beneath (left) and above (right) underground aquifers*





Sources: http://coto2.wordpress.com/ http://crudeoiltrader.blogspot.com/

The hazards with respect to groundwater contamination in these three cases are different. In the first case, the risk arises from failure of drilling or fracturing equipment and facilities, e.g. damaged insulation at the aquifer level or fracturing water spillage on the surface. The insulation could fail not only due to improper construction or installation, but also as a result of seismic activity [9]. In the second case, the hazard arises from highly permeable rocks between the upper shale gas layer and the lower underground aquifer. Here it is important that the geological analysis should reveal the type, composition and characteristics of the (various) rocks above, and sometimes below, the shale layer. The third possible case – where the shale gas layer borders underground aquifers – combines the risks of the first two cases and adds another – namely the direct underground mixing between fracturing fluid and freshwater. Due to this combination of risks, the third case, if found, would most likely be inappropriate for the environmentally acceptable exploration and exploitation of shale gas deposits.

The two most common types of freshwater pollution associated with shale gas extraction are methane contamination and particulate contamination. Pollution may also occur as a result of the introduction of fracturing chemicals – **Figure 15**.

Methane contamination of freshwater is often reported in association with coal and natural gas extraction [29, 59, 61, 77, 83, 87, 94]. Isotope evidence allows us to distinguish between biogenic methane[7] and thermogenic methane[8] (from shale). A recent US study [114] analysed methane[9] contamination in groundwater from 60 groundwater wells (from 36 to 190 metres in depth) in northeast Pennsylvania and upstate New York. Wells were selected from "active" areas of shale gas exploitation (at least one water well within 1 km of a gas well) and "non-active" areas (no gas well within 1 km of a water well), many of which had been earmarked for shale gas drilling. Methane was detected in 51 of these 60 water wells (85%), irrespective of gas industry operations. Thermogenic methane concentrations were substantially higher (on average, by 17 times) in wells in active areas as compared to those in non-active areas. Methane in tap water presents a potential fire and explosion hazard. Use of best-available technologies and practices can minimise methane leakage into groundwater [77, 87].

[7] Biogenic methane is produced by subsurface bacteria and is a common natural source of methane gas in groundwater aquifers used for water well supplies.
[8] Thermogenic methane gas is produced at greater depths through high pressure and temperature processes and is characteristic of deep oil & gas reservoirs that conventional energy wells tap into.
[9] Consisting of dissolved-gas concentrations of methane, higher-chain hydrocarbons and hydrogen isotope ratios of methane.

The good news is that gas producers are indeed interested in minimising methane leaks into water, as such leaks represent a direct loss of income for them. Novel technologies are deemed capable of capturing up to 90% of the methane that is dissolved in water [77, 87]. However, these extra methane-capturing facilities involve an extra cost for shale gas producers. So far, the methane contamination of freshwater / tap water has been largely ignored in the US [59], but it may be regulated in the future[10].

Particulate contamination of ground and surface water may result from seismic, drilling or fracturing activities. Fine particles may be removed from impacted water by means of treatment, but this will involve an additional cost to water treatment facilities and their operators. The severity of particulate contamination will be context specific, as it is influenced by a combination of geological, groundwater resource and extraction practice variables. This issue would probably also vary in severity according to both water scarcity and population density. Particulate pollution of freshwater resources is prohibited under existing European legislation [12].

Chemical additives account for 0.5-2% of fracturing fluid [29, 77, 96]. These chemicals serve a variety of purposes (***Figure 17***). Despite their low relative inclusion rate, some chemical additives may present health and environmental risks, even when present in small concentrations. Given the large volumes of fracturing fluids used, the absolute volume of chemicals deployed will be high, despite the low inclusion rate. For example, fracturing a single well using 15 000 cubic metres of water involves the use of 75 to 300 cubic metres of chemical additives. Some of these chemicals will return to the surface in flow-back water at the end of the fracturing process, while the balance will remain underground [68, 84, 87, 96, 110].

Figure 17*: Typical fracturing fluid additives [77]*

Purpose	Chemical	Common use
Clean up damage from initial drilling, initiate cracks in rock	HCl	Swimming pool cleaner
Gel agents to adjust viscosity	Guar gum	Thickener in cosmetics, toothpaste, sauces
Viscosity breakers	Ammonium persulfate, potassium, sodium peroxydisulfate	Bleach agent in detergent and hair cosmetics
Biocides	Gluteraldehyde, 2,2-dibromo3-nitrilophopionamide	Medical disinfectant
Surfactant	Isopropanol	Glass cleaner, antiperspirant
Corrosion inhibitor	N, n-dimethylformamide	Pharmaceuticals
Clay stabiliser	Potassium chloride	Low sodium table salt substitute

According to a US survey [110], shale gas developers use 652 chemical products in hydraulic fracturing, 29 of which are regarded as toxic substances. Many fracturing fluid additives are relatively commonplace substances that have a number of alternative applications. Other chemicals are hazardous, even in small concentrations [84, 96, 110].

[10] If recommended by the conclusions of the ongoing EPA study on the potential impacts of hydraulic fracturing on drinking water resources [108], due by 2014.

Figure 18 provides a list of the top ten substances of concern that are currently used in hydraulic fracturing in the US, along with their absolute and relative frequency. Methanol is the compound that appears to be the most widely used, followed by ethylene glycol. Methanol is a highly toxic compound that is fully soluble in water. Very small concentrations in drinking water may cause blindness and even death. Methanol can be ingested orally and via the skin, and it burns with an almost invisible flame, which makes it difficult to detect. It is also a strongly corrosive agent and may increase the risk of accidental breakdown of steel-made fracturing fluid infrastructure [8, 106].

Figure 18*: Top ten most frequently used chemical components of concern in hydraulic fracturing in the US. Source: Carcinogens, Safe Drinking Water Act (SDWA) regulated chemicals and Hazardous Air Pollutants (HAP) risks [110]*

Chemical Component	Chemical Category	No of products	% in total
1. Methanol (Methyl alcohol)	HAP	342	52
2. Ethylene glycol (1,2-ethanediol)	HAP	119	18
3. Diesel[11]	Carcinogen, SDWA, HAP	51	8
4. Naphthalene	Carcinogen, HAP	44	7
5. Xylene	SDWA, HAP	44	7
6. Hydrogen chloride (Hydrochloric acid)	HAP	42	6
7. Toluene	SDWA, HAP	29	4
8. Ethylbenzene	SDWA, HAP	28	4
9. Diethanolamine (2,2-iminodiethanol)	HAP	14	2
10. Formaldehyde	Carcinogen, HAP	12	2

A review of the chemical additives used in New York State for hydraulic fracturing identified 22% as having one or more of the following properties of concern: toxic to the aquatic environment or human health; carcinogenic or suspected to be carcinogenic or; mutagenic or having reproductive effects. The list of substances includes: Isopropyl alcohol, Acrylamide, Benzene, Ethyl Benzene, Iso-propylbenzene (cumene), Naphthalene, Tetrasodium, Ethylenediaminetetra-acetate, 2-butoxy ethanol (ethylene glycol monobutyl ether), ethylene oxide, oil-based solvents containing aromatic substances, and hydroxylamine hydrochloride [29, 96]. Many of these compounds may be regulated under EU legislation on water protection, REACH and biocides because of their high potential for affecting human health and the environment [29, 96].

The preservation of the environment, including taking precautionary measures, may be hampered by the lack of information as to the exact compounds and substances that are being used as fracturing fluid additives. Shale gas developers and chemical companies typically do not disclose the full list of shale gas fracturing compounds, as this is considered to be an issue of corporate confidentiality [77, 84, 87, 92, 96, 110]. Fracturing additives are specifically chosen and tuned to certain geology (rock composition), with the result that a shale gas company may use a long list of substances even for the development of a single field. In view of the differences between North American and European geologies, the experience with fracturing additives in the US may be of little relevance to the EU context [96].

Wastewater treatment and disposal: Current hydraulic fracturing technologies for shale gas extraction generate large volumes of wastewater that is potentially harmful to the environment [68, 77, 87, 90, 92, 96, 98, 110, 112]. It usually

[11] Diesel contains benzene, toluene, ethylbenzene, and xylenes.

contains chemical additives used in fracturing and dissolved substances from subsurface materials. Depending on the particular geology of the shale deposit, wastewater may also contain heavy metals and naturally occurring radioactive materials (NORMS) that are leached from shale beds [29, 84, 87, 90, 92, 96, 103]. In the latter cases, special water handling and treatment considerations will apply.

Managing bulky amounts of wastewater from shale gas extraction in a greenfield site, often remote from any existing water treatment facilities, could require substantial incremental investment, even if the shale gas is produced near to existing industrial or municipal sewage facilities. Existing facilities are typically rated at a given flow with a certain reserve that would probably not be sufficient to absorb the huge wastewater streams from shale gas production. Building extra sewage facilities (pipes, stations) to meet the shale gas input could be very expensive and challenging in an area that has already been populated by other industrial users.

So far, the wastewater issue has attracted relatively little attention in the US, because the relevant legislation has been fairly liberal [24, 77, 110]. Underground storage, and deep well injection of wastewater in particular, is (still) allowed [21, 77, 92, 112]. The collection of wastewater for subsequent treatment is a more sustainable, but also a more expensive option – ***Figure 19***. In the EU, there are very strict rules for wastewater management, which include treatment, discharge, control and sanctions. Handling large volumes of fracturing water from shale gas development in compliance with EU regulations may impose significant extra costs on shale gas developers. Shale gas exploitation may not be feasible in areas where no sustainable and legally compliant solution for wastewater can be found.

Figure 19*: A shale gas flow-back lagoon, Greene County, PA*

Source: http://skunkinthewoodpile.com/

There is also a risk of the accidental spillage of water from fracturing operations [92, 96]. The probability of such an accident per shale gas well is in principle comparable to that for similar conventional gas wells. However, the cumulative risk of accidental spillage due to technology failure or malfunctioning is greater for shale gas due to the larger number of wells that have to be drilled compared to those for conventional gas. Spills can also be caused by natural phenomena, e.g. pit overflow due to heavy rainfall. The larger overall volume of wastewater needing treatment also carries a greater risk of breakdown [47, 59, 68].

Alternatives to hydraulic fracturing: In view of the important environmental hazards of hydraulic fracturing, various alternatives are currently being investigated. These include substituting diesel with mineral or plant oil, reusing wastewater (flow-back water), using treated acid mine drainage (AMD) water, and replacing water with liquefied petroleum gas (LPG) or liquefied carbon dioxide (CO_2) as a fracturing component [70]. Although these technological alternatives seem to solve some of the problems of hydraulic fracturing, they may present other techno-economic and environmental trade-offs, including:

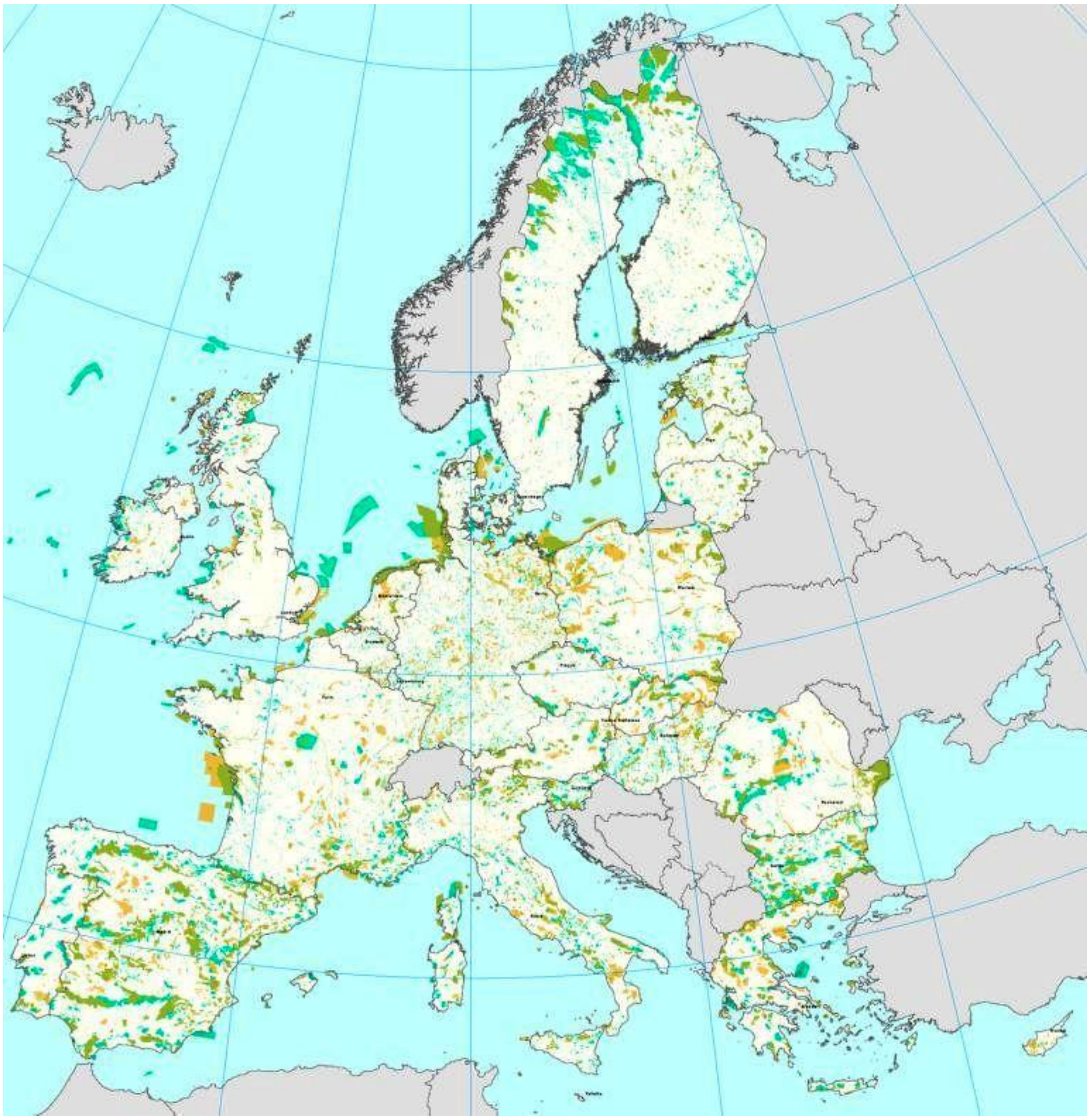
- Recirculation of water reduces total freshwater demand, but it risks blocking the fractures in gas-containing layers with large amounts of substances (e.g. barium, calcium, iron, magnesium, manganese) that were washed out during previous circulations [70]. The flow-back water either needs to be cleaned before re-injection, or should be mixed with freshwater in order to reduce the concentration of contaminants.
- The use of treated acid mine drainage (AMD) water from idle coal mines may also reduce the demand for freshwater [70]. The necessary pre-condition is that sufficient volumes of AMD water should be available within a reasonable distance of the shale gas site. Otherwise, the high transportation costs of bringing AMD water to the shale gas site could rule the scheme out.
- The main advantage of using LPG instead of water for fracturing is that no waste stream (wastewater) is generated, as the LPG used is recaptured [70]. , However, LPG is highly flammable and involves significant fire and explosion hazards. Small fires can be extinguished with dry powder, but large fires should only be tackled by properly trained fire-fighters. LPG is heavier than air and, in the event of a leak, vapour may accumulate in confined spaces and low-lying areas, presenting health and safety hazards. High concentrations have anaesthetic properties. Exposure to very high concentrations may result in loss of consciousness, convulsions and even asphyxiation. As LPG tends to build up a static charge when transferred by pipelines, it is essential that vessels used for receiving and transfer, including the pipelines, should be earthed [7, 107].
- The main advantage of using liquid CO_2 instead of water for fracturing is the much higher yield (up to five times higher) of natural gas [70]. Nevertheless, it may be difficult to justify the free flow of liquefied CO_2 (sometimes mixed with Nitrogen (N_2) in order to avoid ice formation in wells) in a carbon-constrained environment (such as the EU), due to the risk of leakage. The issues with CO_2/N_2 quality (purity) and its impact on transport and storage infrastructure and equipment, as well as with the sufficient availability of CO_2/N_2 transportation infrastructure, further undermine the feasibility of this option [125]. CO_2/N_2 tests to date have been carried out mostly in Canada.

All except the first of these novel technological alternatives to traditional hydraulic fracturing are still in the early stages of research and development. Even if some of them prove to be successful, their implementation at scale is unlikely before 2030 – which is the time horizon of this study – especially in the EU.

Biodiversity and natural conservation: Shale gas development entails intensive surface activity, largely concentrated on well-pads and supported by networks of roads, utility lines and pipelines. Particularly during the well drilling and fracturing phase, truck traffic to service well sites is heavy, and noise nuisance can be considerable. The development of shale gas resources in the EU may therefore be constrained in areas where biodiversity and natural conservation priorities are high.

The Natura 2000 ecological network of protected areas, which builds upon the Birds Directive (1979, codified 2009 [32]) and Habitats Directive (1992 [11]), is the cornerstone of the EU's nature and biodiversity policy. It includes more than 26 000 sites and covers almost 18% of the EU land area. It is noteworthy that a significant share of shale deposits coincides with protected areas in the EU – ***Figure 20***, compared to ***Figure 4*** [59].

Figure 20: *Natura 2000 map of Europe*[12]



Source: Adapted from the European Environment Agency – Data and Maps portal

Local air quality: Emissions from shale gas exploitation may include NO_x, volatile organic compounds (VOCs), particulate matter, SO_2, and methane [88, 103]. Emissions arise as fugitive releases of fracturing chemicals and as combustion-related emissions from equipment used for drilling and fracturing. As ***Figure 18*** shows, the most widely used chemical additives in hydraulic fracturing are hazardous air pollutants. Worsening air quality, as illustrated in ***Figure 21***, ranks among the most frequent complaints of local residents affected by shale gas development [92].

Seismic activity Drilling and hydraulic fracturing activities may lead to low-magnitude earthquakes [39, 59]. Two such seismic events were recently linked to shale gas exploration in the United Kingdom [46, 56], while similar incidents were reported in Texas in 2008 and 2009. The severity and probability of this hazard should be carefully assessed on a case-by-case basis, depending on actual geology and specific local conditions.

[12] Legend: Birds Directive sites, Habitats Directive sites, Sites - or parts of sites - belonging to both Directives;

***Figure 21**: Haze surroundings homes during hydraulic fracturing operations near Pavilion, Wyoming (left side) and Dimock, Pennsylvania (right side)*

Sources: http://wilderness.org/ *http://marcelluseffect.blogspot.com/*

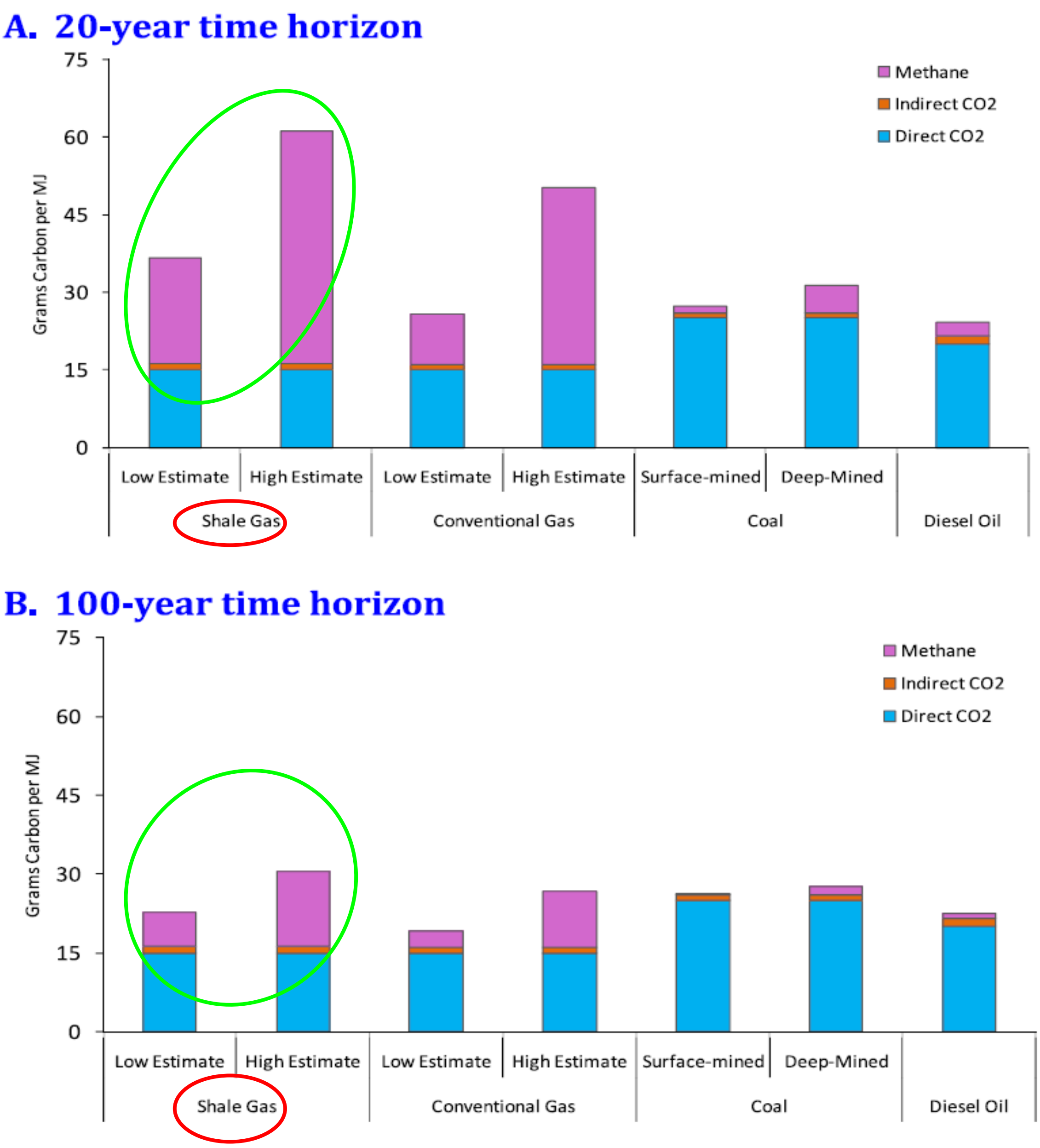
Greenhouse gas (GHG) emissions: With increasing attention being paid to the environmental footprint of shale gas, its comparative GHG intensity relative to other conventional and unconventional energies has emerged as a central point of discussion [15, 80, 105]. To date, there are only few studies on which GHG comparisons between shale gas and other energy forms can be based. Moreover, although such studies are interesting and potentially illustrative, wherever directly collected primary data were unavailable, reports so far have had to rely heavily on secondary data and educated guesswork. It is unclear to what extent information from studies based entirely on operational data might differ from these currently available estimates. There are several other points that will influence such GHG comparisons which are also important to consider:

- The estimates of lifecycle GHG emissions may be significantly higher than estimates of direct, combustion-related emissions. The amount of "upstream" emissions will depend on the particular energy source and on the assumptions made for the upstream processes.
- The time-horizon for calculating the global warming potential (GWP) of respective GHG emissions is similarly pivotal to any such comparisons. The key factor in determining the comparative GHG intensity of shale gas versus other energy forms is likely to be the potential differences in fugitive methane emissions at the extraction stage and after sites are abandoned. Methane has a much higher GWP over a short time horizon (20 years) compared to a longer time horizon (100 years). If a shorter time horizon is considered, the apparent GHG intensity of shale gas relative to the other energy carriers will be higher than if a longer time horizon is considered. There seems to be considerable uncertainty as to the magnitude of fugitive methane emissions associated with shale gas extraction, although these are thought to be higher than for conventional natural gas or coal extraction.
- Comparisons of GHG emissions associated with energy derived from shale gas, conventional natural gas and coal will be influenced by the unit of comparison. Comparisons of GHG intensity of electricity generation must take conversion efficiencies into account. Since gas-fired stations typically have higher conversion efficiencies than coal-fired plants, a comparison on this basis will produce different ratios than would a comparison of GHG emissions for energy from direct combustion.

Most available comparisons refer to conditions in the United States. It is difficult to assess the extent to which such analyses are representative of European conditions, given that technological and site-specific factors can vary widely within and across regions [2, 69]. Total gas production may be highly variable from well to well over their economically exploitable lifetime, and well lifetimes will also differ [19, 29, 69]. The quality of construction and maintenance of shale gas facilities and infrastructure during and after extraction further adds to the potential variability in GHG performance. Poor construction, maintenance, operation or sealing of wells may result in substantial fugitive methane emissions [29, 92]. Making comparisons between studies is also confounded by differences in methodologies. For illustrative purposes, several such studies are discussed below.

One recent study suggests that shale gas is among the most GHG-intensive fuels, performing better than coal only under the most optimistic set of assumptions [63] – ***Figure 22***.

Figure 22: *Comparison of GHG emissions from shale gas, conventional natural gas, surface mined coal, deep (underground) mined coal and diesel oil over 20-and 100-year time horizons [63]*

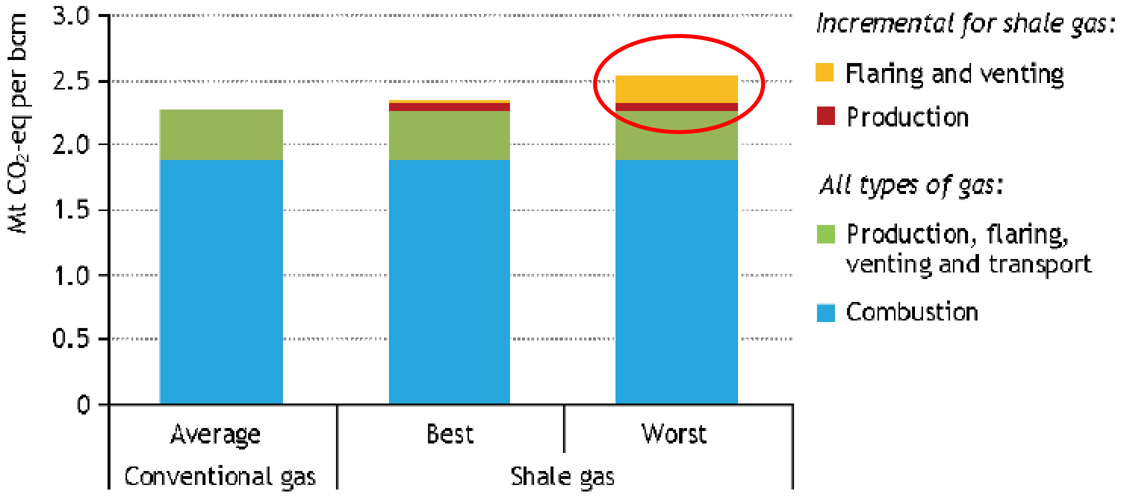


However, these conclusions appear to represent a specific and very unfavourable subset of potential US conditions [1, 87, 93]. Here, the apparently poor GHG performance of shale gas is due to assumed high fugitive emissions of methane of between 3.6% and 7.9% of the total shale gas yield [63]. There are three ways of drastically reducing these emissions:

- ✓ Flaring: methane that is brought to the surface during well development may be flared, converting it into CO_2, which has a much lower global warming potential relative to methane;
- ✓ Capture: releasing methane into the atmosphere represents a net loss of potential income for shale gas developers. Modern technologies are available that enable 90% of the methane that is brought to the surface in flowback water to be captured [63]. The incremental cost of these technologies may be offset by the income from the captured gas [1].
- ✓ Maintaining high quality standards of construction, maintenance and retirement of shale gas wells - proper cementing and sealing of retired wells - seems to be particularly important for reducing fugitive methane emissions [1, 68, 92].

Another study, which assumed flaring or capture of fugitive methane, estimated the GHG balance of shale gas to be much closer to that of conventional natural gas – ***Figure 23***. In the best-case scenario, shale gas emissions are estimated to be only 3.5% higher than those of conventional natural gas, while in the worst case the excess amounts to 12% [68]. Under normal circumstances, it is not reasonable to expect the GHG performance of shale gas to equal that of conventional gas. In general, the greater number of wells necessary to extract the same amount of gas from shale deposits compared to conventional gas fields means that there is a proportionally greater risk of fugitive methane emissions.

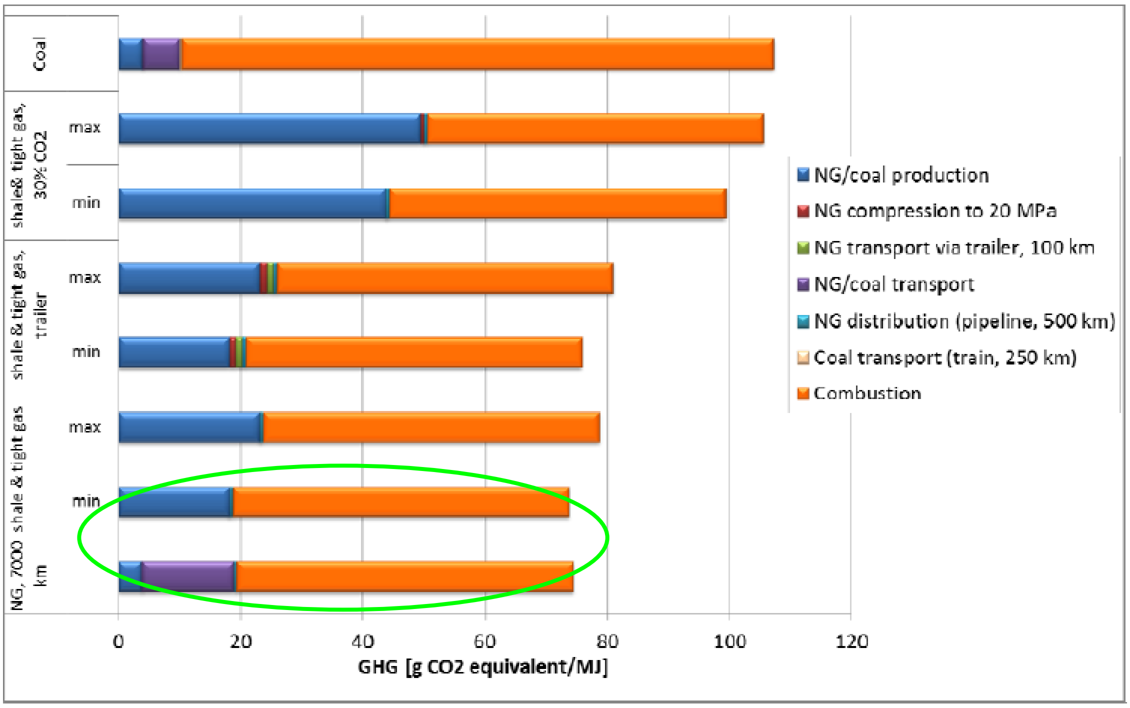
Figure 23: *Well-to-Burner GHG emissions of natural gas [68]*



Some recent projections for GHG performance of shale (and tight) gas versus conventional natural gas and coal intended to represent potential European conditions are also available – ***Figure 24***. These are broadly in agreement with the previously discussed study (***Figure 23***). Here, shale gas is estimated to be more GHG-intensive than conventional gas, but less intensive than coal – a conclusion that is generally borne out by most comparable analyses [69, 96]. It is interesting to note that under the most optimistic assumptions, shale gas from indigenous EU resources performs marginally better than conventional gas that is supplied via pipeline from remote locations[13]. The shale gas advantage results from the shorter distance of transportation by pipeline (500 km) and the better technical status of EU pipelines, where fugitive losses are minimal.

[13] In fact, this is Russian gas from Siberia.

Figure 24: *GHG emissions of shale and tight gas production, distribution and combustion compared to conventional natural gas and coal, extrapolated to European conditions [29] (NG – natural gas)*



Summary: The environmental externalities of current extraction technologies for shale gas are attracting increased attention, and may undermine the potential viability of the industry. The most important environmental concerns (or potential drawbacks) of today's shale gas production appear to be associated with water. These are: 1) Large freshwater demand; 2) Freshwater contamination, mostly with methane and fine particles; 3) Underground and surface pollution with hazardous chemicals, heavy metals or radioactive elements; 4) Wastewater handling, treatment and disposal. Other important potential environmental disadvantages of the industrial exploitation of shale gas are: 5) Impacts on biodiversity, in particular with regard to Natura 2000; 6) Worsened local air quality; and 7) Seismic concerns. The greenhouse gas performance of shale gas is generally poorer than that of conventional gas. This is largely due to fugitive methane emissions. There are cost-efficient techniques, e.g. flaring and capturing that can significantly reduce these fugitive emissions. The sustainable management of environmental externalities of shale gas exploitation requires excellent knowledge of geology, prudent exploitation of shale gas deposits, full and complete disclosure of chemical components that are employed, cautious land-use planning, high building, operational and post-operational conservation standards, and strict governmental control over operational safety and security.

4. SOCIAL DIMENSIONS OF SHALE GAS EXPLOITATION

Many of the issues discussed thus far in terms of economic and environmental considerations may also be framed as social issues. These include land use conflicts associated with high population densities; state ownership of underground resources; and a range of important environmental externalities, including water availability, water pollution, wastewater handling, potential harms to biodiversity, worsened air quality and earthquake concerns. A range of other social dimensions, both positive and negative, also merit consideration. How these challenges are managed is likely to have a significant influence on the social acceptability of shale gas development in the EU.

Such issues have become particularly important in the aftermath of the 2010 British Petroleum Deepwater Horizon and 2011 Fukushima incidents. The NIMBY (Not In My Back Yard) syndrome is likely to play an important role in negotiations as to the location and extent of shale gas developments. This will be particularly critical for regions where population densities are relatively high and alternative economic activities are available [55].

<u>*Visual landscape disturbance*</u>: Like many other industrial processes, shale gas extraction has non-trivial landscape impacts – ***Figure 25***. The extent of such disturbance is the subject of an ongoing debate, with proponents and opponents of shale gas development presenting extreme cases at either end of a representative continuum [87]. Despite new technological advances that reduce the number of well pads necessary to extract shale gas, the cumulative impacts on the landscape may still be substantial, especially in densely populated areas [77, 96]. The numbers and size of well sites, along with supporting infrastructure (roads, utility lines, pipelines, compressor stations, water lagoons, etc. – ***Figure 26***), must be considered in terms of the aesthetic values and uses of the landscape, in particular tourism and agriculture. As described previously, the large size of shale gas fields suggests that their development will necessarily be distributed over correspondingly extensive areas.

Figure 25: *Aerial view of a shale gas well site in the Marcellus Shale Gas Field – house and nearby gas operations.*

Source: http://www.spectraenergywatch.com/

Figure 26*: Aerial views of different shale gas production sites that illustrate the pressure on local landscapes*

Sources: [21]

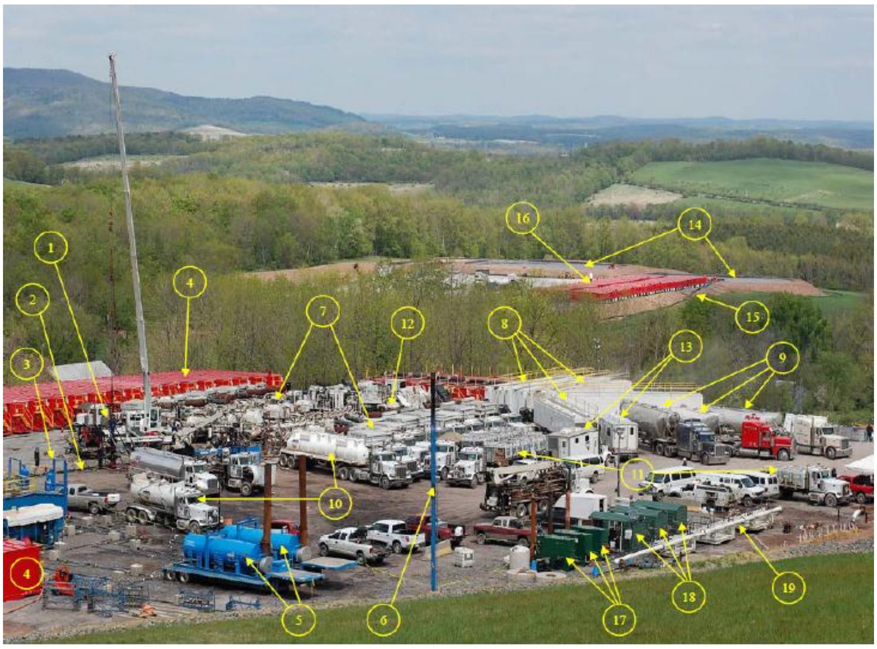
http://www.ogfj.com/index.html

Sources: http://www.ucsusa.org

http://www.albertaoilmagazine.com/

Noise pollution: During the development phase of shale gas extraction, noise pollution may be significant, especially in relation to well-site construction, drilling and hydraulic fracturing operations [92, 96]. These activities also need to be supported by large-scale trucking services (***Figure 27***), which generate additional noise and air pollution, along with burdens on road infrastructure.

Figure 27: *A shale gas well site during a single hydraulic fracturing operation (New York State, 2009)*[14] *[96]*



[14] Legend: 1. Wellhead and frack tree with 'Goat Head'; 2. Flow line for flowback & testing; 3. Sand separator for flowback; 4. Flowback tanks; 5. Line heaters; 6. Flare stack; 7. Pump trucks; 8. Sand hogs; 9. Sand trucks; 10. Acid trucks; 11. Frack additive trucks; 12. Blender; 13. Frack control and monitoring centre; 14. Fresh water impoundment; 15. Fresh water supply pipeline; 16. Extra tanks; 17. Line heaters; 18. Separator-metre skid; 19. Production manifold.

For example, large quantities of water, sand and waste streams need to be transported in order to support hydraulic fracturing operations. ***Figure 28*** provides an estimate of the truck traffic required to support the development of a single shale gas well or an eight-well pad in the US. In Europe, the number of truck trips is likely to be higher, given the generally smaller size of the trucks used. The social importance of noise pollution will largely depend on the proximity of shale gas developments to populated areas, as well as competing and directly affected land uses, such as tourism.

Figure 28*: Truck journeys for a typical shale well drilling and completion site [77]*

Activity	1 rig, 1 well	2 rigs, 8 wells
Pad and Road Construction	10-45	10-45
Drilling Rig	30	60
Drilling Fluid and Materials	25-50	200-400
Drilling Equipment (casing, drill pipe, etc.)	25-50	200-400
Completion Rig	5	30
Completion Fluid and Materials	10-20	80-160
Completion Equipment (pipe, wellhead, etc.)	5	10
Fracturing Equipment (pump trucks, tanks, etc.)	150-200	300-400
Fracture Water	400-600	3,200-4,800
Fracture Sand	20-25	160-200
Flow-back Water Disposal	200-300	1,600-2,400
Total	**890-1340**	**5850-8905**

Socio-economic trade-offs: Besides these negative externalities, it is also important to consider whether or not shale gas exploitation will result in positive socio-economic impacts, such as economic development, GDP/income growth or employment [23, 92]. Several studies on the employment benefits of shale gas development in the US have recently been published. Most of these are industry-sponsored works and come up with rather optimistic conclusions [10, 65, 73, 91, 118]. For this reason, however, quite a few of these studies have been criticised for their lack of peer review, objectivity and transparency, as well as on methodological grounds [57, 72, 116]. Several examples are provided below:

- The Considine studies, commissioned by the Marcellus Shale Coalition (a specific interest group of shale gas producers), monitor and report on the socio-economic benefits of the continuous development of the Marcellus shale gas field. The latest update from 2011 [10] claims that the Marcellus shale gas industry supported 140 000 jobs in 2010, rising to 156 000 in 2011 and 180 000 in 2012. The study projects that, by 2020, the Marcellus field may support more than 250 000 jobs and generate USD 2 billion in State and local taxes and revenues per annum, up from USD 1.1 billion in 2010. The methodological basis of the Considine studies has been criticised on a number of fronts, including inappropriate assumptions about earning and spending percentages of lease and royalty payments by location and time, location of actual job creation (inside/outside the target areas), etc. [57, 72].
- A study by Wood Mackenzie, commissioned by the American Petroleum Institute [118], suggests that shale gas developments in the USA and Canada (if supported by policy) can generate more than 1 400 000 incremental jobs by 2030, while incremental jobs may already exceed 1 000 000 by 2018.
- Referring to data and information from Pennsylvania's Department of Labor & Industry, ExxonMobile claims that the core industry employment in the Marcellus Shale grew by 114% between 2008 and 2011 [36].
- A recent study from IHS Global Insight [65], commissioned by America's Natural Gas Alliance and available free of charge from the IHS Global Insight website, estimates that the US shale gas industry supported more than 600 000

jobs in 2010 - a number that may reach 870 000 by 2015 and 1 600 000 by 2035. The estimated contribution to the US Gross Domestic Product (GDP) was in excess of USD 76.9 billion in 2010, and was projected to be 118.2 billion in 2015, tripling to 231.1 billion by 2035. The US shale gas industry is claimed to act as a high "employment multiplier" – every direct shale gas job presumably generates more than three indirect or induced jobs elsewhere [64].

Other studies on similar subjects, but from non-industry sources, have arrived at less optimistic conclusions:

- A study by Ohio State University [116] suggests 20 000 *gross* incremental jobs compared, for example, to the 200 000 incremental jobs forecast by a Kleinhenz & Associates study on the economic impacts of shale gas in Ohio, commissioned by the Ohio Oil & Gas Energy Educational Program [73]. Net incremental employment would be even lower, as the 20 000 jobs figure did not take into account the displacement impacts, i.e. the number of jobs in other sectors (e.g. tourism, coal mining) that would be lost due to shale gas development. The university study also quotes estimates that, in 2010, the Pennsylvania natural gas industry (including shale gas) employed only 26 000 people, compared to some 400 000 people in tourism – a sector that could be seriously damaged by extensive shale gas developments. The university study further affirms that the overall employment benefits are moderate, given that shale gas is a capital-intensive rather than labour-intensive industry, with most jobs being short-term and created mainly in the early stages of shale gas development.
- The Public Policy Institute of New York State Inc. calculates that, on average, the shale gas industry generated 125 jobs per new well. In contrast, Food and Water Watch calculate that only two new jobs are generated per well drilled [91] for the same region and time period.

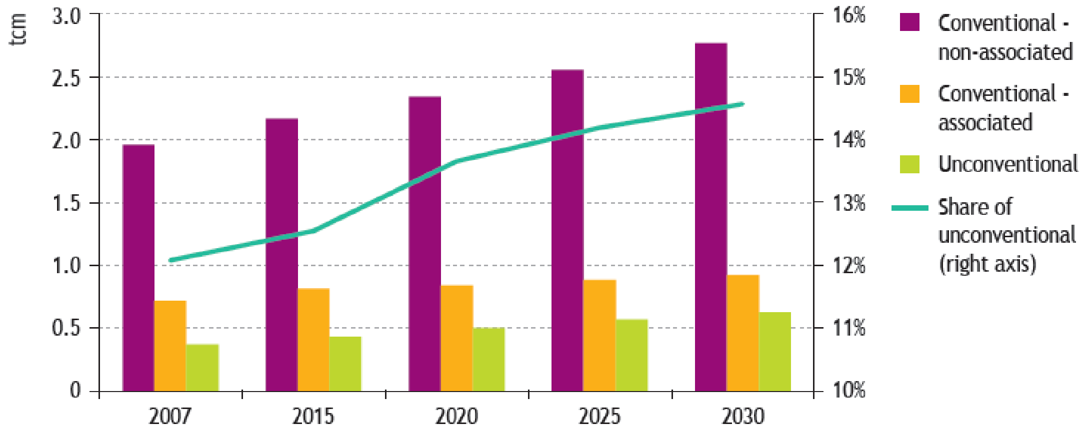
In Europe, estimates of potential socio-economic benefits are understandably scarce. A study commissioned by Cuadrilla Resources (a shale gas industry stakeholder), presents estimates that are decidedly more conservative than those provided by US industry sources [85]. The net socio-economic benefits associated with shale gas development in EU Member States will be strongly influenced by the balance in trade-offs with competing and benefit-generating economic activities and land uses, such as agriculture. This will be particularly important for Member States with large agricultural sectors and/or with large numbers of people employed in agriculture as a share of total employment. Countries with relatively high population densities and/or low freshwater resources per capita may also face challenges in developing indigenous shale gas resources. Calculations of costs and benefits must carefully weigh up the allocation of these limited resources between competing activities and the attendant outcomes for employment and incomes.

Summary: The socio-economic impacts of shale gas development should always be subject to a comprehensive cost-benefit analysis on a case-by-case basis, taking all direct and indirect consequences into account, whether these be positive or negative. Since there is currently no industrial-scale production of shale gas in the EU, coming up with any quantitative projections about the related potential socio-economic impacts is extremely challenging. Direct extrapolation of the North American experience does not appear to be reliable, because of the considerable differences in geological, economic, social and regulatory conditions. Last but not least, it was difficult to find very many genuinely independent and reliable data sources, information and analyses of the social consequences of shale gas exploitation in the course of the study.

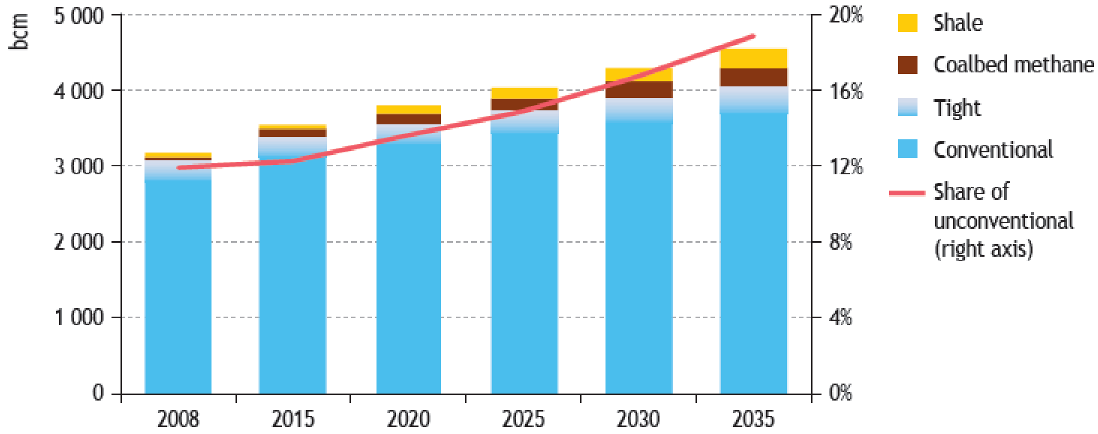
5. CLOSING REMARKS: THE PROSPECTS FOR SHALE GAS IN EUROPE

Regardless of the economic, environmental and social challenges associated with current shale gas technologies and developments, shale gas - and unconventional gas in general - is increasingly expected to play an ever larger part in global gas supply [122] - ***Figure 29***.

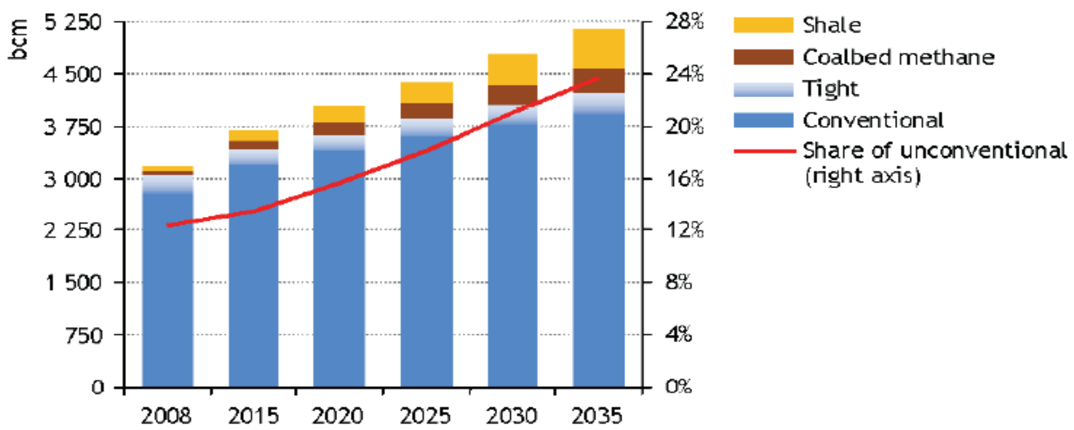
Figure 29*: Evolution of International Energy Agency projections for world gas supply, taking into account the development of unconventional gas reserves*



2009 Projections [66]



2010 Projections [67]



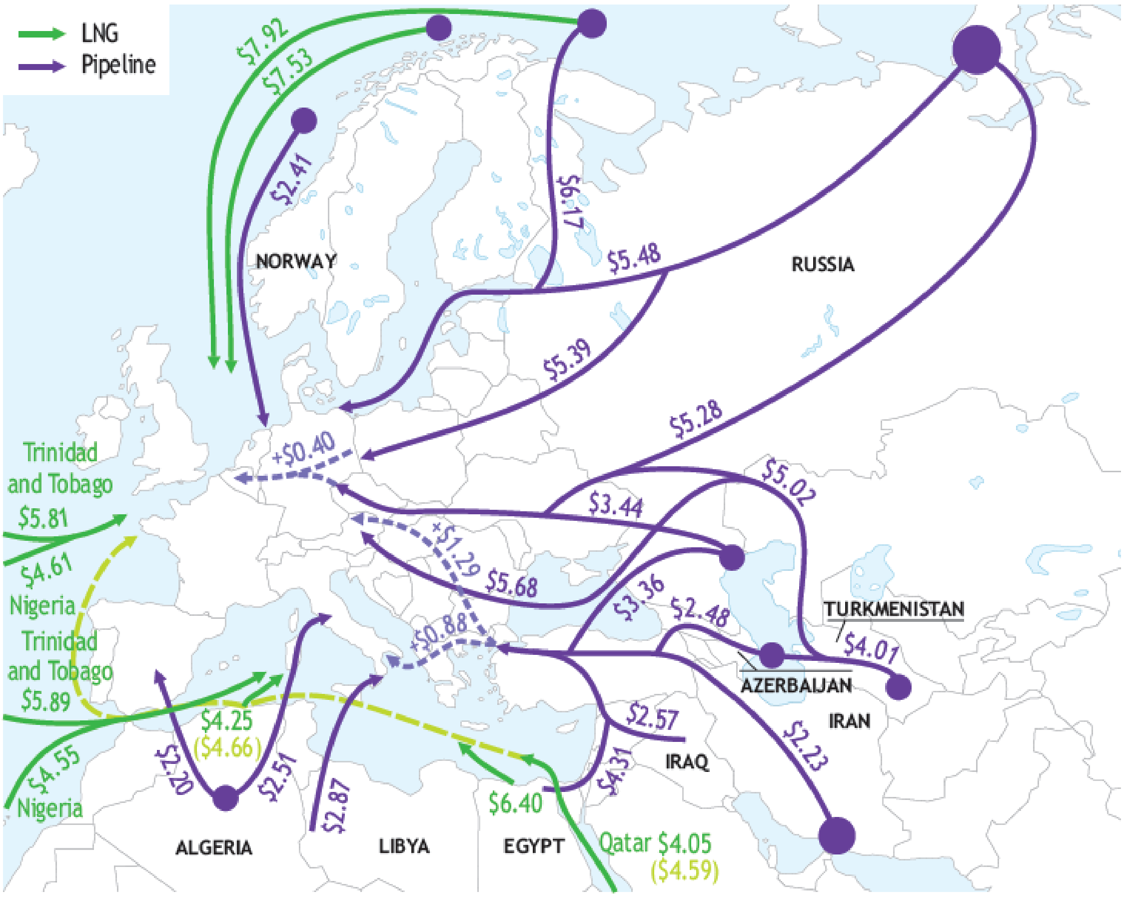
2011 Projections [68]

These developments will come in response to the rapid growth in the global demand for gas, driven primarily by developing countries [101]. According to the latest projections [68], the share of unconventional gas in world gas supplies will reach 24% by 2035, with shale gas - at 11% - being the largest unconventional contributor. Earlier, more moderate predictions suggested that the unconventional gas share would be 19% by 2035 [67], with shale gas contributing 7% by 2030 [82]. These projections share the following common features:

- They present a large degree of uncertainty;
- Most additional shale gas development will take place in North America (USA and Canada) - the birthplace of the shale gas industry - and some energy-hungry countries such as China and (eventually) India [68, 101]. According to some sources, Europe is not being seen as a large prospective shale gas player before 2035 [59, 75, 95], due to a number of techno-economic, environmental, social and political challenges, although in some EU Member States exploration activity is already significant.

As discussed above, the existing diversity of supply options for natural gas and opportunities to expand current sources may indicate that there is less interest in developing indigenous shale gas deposits in the EU. Central to this determination will be the break-even costs for European shale gas resources relative to competing energy sources. Estimates to date are variable and highly uncertain, given the current lack of information on which to base EU-specific estimates. According to OECD-IEA projections, Europe can rely on abundant gas supply in the future at a cost of less than 3.0 USD/MBtu from Norway, Algeria, Libya, Iran, Iraq and the Caspian region – ***Figure 30***. The most expensive conventional gas option – i.e. the Russian Arctic deposits in the Barents Sea - ranges from 7.5 to 8.0 USD/MBtu - ***Figure 30***.

Figure 30: *Indicative costs of potential new sources of gas delivered to Europe, 2020 (USD(2008)/MBtu) [66]*



These figures are lower than some best case estimates for indigenous shale gas from Poland, which exceed 8.0 USD/MBtu – ***Figure 31***. The high-end cost estimates for shale gas production in Europe tend towards 16.0 USD/Mbtu (***Figure 31***) – a value that currently appears totally uncompetitive relative to all the alternative forms of natural gas deposits, not only in Europe, but also worldwide - ***Figure 32***. It remains to be seen whether other forms of unconventional gas will prove more or less competitive than shale gas in the EU. A recent large-scale modelling effort from the European Commission Joint Research Centre – Institute for Energy and Transport, explores the potential impact of unconventional gas (in particular, shale gas) on European Union and global energy markets [123]. It was suggested that shale gas has the potential to extensively impact global gas markets, but only under very optimistic assumptions regarding production costs and reserves.

Figure 31*: Indicative costs for potential new sources of conventional natural gas deliveries to Europe versus development of indigenous shale gas deposits in 2020, USD/MBtu* [59]

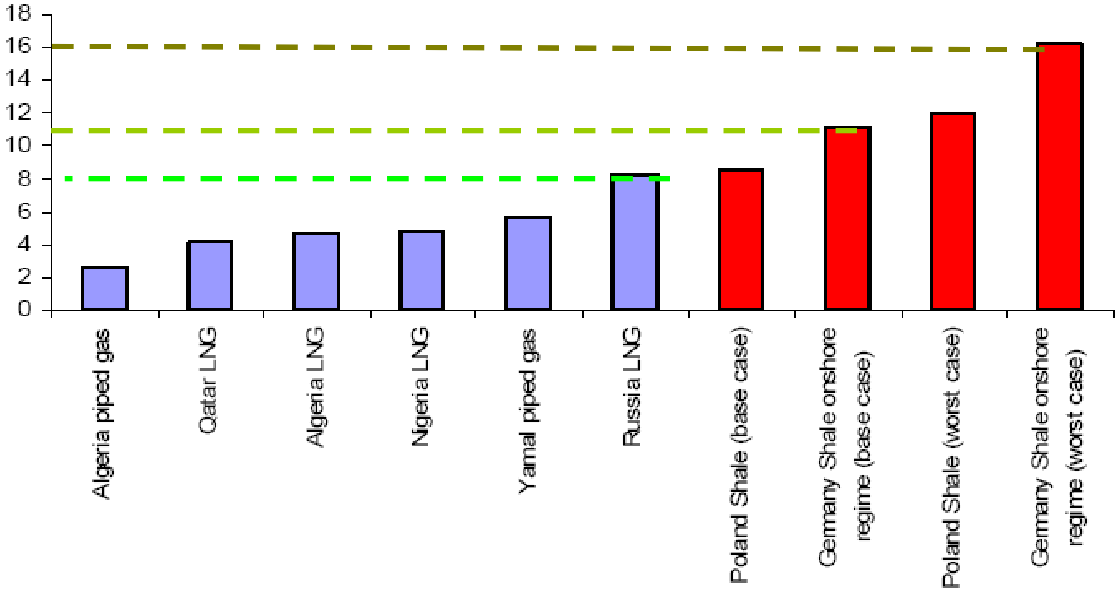
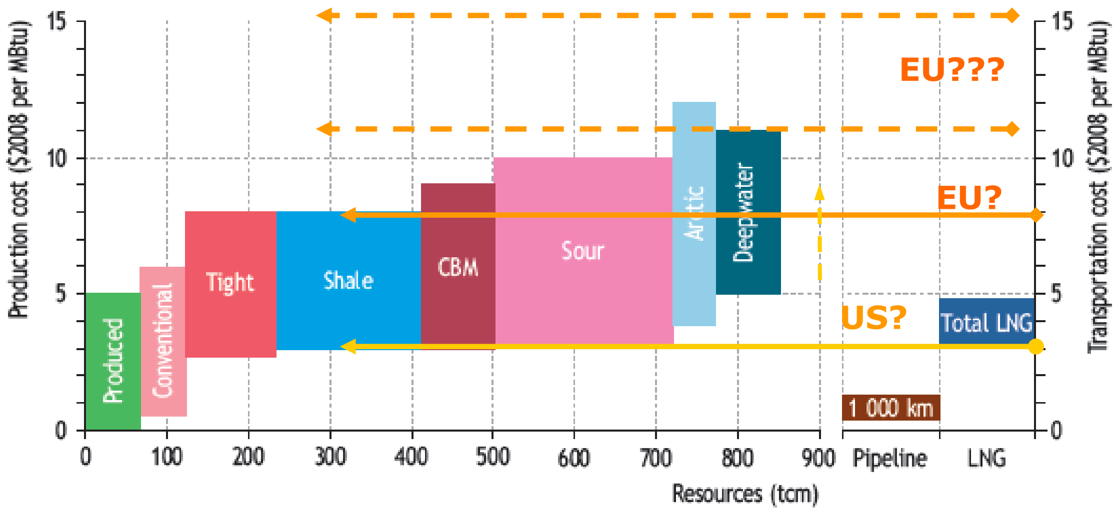


Figure 32: *Long-term natural gas supply cost curve estimate. Adapted from [66]*



Similarly pivotal to the development of a European shale gas industry will be the issue of how to resolve key environmental and social concerns. Certain issues already facing the shale gas industry in North America may prove to be even more challenging in Europe due to higher population densities, tougher competition for land, water and other resources, and the heightened sensitivities of local populations to large-scale industrial developments. At the same time, effective regulatory regimes, the implementation of best practices and the introduction of new technologies to mitigate priority impacts may enable shale gas development that meets the requirements of competing stakeholders and sustainable development. A recent report from the International Energy Agency describes a set of "golden rules" to guide policy makers, regulators, and shale gas developers in managing the potential social and environmental impacts of shale gas development [122]

In short, the future prospects for industrial–scale exploitation of shale gas reserves in Europe have still to be resolved. Alternatively, European energy companies may wish to consider ways of exploring shale gas opportunities beyond European borders, where the ecological and techno-economic conditions etc. are more favourable. European energy leaders (e.g. BP, TOTAL, SHELL) have already embarked on substantial shale gas acquisitions abroad [21, 53].

From the research point of view, the priority issues that need to be addressed in the EU in the short-to-medium term include:

- Improved mapping of shale gas resources across Europe;
- Determining the extent to which the application of best available technologies and practices can mitigate key environmental concerns with hydraulic fracturing, in particular as regards water use and pollution;
- Determination of potential social and economic costs and benefits of shale gas development;
- Determination of the overall economic feasibility of shale gas development when using best available technologies.

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Abstract

The goal of this study is to provide an overview of shale gas development in the USA and assess the implications of findings for the prospects for shale gas development in the EU by 2020-2030. Particular emphasis is given to environmental and social aspects of market-scale extraction of shale gas. Purely technological, techno-economic and regulatory aspects of shale gas exploitation are beyond the scope of this study. The analysis is based on a critical review of a number of literature sources, complemented by the author's analysis. The large majority of background data and information were collected from publicly available sources within the period June-November 2011. The study was finalised in January 2012.

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