Given the natural resource curse, is there an economic interest for EU members to exploit shale gas?

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Executive Summary

Over the last ten years, shale production in the United States has increased from less than 2% of the domestic gas production to more than 35%, slashing domestic gas prices while raising hopes of the US becoming energy independent by 2035. The hype around this *shale gas revolution* has drawn the attention of many, including over-indebted and energy dependent Europe. However, various economic concerns surround the hypothetic shale gas development in the European Union. First, resource windfalls do not always have the expected positive impact on economic growth. Second, numerous recent studies - based on plummeting production rate in US shale plays – have begun to question shale gas actual profitability. Last, what could be profitable in the US might well not be in the EU, as key differences regarding reserves, techniques, financing or legal frameworks could prevent the reproducibility of the US shale gas revolution in the EU. The aim of this paper was to elaborate on these topics, in order to determine whether or not the EU members should consider shale gas an economic opportunity.

The first point seems rather odd, even paradoxical. Indeed, if shale gas was to be considered a resource windfall, then resources rents and additional exports could be used to import more goods, boost capital investment and build up the economy. Therefore it should be considered a blessing. However, a member of the EU, the Netherlands, knows better than many that a gas windfall does not always benefit the economy. Their discovery of a massive natural gas field in 1959 rather had the opposite effect, a phenomenon infamously known as the *Dutch Disease*. Similarly, modern economic theory has recently shown resource abundant countries have tended to growth less rapidly than their resource poor counterparts – fathers labeled this the *Natural Resource Curse*. A new theory, the *Carbon Curse,* which also focuses on the detrimental effects of resource abundance, suggests fossil fuel rich countries are condemned to high carbon intensity[*]. Given the current real EU price of carbon at circa €5 per ton and its implicit cost that could be between 5 and 9 times higher, this latter curse is also an economic one. Fortunately, those curses are not written in stone and several countries managed to overcome them, most notably oil and gas rich Norway. We identified four risks related to the Natural Resource Curse and discussed whether or not the EU could overcome them if shale gas was to be a resource windfall.

[*] Measured by tons of CO_2 emitted per unit (e.g., $) of GDP.

1. *The resource movement effect*, which could switch human and capital resources away from the manufacturing sector (supposedly driver of long-term growth) towards the shale gas sector, is a limited risk. Human resources could be drawn out of unemployment (currently at 11.7% in the EU) and the current financial market development should insure proper access to financing.
2. The *spending effect* happens when extra spending from the resource rent leads to a real increase in the real exchange rate. The threat of a (even) higher exchange rate could be avoided if governments spend their share of the extra income wisely. For example, most EU members could first work on reducing their debt. Would the income happen to be very significant, further measures such as establishing a saving/ sovereign fund or pledging to a capped exchange rate, could be envisaged.
3. The *rent-seeking* risk, which could arise with easily *appropriable resources* (e.g., diamonds) in countries with weak institutions, is mitigated given shale gas is hardly technologically appropriable and EU institutions are generally strong.
4. The *increased exposition to volatile commodity prices*, which could lead to lower accumulation of physical capital, is of importance. However given the EU economic diversification (and the relative low current importance of the gas sector) and the hedging tools available thanks to developed financial market, this risk is well constrained.

In a nutshell, if we have faith in our democratic system and believe our political leaders will implement the right forward-looking policies (rather than short term demagogic ones), then EU members have the tools in hand to turn the hypothetic European shale gas revolution into an economic blessing. On the other hand, given the undetermined impact on fuel mix[*], the risks associated with the Carbon Curse are more ambiguous. Still, we believe emissions from fuel extraction (especially methane) and lower incentive to invest in energy efficiency would likely result in a carbon intensification of the economy. So while the Natural Resource Curse does not seem a sufficient to reject shale gas development in the EU, it appears there already is a tradeoff between shale gas development and low carbon intensity.

[*] Would shale gas be replacing coal, it could have a positive impact. The opposite is true for renewables.

Although, it is now unquestionable that the US has known a gigantic energy revolution over the last decade, the second point that is left to discuss is whether their *shale gas revolution* was and will be truly beneficial. Driven by technological improvements (namely combining fracking and horizontal drilling), surging fuel prices (till summer '08) and decreasing conventional gas production; the US produced approximately 260 billion cubic meters of shale gas in 2012 up 10x since 2006.

The results of this massive supply of gas were plentiful. First, US gas prices fell impressively. Although they are currently trading at the Henry Hub at $4.5 per MBtu, 2.5x higher than their 2012 low point, there are still c. 3x lower than in Europe and have largely de-correlated from US oil prices (which have roughly bounced back to their pre-crisis level). Second, they US electricity price reached a plateau around 2008. Third, while it did have a local impact on the US manufacturing sector – for gas intensives sectors (e.g., fertilizers and petrochemicals) – the impact on US household purchasing power was very limited. Regarding jobs created to date, we estimated it to be lower than 0.25% of the total US workforce. All in all without shale gas, the US GDP in 2012 would likely be maximum 1% lower.

Regarding profitability, shale gas requires significant upfront investment, which should have easily been paid back. Problems arise when facing with production rate declining typically between 80 and 95% within 36 months (versus sweet spots forecasts) and very low selling prices. In 2012, the gap to finance between revenues and required investment just to maintain production was estimated at $9.5 bn. As per Rex Tillerson, ExxonMobil's CEO: *"we are not making money, it is all in red"*.

Regarding the environmental consequences, many will argue shale gas had a major role in the US 9.1% decrease in CO_2 emission between '07 and '13, allowing for a switch from coal to gas. While this is a major achievement especially given the 6% real growth in output, we claim at least 80% of this decrease comes from the US decrease in energy consumption and the switch away from fossil energy (towards renewables). Furthermore, we argue cheap shale gas reduces incentives to invest in renewables and this 9.1% decrease might have been bigger without shale gas. Besides, side effects from shale gas exploitation encompass: substantial water usage, more emissions of GHGs (especially methane), earthquakes and public health concerns regarding chemicals used. While a new experimental technique based on heptafluoropropane could one day prove clean on a large scale, there is no further evidence yet. Last thing we can draw from the past on US shale gas development is that it received a lot of support from the public sector, most notably thanks to R&D funding (via the Gas Technology Institute) and the infamous "Halliburton loophole" in the "Safe Drinking Water Act". The latter exempts fracking from federal oversight, freeing them from (environmental and regulation associated) costs they would otherwise face.

Looking forward, there are two visions. On the one hand, the enthusiasts (such as the EIA and the IEA) believe US shale gas production will increase at an average yearly rate of 6% between 2011 and 2020 (a total 152 bcm increase). This could allow the US to become net gas exporter before 2020 and greatly reduce[*] its energy dependence for 2035. These estimates are based on 207 tcm of *technically recoverable resources* (TRR) of shale gas worldwide (though only 1.3% are proven), of which the US has 9% (19 tcm) or 84x 2011 production. In a nutshell, there is no problem, they say, keep driving. On the other hand, shale gas detractors argue the EIA has generally been overstating fuel fossil production and they do so because they overstate TRR. They overestimate TRR because they disregard decline in production rate and overstate average recovery efficiency of shale gas (versus conventional gas). Their view is that US TRR are around (6.8 bcm) or 10x 2011 production. Yet, they agree *in situ resources* are gigantic, but they believe the enthusiasts underestimate the economic barrier (technology and price) and the *Energy Return On Energy Invested* barrier (EROEI). You hit the first economic barrier when it becomes unprofitable or technically impossible to exploit the resource. You hit the second (EROEI) barrier when the energy returned (from the resource) is lower then the energy invested. Indeed, it takes energy to get energy. If the EROEI is below 1:1, then the resource cannot be considered a net source of energy and should rationally not be exploited. The EROIE barrier does not include financial investment and environmental costs, the more general Energy Return on Investment (EROI) includes them, which further raise the bar, hence the TRR. We believe measuring the EROI ratio for shale gas, estimating the necessary energy required to extract shale gas while fairly pricing the associated environmental costs, will prove the tipping point between the enthusiasts and the detractors.

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[*] Net imports as % of consumption would fall from 16% in '12 to 3% in '35.

The third and last point we have touched upon in this paper is to what extent the US shale gas revolution could be and should be replicated in Europe where shale gas is still at an infant stage. Indeed, while the US drilled more than 12,000 exploratory wells between '05 and '10, in the EU barely 50 explorative shale gas wells have been drilled to date. Knowing US Shale gas TRR estimates are still highly volatile, it is clear that European estimates are speculative, at best. Guesstimates (from the enthusiastic EIA) currently add up to 13.3 trillion cubic meters of shale gas TRR in the EU (vs 19 tcm in the US), of which more than 60% is supposedly located in Poland and France. The total TRR estimated represents 27x total consumption of natural gas in the EU in 2011. However, many believe these TRR numbers are overly optimistic[*]. So to begin with, TRR are likely to be smaller but also EU plays are supposedly harder to exploit given geological factors. Second, shale gas requires space and the EU is on average 3.5x more densely populated and has a much more fragmented landscape, which would require specific regulation (such as the US "pooling and unitization" system). Third, the US has developed a technical edge regarding unconventional resource exploitation, implying higher EU production costs. Fourth, more stringent legal framework such as complete ban in France or temporary suspension in the Netherlands, could simply forbid shale gas development. While on the other side of the ocean, difference in landholder ownership and Halliburton loophole, make the US legal landscape generally more favorable to shale gas exploitation. Last, stronger environmental concerns and risks associated to oil & gas producers PR image could prevent European corporates to develop shale gas (e.g., BP feared to "attract the wrong kind of attention").

Given the specificities discussed here above, we believe it would not be possible for the EU to replicate the US shale gas boom. Moreover, despite this gigantic production boom, the revolution did not have a huge economic impact in the US. The real GDP per capita grew, in fact, at a faster rate in the EU (than in the US) over the '05 – '12 period. Besides, would the energy required (for shale gas production) be accurately measured and environmental costs be fairly priced (e.g., abolishing the Halliburton loophole), shale gas real EROI could imply much smaller TRR (than expected), greatly reducing its future potential. What is more, other energy sources, which are carbon neutral and infinite, show – in opposition to fossil fuels – increasing trend in terms of EROI. By definition, renewables do not deplete, hence they are the only long-term way to become energy

[*] For example, the Polish Geological Institute estimates its own TRR 80 to 90% below the EIA's numbers.

independent. While we acknowledge we are uncertain of shale gas potential in the US (and in EU), our recommendation would be not to consider shale gas development an economic priority for the EU members but rather focus on enhancing renewable development. On the one hand, would the shale gas actually happen to be a truly beneficial for the US, Europe will share a part of the benefits with cheaper gas prices given LNG development. Further, if scientists were to develop a clean efficient method to exploit shale gas resources, EU TRR will not have vanished over the waiting time; we can keep this real option open. On the other hand, would shale gas prove uneconomic and environmentally dangerous, EU would have developed an edge in another source of energy that we know for sure yields increasing EROI and would have avoided a costly waste of time and energy.

In conclusion, we believe EU members should not (currently) consider shale gas an economic opportunity, despite rejecting the Natural Resource Curse. We acknowledge current US low gas prices might be luring European corporates, however we hope government will not listen to Oscar Wilde and *"resist then temptation by* not *succumbing*" to shale gas development. Indeed, money is not the prime mover of the economy; in fact it is energy that gets things done. On the long run, the only long-term way to provide profitable and environmental friendly sources of energy is to engage on the renewable path. We believe the earlier the better. Hence, our opinion is shale gas should not be considered an economic opportunity, but rather a real option, which might well remain unexercised.

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Introduction

Within the last ten years shale gas production in the United States has increased tremendously. Starting from less than 2% of US total natural gas, it is now their single biggest gas supply source. Some experts argue the shale gas revolution, which slashed US energy cost, helped them overtake the latest financial crisis, created hundreds of thousands of jobs and could allow them to become energy independent before 2035.

Although this formidable boom has raised many environmental concerns, it is foremost the impressive economic opportunity that is currently at the heat of the discussion. Indeed, many believe shale gas could be a solution for over indebted and energy dependent Europe. However, even leaving aside the environmental aspects, many economics concerns remain.

First, History shows that natural-resource rich countries have not all enjoyed the expected positive impact on their economy. For example, the real average annual output growth of the OPEC members was one percent[*] lower between 1965 and 1998 than peers, despite their large oil & gas production. This phenomenon, labeled *Natural Resource Curse*, is known for taking place in developing countries where specific factors such as corruption or despotism are more likely to hinder the use of the resource. More surprisingly, developed country – most infamously the Netherlands in the 60s – endured similar faith following the discovery of a new resource. Specifically, the Dutch discovered a massive natural gas field in Groningen in 1959, which quickly made them a net massive gas exporter. Appreciation of the real exchange rate and relative deindustrialization swiftly moved the country into recession. Although, this economic failure – labeled *Dutch Disease* – is a real treat, it is by no mean unavoidable. Several countries such as the Botswana, Chile or Norway have fruitfully managed the opportunity of a new resource via strong institutions and forward-looking policies.

Second, many authors have began to question the seemingly overly optimistic forecasts of the US shale gas boom… Recent studies indeed show that shale gas wells production rate decreases much faster than initially forecasted, raising concerns regarding the

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[*] OPEC members experienced a real GDP annual growth rate of 1.3% versus 2.2% for other developing countries (not fuel rich) over the 1965 – 1998 period.

profitability of the investment made and the actual size of the technical recoverable resources.

Third, major differences exist between the US and the EU and what could turn profitable for Uncle Sam might well not be elsewhere. The amount of the shale gas recoverable, the availability of techniques to do so, the willingness to finance the required heavy infrastructure, the readiness to bet on the environment, or even the legal framework surrounding shale gas, might all prove tipping points regarding shale gas development in the EU.

The aim of this paper is to discuss these economic concerns in order to elaborate a thoughtful judgment on whether or not shale gas should be considered an economic opportunity by the EU members.

Part 1: The Natural Resource Curse

1. Academic Review

Natural resources are a blessing. The Mythology told us Zeus grew up and survived thanks to Cornucopia (the horn of plenty), which had the supreme power of providing unending nourishment. Back on earth, an abundance of natural resources should also foster (economic) growth. Indeed, additional exports and resources rents could be used to import more goods, boost capital investment and build up the economy. However, most resource-rich countries, mostly in Africa, the Arab World and South America, have in fact underperformed.

Although the term (Natural Resource) Curse first appeared in 1988, when it was used in Gelb's book (1988) "Oil windfall, blessing or curse?", the course of history has seen numerous resource-rich economies toppled by resource-poor ones. For example, relatively resource-poor Netherlands in the seventeenth century became the continental economic power despite Spain's large inflow of resources (e.g., gold, silver) from its colonies in the Americas. Over the last two centuries, Japan resource-poor economy eclipsed Russia and its abundant resources. Nevertheless, this "Robin-Hood peculiarity of the poor taking over the rich" does not always hold. The abundance of a specific resource (e.g., coal and iron) also proved key to the development of economies, as coal and iron was for the UK and the US in the nineteen-century or diamonds to Botswana over the last century. However, failing transport costs (paradoxically driven by the rise of our carbon-based economy) made the necessity – to have a specific resource within an economy to achieve a strong economic growth – nowhere as important as it was two centuries ago. The advantage of owning natural resources has thus been partly offset by the decrease in cost of transport. Still, the question remains open: how this blessing could de facto be a disadvantage not to mention a curse?

Several early hypotheses can already be drawn to explain this oddity:
From a social perspective, one could simply argue that easy riches lead to laziness; the "lazy kings" – of the seventh and eight century – are another example of History. A more sophisticated approach from Lane and Torrel (1995), argued that politicians in resource-rich economies are more subject to *rent-seeking behavior*, which could lead to a "feeding frenzy" were competing factions deplete the resource fighting each other. This

is unfortunately best illustrated with Nigeria, were oil revenue per capita increased form US$[*]33 in 1965 to $365 in 2000. While, income per capita stagnated around $1100 and inequality skyrocketed putting Nigeria in one of the 15 poorest populations in the world. From a strict economic point of view, Prebish and Singer (1950) among others argued that a resource-based growth would be ineffective as the world prices of primary exports relative to manufactures have long term negative trends. Similar views state that the global demand for manufactured goods will outpace the one for primary products. Moreover, economies relying on a primary resource are more exposed to swing in prices and external economic shocks. Furthermore, papers from Hirschman (1958), Seers (1964) and Baldwin (1966) converge with the main idea being manufacturing requires a more complex division of labor, as opposed to resource-based production, which leads to a higher standard of living.

Later van Wijnbergen (1984) and Matsuyama (1992) developed models of "*forward and backward linkages".* The later postulated that a surge in primary goods exportation could negatively affect economic growth through these linkages. His model has two sectors, agriculture and manufacturing. The latest has "learning economies (i.e., learning-by-doing)", meaning the sector efficiency is positively correlated with the total manufacturing output. If resources shift away from manufacturing to agriculture, this could hinder the learning, hence future economic growth (in case of a small open economy).

In conclusion, many relevant theories were developed prior to the work of Sachs and Warner [†](1995) that could help explain the paradox raised by the natural resource curse. If we were to vulgarize, we could say they all fit into two boxes. The first category encompasses the theories that state weak institutions and short-sited governments led to a misuse of the resource. The second argues it is a switch away from the manufacturing sector – supposedly guarantor of long-term economic growth – that had negative impact on output. We have purposely omitted the work of Corden and Neary (1982) on the Dutch Disease, as we considered it core to the explanation of the Natural Resource Curse and decided to detail it in the section hereafter.

[*] $ stands for US$, unless otherwise stated.
† See 1.B Summary Findings

a. The Dutch Disease Model

Corden and Neary (1982) developed what is now considered the core Dutch Disease model. The framework evolves around a small open economy, which consists of three sectors: a tradable natural resource sector, a tradable (non-resource) manufacturing sector and a non-traded sector. Under several assumptions[*] and different cases, they studied the impact of a resource boom on the economy through two main effects: the resource movement effect and the spending effect.

The *resource movement effect* illustrates the fact that the boom in the natural resource sector raises the marginal products of the mobile factors employed there (e.g., a higher equilibrium wage rate, higher return on capital) and so draws resources out of other sectors.

The *spending effect* translates the impact of the increase in income of a country (through a boom in the natural resource sector). Higher real income leads to extra spending on both tradables (e.g., manufacturing) and non-tradables (e.g., services), which raises their prices. However tradable goods prices are set internationally, hence extra spending leads to a relative increase of the prices (and wages) of the non-tradable sector versus manufacturing and results in an increase in the real exchange rate. Moreover, it switches mobile factors (e.g., labor, capital) out of the manufacturing sector.

As a result, the real exchange rate appreciates and the manufacturing sector shrinks, this phenomenon is called the "disease". Although there is nothing wrong in itself in the shift away from a manufacturing sector, this could lead to future chronic slow growth if manufacturing is characterized by positive externalities (i.e., linkages and learning economies). With other words, a country – that could trigger a boom in its natural resource sector (e.g., following the discovery of a new resource) – faces a trade-off between short-term economic improvements (thanks to the new revenues from the resource) against potential long-term cost of a lagging-manufacturing sector. However, the authors remind us that governments could play a major role in offsetting the spending effect, hence partially preventing the deindustrialization. Indeed, a large part of

[*] Major assumptions include: models are purely real ones that ignore monetary considerations, all goods are used for final consumption only (later relaxed), national output and expenditure are always equal (so that trade is always balanced overall), real wages are perfectly flexible (ensuring full employment, later relaxed).

the rents of the natural resource sector typically goes to the government via taxes or state-owned enterprises. The manner in which the public authority decides to devote this extra income could switch the magnitude and even the direction of the spending effect (e.g., exchange-rate protection).

b. Summary Findings

Sachs and Warner (1995) work is considered the classical most comprehensive on the Natural Resource Curse. They empirically demonstrated, through cross-country regressions, a negative correlation between abundant natural resources and economic growth[*]. Their paper shows that, even controlling for other relevant variables, economies with a high ratio of natural resource exports to GDP experienced significant sub-par growth rate between 1971 and 1989. Interestingly, other factors seem to have statically significant positive impact on economic growth such as *Openness* or the integration within the global economy (i.e., trade policy), characterized by low tariffs and quotas as opposed to protectionism; *Investment* relative to GDP; *initial real GDP per capita*; and the *quality of Bureaucracy*. The *terms of trade volatility* or the *income inequality* did not prove significant when controlling for the other variables.

The authors conclude that natural resource intensity and openness represent additional explanations for economic growth even in the presence of other variables. Moreover there were only two[†] cases of resource-rich developing economies, Malaysia and Mauritius, which manage to achieve a per capita growth rate of at least 2% over the period. The authors argue that this is very interesting as both are very open economies with zero tariff Export Processing Zone to stimulate manufacturing exports. They argue that even in this case, the growth was rather driven by their manufacturing exports than by their abundant resources. Finally, they conclude with a recommendation to resource-rich governments not to solely focus on promoting non-resource industries via subsidies or other protection. Indeed, exploiting new natural resources may prove valuable for consumption (though less for growth) and simpler policies such as open trade should have a more significant impact on growth. While acknowledging the quality of their work, several authors (among others van der Ploeg (2010) – see hereafter) suggest several other factors should be taken into account (e.g., volatility, education, wars) and highlight the necessity to move from cross-country regressions to panel data. Nevertheless, their work and findings are considered key to this paper.

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[*] As measured by real growth rate of purchasing power parity adjusted GDP.
[†] Botswana would probably also have been included but observations were missing.

Auty (2003) states that there are two main reasons to explain the better economic performance of the resource-poor countries. First, these countries are more likely to develop *independent political system* focusing on raising the welfare of the entire population (i.e., the staple strap model). Second, chances are they diversify much faster into manufacturing, bringing high and efficient investment to this sector (i.e., the competitive industrialization model).

In the same paper Auty also provides guidance on how to manage different type of resources, more interestingly for this work, finite resources. Despite the apparent contradiction, economists believe it is feasible to exploit finite resources in a sustainable way. Indeed, sustainability does not require the resource to be passed onto the next generation but rather the *capacity to sustain the income stream* from the finite resource, with for example an educated workforce. At the local level, he recommends communities to avoid increasing their dependence on the resource and save a fraction of the rent to latter provide alternative employment opportunities and restore the environment to its pre-exploitation state. At the national level, the capital-intensive characteristics of many finite resources (e.g., oil, gas, mining) versus more labor-intensive renewable sources (e.g., forest, agriculture), leads to concentration of the resource within few hands including the government through taxation and state-owned operations. This greatens the risk of policy failure due to an accelerated absorption of the finite resource rent, compare to the higher savings rate one could expect from a larger number of individuals (e.g., farmers). Indeed, governments tend to overspend while most individuals have a greater tendency to save. The author suggests the use of environmental and natural resource accounting (EARA) tools to avoid these policy failures. First, he goes in the direction of Pearce (1996) arguing the ENP (defined hereafter) should not be declining over time. Second, he introduces the concept of genuine savings (GS, defined hereafter) stating that newly industrialized countries have high and rising GS/ GDP ratio between 20 and 30%. Whereas, resource-rich economies show low to negative numbers, suggesting part of their growth is not sustainable. EARA key finding suggest these resource-abundant countries should reallocate resources away from depleting these resources towards diversified investments in order to lower their reliance on finite resources.

1) $ENP_2 = GNP - D_P - D_R - D_E + E$
   - ENP_2 = environmental national product adjusted for depletion of finite and environmental resources
   - GNP = gross national product
   - D_P = depreciation of produced assets
   - D_R = depletion of finite natural resource assets
   - D_E = depletion of environmental assets (i.e., pollution, destruction)
   - E = net increase in education

2) $GS = ENP_2 - C - G$
   - C = private consumption
   - G = government consumption

More recently, van der Ploeg (2010) discusses the factors that differentiate natural resource abundance from being a blessing rather than a curse. Based on his work enriched with the views of the authors he refers to, we were able to summarize key effects of a natural resource windfall. As previously discussed, a resource windfall leads to appreciation of the real exchange rate (spending effect), a draw of resource out of the manufacturing sector (resource movement effect), which leads to deindustrialization (i.e., the Dutch Disease model). Moreover, it can also result in *a global decrease in the quality of institutions* and an *increased exposure to volatile commodity prices*.

i. Quality of Institutions

The vast majority of studies tend to agree that the quality of institutions (including government) has a strong positive correlation with economic growth. Unfortunately, a resource windfall could result in a worsening of their quality unless they were strong and resilient enough. Indeed, resource-rich governments have more power and more value to be in power. Thanks to their resources, they can, among others, buy off political opponents (e.g., Mobutu) or bribe citizens (e.g., grant private license, offering well-paid inefficient public job) to remain in power and therefore lowering their political accountability. While grabbing the (short-term) rent of their policy, political elite actions could also result in a reduced overall transparency and efficiency of the legal system – hence effectiveness of property right – increased in corruption, crimes, conflicts and even wars. So the behavior of the people in charge could clearly lower the quality of institutions, which could have disastrous impact on economic growth and social welfare. Here is how.

First, weak institutions incentivize rent-seeking behavior. This is true for political leaders, which in extreme cases could lead to armed conflicts or civil wars with the well known disastrous impacts. But also for productive entrepreneurs who might enjoy higher return rent seeking if, for example, property rights are neglected. In equilibrium, there are fewer productive entrepreneurs and the economy is worse off. This is especially proven if the resources are easily *appropriable* from both a technical and an institutional point of view. With other words, Boschini and his colleagues (2007) demonstrated that the more a resource is valuable, can be easily transported, stored and sold (e.g., diamonds or gold) the more attractive it is to rent seeking, hence the larger the negative impact on growth. Interestingly, they also showed that the quality of institutions could completely offset the economic impact of a resource on a given economy. That means, when provided with the appropriate institutional framework, any resource could prove an economic boost.

Second, a false sense of confidence – given by the resource bonanza – might lead governments to take on unsustainable policies. A common mistake made by resource-rich countries was to borrow excessive amount using the resource as collateral. When the resource price fell this led countries into debt crisis. Another example of unsustainable policies is the response of the Dutch governments following the discovery of the natural gas plan. They built a too generous welfare state, among others expanding unemployment and disability benefits and raising the minimum wage. After what, it took them more than two decades to put their economy back on track.

Third, it is self-obvious that weak institutions result in a reduced social welfare. A weaker juridical system will induce more crimes, a lower education and more poverty. So long as welfare can be measured, this results in lower life expectancy and human development index score.

On the contrary, Acemoglu et al. (2001) have shown African colonialist institutions have in general persisted and have had a very important impact on current institutions. So the view institutions could be worsened should be taken with precaution, tough History shows governments have often behaved unwisely following a resource windfall.

ii. Exposure to volatile resource prices

Given the (short-term) low price elasticity of their supply, resource prices and revenues are highly volatile. As previously discussed volatile resource prices can throw countries into debt crisis. Besides, Cashin (2004) empirically found out a relationship between resource prices and real exchange rate of the resource-exporting country. Hence an increased volatility of the real exchange rate or with other words increased uncertainty for foreign investors. This increased risk coupled with a poorly developed financial system (where for example only debt is available) may result in liquidity issues leading to costly bankruptcy. As a result, interest rates rise, there is less investment and reduced economic growth. Furthermore, increased volatility and risk encourages rent seeking, which destroys value.

The perverse effect of volatility on growth is especially strong for countries with technically appropriable resources with weak financial institution. In this context volatility is not only bad for growth and investment but also for income distribution, poverty and educational attainment (Aizenman and Marion, 1999).

Leong & Mohaddes (2011) revisits the resource curse paradox and argues that volatility, rather than abundance per se, drives the curse. Their results not only show the expected negative effect of resource rent volatility on growth, but it also indicates that resource abundance (proxied by real resource rent per capita growth) has, in fact, a positive impact on economic growth. Moreover, their findings suggest that sound policies and good institutions can offset part of the negative growth effect of the volatility. Indeed, good institutions can help set up accountable and transparent government bodies, which will productively use the rents and prevent rent-seeking behaviors. They go further suggesting resource-rich (developed) countries could offset the volatility curse by setting up forward-looking institutions such as Sovereign Wealth fund or stabilization fund (saving when prices are high – spending when they are low). Proceeds could be used to further develop institutions and human capital in order to enhance productivity and ultimately growth. Last, they join many authors highlighting the role of financial market in reducing uncertainty, hence volatility. In a later article, Mohaddes et al. (2012) illustrated how commodity price volatility impacted the three growth channels: total productivity factor, physical capital accumulation and human capital acquisition. Their results suggest volatility mostly lowers the accumulation of physical capital. This is likely for three reasons. First, economic agents might perceive the resource rent as permanent source of future income, therefore saving less. Second, risk adverse agents would choose to accumulate less physical capital if its value is highly volatile. Third, macro-economic volatility negatively affect the default risk, increasing interest rate and lowering the borrowing capacity. All in all, volatility seems to negatively impact output growth through lower accumulation of physical capital. This result is in line with many authors including Papyrakis and Gerlagh (2004), Gylfason and Zoega (2006) and Esfahani (2009). Data from the World Bank and authors previously cited (Auty and van der Ploeg) also show that resource-rich countries often have *negative genuine savings rate*.

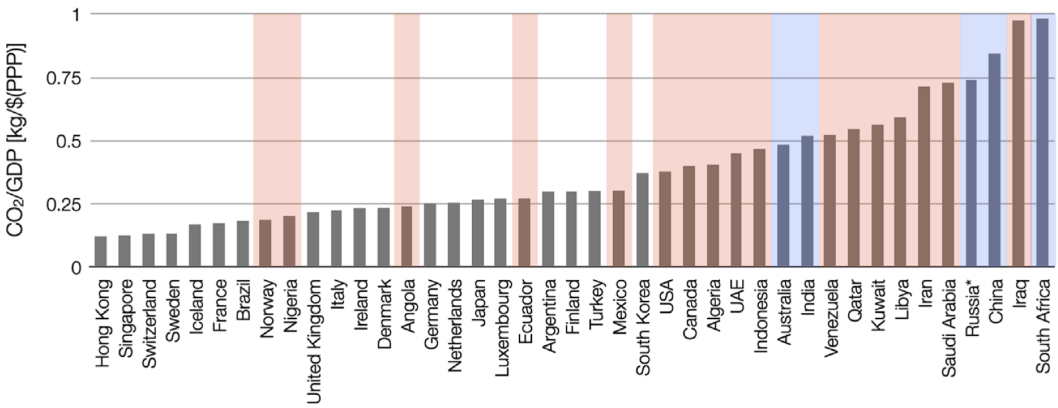
In a tentative to recapitulate, we would try to end this section on a bright note. Indeed, we share the opinions of many and are convinced a natural resource windfall is not per se a curse. With strong institutions preventing rent seeking and forward-looking governments putting in place the appropriate policies, it could well be a blessing. As Gandi said "the world has enough for everyone's need, but not enough for everyone's greed".

c. The Carbon Curse

Friedrichs and Inderwildi (2013) have developed the Carbon Curse: a new theory, related to the Natural Resource Curse but standing on its own. Their findings suggest fuel rich countries are condemned to high carbon intensity*. While both theories focus on detrimental effects of resource abundance (i.e., curses), the Carbon Curse stands on its own and seems less paradoxical. When most would expect a fuel rich country to emit more CO_2, little would believe a resource windfall to have a negative effect on growth. Even if less paradoxical, the Carbon Curse is still highly interesting given the undesirable effect of green house gases (GHGs) on climate change and the "new" economic cost of CO_2 emission. Even though current carbon world prices are quite low, the Economist in December 2013 highlighted how the internal carbon price used by some companies was much higher. At the time, the market price was €4.90 ($6.70) per ton of CO_2 in the EU and $11.50 in California; while internal prices for big oil company were above $34 (up to $60 for Exxon Mobil). Moreover, the US administration recently estimated the social cost of carbon at $37 a tone. At these prices, the Carbon Curse becomes more than an environmental curse; it becomes an economic one.

Figure 1: National Carbon Intensities in 2008.

Source: http://data.un.org - compiled by Friedrichs and Inderwildi.



The researchers based their findings on an explanatory data analysis, yet using a representative sample. Figure 1 shows oil-rich countries in red and coal-rich countries in blue†; it clearly indicates how fuel rich economies tend to emit more CO_2 to produce the same amount of GDP all other things being equal. When, technically advanced resource

* Measured by CO_2 per GDP.

† While Russia could be considered oil, ga zand coal rich.

poor economies show lower carbon intensity. The only outliers are Norway, Nigeria and Angola. While Norway is a positive outlier we will later discuss. Nigeria and Angola relative low carbon intensity is explained by a lower income per capita and level of industrialization.

Interestingly, the Carbon Curse is not a static theory. The authors also looked at how the carbon intensive evolved between 1996 and 2008 to determine whether or not they would be able to draw significant patterns in term of decarbonization. As a matter of fact, they distinguished three groups:

1. Seven countries managed an absolute decrease in carbon emission over the period. All of them were highly developed, technically advanced and fuel poor (e.g., France, Denmark, Germany, Singapore, Sweden). With the only partial exception of UK, which could have been considered fuel rich[*].

2. Others reduced their relative carbon intensity but at a slower pace than the growth of their economy. The compounding effect resulted in an absolute increase in carbon emissions. This group, unfortunately, includes the largest players such as China, India and the US. Friedriechs (2013) stated: "during the 2000's the (global) economy decarbonized by 0.77% per annum but this was more than offset by average economic growth. As a result, global CO2 emissions kept rising."

3. The last group suffered massive emission intensification due to a relative increase in carbon intensity coupled with output growth. All countries within this group are either major coal producers or petro-states. Moreover, they are all OPEC members but for Norway.

Invariably, countries with the highest absolute growth of CO_2 are fossil-rich.

Trying to explain this phenomenon, the authors suggest the Carbon Curse has, at least, four roots. The extractive emissions from fuel, the fuel-related resource movement

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[*] British Oil & Gas production peeked around the year 2000 and they became net importer five years later. Therefore, we can't hardly considered them fuel-rich

effect, the reduced incentive to invest in energy efficiency research and the pressure to provide cheap fuel.

i. Extractive emissions from fuel

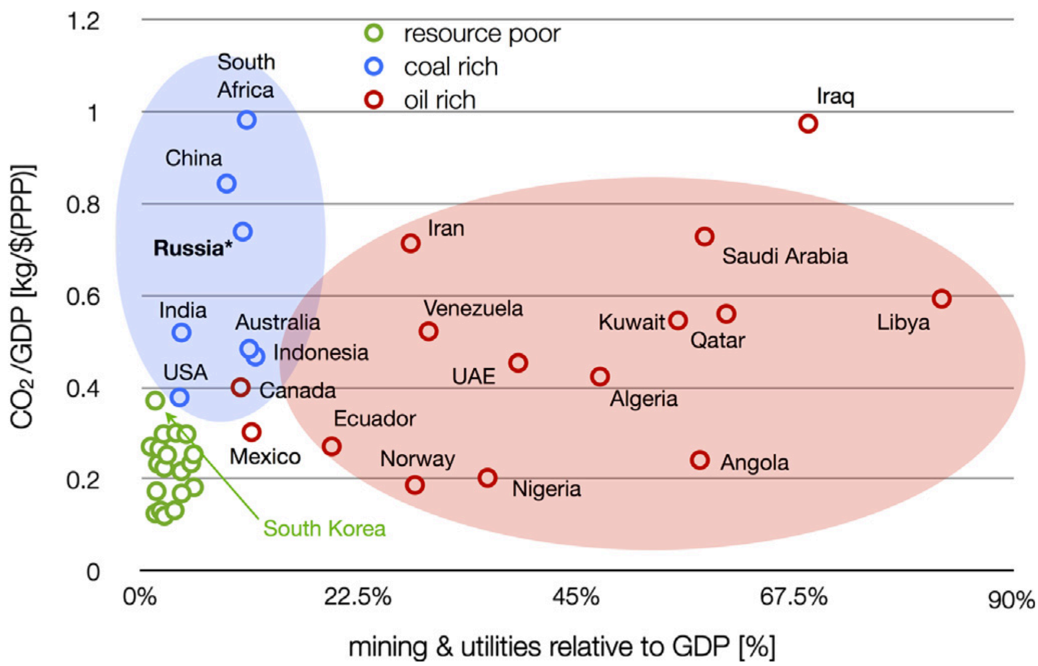
First, it takes energy to get energy. Hence, fuel-rich countries emit significant amount of GHGs in the extraction of their domestic fuel. This is the concept of *energy returned on energy invested* (EROEI), which will greatly be developed in the part 2. Different sources yield different results, but people tend to agree these rates are declining and while Old Conventional Oil yielded 100:1, New Conventional Oil is closer to 25:1, Tar Sands between 5 and 3:1 and first generation biodiesel below 2:1. Even with a highly beneficial EROEI, the mere size of the extracting sector is sufficient to generate significant emissions. But when focusing on harder resources to exploit, like Tar Sands in Canada, lower EROEI results in even more CO_2. Interestingly for this paper, unconventional sources (e.g., shale gas) are characterized with (much) lower EROEI than conventional sources (see Part 2).

ii. Fuel-related resource movement effect

Second, the Dutch Disease plays a (dual) role. As previously discussed, a resource windfall through the resource movement effect leads to deindustrialization. Although, this first effect could have a negative impact on output growth, this has a positive impact on carbon intensity. The manufacturing sector being one of the most polluting, a deindustrialization reduces the amount of CO_2 emissions keeping all other things equal. Sadly, this is no the end of the story. Easy access to domestic resource greatly influences country fuel mix. For example, Saudi Arabia generates 65% of its electricity via oil, despite a high potential for renewables and vast gas resources.

Figure 2. Relationship between carbon intensity and the size of mining and utilities relative to GDP.

Source: http://data.un.org - compiled by Friedrichs and Inderwildi.



As a rule of thumb, coal has the biggest carbon footprint of all fossil fuels, while gas has the smallest and oil is somewhere in between. Figure 2 helps distinguish three groups.

1. In green, fuel-poor countries all show a small relative size of their extracting industries and a low carbon intensity. Even the negative outlier, South Korea has modest carbon intensity.

2. In blue, coal powered countries (including Canada with its Tar Sands) have higher carbon intensity while maintaining small mining & utilities sectors. The authors argued this happened for historical reasons; coal has first enabled their industrial development rather than being directly massively exported. However the dramatic carbon footprint of coal results in disproportionately high carbon intensity with regards to their extracting sectors.

3. In red, oil-rich countries may show very different carbon intensity. Some countries manage to effectively fight extractive emissions and crowding out effect, such as Norway. While others use the resource wealth for high-carbon

lifestyle such as Saudi Arabia. Even worst, Iraq, one of the most carbon intensive countries, is also in the top-five of gas flaring countries according to the World Bank.

iii. Lower incentive to invest in energy efficiency

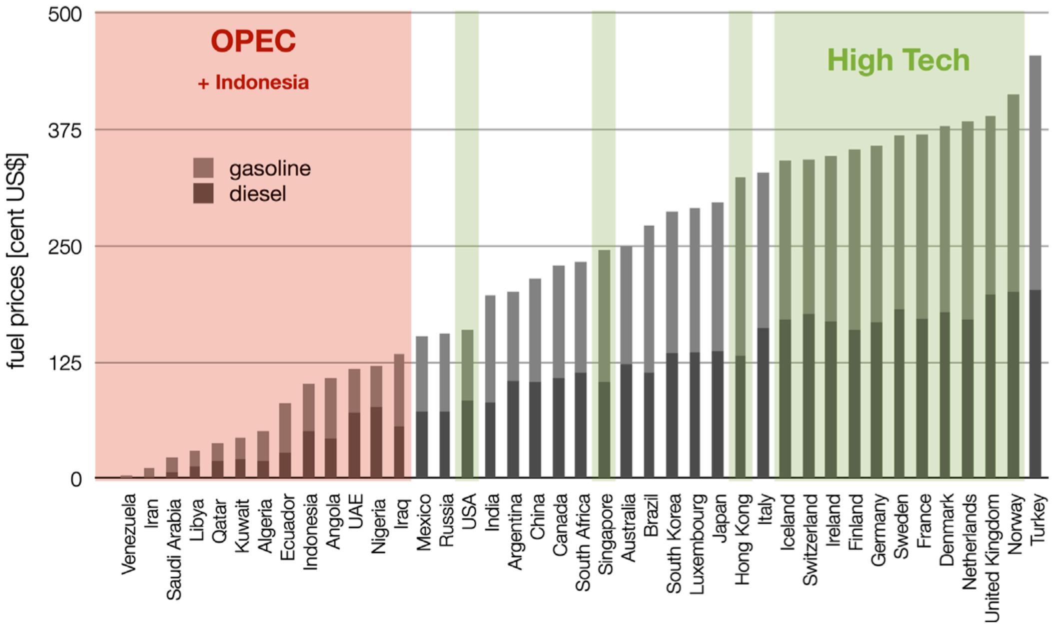
Third, fuel abundance tends to weaken incentive countries may have to invest in energy efficiency research. Obviously, this results in higher energy consumption per GDP unit. The security and sense of confidence given by their cheap source of abundant energy, lowers their needs to spare. One could argue that high world prices could suggest more domestic conservation for fuel rich countries, however people within fuel-rich economies often deal with heavily subsidized prices.

iv. Pressure to provide cheap fuel

Fourth, people in fuel-rich economies often feel birthright to enjoy low fuel prices, which put pressure on governments to offer them so. Moreover, given the large spread between the market price and the production cost, subsidizing fuel is often not a fiscal expenditure but rather an opportunity cost. For fuel rich a loss of potential export income is more acceptable than a direct cost. This leads to very different prices per countries.

Figure 3. Combined fuel price for diesel and gasoline as of November 2010.

Source: GIZ (2012) – compiled by Friedrichs and Inderwildi.



On Figure 3, one could see combined pump prices for diesel and gasoline per country. This is used as a proxy of the net affect of subsidies and taxes on fuel. First, it is remarkable to see the wide rang of prices for one litter of gasoline plus one litter of diesel, starting at $0.03 in Venezuela to reach $4.55 in Turkey. Leaving aside the Turkish outlier, the upper range consists of only high tech countries[*], while all[†] the OPEC countries are at the bottom. This highlights the correlation between fuel-rich and fuel subsidy. Not only were those 12 OPEC countries heavily subsidizing fuel, but also none of them saw a decrease in emission between 1996 and 2008. Moreover, 8 of them have even seen a worsening of their carbon intensity.

To finish on a brighter note, the authors looked at the positive outliers, namely Norway and to a lower extent (see here above) the UK. Despite Norway being one of the world largest oil exporters, their carbon intensity – tough increasing – is on par with other developed fuel-poor countries (see Figures 1 and 2). Their recipe lies between high R&D investments in energy efficiency (e.g., leader in carbon capture and storage (CSS)), strong regulators managing the resources and imposing hefty taxes on fuel (see Figure 3) and aggressive promotion of renewable energies. Similarly to the Natural Resource Curse,

[*] The fifteen most advanced high-tech economies as defined by the Global Competitiveness Report.
† Indonesia considered OPEC, as they were a member till 2008

strong (environmental) institutions seem to be a (if not the) solution to the Carbon Curse. However, the later seems even harder to tackle, as even developed countries are not immune to it. In December 2011, Canada announced its withdrawal from the Kyoto Protocol to further exploit its tar sands. The Carbon Curse could also affect Australia and Germany (though a leader in renewable energy), which heavily rely on coal. Even more dramatic, the authors suggest: "there may even be a be a Carbon Curse at the planetary level. Climate change would be less severe if the planet were less richly endowed with fossil fuels, or if fossil fuels were harder to get (…)". Fortunately, all is not gloom and there are also positive outliers who prove the Natural and the Carbon Curses are not written in stone. The next section will be a focus on the notorious Norway example to get a better understanding on how they overcame these curses.

2. Case Study on Norway*

Norway is a cold northern sparsely populated country, . According to the CIA, there are just over 5.1 millions inhabitants, which ranked Norway 121st most populated country. However, it is of economic significance with a GDP estimated at $516 billions (slightly larger than Belgium or Poland). But we are not interested per se into their economics muscles, what drew our attention to this country is what lies underneath their grounds (and seas) – most notably how they successfully exploited it. Indeed, Norway is respectively the 3rd and 9th largest net exporter of natural gas and crude oil in the world (see Appendix 1). As previously discussed, one could expect Norway's economy and carbon intensity to be (largely) lagging behind peers due to the combined effect of the Natural Source and Carbon Curses. However they managed to vastly overcome both curses and we are going to study how.

a. Historic Background

First known through the Vikings, the first sign of a united Norway kingdom is to be found around the year 900. After half a millenary of sovereignty, Norway was included in a union with Denmark till 1814. That year, they resisted a cession of their country to Sweden and adopted their own constitution. This did not last long, as Sweden invaded Norway shortly after. In 1905, a referendum finally led to Norway's independence. They have remained independent, though occupied by the Nazis during World War II, until today. Discovery of large offshore oil and gas reserves in the late 1960s led to strong economic growth. In 1972 and 1994, their population voted against joining the European Union.

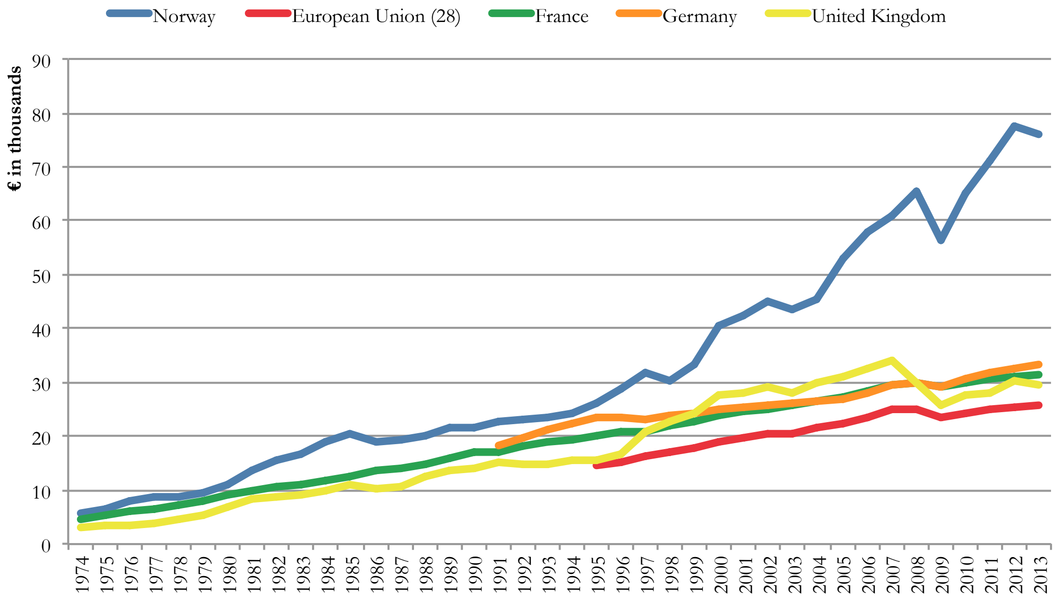
b. Evidences of success

With the Figure 4 below, we wanted to highlight Norway's economic success, as proxied by GDP/ capita. The Figure illustrates the GDP/ capita at current market prices for the three largest economies in the EU, for Norway and the EU (28 countries) average. Often the scarcity of reliable historical data complicates analysis. However, Norway's economic edge towards its available benchmarks is so gigantic that we believe no further analysis are required to demonstrate its economic success.

* Most of the data comes from the CIA World Fact Book and was crosschecked with other sources including the IMF, the World Bank and the United Nations.

Figure 4: GDP/ capita at current market prices for Norway and available benchmarks

Source: Eurostat.



So today, it is clear that Norway's story has been a success. In numbers, they have one of the world's highest GDP/ capita around $100,000*, a low public debt at around 30% of GDP, one of the highest budget surplus at 13% of GDP and a stunning unemployment rate at 3.6%. From a social perspective, it has one of the 7th most equal distribution of income with a Gini Index score of 25 and simply the highest Human Development Index score. In terms of ecology, the picture is bright but not perfect. Given their large production of oil and gas, their carbon intensity has been increasing (see Carbon Curse) and lies within European peers (see Figure 1), yet below Denmark and Finnish neighbors. To be comprehensive, we have to add that Norway also faces domestic issues among which its ageing population looks the most significant. Besides, Castellacci (2008) shed new light on the so-called Norwegian Paradox, according to which Norway is characterized by a peculiar low innovation and high economic performance. He argues Norway's innovative activities are, on average, above peers but that the crowding out effect (due to the boom in the energy sector) led to underinvestment, lack of resources and scale within these productive sectors – resulting in an aggregate below average innovation. He suggests this might put the economy at risk in the post oil era if no "pro-innovation" policies are taken (e.g., an incentive scheme to encourage private

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* The IMF, the World Bank, the CIA and United Nations all rank Norway in the top 5.

investments and the entry of firms in high-tech sectors). Nevertheless, most will think the pros largely outweigh the cons and conclude Norway is in an excellent economic and environmental shape. All in all, they overcame the two curses. The question we have – already touched upon – but have yet to answer is how they achieved this.

c. Norway's path to success

In this section we will look at the necessary structures (e.g., strong institutions) and the specific policies (e.g., Sovereign Wealth Fund) developed by Norway. We will mostly focus on their peculiarities (e.g., importance of the state) and their specific policies rather than their general institutions, as considered more insightful in our case (EU members have, in general, democratic governments, strong institutions and an open economy).

i. Strong democratic government and institutions

According to the Constitution of Norway, passed in 1814 – shortly after the country freed up from Denmark – the country is a constitutional monarchy with a unicameral parliament, the Storting. In 1905, the parliament (which holds the legislative power) proclaimed independence from Sweden and crowned Prince Carl as King. As far as quality is measurable, A Pestle Analysis by Marketline, states the domestic government is considered to be one of the best in terms of policy implementation (e.g., heavy tax reforms in 2008 and strict environmental policies). An older example of their avant-gardist policy implementation was to introduce universal suffrage for women as early as 1913 (long before the UK in 1928 or France in 1944). It is important to know that the country has a multi-party system[*] wherein the different political forces often have to form coalition to gain majority. However, the Labor Party is and has often been the largest party in Norway. It governed the country from 1935 till 1981 except for three[†] short periods of time. After what, Conservative-led coalitions succeeded Labor-led governments several times until now when Erna Solberg (Conservative) succeeded Jens Stollenber (Labor) as prime minister (which de facto holds the executive power). Norway's recent key economic policies were: to achieve a more equal distribution of income (by regulating income tax), to implement a 4% limit on using returns of the

[*] Following the 2013 election, eights parties are represented in the parliament, of which the Labor Party (55 seats) is the largest followed by the Conservative Party (48) and the Progress Party (29).

[†] 1963, 1965-1971, 1972-1973.

Sovereign Wealth Fund, to increase spending on education and health and last but not least to pledge to reach Carbon Neutral by 2030.

The Norwegian's government is not only strong in policy implementation but also in terms of corporate control. According to Marketline (2013), the state accounts for more than 50% of the country's GDP and owns around 35% of the market capitalization of the listed companies on the Oslo stock exchange. For example, they held large stakes in key sectors including:

- Petroleum (around 67% stake in Statoil)
- Telecommunications (around 54% stake in Telenor)
- Aluminum production (around 44% stake in Norsk Hydro)
- Fertilizers (around 36% stake in Yara International)
- Hydroelectricity production (100% stake in Statkraft)
- Banking sector (around 34% stake in DNB bank)

Now that we have covered the legislative and executive power, we shall turn towards Norway's judicial system. As one would expect, it considered very liberal, sound and effective by most; enforcing property rights and contracts. Perhaps more surprising, it even has the power to suspend a ruling passed by the government. This strong and judiciary is probably to be credited for one of the lowest corruption[*] in the world.

All in all, these result in Norway being ranked 9th by the World Bank (June 2013) on the ease of doing business, better than any member of the European Union but for Denmark.

ii. Economics openness and developed financial market

Although the Norwegians rejected their government's recommendation to join the European Economic Community (EEC) in 1972, the country signed a free trade agreement[†] with the EEC one year later. Norway has also ratified the EU-EFTA accord, which created the European Economic Area[‡] (EEA) in 1994. Furthermore, a member of

[*] The Corruption Perception Index currently ranks Norway 5th best (out of 177 countries).
[†] Norway currently is a member of the European Free Trade Association (EFTA).
[‡] EU plus Iceland, Liechtenstein, and Norway.

the World Trade Organization since its foundation in 1995, they also implemented a Generalized System of Preference (GSP) – scheme, under which 90 developing countries benefit from a duty relief on the vast majority of products. These favorable trade links, sign of clear openness, have helped the economy flourish over the past decades.

In terms of financial development, which can help tackle the Volatility Curse (hence the Natural Resource Curse – see above), Norway first significant step was to set up the Norges Bank, their central bank, in 1816. Their website states: "Norges Bank shall promote economic stability in Norway. Norges Bank has executive and advisory responsibilities in the area of monetary policy and is responsible for promoting robust and efficient payment systems and financial markets. Norges Bank manages Norway's foreign exchange reserves and the Government Pension Fund Global". We will mostly focus on two of these roles, namely the promotion of the financial market and the management of the Government Pension Fund (i.e., their Sovereign Wealth Fund).

The ancestor of Norway Stock Exchange, the Christiana[*] Exchange (Christiania Børs) was set up three years after the Norges Bank in 1819. At that time, the economy was weak and money was rather scarce so the exchange was set up as a meeting place for investors to auction mostly share in ships and a bit of commodities and currencies. It is only in 1881, that the place started listing financial instruments (i.e., railway shares and 30-y bonds). At the end of 2013, the Annual Report of the Oslo Børs counted 218 companies listed on the exchange with a total market capitalization of NOK1968 bn (i.e., $325 bn). To allow cross-country comparisons, we used total market value of publicly traded shares per capita (using data from CIA[†]) as a proxy for a country financial market development. According to this data, Norway ranked 12th most financially developed country in the world, and 5th in Europe. Though far behind Luxembourg and Switzerland, it is only slightly below Sweden and the UK. Moreover, the ratio is almost twice bigger than the one's in Belgium, France, Ireland or Spain and more than 2.3x higher than the European Union. In a nutshell, Norway had the financial weapons to fight the curse.

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[*] Christiana was the name of the capital at that time.

[†] Only data found that allowed for cross-country comparisons. The market value data is as of December 31st, 2011, but we believe this outdated data is still meaningful to compare countries.

iii. Sovereign Wealth Fund

Another institution key to the development of Norway is their world famous sovereign wealth fund, supposedly[*] the largest in the world with NOK5206 billions (i.e., $858 bn or almost 1.7x their GDP) worth of assets at the end of 2013.

In a report dated April 4 2014, addressed to and approved by the Sorting (i.e., the parliament), the Ministry of Finance detailed the management and the performance of the Government Pension Fund in 2013. The report starts with the idea behind the fund: "After Norway discovered oil in the North Sea in 1969, it soon became apparent that the values involved might be significant. It was also acknowledged that the revenues from the petroleum activities are not revenues in the ordinary sense, as these are partly offset by the extraction of a non-renewable resource. It was further acknowledged that the revenues would fluctuate significantly with the oil price.(…)". These three sentences say it all. Not only they understood the size of the rent but also its dangerous volatile characteristic and its non-renewable component. However, in agreement with Auty (2003 – see Section 1.B): sustainability does not require the resource to be passed onto the next generation but rather the capacity to sustain the income stream. So there was (at least) one way to exploit this finite resource in a sustainable way, and the way chosen by the Norwegians was to set up a Sovereign Wealth Fund.

[*] According to the Sovereign Wealth Fund Institue.

Figure 5: Historical Development of the Government Pension Fund Gobal (NOK bn)

Source: Ministry of Finance and Norges Bank

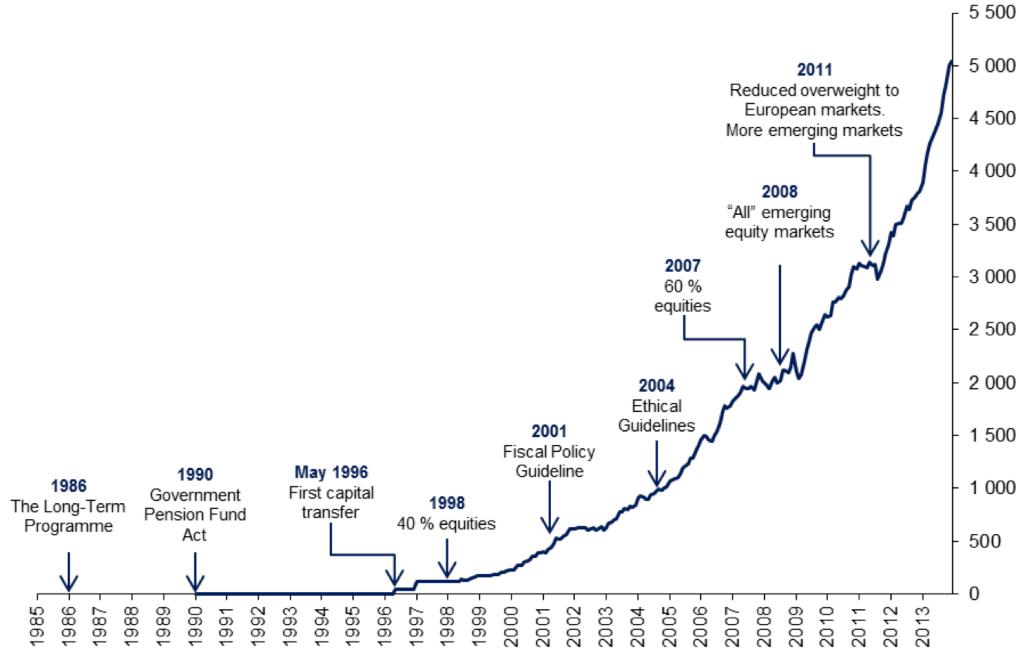

Figure 5 details the historical development and the growth in market value of their Government Pension Fund Global (GPFG), which with the Government Pension Fund Norway (GPFN – worth NOK168bn) forms the Government Pension Fund (i.e., their sovereign fund). Although the figure is quite exhaustive, it doesn't show when the idea of a fund was first launched. And because Matthew (22) wrote: "*Reddite ergo, quae sunt Caesaris, Caesari et, quae sunt Dei, Deo*[*]"; we must mention that it is in 1983 that the so-called Tempo Committee launched a proposal of a fund to smoothen the spending of petroleum revenues. In 1986, the establishment of a fund was part of the government "Long-Term Programme". Four years later, the fund act was passed. Nevertheless, it remained an accounting tool for six more years, barely keeping track of the amount return to cover the non-oil deficit. Finally, in May 1996 the first net allocation was made to the fund.

Now that we understand why and how the fund was set up; we will discuss how it currently works and under which principles. The GPFG and the GPFN have no governing bodies of their own; they are managed by the Norges Bank and the Folketrygdfondet, respectively – both under mandates set by the Ministry of Finance. As

[*] "Therefore give back those things that are Caesar's to Caesar and those things that are God's to God."

the GPFG represents most (i.e., 97%) of the GPF, it will be the focus of our analysis. The system is pretty straightforward: government revenues from the petroleum activities are transferred to the GPFG, which re-invest it with the purpose of financing pension expenditure and support long-term considerations spending. The objective is to maximize the international purchasing power of the capital over time, given a moderate level of risk. This risk is mainly defined by the asset allocation:

- A fixed[*] *60% in equity* following an unknown benchmark index comprising 46 countries (o/w 22 are defined as emerging markets by the index provider FTSE)
- Not less than *35% fixed income* following an unknown benchmark index comprising 21 currencies (o/w 10 are from emerging markets)
- No more than *5% in real estate*

The benchmark adopted by the Ministry implies that the composition of investments in equities and corporate bonds adheres to the principle of market weights, whilst the composition of investments in government bonds is based on the sizes of countries' economies, as measured by gross domestic product (GDP weights).

All in all, we understand this is mostly a quasi-passive strategy (i.e., benchmark tracking) with a very long-time horizon. In theory, the financial target of the fund is to realize a 4 % real rate of return in the long run. This 4% target coincides with the upper limit of the allowed petroleum transfers (see below). In practice we can say their results are in line with their expectations, the fund has achieved a net[†] average annual return between January 1997 and December 2013 just below 3.9%. However, due to the large portion of equity the fund has a quite volatile performance (e.g., in 2013 the return on GPFG was 15.9% driven by a global stock price increase in developed markets). Although these financial results are of interest, what principally matters to us is the contribution the fund makes to the Norwegian economy. With other words, the amount transferred from the GPF to the government. In the fiscal budget for 2014, this amount is estimated to be NOK139 bn (i.e., $24 bn), which reflects a substantial 4.5% of their GDP; but seems[‡] still below the upper 4% limit. Given its (growing) size and active contribution to the Norway's economy, it could hardly be argued that this fund is not and will not be capable of sustaining the (oil and gas) income stream for the future generation.

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[*] If it deviates from 60% by more than 4% at the end of a month, it has to be rebalanced.
[†] Net of inflation and management fees.
[‡] We cannot provide an accurate number as the government revenue from the petroleum activity (an inflow to the fund) in 2013 is not available.

iv. Pro-Environment Measures

Last but not least, Norwegians are of course well known to have tackled the Natural Resource Curse, being successful from an economic point of view. But they are also famous (though a bit less), for overcoming the newly discovered Carbon Curse. As a reminder, they managed to keep a low carbon intensity despite massively exploiting their oil and gas resources (see Carbon Curse). One might wonder how they have done this, especially given their (very) cold climate and their (very) well-off population (proponent to consume, hence pollute more).

We would argue the major step towards a comprehensive environmental policy in Norway started with the foundation of the Ministry of Environment[*] in 1972, three years after their large discovery of oil in the North Sea. However, one should not forget the role played by the Finance Ministry, which had already introduced taxes on petrol (1931) and on sulfur in mineral oil (1971). The combined actions of both Ministries resulted in several environmental acts and taxes (see Appendix 2), which helped protect the environmental landscape of the country and ensured proper utilization of the petroleum resources. As examples, hefty taxes on fuel (see Carbon Curse) and CO_2 taxes surely helped reducing carbon emission. While acts such as: "The Environmental Information Act" – increased environment awareness among Norwegians – or "The Greenhouse Gas Emission Trading Act" – promoted the usage of transferable emission allowances – all contributed to lower emissions.

Moreover, Norway also put words into actions by heavily investing in hydroelectric plants. As a result, more than 90% of Norway's electricity is currently produced through those plants. This was done on the contrary to many fuel-rich countries, which have used cheap domestic fossil fuels as their main source of electricity (e.g., Saudi Arabia). Furthermore, their largest hydroelectric plants: Kvildall, Aurland and Tonstad have seen the bulk[†] of their capacity construction initiated after 1969 (and the discovery of oil).

More recently in 2008, the country even pledged to become carbon neutral by 2030. Although very ambitious, their plan relies heavily on the international emission-trading scheme, making them the world-third largest country carbon buyer at that time.

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[*] Called "Ministry of Climate and Environment" as of January 1st 2014.
[†] Only ¼ of Tonstad capacity was installed in 1968,

Therefore this is a sort of "'indirect" contribution to emission reduction (i.e., they buy the right to emit more rather than decrease their emissions). On the other hand, Norway also has promotes specific "direct" policies, by for example being a leader in carbon capture and storage (CCS) technology; setting up a specialized technology center (in Mongstad in 2012) alongside corporates (a.o., Statoil, Shell and Sasol). If they manage to scale it up at a reasonable cost, this technology could have a bright future as the Intergovernmental Panel on Climate Change (IPCC) estimated that a plant with CCS could reduce its CO_2 emissions by 80–90%; however, the plant would require to generate 10–40% more energy.

Last, this would not be Norway if the sovereign fund were not involved. Indeed, a significant portion of the Fund is dedicated to environmentally friendly investments. Today about 6% of the market value of the equity part of the GPFG (i.e., NOK180 bn) is made of "eco-friendly[*]" companies.

Trying to conclude this case study on Norway, we would like to highlight how this country has been an advocate of strong institutions (and government); especially given institutions' facilitating role to implement forward-looking and courageous policies. At the beginning, right after ratifying their constitution (1814), they set up their central bank (1816) and the premises of their stock exchange (1819). Later, shortly after the oil discovery (1969), they created the Ministry of Environment (1972). While the central bank and the stock exchange helped them to later (1990) develop their Sovereign Wealth Fund; their government was also helped by the Environment Ministry to pass strong environmental acts and taxes. Although the Norwegians refused twice (1972 and 1994) to enter the European Union, they have always remained an open economy signing (free) trade agreements with many parties. Obviously, some will say Norwegians were simply fortunate enough to learn from the failure of others (e.g., Dutch Disease) before implementing their policies. To those we will answer, we just provided an example – though at a small scale – of a country that managed to effectively exploit its carbon-based resource in both an economic and an environmental way. Let them inspire our policies going forward!

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[*] Companies that derive more than 20 % of their earnings from environment-related activities, and which therefore meet the environmental requirements in the FTSE Environmental Opportunities All-Share Index

3. Would Shale Gas be a Curse for the EU members?

If we were to assume shale gas was a resource windfall for the EU members (which we will later evaluate in Part 2 and 3), one would be wise to question whether or not their members would be confronted with the Natural Resource and the Carbon Curse. In this section, we will try to provide an answer to this interrogation by discussing the different problems arising with a resource bonanza and how EU members could or would solve them. We will start with four risks we attribute to the Natural Resource Curse and finish with those associated to the Carbon Curse.

First, a resource windfall – combined with weak institutions and short-sited government – has often led to rent seeking (or even armed conflicts), especially in the case of an easily appropriable resource (e.g., diamonds). However, we believe EU members have now developed strong enough political system to resist those temptations, lowering the institutional appropriability. Moreover, shale gas exploitation and transport requires heavy investment, making it hardly technologically appropriable. Thus, strong governments plus low appropriability clearly offset the risk of rent seeking. Nevertheless, the capital insensitivity nature of the resource would tend to concentrate the rents in fewer hands. Governments are likely to be one of them (through SOEs or taxes) and should be wary no to succumb to a false sense of confidence given by the new income. Indeed, we have seen many granting over-generous social policies or take on more debt rather than using the proceeds more cautiously. For example, we believe many EU governments would be prudent to use the potential extra income, first to limit their deficit, then to reduce their debt and later setting up a sort of savings fund for the future. Furthermore, it is of the highest importance governments understand the notion of keeping a positive genuine savings in order to exploit a finite resource in a sustainable way.

Second, a resource windfall could draw resources towards the resource sector, hence out of the manufacturing sector. This phenomenon, labeled resource movement effect, can result in deindustrialization and chronic slow growth. Although this is a significant risk faced by the EU members, we believe the current economic conditions partially counterbalance it. On the one hand, we consider likely that human resources will not switch away from the manufacturing sector towards shale gas exploitation. Indeed, we expect new demand for human resources to be filled with unemployed workers, which are unfortunately largely available across the EU with latest unemployment rate at 11.7%. On the other hand, the shift in financial resources towards capital-intensive shale gas is a real threat to the industry! Nonetheless, we would remain optimistic because developed EU financial markets combined with easy access of foreign investment will still be a source of liquidity. What is more, many believe access to cheaper source of energy (resulting from shale gas exploitation) would give an economic edge to an energy-intensive manufacturing sector. Others would argue this lower their incentive to invest in energy efficiency measures, which on the long term might prove costly. This was illustrated by the American automobile sector, which had to be bailed out during the recent financial crisis by the US government. But this is another debate. All in all, it seems the resource movement effect (especially regarding capital) is a risk faced by the EU manufacturing sector, though clearly not insurmountable given easy access to developed financial markets and other means of financing (e.g., foreign investment, private equity, project finance).

Third, a resource windfall could lead to extra spending and therefore a real increase in the exchange rate, labeled spending effect. Again, we acknowledge this risk but believe governments have the keys in hand to mitigate it. To start of with, it seems likely governments will have in hand a significant part of the extra income. This is relevant because they then have the choice not to transform it in extra spending but rather in reducing their deficit (then debt) and later, if need be, by setting up a savings fund. Then, some EU members – not in the Eurozone - might have the financial muscles to pledge to cap their currency as to avoid a real increase. A recent example comes from the Switzerland neighbor (though not a EU member), where the central bank in 2011 pledged to buy unlimited amount of foreign currencies as it would not allow the Swiss Franc to be worth more than €0.83 (i.e., SFr1.20). Last, Eurozone members might well see the effect mitigated between its 18 members, unless the zone (as a whole) becomes net exporter of gas (which seems unlikely – see part 3).

Fourth, a resource windfall increases the exposition of an economy to volatile resource prices. Therefore, it results in a more volatile economy, which is often correlated with lower accumulation of physical capital. One more time, we recognize this possibility exists but should not be considered a real hurdle to exploit shale gas. Indeed, diversification within the EU economies vastly reduces the volatility introduced by resource exploitation. Moreover and as we have seen with Norway, strong financial institutions and if need be a sovereign wealth fund, seem working solutions to tackle the inevitable cycles of commodity prices.

Fifth, a carbon resource windfall could result in an increased carbon intensity, which we would like to remind has an economic cost (expected to rise), hence economic consequences. Anyway, emissions are expected to surge for several reasons. One, it requires energy to get energy. Therefore, emissions from fuel extractions are inevitable, especially given the supposedly low EROEI of shale gas. Two, apparently cheap shale gas would replace another source of energy in the fuel mix. If it were to be coal, then it could have a positive net effect on the carbon intensity. However if it were at the expense of conventional gas or renewables[*], the impact would be dramatic. Third, access to cheap fuel reduces incentive to invest in energy efficiency and builds pressure on politicians to provide cheap fuel. For example even if France is not oil rich, we have seen how tempting it was to François Hollande to promise a price cap (with a floating tax system) on oil prices in his 2012 campaign to become president. Fortunately, this demagogic measure was never enacted. But this highlights how these long-term environmental issues are difficult to tackle. Norway seemed to have found a way around it. Although their carbon intensity has increased recently, they actively fight carbon emissions and they announced they would become carbon neutral by 2030. However, their plans rely heavily upon being a large net buyer of carbon certificates – which is possible at the scale of Norway – but might prove much harder at the scale of the European Union.

To wrap up, it seems to us that the Natural Resource Curse is not a valid reason to prevent the exploitation of shale gas in the EU. Although there are foreseeable economic risks, we believe EU members have the required institutions to empower governments and help them implementing the right policies, which would transform the curse into a blessing. Moreover, we have seen it is feasible to exploit finite resource in a sustainable way if countries manage to keep a positive genuine savings rate. Nevertheless three questions remain largely open. First, do we sufficiently trust our democratic system to believe our political leaders will not succumb to demagogic generous policies and will

[*] We have intentionally left aside nuclear. Although it is clear that replacing nuclear by shale gas would result in more CO_2 emissions, the net impact on environment is harder to assess due to nuclear waste.

implement the right forward-looking policies? Second, is there a way at the EU scale to exploit shale gas in an environmental friendly way? Last, is shale gas really a resource windfall or is it a costly waste of time? While we will try to answer the last two questions over the next two sections, we will leave the first to the appreciation of the reader.

Part 2: Shale Gas Economics in the US

The aim of this part is to determine whether or not shale gas should be considered a resource bonanza. We will try to provide very different, often opposing, point of views in order to better assess shale gas economic impact. While many, such as Daniel Yergin[*], argue shale gas is the biggest energy innovation so far in the 21st century; others, including Richard Heinberg[†], believe it is a very costly waste of time and resources. Section 1 will define shale gas and explain how it is produced. In the second section, we will give an overview of the current US situation, the clear leader in this sector. We will start by measuring the size of the sector and its recent growth, to better grasp its significance. Then, We will then zoom in, trying to understand the financial dynamics of the industry. After what, we will try to enhance the readers' awareness towards the multiple environmental concerns regarding shale gas. Finally, we will discuss the legal and institutional framework that surrounded shale gas development. The third section should be the heat of the discussion, confronting two (somehow caricatured) points of view. On the one hand, we will put ourselves in the shoes of those who believe shale gas is the US way for the quest of the Holy Grail: energy independence. On the other hand, we will oppose those who regard fracking[‡] as a false promise.

1. What is Shale Gas?[§]

Shale gas is one of the four forms of *unconventional gas*. Although uneasy to define, there exist two definitions of unconventional gas. From a technical point of view: "natural gas is classified as unconventional gas if it is situated in rocks formation with a permeability of less than 1 millidarcy[**]". However this definition has its limitations, as it does not

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[*] Daniel Yergin is a Pulitzer Prize-winning American author, speaker, and economic researcher. He is the co-founder and chairman of Cambridge Energy Research Associates, an energy research consultancy that is now part of IHS Inc. One of his most famous books is the Quest (2011).

[†] Richard Heinberg is an American journalist and a senior fellow at the Post Carbon Institute. He writes extensively on energy, economic, and ecological issues, including oil depletion. He is the author of eleven books including Snake Oil (2013).

[‡] Fracking is the abbreviation of hydraulic fracturing, the technique used to produce among other things shale gas. This will be developed in the next section.

[§] This section, which does not involve much judgment but is merely a vulgarization of complex facts, essentially relies on the work of Chen, X., A. Jha, H. Rogers and X. Wang (2013). Their recent paper gives a very comprehensive overview of the US shale gas industry compiling more than 300 sources.

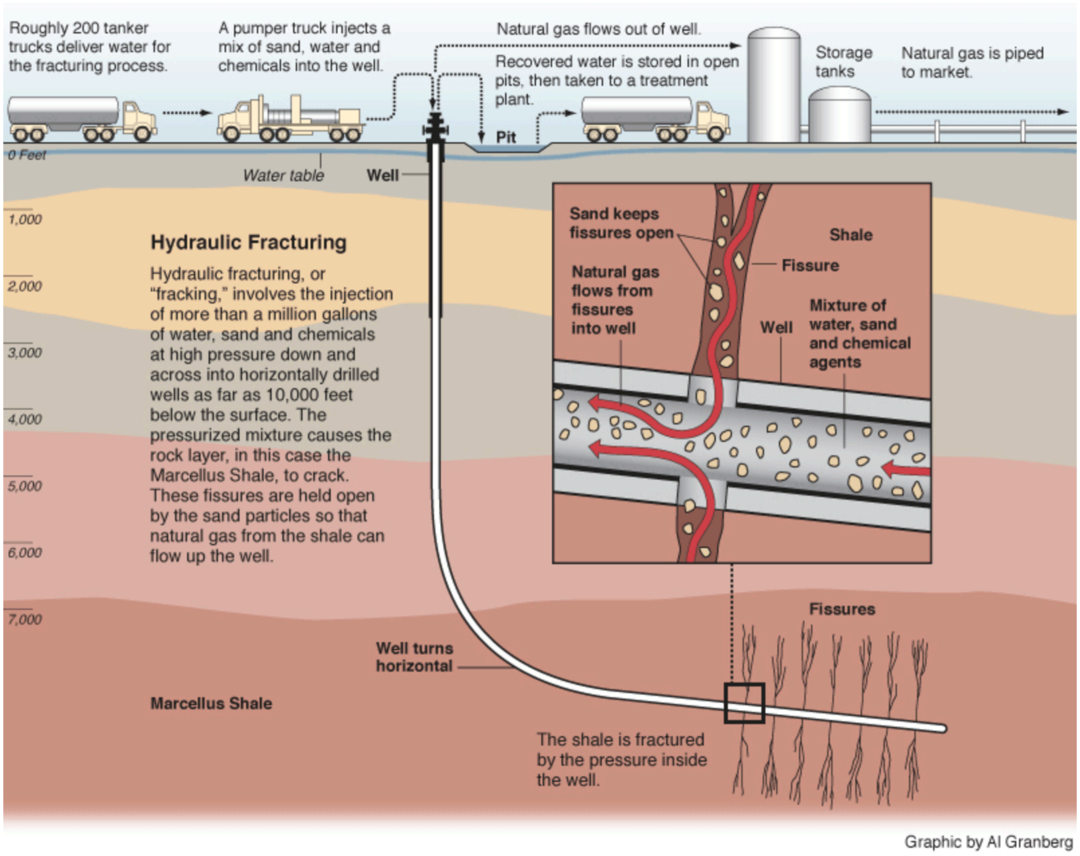
[**] The darcy is a unit of permeability. A medium with a permeability of 1 darcy permits a flow of 1 cm^3/s of a fluid with viscosity 1 cP (1 mPa·s) under a pressure gradient of 1 atm/cm acting across an area of 1

encompass economic significance. Hence, the updated economic definition of unconventional gas is: "natural gas that cannot be produced at economic flow rates nor in economic volumes of natural gas unless the well is stimulated by a large *hydraulic fracture treatment*, a horizontal wellbore, or by using multilateral wellbores or some other technique to expose more of the reservoir to the wellbore".

By definition, shale gas is then closely related to hydraulic fracturing (commonly known as fracking). The figure below illustrates and explains this process. Simply put, fluids (mainly water) are pumped deep underground to break apart the rock and release the gas (or oil).

Figure 6: Typical Hydraulic Fracturing in the Marcellus Shale (US)

Source: www.propublica.org/special/hydraulic-fracturing-national



To create the fractures and maintain them open, operators inject different kind of chemicals along with water. Once the fracking is complete, the internal pressure of the

cm². Typical values of permeability range as high as 100,000 darcys for gravel, to less than 0.01 microdarcy for granite. Sand has a permeability of approximately 1 darcy.

geologic formations make these injected fracturing liquids rise back through the drill above the ground. This is the so-called produced water (or flowback).

We previously stated, that shale gas was one of the four forms of unconventional gas, alongside with tight gas, coal-bed methane and methane hydrates.

- *Shale gas:* Shale gas is in shale deposits, which are typically found in river deltas, lake deposits or floodplains. Shale is both the source and the reservoir for the natural gas. This can either be "free gas" which is trapped in the pores and fissures of the shale rocks, or adsorbed gas which is contained in surfaces of the rocks
- *Tight gas:* Unlike shale gas or coal-bed methane, tight gas is formed outside the rock formations where it has migrated over millions of years into extremely impermeable hard rock or sandstone or limestone formations which are unusually non-porous
- *Coal-bed methane:* Coal-bed methane is produced from and stored in coal seams which are of extremely low permeability
- *Methane hydrates:* Methane hydrates is a crystalline combination of methane and water formed at low temperatures under high pressure in the permafrost and under the oceans

Although Methane hydrates have a gigantic potential with resources estimated to be 10 to 100 times as plentiful as US shale gas, production currently poses huge technological challenges and there have only been so far experimental projects. Methane hydrates are thus excluded from the scope of this paper but more information can be found in Appendix 3.

According to the International Energy Agency (IEA), unconventional gas production is split as follow by type (see Figure 7) and by geographies (see Figure 8). In 2011, the US and Canada accounted for c. 90% of the total unconventional gas production. Interestingly, at that point tight gas accounted for a larger portion than shale gas with 45% and 41% respectively. However, given shale gas recent growth versus tight gas relative stagnation, it is more than likely that shale has already overtaken tight in the world today.

Figure 7: Global Unconventional Gas Production Split by Type in New Policies Scenario

Source: IEA – World Energy Outlook (2013) – Compiled from Table 3.5

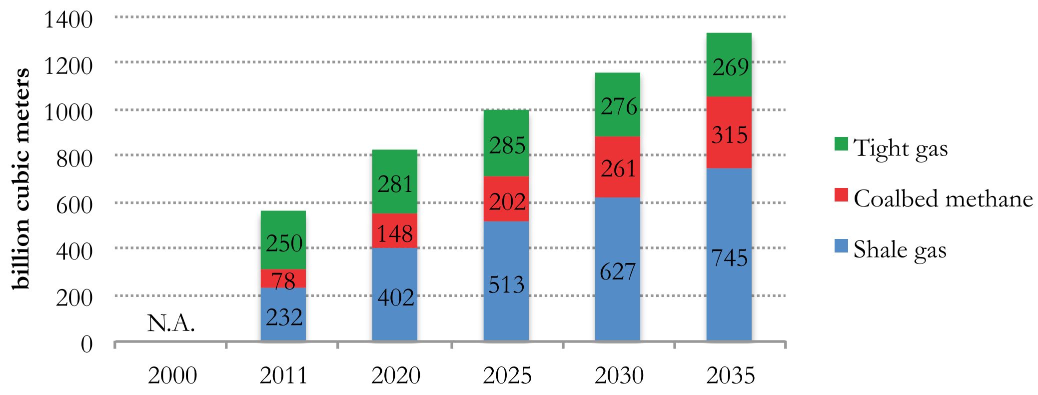
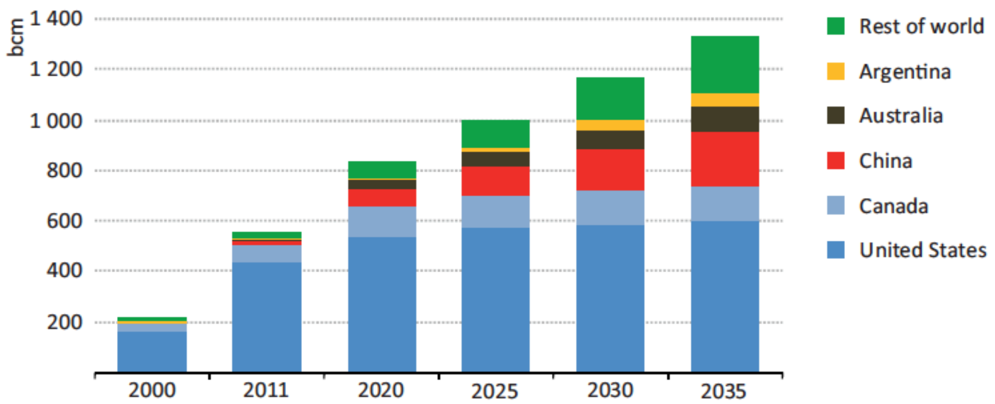


Figure 8: Unconventional Gas Production Split by Geographies in New Policies Scenario

Source: IEA – World Energy Outlook (2013) – Figure 3.7



We believe that these two figures are self sufficient to highlight why we decided to focus on shale gas in the United States. Indeed, Figure 7 shows the much larger potential of shale gas as a source of natural gas production (versus the other two types). While figure 8 illustrates the current (i.e., in 2011) edge of the US in terms of unconventional gas (hence shale gas) production versus the rest of the world, their domestic production amounting for c. ¾ of the global production. If this would not be sufficient, Figure 22 shows the US accounted for 97% of the world's shale gas production in 2011, the next section will therefore focus on how they reached such a dominance.

2. Evolution of Shale Gas in the US till today

a. Evolution of the Production of Shale Gas

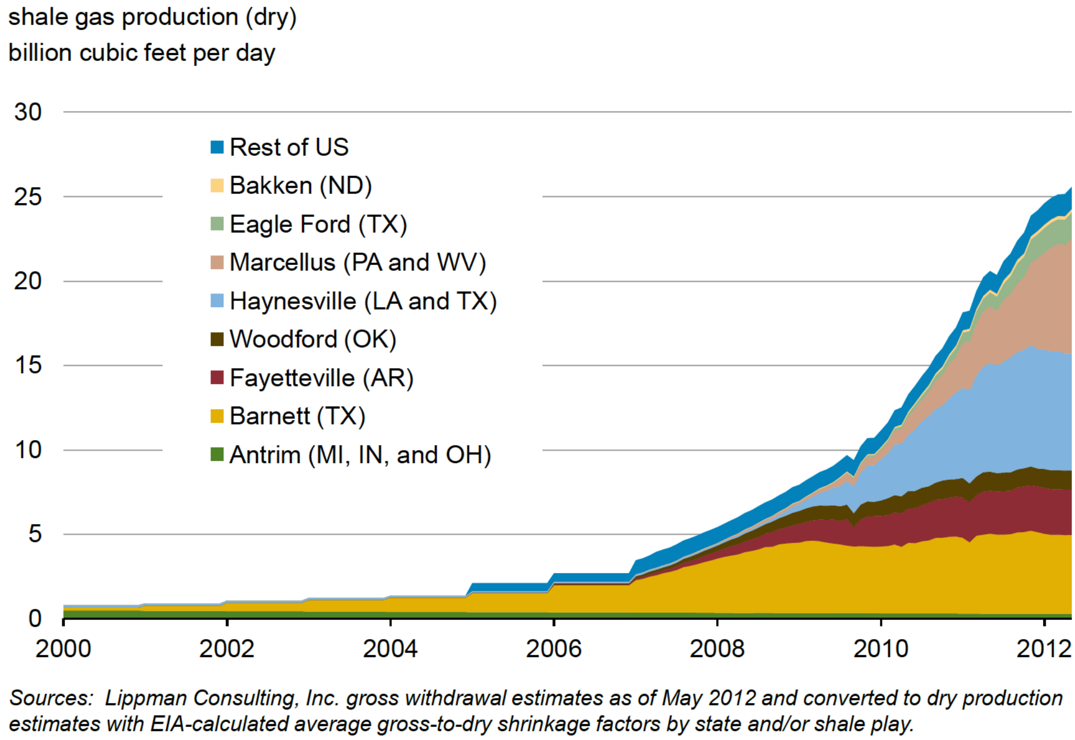
To trace back the roots of shale gas, one has surprisingly to look towards the state of New York. It is indeed in 1821, that shale gas was produced for the first time from shallow shale wells in the Devonian Durkik Shale (near Chautauqua, New York). Over the nineteenth century, production expanded slowly in this region – south east of lake Erie.

However in the 1850s, the discovery of large conventional gas reservoirs (e.g., Drake Well) discouraged investment in alternative sources of energy such as shale gas. Indeed, there are two engines that drive alternative fuels. First, it is the availability of conventional fuel. Second, the environmental concerns about conventional sources of energy. Because at the time, very few (if not nobody) cared about the second point, the only reason to develop unconventional gas would be a scarcity in cheap conventional sources (i.e., conventional gas, oil or coal). Hence, as long as oil prices were low and gas was available through conventional production, little was done to develop shale gas. Nevertheless, exploration continued slowly and significant shale gas reservoirs were discovered in West Kentucky and West Virginia, in 1863s and 1920s respectively. 1947 is also a key year for shale gas. This marked the first use of hydraulic fracturing in Grant County (Kansas) by Pan American Petroleum Corp. Although these developments were all of significance, the availability of conventional fuels largely slowed down the pace of innovation.

In 1970s, the story completely changed. The 1973 and 1979 oil crises resulted in skyrocketing oil prices. The first time, they surged from c. $3 per barrel to c. $12. In 1979, starting with the Iranian Revolution, prices rose from c. $16 to c. $40 over the course of a year. All-time high oil prices clearly stopped many cars' engines worldwide. However, they also fueled the first engine that drives research for alternative fuels. At that point in time, the Barnett (Texas) and Marcellus (Pennsylvania) shale had already been discovered. Yet, given their low permeability and their deepness, they were previously considered too difficult to exploit. This changed when climbing oil prices convinced the US Department of Energy to launch several public initiatives (see Section 4), including the Eastern Gas Shale Project (EGSP), to deeply study the subsoil resources and define the best way to exploit them. At the same time, several private corporations started investing more heavily into shale gas experimentations. Particularly Mitchell Energy & Development Corp. in the 80s tested hydraulic fracturing for a decade in the Barnett shale. After many unsuccessful attempts, they finally found a way to use hydraulic fracturing on a large scale that yielded positive financial returns. This changed the face of the shale gas industry. As a result of joint public and private efforts, the US Energy Information Agency (EIA) reckons shale gas production increased by more than 7 times between 1979 and 2000. Nevertheless, the amount of shale gas produced in 2000 still accounted for less than 2% of the US natural gas production. It was not yet a game changer. After 2000, as one can see from Figure 9 below, shale gas production skyrocketed in the United States, first largely driven by the Barnett Shale, then by the Haynesville and Marcellus plays. In 2011, shale gas accounted for roughly than 35% of the US natural gas production (see Figure 22). This was a revolution!

Figure 9: US Shale Gas Production by Play since 2000

Source: Lippman Consulting and EIA.



This gigantic increase in production that allowed them to reach c. 25 billion cubic feet per day in 2012 (i.e., c. 260 billion cubic meters per year) can be attributed to three factors: technological improvements, surging fuel prices (till 2008) and (slow but real) decrease in conventional gas production.

i. Technological improvements:

First, many private corporations, including Goodrich Petroleum and XTO Energy, joined forces to drive technological improvements. Most notably in 2002, Devon Energy Corp. acquired Mitchell Energy & Development for a mix consideration of around $3.5 billion in cash and shares. This allowed them to combine horizontal drilling and hydraulic fracturing techniques: the state of the art techniques at the time. In 2004, less than 10% of US wells were horizontal, in '12, the figure was 61%.

As Crooks puts it in the Financial Times (2014): "Fracking – pumping water, sand and chemicals into a well at high pressure to open up cracks through which the oil and gas can flow – has been spectacularly effective only when combined with horizontal drilling. Modern shale wells are no longer sunk like straws poked into the earth, but drilled down and then sideways for a mile or more, to open up a much larger hole through a layer of resource-bearing rock."

ii. Surging Fuel Prices

Second, not only gas but also oil prices increased in the early 2000s. As previously discussed, a restricted (e.g., through price) access to conventional sources of energy leads to development of alternative energies. To highlight the surge in prices we provide the evolution of four selected commodity prices since January 1988 till December 2012. We divided this period in two with March 1999 as the midpoint. We choose this midpoint as it represents roughly the lowest point in commodity prices for this period. The four commodities chosen are:

- Crude Oil – WTI represents the spot price of West Texas Intermediate in Cushing Oklahoma (in $ per barrel)
- Crude Oil – Brent represents the spot price of Europe Brent Free on Board (in $ per barrel)
- US Natural Gas Wellhead is calculated by dividing the total reported value at the wellhead by the total quantity produced (in $ per thousand cubic feet)
- US Gasoline represents US city average retail price of all grades of gasoline, (in $ per Gallon including taxes)

Finally, we decided to rebased prices in 100 basis as of January 1988 for Figure 10 and March 1999 for Figure 11 as to make them comparable. Figure 12 gives the absolute values at these dates.

Figure 10: Rebased Selected US Fuel Prices 1988 – 1999

Source: Data from EIA.

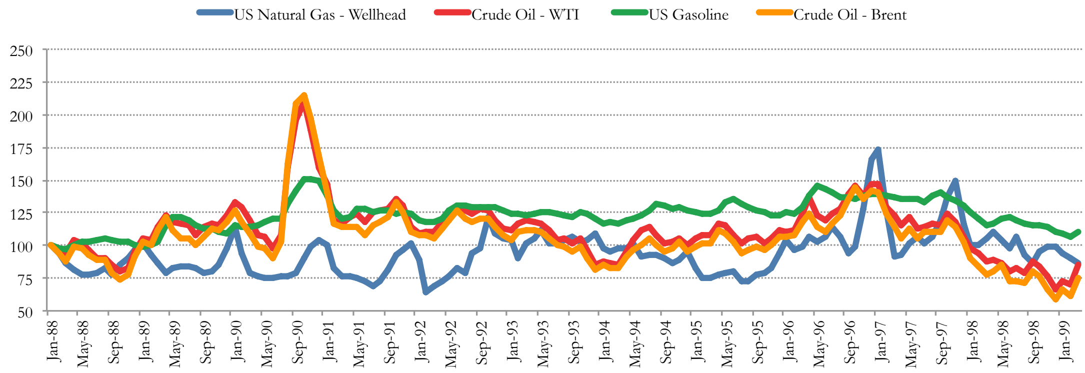


Figure 11: Rebased Selected US Fuel Prices 1999-2012

Source: Data from EIA.

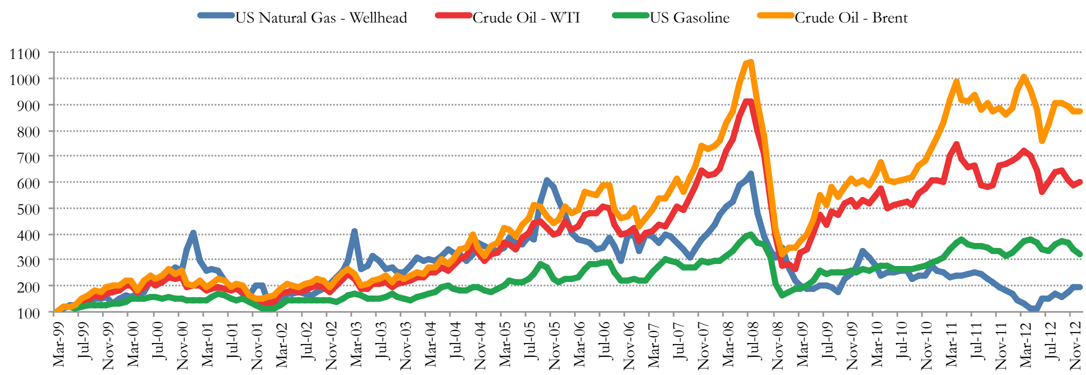


Figure 12: Selected US Fuel Prices

Source: Data from EIA.

Commodity	Unit	January-88	March-99	December-12
US Natural Gas - Wellhead	$ per '000 cf	1.96	1.70	3.35
Crude Oil - WTI	$ per barrel	17.13	14.68	87.86
US Gasoline	$ per gallon	0.95	1.05	3.39
Crude Oil - Brent	$ per barrel	16.75	12.51	109.49

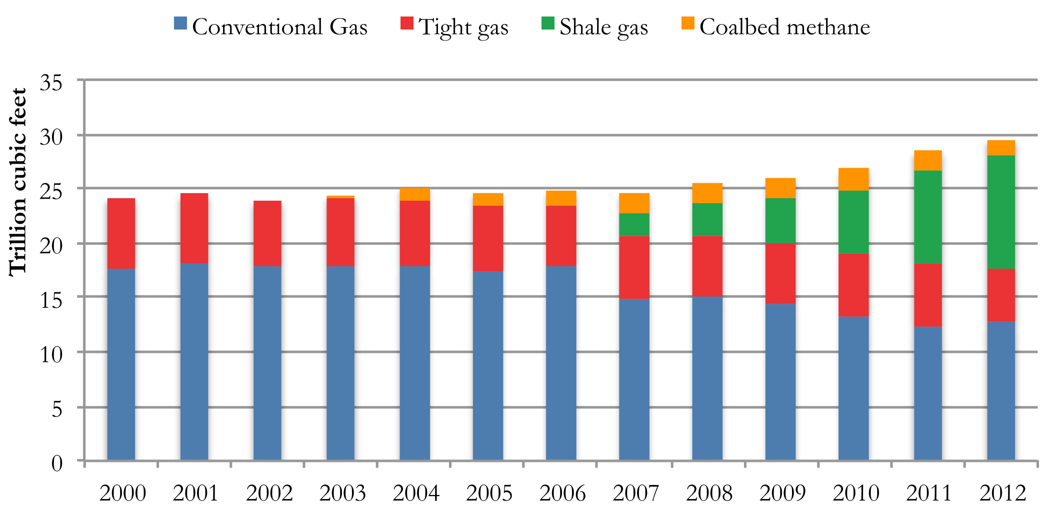
We believe these three figures are especially interesting in our case. Figure 10 allows us to say that fuel prices, though volatile, do not always show increasing trend. Indeed crude oil and gas prices decreased over this first period. Hence, this further highlights the unique characteristic of the second period. It is indeed after March 1999 that prices started to rocket. For example, crude oil prices doubled in a year, and were even multiplied by 9 and 10.5 in July 2008 for WTI and Brent, respectively. US Gas and Gasoline prices also increased dramatically before the financial crisis reaching 6 and 4 times their March 1999 prices respectively. So looking back at Figure 9, we can clearly testify a correlation between rising prices of conventional fuel and development of unconventional sources of energy. Moreover on figure 10 and 11, one can already notice the strong correlation between crude oil prices, though a gap start to widen as of early 2011. Interestingly for us, we can see that, though not fully correlated, gas prices seem to roughly follow oil prices till mid 2007, were they seemed to already lack behind oil prices. But it is surely after March 2009 when the oil prices started to climb back US natural gas failed to reproduce the same pattern. Prices as of December 2012 are still the same as those post financial crisis. It is clear that another variable entered in play.

iii. Decreasing Conventional Gas Production

The third reason that could provide an explanation to the shale gas boom is to be found in the decreasing output of conventional gas in the US. Figure 13 illustrates how shale gas[*] really picks up in 2007, when conventional endured its largest drop. Since then, conventional gas output never recovered and continued it slow but real decrease. While shale gas more than compensated this loss. As a result, natural gas output[†] kept increasing over the same period.

Figure 13: US Natural Gas Gross Withdrawal per type

Source: Data from EIA.



[*] The EIA does not provide a split for shale gas before 2007. As discussed, it existed before but in non-significant quantity.

[†] Figure 13 illustrates Gross Withdrawal, which includes gas that will later be flared. Hence, it overstates the net output by c. 15%, however this does not impact the message.

All in all, shale gas has clearly been a game changer for the US energy landscape over the last decade. Although it is not new per se, recent technological changes – most notably the combination of hydraulic fracturing and horizontal drilling – led the charge to turn shale gas into an energy revolution (if not an evolution). The years pre-financial crisis of high fuel prices, '06 and '07, saw shale gas most dramatic increase in growth rate. This reinforce the carbon curse paradox were high/ low fuel prices are incentive/ disincentive to research alternative energy sources. Now that gas prices have fallen back to lower level, thanks (or due to) to the availability of cheap shale gas (see Figure 11), one could wonder what will be the impact on the US economy carbon intensity. The impact shale gas had on natural gas prices, the impact of low natural gas prices on the profitability of shale gas itself and its environmental consequences will all be discussed here below.

b. Short-term impacts on the US economy

This section has for purpose to assess the impact shale gas had on the US economy since its clear takeoff, around '06-'07. We will assess to what extent it helped mitigated the financial crisis and following recession. First, we will consider the impact that falling gas prices (see Figure 11) had on households and businesses. Cheaper fuel prices are supposed to provide the US manufacturing sector with a competitive edge, this will be the second point of the discussion. Then, global impact of unconventional fuel on GDP will be estimated. Finally, we will put in perspective the impact on job creation. We would like to thank Mathieu, M., O. Sartor and T. Spencer (2014) for their thorough economical analysis on US shale gas, it has been a great source of inspiration.

i. Lower US gas prices

Figure 11 shows that gas prices significantly dropped from their high $10.8 per thousand cubic feet in the summer 2008. As previously discussed, this is mostly due to the financial crisis. However, US gas prices (unlike oil) never really bounced back and fluctuated around $3 at then end of 2012. This is partly the result of an increased supply of natural gas via unconventional sources, most notably shale gas. Nevertheless, this gigantic price drop failed to largely impact most households and business. On the first side, gas prices impact household on primary two fronts: direct consumption and impact on energy prices.

Figure 15: Gas Prices by consumer type

Source: EIA compiled by Mathieu et al. (2014)

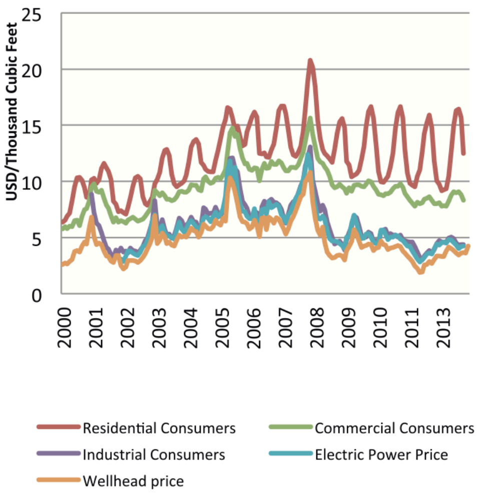


Figure 14: Annual US household energy expenditure

Source: US Census Bureau by Mathieu (2014)

	2012 expenditure (USD)	2012 expenditure vs 2005 (USD)	2012 expenditure as a share of 2012 post-tax income (%)	2005-2012 change as a share of 2012 post-tax income (%)
Natural gas	359	-150	0.57	-0.24
Electricity	1.388	122	2.19	0.19
Fuel oil and other fuels for heating	137	-1	0.22	0.00
Gasoline and motor oil	2.756	529	4.35	0.83

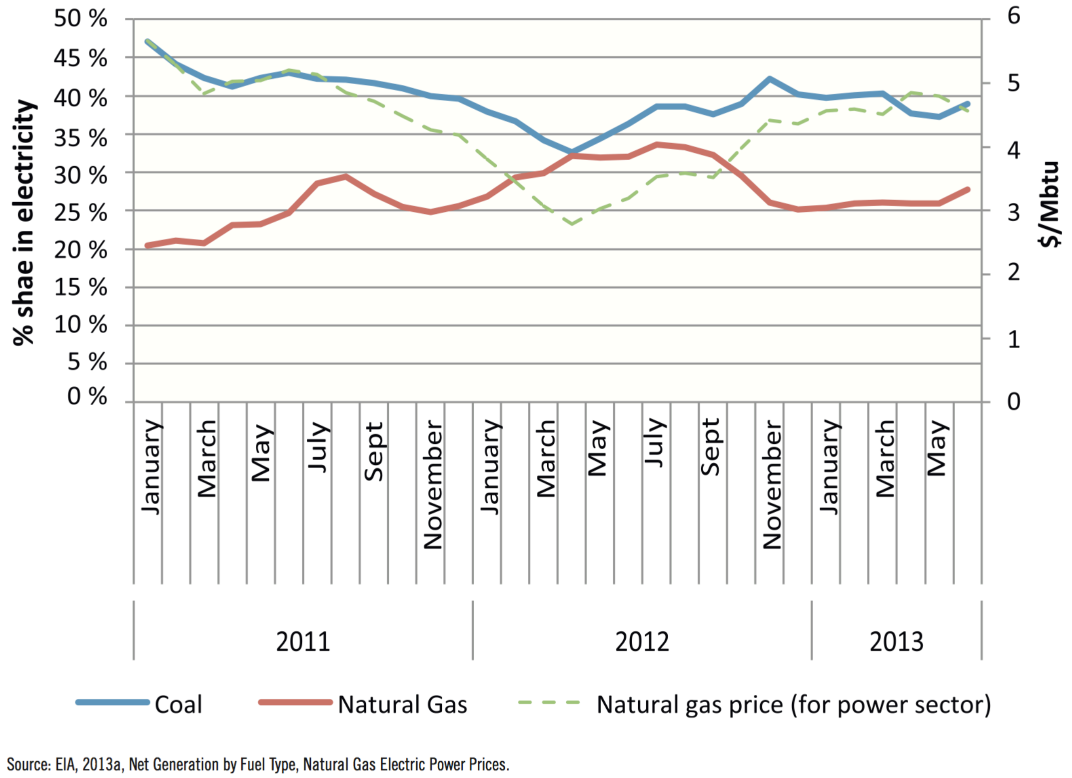
Source: US Census Bureau, 2012, Consumer Expenditure Survey.

Figure 15 shows the same trend as figure 11 regarding cheapest wellhead prices. Interestingly Industrial consumers and Natural gas use for electricity closely follow the wellhead prices with a small (i.e., transport) premium. However, commercial users did not benefit as much from the decrease. With prices almost twice as expensive as wellhead. Residential consumers (i.e., households) have experienced not only more expensive but also much more volatile gas prices, sometimes as high as three times the prices at the wellhead.

Nevertheless, bills paid for gas by households in the US still decreased on average. Figure 14 shows a decrease by $150 (i.e., 0.24% of '12 post-tax income) of the yearly bill between '05 and '12. This relativizes the impact on household purchasing powers especially given this decrease was more than offset by combined increasing electricity and gasoline/ motor oil bills. Something is puzzling about those facts. Figure 15 clearly highlights the decrease in the price electricity producers have to pay for one of their inputs (i.e., natural gas), so why is the electricity bill increasing? Figure 16 provides element of answers to this question by showing the evolving share of gas in the production of electricity in the US. This ranges between 20 and 35%, while coal has always kept a larger part of the pie. Gas and Coal amount together for c. 65% of the US electricity production. The rest is largely due to Nuclear, Renewables and Oil. Hence, if prices of other inputs – especially coal – increased relatively more than gas decreased, the US electricity prices will follow.

Figure 16: Share of Coal vs Gas in US Power Generation

Source: EIA compiled by Mathieu et al. (2014)



So natural gas reduced price has had a somewhat minimal impact on households' purchasing power and though it might have prevented electricity prices from rising further, the impact was also somehow constrained. Nonetheless, it had an impact on specific gas voracious businesses and this will be the focus of the next point.

ii. Impact on US manufacturing sector

To cut a long story short, shale gas did have an impact on the US manufacturing sector but this was largely constrained to the four manufacturing sub-sectors largely relying on gas as a feedstock. Mathieu et al. (2014) largely detailed this, highlighting petrochemicals, nitrogenous fertilizers, plastic materials & resins and other basic organic chemicals as the key sub-sector. Especially, Nitrogenous fertilizers and petrochemicals that saw there valued added between '06 and '11 increased by 280% and 54% respectively. Mathieu et al. also mentioned industries relying on gas as a fuel (not a feedstock). They singled out aluminum processing, iron & steel processing and petroleum refineries. However, their gas bill amounts "only" for 6% of their added value on average, hence they will be less sensitive to shale gas prices. While the first group (i.e., relying on gas as a feedstock) is clearly sensitive to shale gas, the second group (i.e., relying on gas as fuel) is less. What is more, the total domestic manufacturing sector accounted for 11.8% of the US GDP. Out of this, the smaller first group combined with the larger second one, accounted for c. 10% (it is hard to accurately split them due to sub-sector overlaps). As a result, these two categories only add up to c. 1.2% of US GDP.

In conclusion, shale gas and the associated lower natural gas prices might well give the US an edge in petrochemicals and associated derivatives manufacturing. We acknowledge that these products are inputs for many other downstream goods but lack of studies make the repercussion on the whole downstream industry harder to quantify. However, aggregate observations do not show that the chemical industry as a whole is shifting away from the EU to the US despite 7-8 years of shale gas "revolution". So in terms of manufacturing, shale gas has had a real impact, however constrained on (very) few specific sub-sectors. However, shale gas impacted the US output not only via manufacturing but also through other channels. This will be discussed in the next point.

iii. Impact on US GDP

Mathieu et al. (2014) studied the impact unconventional fuels had on the US economy both in the short run and in the long run.

On the short run they identified two effects. The first one is due to relative reduction in household total energy spending (compared to what it would have been without unconventional sources), which freed up resources to be spent elsewhere. They estimated the reduction in natural gas expenditure to amount for $40 billion for the period '08-'12, divided by an average US GDP of $15 trillion and multiplied (by a generous) 1.5x GDP-multiplier, results in a one-off increase of c. 0.4% of GDP. Then, oil and gas companies invested more, than one would have done in a recession context, resulting in additional spending. They evaluated this second stimulus to account for c. 0.5% of GDP. All in all, the unconventional fuel revolution had a short-term stimulus impact of no more than 0.9% between '08-'12. With other words, the US GDP in 2012 would have been (maximum) c. 0.9% lower without the change. The authors stress that 0.9% is already conservatively large (given for example the large GDP multiplier). While almost 1% of GDP is significant, one must remember this was measured in a context of recession. Mathieu et al. quotes the IMF (2013) saying US GDP would have been c. 5% higher in 2013 if it did not went through a recession context.

On the longer run, impacts are even harder to forecast, as they require many more assumptions. Again they distinguish two "sub-channels" to explain the impact of the unconventional gas revolution on the US output. On the one hand, cheaper fuel prices may free up additional resources to produce and consume other goods or services, hence improving the productivity of the economy. In terms of gas cost, they argued: *"the level of GDP between 2014 and 2040 due to greater productivity from lower gas costs will be in the order of c. 0.58% of GDP. (...) This figure is broadly consistent with the results of a recent modeling inter-comparison project* which estimated the long run GDP impacts of the shale gas revolution at an increase of 0.46% in the level of US GDP."* Regarding reduced needs for oil imports thanks to the potential availability of tight oil, they estimated the impact at 0.26% (this is beyond the scope of purely shale gas). All in all, the long-term one-off effect on the US economy would be estimated at 0.84% for the period '14-'40, a significant but relatively low amount compare to growth expected from other sources. As a reminder, over 26 years a 1% or 2% constant annual growth rate equals a one-off of 29.5% and 67.3% respectively. So regardless of the assumption on the future growth rate of the US output, the part that would be amounted to shale gas (i.e., one-off of 0.58%) or tight oil (i.e., one-off of 0.26%) is rather small.

iv. Job creation

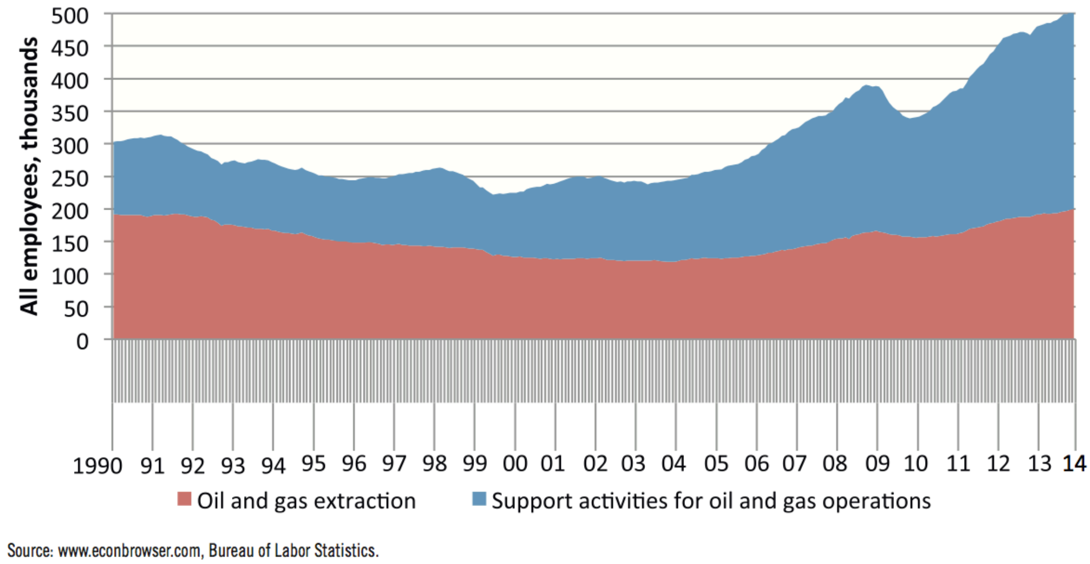
As we mentioned in the above point, oil and gas companies invested more resources than they would have done without the unconventional fuel "revolution". As a result, they also created jobs in extraction and support activities. Figure 17 below illustrates this evolution. Although a c. 200,000 increase since 2007 to reach half a million employees in 2014 is surely significant, it has to be compared to the total US labor force of 155 million people. 200,000 jobs represent 0.13% of the total workforce. Even if we were to consider studies (IHS 2011) that argue shale gas employment multiplier is 3:1 (i.e., for each direct job created in shale gas, three indirect are created) and as a result it created 600,000 jobs to date, it would only represent less than 0.4% of the workforce. Moreover, if it weren't for unemployment these jobs would merely represent a switch from another sector

* Energy Modelling Forum (2013). "Changing the Game? Emissions And Market Implications of New Natural Gas Supplies", Stanford University.

towards the oil & gas one. Being measured over a period with roughly 6% unemployment rate, one could assume a significant part of these jobs are "true new jobs". Still, the truth probably lies below 0.25% of the total workforce.

Figure 17: US Employement Evolution in the Oil and Gas Sector

Source: US Bureau of Labor Statistics – compiled by Mathieu et al. (2014)



In conclusion of the previous three points, we agree with Mathieu et al. (2014) and argue that despite an extraordinary increase in production of unconventional fossil fuels, the economic impact of the US shale gas revolution has been quite modest, sector-specific and local.

c. Economic profitability of Shale Gas at current prices

Around 2006, shale gas production started to rocket (see Figure 9). We labeled this significant increase in production "a revolution". The underlying assumption of this development is that producing shale gas was (very) profitable. If it weren't the case, given the associated environmental concerns, companies would have focus on another – maybe renewable – alternative fuel. Shale gas profitability is or was unquestionable. However in 2006 the average natural gas price at wellhead evolved around $6 per MBtu[*] (see Figure 11 and 14). Later when US natural gas prices started to fall due to the combined effect of a declining economy and a supply glut, the story changed. On June 27, 2012 the Wall Street Journal and the New York Times quote ExxonMobil's Chairman and CEO Rex Tillerson saying: "We are all losing our shirts today" speaking of low natural gas prices. He added: "We are making no money. It is all in red". At that time, natural gas prices at wellhead were around $2.6 per MBtu, already 34% above April 2012 ten-year low. Moreover, Ahmed[†] N. published an article in le Monde Diplomatique in March (2013) gathering the work of many experts highlighting the unprofitable characteristic of shale gas at current prices. All in all, he says the large amount of capital needed to exploit shale gas pushed company to borrow massive amount of debt. Now falling prices and even more worryingly, steep declining production rate (see below), pushed companies into drilling more and more quickly to face their debt. Or as W. Richter (June 2012) puts it: "*At today's price (…) drilling is destroying capital at an astonishing rate, and drillers are left with a mountain of debt just when decline rates are starting to wreak their havoc. To keep the decline rates from mucking up income statements, companies had to drill more and more, with new wells making up for the declining production of old wells. Alas, the scheme hit a wall, namely reality.*" This seemingly Ponzi scheme or at least, artificial bubble, will, according to Ahmed and many others, burst resulting in fuel shortage and surging prices. This is probably an extreme point of view, nonetheless worrying. In any case this point of view has the advantage to challenge the apparently unquestionable profitability of shale gas. In this section we will review some arguments discussed here above so that the reader can forge an opinion for himself. We will start by looking at Exxon's financials to determine whether Mr Tillerson was exaggerating or not. Then, we will discuss the steepness of shale gas declining production rate.

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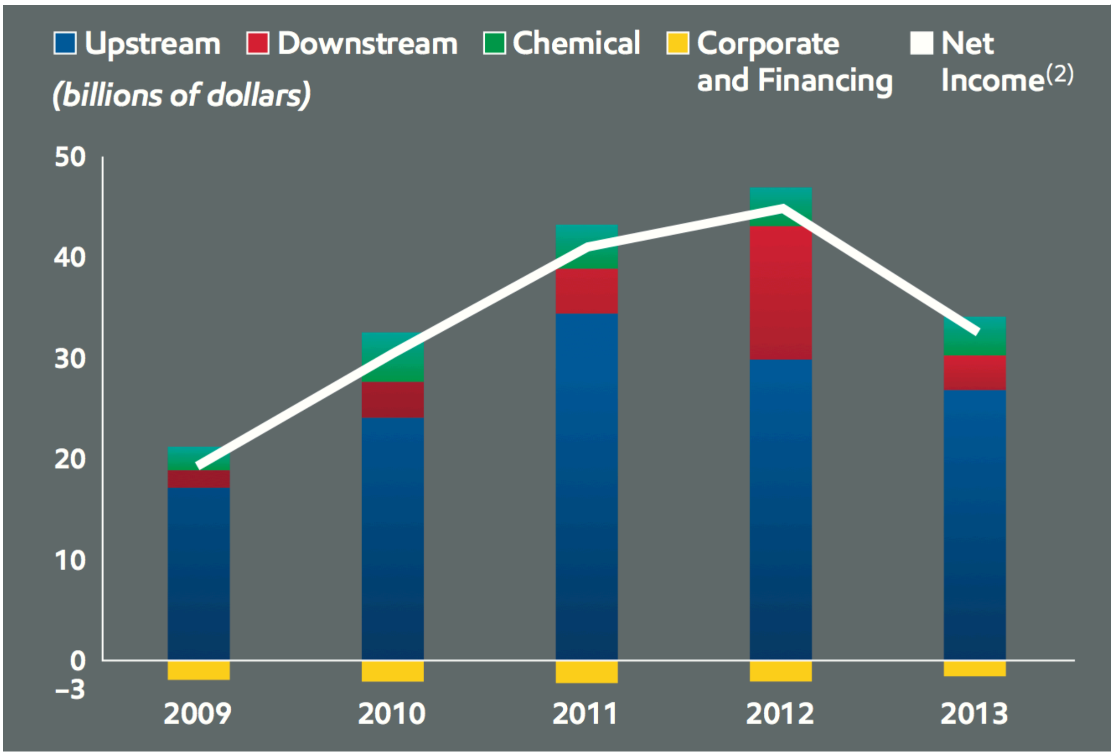
[*] 1 thousand cubic feet = 1.027 million Btu = 1.027 MBtu.

[†] Nafeez Mosaddeq Ahmed is a bestselling author, investigative journalist, and international security scholar. He is an Executive Director of the Institute for Policy Research and Development.

First, we would like to come back on Mr. Tillerson statements. He leads the world's largest publicly traded oil and gas company, so his opinion is of importance. We tried to dig into ExxonMobil's 2013 annual report to find pieces of evidence of low natural gas price driving their business into red. Shareholders can be reassured, 2013 net income amounted for $32.6 billion. They will not starve tomorrow. However, it is down from '11 and '12 mostly driven by a decrease in Upstream (by far their largest segment in terms of capital employed and earnings). This is illustrated by figure 18 below.

Figure 18: ExxonMobil's Functional Earnings

Source: Exxon Mobil 2013 Annual Report.



In '13 compare to '11, upstream income is down 22% while average capital employed is up 18%. At the same time, liquids and natural gas production (in volume) are down 5 and 10%, respectively. These aggregate numbers suggest a decrease in selling prices and foremost in production rates. As more capital is needed to produce less output. Nevertheless, at the aggregate level this is not worrying with upstream yielding a ROCE of 17.5% for 2013.

Digging deeper (a trend in the industry), one could ventilate US from non-US operation. Unfortunately, the granularity of their report does not allow to accurately distinguish shale gas from conventional gas production (was this deliberate?). However, given what we have discussed (see Figure 13), we can proxy that in the US shale gas accounts for a major part (roughly half) of the production while elsewhere it is yet non-significant. Looking at numbers, Upstream in the US failed to deliver a ROCE superior at 7% for '12 and '13, while Upstream elsewhere delivered 32% and 24% for '12 and '13, respectively. We acknowledge the superficiality of our analysis does not allow us to definitely conclude anything on the profitability of shale gas. However, it clearly does not clear up the concerns raised here above. If anything, it reinforces them.

Second, the steepness of the decline in shale gas production rate has been a key point in recent discussions. Why is this technical detail of such a high importance? Simply because the net present value (NPV) of a project only depends on three parameters: the initial investment, the discount factor (or associated risk) and the expected future cash flows. For example, with a 10% discount factor, an initial \$100 investment and a constant recurring cash flow of \$20. If the project runs forever (i.e., it is a perpetuity), then the NPV is positive and is worth \$100. If we were to say the cash flow (for example from the well) dries up after 10 years, then the NPV falls to \$22.9 and anything below 8 years would destroy value. So the lifetime of the well, or with other words the number of years it produces gas before it starts declining is of the upmost importance in the profitability of shale gas.

D. Hughes, in a report published in the Post Carbon Institute (2013) with the non-equivoque title "Drill, Baby, Drill", studied data from 65,000 shale wells in the US. His studies highlight on the one hand, the steep declined in shale gas field productivities. Typically, shale gas well production drops between 80-95% in its first three years. On the other hand, he stresses the current lossmaking aspect of many shale-gas plays at current gas prices. Furthermore, he develops the capital voracious aspects of the industry. For 2012, 7,200 new drills were needed to maintain production. This represents more than \$42 billion simply to offset the declines, while the value of shale gas produced the same year amounted for "just" \$32.5 billion[*]. Appendix 4, which shows the production of the top 5 US shale gas plays (account for 80% of US shale gas), supports his findings. It also illustrates the fact that when a new play is discovered, first sweet spots (of high productivity) are drilled, so that average productivity rises at first then drop. Since 2010,

[*] Although liquid hydrocarbons produced from some wells might improve this number.

4 out of the 5 top shale gas play have seen their productivity declined. The only exception is the young Marcellus play where sweet spots are still being found. Overall well productivity will keep declining, as sweep spots will be harder and harder to discover. At some point, production will also be limited as there will be no more (profitable) drilling locations available. And when this happen, production will drop by more than 80% within three years, until it completely dries out. The question of when this happen will be the focus of the next section.

In conclusion and enlightened by these facts, it becomes clearer that shale gas is neither inexhaustible, neither (that) cheap. It seems unlikely that shale gas production will remain at such high levels if natural gas prices do not increase significantly. Bearing that in mind, declaring US energy independence based on shale gas seem very brave, not to say bold.

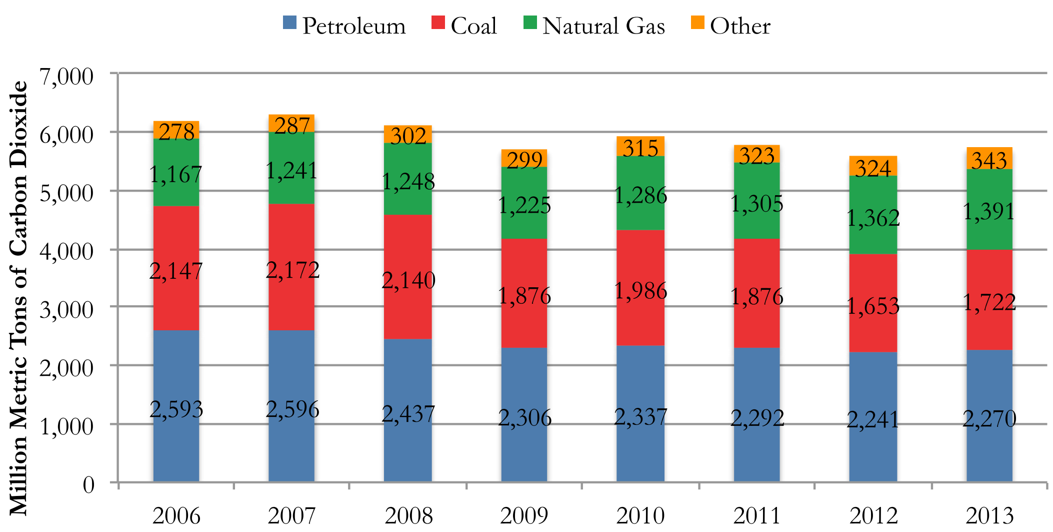
d. Environmental impact of Shale Gas and the New Technology

As a reminder, we decided to focus on the economics of shale gas rather than its political and environmental concerns. Nevertheless, and in accordance with the previous section on carbon curse, CO_2 emissions already have a price and many expect this price to increase significantly. Hence, high carbon intensity results in a non-negligible cost. In this point, we will focus the discussion on the actual impact of shale gas on carbon dioxide emissions. Later, we will touch upon various other environmental concerns that have already been raised. Finally, we will discuss the potential of a new "cleaner" technology to exploit shale gas.

Although there is still uncertainty regarding shale gas life-cycle emissions, a rule of thumb let us believe that use of natural gas – even produced in an unconventional way – is less carbon intensive than coal. So a switch away from coal towards shale gas should result in fewer tons of carbon emitted for the same amount of GDP. Figure 19 shows total CO_2 emissions in the US by source since 2006, roughly the year the shale gas revolution kick started.

Figure 19: Carbon Dioxide Emissions from Consumption by Source

Source: US Energy Information Administration (EIA)



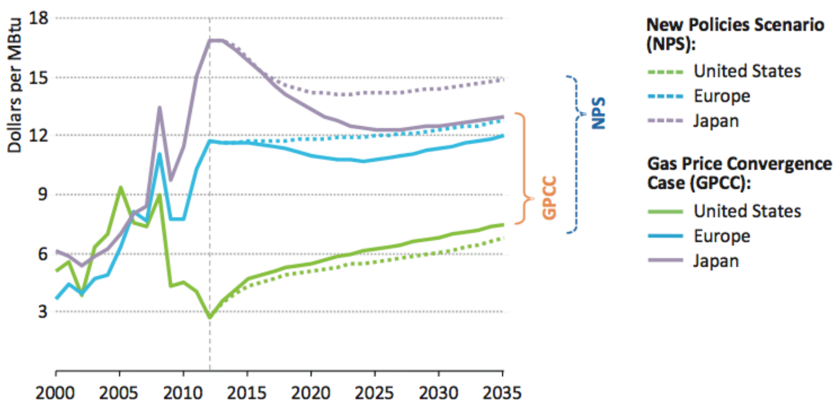
In 2007, the US reached its all-time high in terms of Carbon Dioxide Emissions mostly driven by petroleum (41.2%), coal (34.5%) and gas (19.7%). Since then, it firstly declined in '08 and '09 mostly driven by the economic recession, the US economy indeed shrunk by more than 3% in real terms over those years. Later emissions did bounce back also driven by the economic environment. Nevertheless, between '07 and '13 emissions went down by 9.1% (i.e., 570 m tons) while real GDP grew by 6%. Carbon intensity did effectively reduce. Although it's uneasy to see at first sight on Figure 19, one could calculate that the share of gas in the carbon dioxide emissions has increased year after year since '06 till '12 from 18.9% to 24.4%. This has been a switch away from coal, which reduced in relative terms from 34.7% to 29.6% over the same period. Although a decrease – by more than half a billion ton over half a decade while maintaining economic growth – is a great achievement, many will question its sustainability, its reproducibility, the role of shale gas and its "side effects".

i. Sustainability:

Let's start with the sustainability of such a decrease. Although gas prices have been very low in the US, they won't remain there forever. In April 2012, Henry Hub gas spot prices were trading below $2 per million btu. Early 2014, they traded between $4.5 and $5.0. While elsewhere, the price is much higher, roughly 3 times in Europe, 4 times in Japan. The world energy outlook forecasts under different scenarios a convergence of those prices driven by the rise of liquefied natural gas (LNG). Although LNG requires colossal upfront investment in order to develop the plants that liquefy gas, once developed it allows long distance shipping at a very low price. The IEA in its world energy outlook 2013, prices LNG in an optimistic scenario as follow: $3 per MBtu for liquefaction, $0.3 for regasification and shipping depending on the itinerary $1 for US to Europe $2 for US to Japan. Adding up theses prices, the spread between European gas and American gas could not exceed $4.3 in the long run (or $7.5 in a pessimistic scenario). The Figure 20 below best illustrates this (regardless of the two scenarios).

Figure 20: Regional Gas Prices Forecasts

Source: IEA – World Energy Outlook 2013 – Figure 3.11

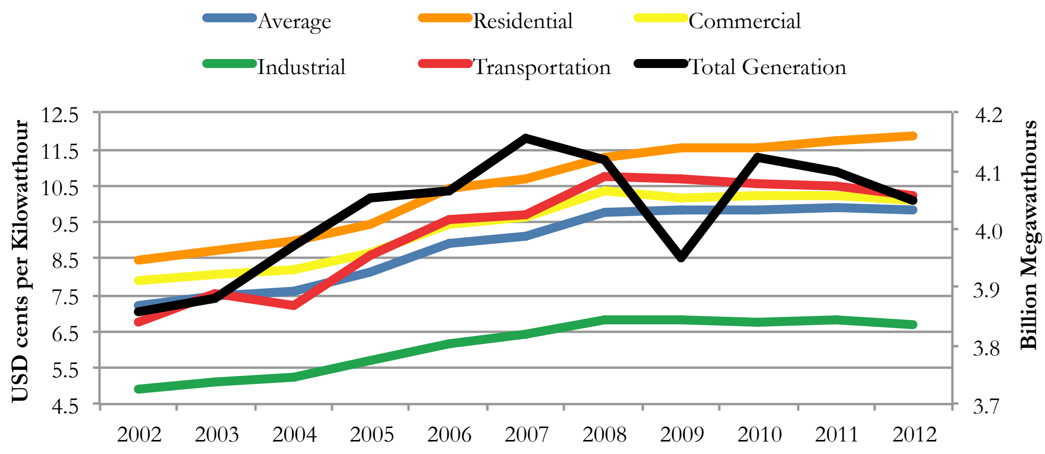


All in all, we argue gas prices won't remain forever at these record low levels. Recent trading prices proved us right with US prices below $3 per MBtu in 2013 and already above $4.5. In comparison, US coal prices have not much changed and though volatile and local, the average yearly price to Electricity Power Sector across the US has remained around $45 per short ton (data from the EIA) since 2009, which means less than $2.2 per Mbtu. As long as carbon dioxide emissions are not taxed (much) more heavily, coal power plants will remain the driving force for electricity production, while gas plants (more expansive) will be switched on mostly to cover peak demand. Figure 16 illustrates this phenomenon. However, a very recent Obama's proposal to cut power plant emissions by 30% (see Section 4) might well change the game and further push the switch away from coal. Whether this will be compensated by gas or another source of energy, such as renewables or nuclear is yet to be seen. In any case, low gas prices surely had another effect on the long-term sustainability of the US energy sector.

Regardless of the size of the reserves and the profitability of the resources, fossil fuels are finite resources. By definition, at some point we run out of them. Pessimists will argue rather sooner than later, but in any case at some point they dry up. Moreover, we have discussed above the impact of fuel prices on the development of new sources of energy. Here, we would like to highlight that low energy prices surely hinder the development of renewable energies. Indeed, early stage renewables may struggle to be profitable as long as they have not reached a critical size to achieve economies of scale and sufficient time to benefit from learning by doing. This was the context before the shale gas revolution. Before the revolution, entrepreneurs were expecting decreasing availability of conventional fuels combined with growing needs of the population to drive up energy prices. Hence, easing their way into business as energy providers, mostly electricity sellers. However, this did not fully happen as not only energy demand but also electricity prices reached a plateau. Figure 21 illustrates these statements, with US average electricity price in blue almost flat since 2008. Falling demand – assuming total generation (below in black) is a good proxy for demand – after the 2007 peak, combined with cheap shale gas are likely the causes of the flattening energy prices.

Figure 21: US Electricity Prices and Amount Generated

Source: EIA



To come back to our sustainability argument, we maintain shale gas development through its impact on gas and electricity prices will hinder the development of renewables. Therefore, on the long run this will slow down the United States shift away from fossil fuel towards non-finite resources such as renewables. This is clearly non-sustainable in the long run. We already hear the critics quoting John Maynard Keynes: "In the long run, we are all dead". Well, we might well be but our children and/or grandchildren might well not.

ii. Reproducibility:

Now that we have looked at the questionable sustainability of this carbon reduction on the short run and the non-sustainability in the long run, we will discuss its reproducibility. To cut it short, given the proven reserves elsewhere, it seems more than unlikely that the EU would experienced the same sort of large and rapid shale gas revolution. Moreover, many countries already present a much different product mix where nuclear[*] for example, takes a larger share of the pie. Examples are Belgium, France or Japan. For them, increasing the part of gas in their energy mix will likely result in an increase in their carbon reduction.

iii. Role of Shale Gas:

The third point – we wanted to discuss regarding the US recent decrease in carbon dioxide emissions – is the role of shale gas actually played. Indeed, it is true that a switch

[*] We acknowledge the environmental impacts and risks nuclear involves. However, this is far beyond the scope of this work.

away from coal to gas surely contributed to the 9.1% (i.e., 570m tons) decrease. However, there are two other parameters, which have to be taken into account. First, the '07-'13 period coincides with a period of decrease in US energy consumption. Data from the EIA, shows total US energy consumption went down from 101.3 to 97.5 quadrillion[*] BTU, a decrease of 3.7%. So a large slice of the 9.1% decrease is to be related to the US reduced consumption. Second, all other things being equal, the share of renewables (which are virtually carbon neutral) in the primary energy consumption increased from 6.5% to 9.5%, while the one of fossils decreased from 85.1% to 81.8% (nuclear accounts for c. 8.5% left). The second effect, a switch away from fossil, results in a 3.3% decrease. Compounding these two effects, carbon dioxide emission would have already decreased by c. 7.3% without taking into account the switch from coal to gas, we attribute to shale gas. With other words, 80% of the decrease in CO_2 emissions cannot be attributed to shale gas. What is more, the availability of cheap gas certainly played against the two effects we just discussed. First, high gas prices would have surely played as an incentive to further work on becoming less energy voracious (see Carbon Curse). Second, the availability of cheap gas and its impact on electricity prices (which would otherwise have been higher) probably had a negative impact on the developments of renewables, hence reduced the switch away from fossil fuels. In conclusion, while we do acknowledge the limited (max 20%) role shale gas played in the '07-'13 carbon emission, via a switch from coal to gas. We wonder if the magnitude of the decrease would not have been higher without the shale gas revolution. As discussed, it is likely the decrease in US energy consumption and the switch away from fossil (not only coal) would have been greater. Therefore resulting in a larger than experienced reduction. However, this is only hypothetical and could be the subject of interesting further studies.

iv. Side Effects:

To finish this discussion on the recent decrease of carbon emissions in the US, which can in part be linked to the shale gas revolution, we would like to touch upon the side effects of this new fuel. First, hydraulic fracturing uses a lot of water. Indeed, the Financial Times (2014) "US shale under fire over thirst for water", states 40% of oil and gas wells drilled since 2011 are in "extremely high" water stress areas. Knowing that hydraulic fracturing uses typically more than 2 millions gallons (i.e., 7.6 m liters) per well and adds many toxic chemicals to this water, this further raise the need for recycling of

[*] One quadrillion = 10^{15}

these "flawback" waters. Second, though natural gas is supposed to emit roughly half of carbon dioxide as coal when use in efficient power plant, uncertainty remains around shale gas. Especially, the extent of methane leaks – associated with shale gas – resulted in conflicting conclusions whether or not the GHGs footprint of shale gas is better than oil or coal. Methane has indeed a global warming potential that is 72x and 33x higher than carbon dioxide on a 20-year and 100-year period, respectively. Various experts have estimated the leakage of methane, ranging between 0.6%[*] of methane produced over the lifecycle of a well up to 4.0%[†]. Depending on this number, shale gas could be considered either better than oil or worst than coal regarding climate change. In any case, capturing the largest extent of those methane leakages is key to shale gas "clean" development. Third, injecting large amount of fluid deep under the ground to brake shale could eventually lead to earthquakes. Although this is far beyond the scope of this work, USGS experts have already concluded that systemic rate changes (which have greatly increased) in the US midcontinent were almost certainly manmade (see Ellsworth et al. (2012)). Last, the vast numbers of chemicals used for fracking are of concerns towards public health. The Chemical Abstrast Services (CAS) in 2011 identified 353 different chemicals in shale gas operation, of which 75% can affect different organ of the body and 40% can have ecological effects (i.e., they could harm aquatic and other wildlife). The significance of the risks related to these chemicals is again far beyond the scope of this paper. Yet bearing in mind the cost of healthcare, this already raises a substantial financial risk.

v. Potential for a new "clean" technology

As discussed here above, there are many environmental concerns associated with shale gas, which led French President François Hollande to clearly rule out fracking in France in his May 2012 investiture speech, he declared: *"In the current state of our knowledge no one can say that the exploitation of gas and oil shale by hydraulic fracturing, only known technique today, is free from serious risks for health and the environment"*. Nevertheless, some members of the French government, most notably Arnaud Montebourg, are openly in favor of shale gas. Especially, if a clean(er) technology can be developed. In this context, J. Lenoir working hand in hand with EDF, recently published a report on alternative techniques to hydraulic fracturing. The new experimental technique is based on non-flammable propane, heptafluoropropane. The report states: *"Heptafluoropropane is not flammable, it is*

[*] Stephensen et al. (2011)
[†] Pétron et al. (2012)

injected underground and then fully recovered, making it harmless for the environment. And no water is used". Yet, Fluoropropane is far from being clean. It is currently banned in France, as it is 320 times more harmful than CO_2 for the greenhouse effect and its production also emits greenhouse gases. So this prototype technique should first obtain a clearance for experimentations by politicians. Then, it will have to be found cleaner and economically viable. There is very little chance of this happening rapidly. Given the current knowledge, arguing in favor of shale gas development based on the potential development of the "right technology" is like advancing blindfolded. Remember that with the "right technology" alchemist could transform lead into gold. Alas, they have been searching for hundreds of years, and there are still not rich.

e. Legal and institutional framework

We discussed previously that shale gas development in the US, was made possible thanks to public and private initiatives. While, we touched upon corporates before, in this point, we will discuss institutions and texts that were key to its developments.

The story began with the US Department of Energy that was officially set up in 1977 amid the oil crises, though various energy-related programs were previously developed across various other federal agencies. In their role to address Energy and Environmental challenges, they launched the Eastern Gas Shale Project (EGSP) in the late 70's, which basically provided R&D funding, to evaluate the potential of the Devonian and Mississippian shale plays. The Gas Research Institute (GRI) was established around the same period to manage these types of specific gas R&D programs. Growing in scope, addressing funding not only for upstream but also for transmission, distribution and end-use, the GRI became the Gas Technology Institute in 2000. They have been along the years the leading R&D and training organization addressing US gas issues.

We addressed at the end of part 3, the specifics of US sub-soil rights and their "pooling and unitization" system, which were key elements of their shale gas development. While it is not the point of this section to be fully exhaustive on the various legal texts that surrounds shale gas, we believe it is of importance to highlight two texts.

First and foremost, we want to mention the "Safe Drinking Water Act" (SDWA) and most notably its so-called Halliburton[*] loophole for fracking that was introduced by the Energy Policy Act of 2005. The US Environmental Protection Agency (EPA) website states: "*The SDWA specifically excludes hydraulic fracturing from Underground Injection Control (UIC) regulation under SDWA § 1421 (d)(1), (…)*". This basically exempts fracking from federal oversights, leaving the regulation power in the states' hands. In the absence of stringent local regulation, this leaves the oil & gas companies free from submitting project environmental assessment and free from providing toxic release inventory, which would otherwise have been required by federal laws.

[*] In 2005 Congress—at the behest of then Vice President Dick Cheney, a former CEO of gas driller Halliburton—exempted fracking from regulation under the Safe Drinking Water Act.

On the other hand, a new proposal – the Clean Power Plan – unveiled by Barack Obama on June 2nd, 2014 lays ground for a large cut in CO_2 emissions. He said: *"The shift to a cleaner energy economy won't happen overnight, and it will require tough choices along the way but a low-carbon, clean energy economy can be an engine of growth for decades to come."* The plan is to cut carbon emission from the power sector by 30% nationwide below 2005 levels, knowing power plants represent the US largest source of carbon pollution and roughly 1/3rd of all GHGs emissions. This will surely negatively affect coal, which is the largest provider of electricity in the US (c. 37%) and the most polluting. For gas, the story is less certain as it also is carbon intensive (especially unconventional gas) but a better alternative than coal. However, switching to gas might not prove sufficient to achieve the targeted 30% reduction and alternative sources such as renewables or nuclear might be the chosen solution. The significance of sanctions in case of infringement, the price of natural gas, the legal landscape surrounding nuclear and the incentives for renewables, will surely prove key to whether this proposal will lead to more gas or more renewables.

3. Expected development of Shale Gas exploitation: 2 points of view

"Life can only be understood backwards (…)" – this is why in the previous sections we have looked at what has happened in the last couple of years, to better understand the shale gas revolution – "(…) but it must be lived forwards" (S. Kierkegaard). For this reason, we will try to assess the different views of how shale gas exploitation could develop in the future. Different experts have different views. On the one hand, there are those shale gas excites, they dream of: a cheap natural gas fuel that gives an edge to the American manufacturing sector, a booming upstream sectors that creates hundreds of thousands of jobs, reserves large enough to insure centuries of consumption and ultimately US energy independence. To different extent, this is the view share by the oil & gas industry but also by very respected agencies that control most of the statistics: the US Energy Information Administration (EIA) and the International Energy Agency (IEA). We have often used their data's in this paper, however we have done so only looking backwards, as we trust their historical data. Their forecasts (see Figure 7 and 8) have yet never been used to draw any conclusion. On the other hand, you have a much less organized team, represented by some academics, independent petroleum geologists and energy analysts. Richard Heinberg, with his book "Snake Oil" and David Hughes and his work "Drill, Baby, Drill" are two of the spearheads of this team. They believe the shale gas "revolution" might be over (much) sooner that the enthusiasts think. They say the promise of unconventional fossil fuel abundance is exaggerated and the actual economics behind the fracking boom are unsustainable. Moreover, they highlight the environmental consequences of fracking and suggest shale is not the path towards US energy independence. Whatever the reader's views, we will try to provide arguments for both camp and to center the debate on one of the most fundamental questions: timing. Indeed, fossil fuels are finite. Declining production and depletion are thus inevitable. Knowing how fast the US are going to run out of shale gas is key to determine whether this revolution has indeed the expected potential.

a. The enthusiasts

To start of this discussion, we will put ourselves in the feet of the shale gas enthusiasts. We will first look at their forecasts in terms of production and resulting gas prices. Then, we will examine the assumptions on which they base those forecasts most notably looking at the current proven and technically recoverable reserves required to achieved to forecasted production. Third, we will study the expected influence of shale gas on US GDP. Finally, we will see when the US energy independence is forecasted. Please bear in mind, this it the (vulgarized) view of the shale gas enthusiasts. Not ours.

i. Gas production and prices forecasts

In Figure 22, we summarized IEA[*] (in the World Energy Outlook 2013) and EIA[†] most recent forecasts for natural gas production with a focus on unconventional and shale. (Figure 7 & 8 and Appendix 5 illustrates the IEA and the EIA forecasts, respectively.)

Figure 22: Gas Annual Production Forecasts by IEA and EIA

Source: IEA (World Energy Outlook 2013) and EIA (Annual Energy Outlook 2014)

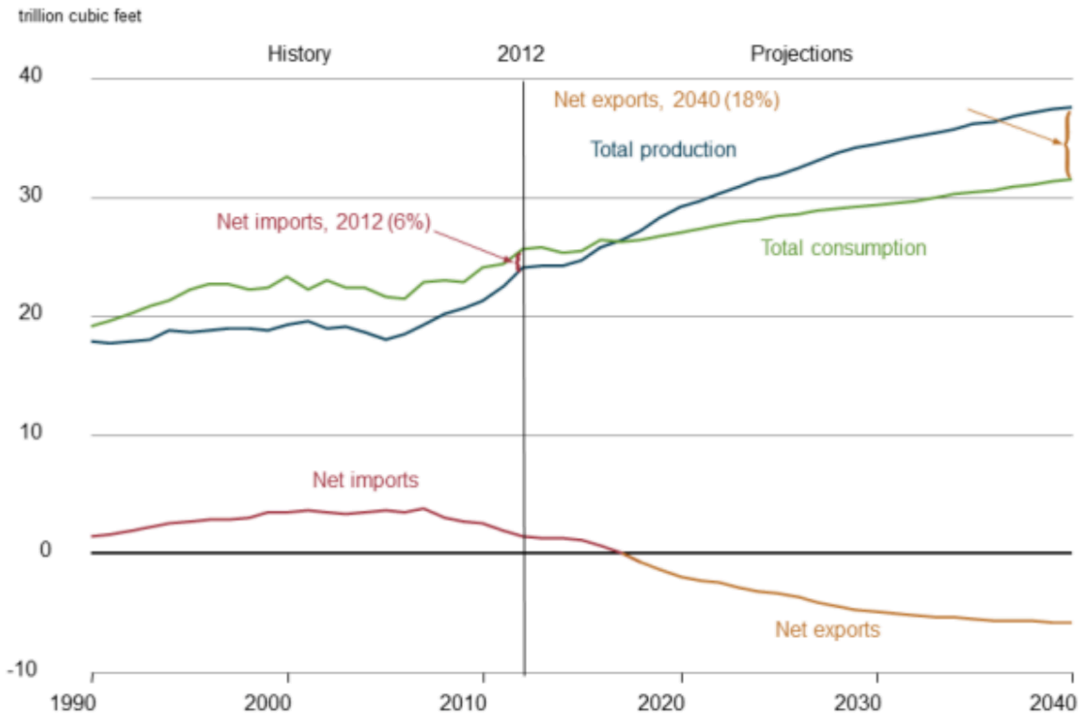
(Billion Cubic Meters)	2011	2020	2035	CAGR '11-'20	CAGR '20-'35
World Natural Gas (IEA)	3370	3957	4976	1.8%	1.5%
World Unconventional Gas (IEA)	560	831	1329	4.5%	3.2%
World Unc. as % of World Nat.	*17%*	*21%*	*27%*		
World Shale Gas (IEA)	232	402	745	6.3%	4.2%
World Shale as % of World Unc.	*41%*	*48%*	*56%*		
US Natural Gas (IEA)	649	764	837	1.8%	0.6%
US Natural Gas (EIA)	638	824	1022	2.9%	1.4%
US Natural Gas as % of World	*19%*	*21%*	*21%*		
US Unconventional Gas (EIA)	416	608	812	4.3%	1.9%
US Unc. as % of World Unc.	*74%*	*73%*	*61%*		
US Unc. as % of US Nat.	*65%*	*74%*	*79%*		
US Shale Gas (EIA)	225	377	524	5.9%	2.2%
US Shale as % of World Unc.	*40%*	*45%*	*39%*		
US Shale as % of World Shale	*97%*	*94%*	*70%*		
US Shale as % of US Nat.	*35%*	*46%*	*51%*		
US Shale as % of US Unc.	*54%*	*62%*	*65%*		

[*] IEA forecasts are those of their "New Policies Scenario".
[†] EIA numbers for Unconventional and Shale exclude Alaska.

We decided to divide the forecast into two periods, a first one till 2020 and a second till 2040. During the first period, if we were to believe the EIA numbers for US Natural Gas, it is interesting to notice how US shale gas yearly production is expected to quickly expand at a 5.9% constant annual growth rate (CAGR). This 152 bcm increase in production accounts in the world for: 90% the world shale gas production increase and more than half of the increase in world unconventional gas production. In the US, shale gas accounts for: 80% of US unconventional gas production increase and 82% of US natural gas total production increase (given the slight decrease expected in US conventional gas production). US shale gas is indeed the heat of the current revolution. Yet, unconventional gas is only expected to reach 21% of the global natural gas production. Over the second period, US shale gas will keep increasing but at a much lower pace of 2.2%, while other countries are expected to develop shale – mainly China and Australia. Nevertheless, the US is expected to remain (by far) the largest producer with 70% of the shale gas produced on their ground. Over the whole period, shale gas world production is expected to growth on average by 5% annually. This seems very enthusiastic, not to say optimistic. As a result, US natural gas prices are forecasted by the IEA and the EIA to steadily growth to reach c. $7 to $8 per Mbtu by 2035 (see Figure 20). According to the EIA, their "worst case scenario – of low oil and gas resources" would barely see natural gas prices cross $10 per Mbtu by 2035. Moreover as they expect the US production to increase faster than its domestic consumption, they forecast the US will become a net exporter before 2020. Figure 23 below illustrates the EIA Reference Case.

Figure 23: US Natural Gas Production and Consumption in EIA Reference Case

Source: EIA (Annual Energy Outlook 2014 – Figure MT-42).



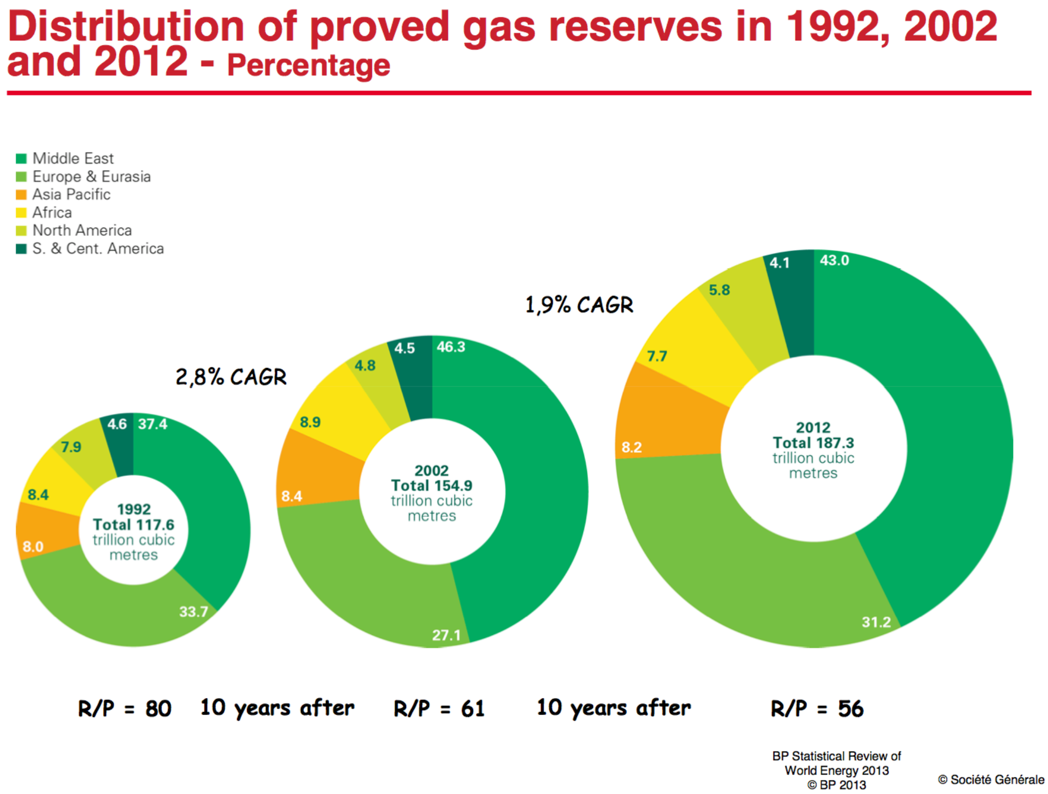
As discussed, those assumptions of rising US natural gas production from 638 bcm to 824 bcm in 2020 and 1022 bcm in 2035 are mostly based on a huge increase in shale gas production. According to the EIA predictions, shale gas should account for 82% of the total increase over the first period and 75% over the second period. Hence, this trend relies mostly on shale gas. In the next point we will assess the assumptions on which these statements are based. With other words, we will look at how much shale is supposedly available in the US to allow this increase in production.

ii. Estimated Reserves

The IEA states: *"The world's remaining resources of natural gas are more than sufficient to meet any conceivable level of gas demand for the next several decades. Proven reserves* of gas stood at 187 trillion cubic meters (tcm) at the end of 2012 (BP, 2013)".* This is 56x current production! Although the proven reserves increased over the past twenty years, the ratio reserves/ production has decreased by more than 20. Moreover, it is interesting to notice that 82% of those proven reserves are either in Europe or Asia. North America only accounts for 5.8% (see Figure 24 below).

Figure 24: Proven Gas Reserves by BP

Source: BP Statistical Review of World Energy 2013 – Compiled by Société Générale.



What is more, proven reserves are a (very) narrow indicator of the size of the resource base. A much broader indicator, though less certain, is based on technically recoverable resources. The IEA states again : *"Cumulative gas production to date amounts to some 109 tcm,*

* Proven reserves are an estimated quantity of all hydrocarbons statistically defined as crude oil or natural gas, which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions. Reservoirs are considered proven if economic producibility is supported by either actual production or conclusive formation testing. Definition by OPEC.

meaning that around 12% of ultimately recoverable resources (i.e., 810 tcm) have been produced. In the New Policies Scenario, an additional 100 tcm is projected to be produced, implying that more than three-quarters of ultimately recoverable resources would still remain to be recovered as of 2035. In practice, further upward revisions to resource estimates are likely as our understanding of the resource base – notably for unconventional gas – improves." The Figure 25 below illustrates their statement.

Figure 25: Remaining Technically Recoverable Natural Gas as of end 2012 (in tcm)

Source: IEA WEO 2013 – Table 3.3.

	Conventional	Unconventional				Total
		Tight gas	Shale gas	Coalbed methane	Sub-total	
E. Europe/Eurasia	143	11	15	20	46	190
Middle East	124	9	4	-	13	137
Asia-Pacific	44	21	53	21	95	138
OECD Americas	46	11	48	7	66	112
Africa	52	10	39	0	49	101
Latin America	32	15	40	-	55	86
OECD Europe	26	4	13	2	19	46
World	**468**	**81**	**212**	**50**	**343**	**810**

Notes: Remaining resources comprise known reserves, reserves growth and undiscovered resources. Unconventional gas resources in regions that are richly endowed with conventional gas, such as Eurasia or the Middle East, are often poorly known and could be much larger. Sources: BGR (2012); US EIA (2013); USGS (2000); USGS (2012a and 2012b); IEA databases and analysis.

Interestingly shale gas accounts for just more than a quarter of those remaining resources. More amusing, the vast majority of those so-called remaining shale gas reserves are out of US (as only 25% are in OECD Americas). Bearing in mind that there is virtually no large-scale shale gas production out of North America yet, we leave to the reader the appreciation of the quality of those supposedly recoverable resources (especially given the technical complexity of shale gas exploitation). To finish this parenthesis, we invite the reader to look at the notes where it is written: *"Unconventional gas resources (…) are often poorly known and could be much larger"*. We would appreciate to raise one question: could they also be much smaller? As Warren Buffet puts it: *"Forecasts may tell you a great deal about the forecaster; they tell you nothing about the future."* However, we have to admit the EIA – working together with the ARI (Advanced Resource International) – found relatively similar numbers. They estimate world shale gas technically recoverable resources at 207 tcm in 2013, of which only 1.3% are proven (i.e., currently all proven resources are in the U.S.). According to their work, 80% of the recoverable resources are in the hands of ten countries, of which none is a member of the European Union.

Furthermore, China (with 15% of the world's technically recoverable resource), Argentina (11%), Algeria (10%), the US (9%) and Canada (8%) are supposedly the richest in terms of shale gas. Their current estimate for the US is 19 tcm, which is 84 times 2011 level of production or 50x the expected 2020 production. If we were to believe the reserve numbers, which the EIA and IEA both expect to increase, then the increase in production could actually happen as forecasted. The true question is whether those shale gas resources do exist and if they do, are they economically recoverable? With other words, does it make sense to invest money, time and energy to extract this energy (i.e., shale gas)? The enthusiasts will argue it is the way towards an energy revolution and this will have a significant positive impact on the US economy. In the next point, we will develop what could be this impact if the shale gas revolution happens as planned by the enthusiasts.

iii. Forecasted economic impact

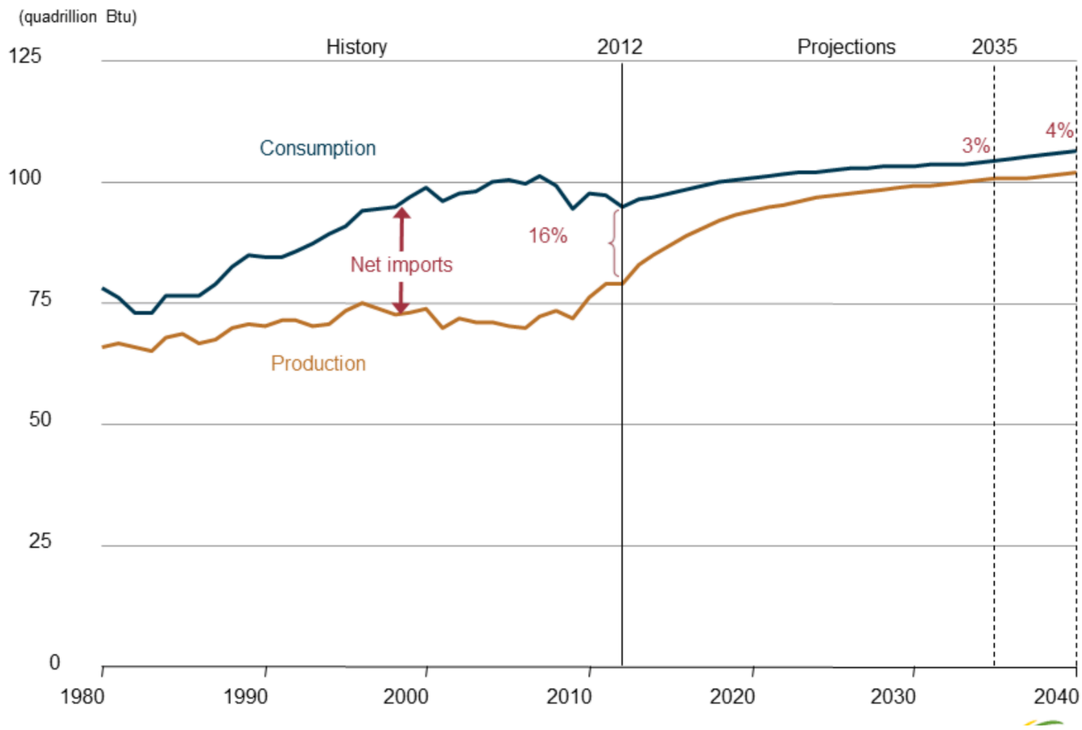
One of the most "enthusiastic work" done by Sarica et al. of Purdue University (2013) in their: "Assessment of the Economic Impacts of the Shale Oil and Gas Boom" states for example that *" US GDP over the entire period of 2008-2035 on average would be 3.5% higher than it would have been without the shale boom"*. Moreover with the shale gas boom, they forecast the US natural prices (at wellhead) to remain below $10 per MBtu till 2025, and even till 2040 in their "low price" scenario (i.e., they roughly follow the EIA forecast). Their argument is pretty simple. The shale gas revolution will drive an era of cheap natural gas. This has already helped the US out of the financial crises and will keep driving up the economy. The main underlying assumption is, as always, the presence of very large untapped reserves of shale gas (financially profitable even at low natural gas prices). What is more on economy is the current large trade deficit the US maintains, mostly due to energy imports. R. Anderson writes for the BBC (2014): *"Last year, the United States spent about $300bn on importing oil. This represented almost two-thirds of the country's entire annual trade deficit. (…) The holy grail of American leaders over the past four decades, from Richard Nixon to Barack Obama, has been energy independence, and thanks to shale oil and gas, the dream could soon become reality*". The next point will be a short assessment of this statement, to determine whether or not the US could be come energy independent in a near future..

iv. Potential US energy independence

To cut a long story short, not even the enthusiastic EIA believes in the US energy independence per se, over a 30-years horizon. However, their forecasts suggest the US could greatly reduce its net import share of the total domestic energy consumption (see Figure 26 below).

Figure 26: US Energy Production and Consumption 1980 – 2040

Source: EIA – AEO 2014 – Figure 10.



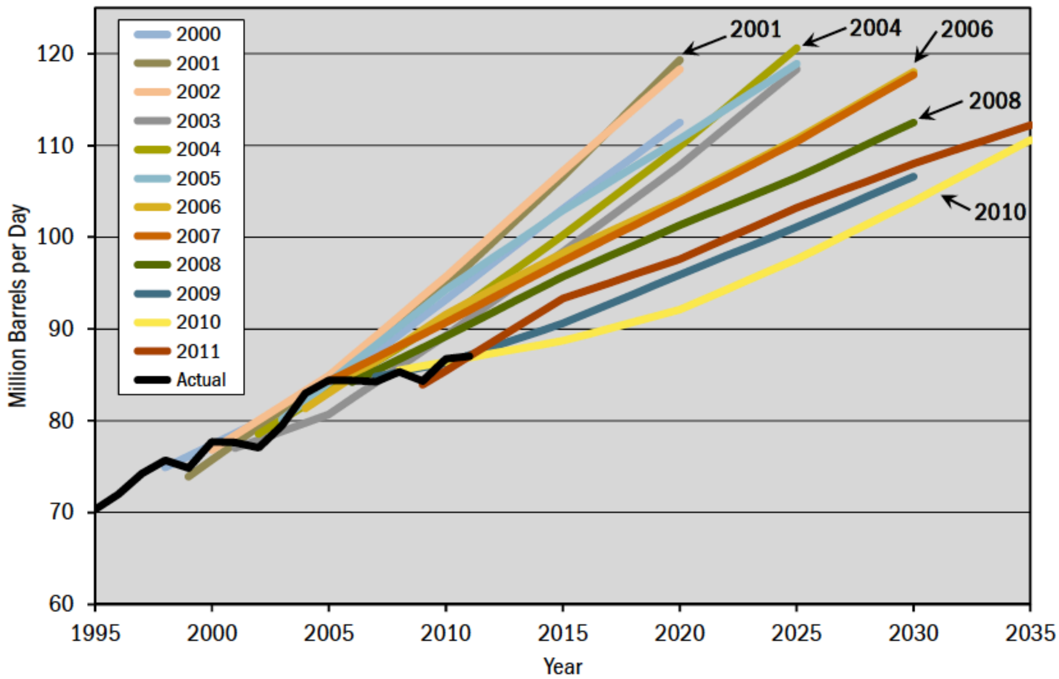
They believe the 29.3% increase in energy production (between '12 & '40, mainly driven by natural gas, hence shale gas) could allow the US to reduce the net import share of total U.S. energy consumption to 4% in 2040, compared with 16% in 2012 and about 30% in 2005. In relative terms (i.e., as % of total production), coal, oil and nuclear are forecasted to decline. Almost 2/3rd of this increase in energy production is to be attributed to natural gas, hence to a large extent shale gas. At the risk of sounding repetitive, this hypothetic increase in US shale gas production relies on the availability of technically and economically recoverable resources. The enthusiasts believe in their abundance. The shale gas detractors clearly do not. We will now study on what basis they question these numbers.

b. The detractors

Those who do not believe in shale gas points out at different things including unprofitability (at current gas prices) and environmental concerns, but more often than not, it drills down to reserves. Their view is the oil industry largely overstates them, hence the future production. Although we cannot judge whether the resource estimates and the forecasted production are right or wrong, what we can do is look at the prediction made historically. The Figure 27 below illustrates the EIA's predictions for world oil production. While this can't be done for shale gas (given the recent boom), we believe this highlights how they have been bullish on fuel production in the past.

Figure 27: World Oil Production EIA 2000 – 2011 forecasts till 2035

Source: Data from EIA – Compiled by D. Hughes in "Drill, Baby, Drill" - Figure 25.



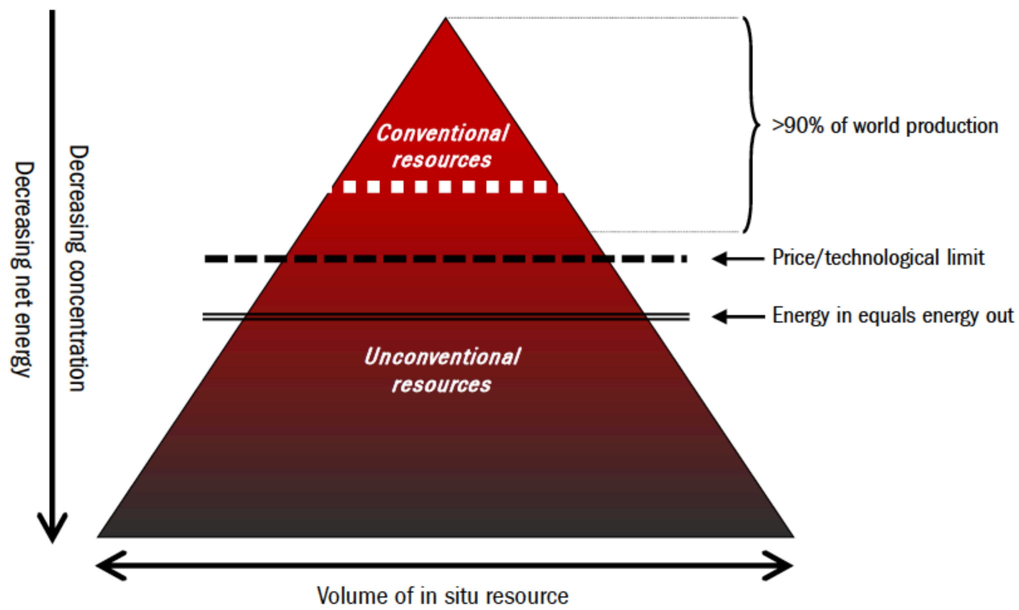
Regarding technically recoverable resource of shale gas in the US, the EIA also greatly revised its first estimates. While in the Annual Energy Outlook 2011, they estimated it at 23.4 billion cubic meters, in June 2012 they revised it to 13.6 bcm, a 40% cut. In 2013, they revaluated it to 18.8 bcm. The question one could ask is why estimates of such important vary so greatly. First, because many US plays are relatively new and estimates are adjusted once the first few wells have been drilled (e.g., Marcellus in 2011). Fallen production rate from shale gas wells (as previously discussed) has been the greatest concerns to approximate the recoverable resources. Obama, himself, in 2011 was quoted saying: *"Recent innovations have given us the opportunity to tap larger reserves – perhaps century's* *worth – in the shale under our feet"*. However new data showed production from shale gas wells typically decline by 80 to 95% in the first 36 months, hence the US may have fewer than 10 years of shale gas supply (according to R. Sandrea – "Evaluating Production Potential of Mature US Oil, Gas Shale Plays). The 100-year estimate for Natural Gas (not only shale) was based on production from shale gas sweet spots (see above). Moreover, R. Sandrea argues: *"the average recovery efficiency is about 7% (for shale gas), in contrast to recovery efficiencies of 75-80% for conventional gas fields. This suggests that the estimate of recoverable gas for all US shale plays should be near 240 tcf* (i.e., 6.8 bcm – hence c. 10x '11 US shale production*)"*.

So recoverable resource of unconventional fuels, specifically shale gas ones, are complex to measure as they rely on many parameters including recovery efficiency and declining production rate. So in any case, they remain highly speculative and largely unproven. What is more certain, it the actual presence of immense unconventional resources per se. However, the slice that can be both technically & economically recovered, as well as recovered at a net energy profit (remember it takes energy to get energy) is much tinier.

The pyramid below illustrates the relationship between available volume and concentration/ net energy "extracted". The lower in the pyramid, the lower the quality of the resource, the higher the energy need to extract it, the larger the available resource.

Figure 28: The pyramid of oil and gas resource volume versus quality

Source: D. Hughes in "Drill, Baby, Drill" - Figure 37.



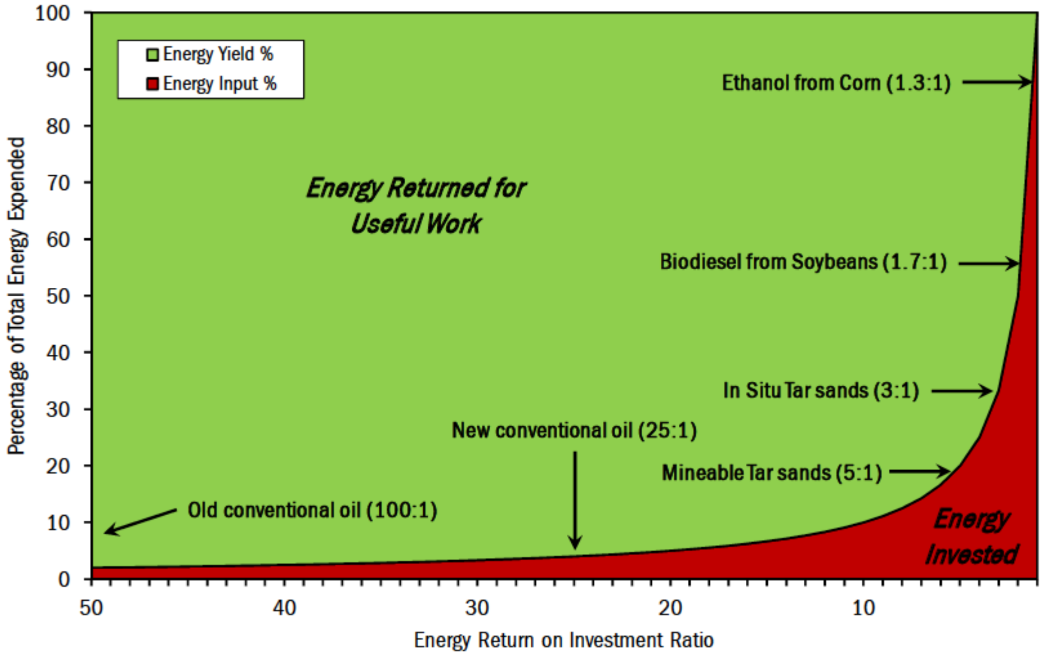
To put numbers on this, the UK Research Center (2009) states: *"Although there are approximately 70,000 active oil fields in the world, 60 percent of production comes from 374 fields and 20 percent from only 10 fields, with one field—Ghawar in Saudi Arabia—accounting for 7 percent alone."* This would be the very top of the pyramid, the sweet(est) spots; yet there are few. At the very bottom, the volume of resources is gigantic but it is totally unusable. To make it simply, there is a trade-off between quantity and quality. However, there are several limits to the quality one can accept.

First, there is an economic limit, which can be split into two. Either the difficulty to exploit the resource makes it too expensive at given price that it is just not profitable, this is the financial/ price limit. Or, the difficulty currently surpasses or technology, which makes the exploitation impossible, this is the technological limit. Those two are related, as more investment in technology could push the technological limit. While a better technology could make the process more efficient, further pushing the financial/ price limit. In any case, time has often moved this limit up (when prices fell) but more often down (technology improvement and risen fuel prices) the pyramid. Nevertheless, this economic limit has its floor. This is when the amount of energy in the resource that are extracted is lower or equal to the amount that is need to extract them. All resources below this limit cannot be qualified as energy sources as the process is net consumer of energy or net energy[*] negative. This allows us to (re) introduce to concept of energy returned on energy invested (EROEI). Murphy and Hall, the fathers of this concept, provide estimates for different sources, unfortunately not for shale gas.

[*] Net energy is the left after subtracting all energy inputs in acquiring the resource.

Figure 29: The EROEI Cliff – EROEI for different sources

Source: D. Hughes in "Drill, Baby, Drill" - Figure 38.



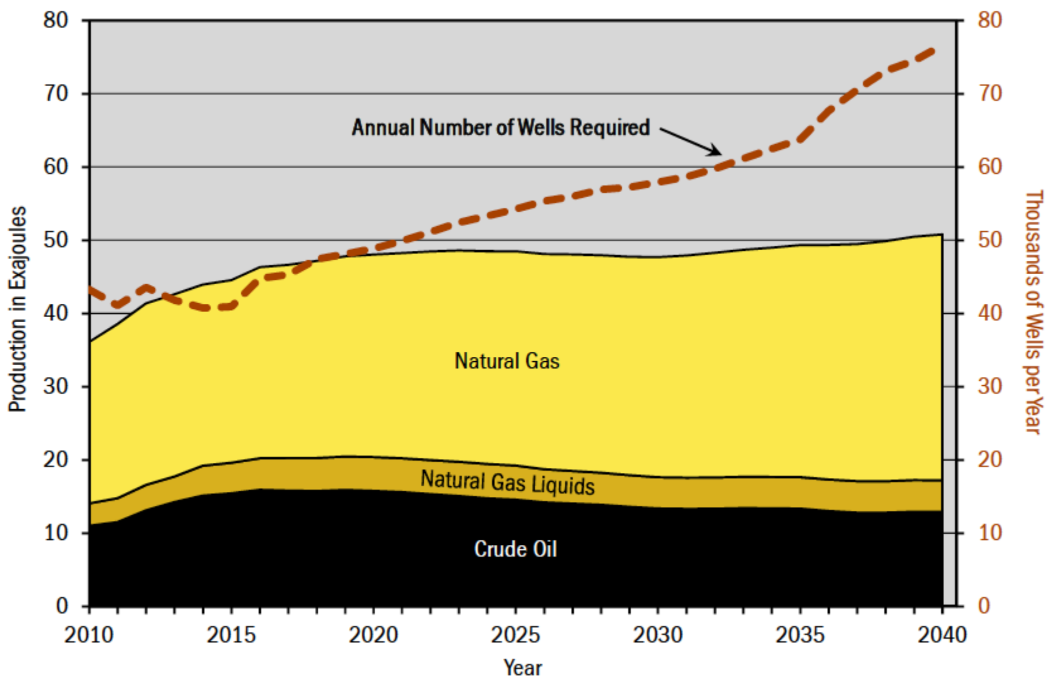
The ratio EROEI must be understood properly. First, it is obvious that when the EROEI declines to 1:1, the net energy is null, hence the resource stop being an energy source per se. What's more tricky is that a 100:1 EROEI – as it used to be in the glory days of oil – is more than 20x more beneficial than a 5:1 ratio (like mineable Tar sands). Indeed, to produce 100 unit of oil in the good old days, you needed one barrel as input. The net process delivered 99 barrels. For Mineable Tar sands, you need to burn one barrel to deliver 5, yield 4 barrels net. 99/4 is bigger than 20. Moreover, the EROEI cliff really starts to kick in below 5:1. Each increment of decline is much more decisively detrimental. For Ethanol, you would have to burn more than 3 barrels to produce one net. In 1943, White established his law: "culture evolves as the amount of energy harnessed per capita per year is increased, (…)". Ignoring EROEI could be of great cost. Although, we do not the accurate EROEI of shale gas, scientists (including Butler and Wuerthner) estimated it for conventional natural gas slightly below 20:1. It is widely approved that unconventional resources yield (much) lower EROEI than their conventional counterparts (e.g., convention oil 25:1 vs unconventional 5:1). Moreover, on average, oil yields larger EROEI than gas. Therefore, we believe probable that shale gas has a EROEI below the 5:1 "limit", straight into the energy cliff.

EROEI has a big brother EROI, which stands for energy return on investment. The latter includes the investment of energy in energy production (just like EROEI), but also includes capital and environmental investments. Hall, the father of those concepts, writes that *"the world's most important fuels, oil and gas, have declining EROI values"*. This pattern was found, for example, for US oil and gas, Norwegian oil and gas, Chinese oil and Canadian gas. A new similar unit was introduced by McKay (2013) labeled "petroleum production per unit of effort" (PPUE). Though world PPUE improved between 1980 and 2000, it has declined dramatically (almost 50%) since 2000. With again other words: *"Oil production technology is giving us ever-more expensive oil with ever-diminishing returns for the ever-increasing effort that needs to be invested."* R. Pierrehumber (Professor, University of Chicago)

To come back to our shale, we just discussed the EROEI is likely to be low. Moreover, the capital expenditure (i.e., capex) associated with horizontal drilling and fracking are known to be high (see above). Given falling production rate of shale gas (see Appendix 4), the oil and gas industry will have to drill more and more to achieve the expected growth. Figure 30 below illustrates the increasing numbers of drills needed (i.e., 71%) per year to achieve the 40% expected growth between 2010 and 2040.

Figure 30: US oil and gas production forecasts versus drilling requirements

Source: Data from EIA – Compiled by D. Hughes in "Drill, Baby, Drill" - Figure 35.



Bear in mind, the data presented in this graph comes from the EIA. Although enthusiast, they acknowledge some relative declining productivity of wells (i.e., as their forecasts illustrate). On the other hand, Hughes estimated the number of wells needed per year, not to achieve this 40% growth over 30 years, but simply to offset the annual decline in production rate. The table "key statisitcs" in appendix 4, highlights again how quickly production rate falls (see column first year annual decline) and estimates the number of wells per play required to offset the decline. Further, he estimates the amount to be invested in the top 14 plays to maintain shale gas at $42 billion (see Appendix 4 – Annual drilling costs). This is to maintain the '12 US production estimated at 280 bcm (i.e., 9900 bcf). With an average 2012 selling price of $3.3 per thousand cubic feet (roughly 25% above the average wellhead price), the total revenues from shale gas extraction would approximately amount to $32.5 billion. According to these rough estimates, shale gas operators consumed $9.5 bn just to maintain shale gas production. R. Smith (operations geologist with International Western Oil) said: *"Eventually, horizontal drilling is suspended because operators reach a point where there are just burning cash"*. This relates back to Exxon Mobil's CEO declarations of shale gas operations being all in red. Eventually, US natural gas prices are in 2014 well above their levels of 2012, giving some financial leeway to oil & gas operators. Nevertheless, given the likely low EOREI of shale gas, the vast amount of capital required, not to mention the associated environmental costs, the EROI should be even more dramatically low. All in all, the shale gas detractors will in fact agree with the enthusiast saying that the world will never completely run of fossil fuels. However, the detractors will try to demonstrate vast quantities of fossil fuels (including shale gas) are neither economically nor technically recoverable, and even if they were, the ERO(E)I would be so low that they would not be sources of energy per se.

The detractors would have perhaps liked a simpler message like: "we will quickly be running out of fossil fuel (a.o., shale gas)". However, reality is more complicated and we will in fact not. On the other hand, detractors show that the fossil fuel resource quality and EROEI are declining (quickly), hence most of those resources will never be recoverable. To think new technology would be sufficient to free up these resources at positive EROI is illusionary (especially given environmental consequences). Given these elements, to base our future economic prospects on economic fossil fuel energy abundance seems at least risky. But when we know that there are alternatives, which have shown increasing ERO(E)I over the past decades (i.e., renewables), not reducing our dependency on fossil fuel seems foolish. To the enthusiasts who dream of energy independence, declining (unconventional) fossil fuels is not the long-term answer. It is renewables. R. Heinberg concludes his book "Snake Oil", summing up these views: *"With every passing year the fossil fuel industry consumes a larger portion of global GDP, reducing society's ability to fund an energy transition. And every year the environmental costs of continued fossil fuel reliance compound. Everything depends upon our recognizing the mirage (of economic fossil energy abundance) for what it is, and getting on with project of the century."*

4. Is Shale Gas an Economic Progress for the United States?

Before considering a potential development in Europe, we would like to assess whether or not the US shale gas development has actually had a positive impact on their economy and future prospects. This is what we will try to answer in this section.

It is now unquestionable that the US has known a gigantic energy revolution over the last decade. Driven by technological improvements (namely combining fracking and horizontal drilling), surging fuel prices (till summer '08) and decreasing conventional gas production; the US produced approximately c. 260 bcm of shale gas in 2012 up 10x since 2006 and representing more than 35% of total US Natural Gas Production. This is what we called the shale gas revolution.

The results of this massive supply of gas were plentiful. First, US gas prices fell impressively low. Although they are currently trading at the Henry Hub at $4.5 per MBtu, 2.5x higher than their 2012 low point, there are still c. 3x lower than in Europe and have largely de-correlated from US oil prices (which have roughly bounced back to their pre-crisis level). Second, they US electricity price reached a plateau around 2008 probably due to availability of cheap gas prices. Third, while it did have a local impact on the US manufacturing sector – for gas intensives sectors (e.g., fertilizers and petrochemicals) – the impact on US household purchasing power was very limited. Regarding jobs created to date, estimates vary but we believe it to be lower than 0.25% of the total US workforce. All in all without shale gas, the US GDP in 2012 would likely be maximum 1% lower, while the IMF states the same US GDP could be 5% higher if the financial crisis did not happen.

Regarding profitability, shale gas requires significant upfront investment, which should have (according to their forecasts) easily been paid back. Problems arise when facing with production rate declining typically between 80 and 95% within 36 months (versus sweet spots forecasts) and very low selling prices. In 2012, the gap to finance between revenues and required investment just to maintain production was estimated at $9.5 bn. As ExxonMobil's CEO puts it: "we are making not money, it is all in red[*]".

[*] Their books show the ROCE for Upstream US (which roughly is half unconventional made) was 7% in '12 and '13 compare to 32% and 24%, respectively elsewhere (almost pure conventional).

Regarding the environmental consequences, many will argue shale gas had a major role in the US 9.1% decrease in CO_2 emission between '07 and '13, allowing for a switch from coal to gas. While this is a major achievement especially given the 6% real growth in output, we argue at least 80% of this decrease comes from the US decrease in energy consumption and the switch away from fossil energy. Furthermore, we argue cheap shale gas reduces incentives to invest in renewables and this 9.1% decrease might have been bigger without shale gas. Besides, side effects from shale gas exploitation encompass: substantial water usage, more emissions of GHGs (especially methane), earthquakes and public health concerns regarding chemicals used. While a new experimental technique based on heptafluoropropane could one day prove clean on a large scale, there is no further evidence yet. Last thing we can draw from the past on US shale gas development is that it received a lot of support from the public sector, most notably thanks to R&D funding (via the Gas Technology Institute) and the infamous "Halliburton loophole" in the "Safe Drinking Water Act". The latter exempts fracking from federal oversight, freeing them from (environmental and regulation associated) costs they would otherwise face.

Looking forward, there are two visions. On the one hand, the enthusiasts (such as the EIA and the IEA) believe US shale gas production will increase at a average yearly rate of 6% between 2011 and 2020 (a total 152 bcm increase). This could allow the US to become net gas exporter before 2020 and greatly reduce its energy dependence for 2035 (net imports as % of consumption would fall from 16% in '12 to 3% in '35). These estimates are based on 207 trillion cubic meters of technically recoverable resource (TRR) of shale gas worldwide (though only 1.3% are proven), of which the US has 9% (19 tcm) or 84 times 2011 shale gas production. In a nutshell, there is no problem, they say, keep driving. On the other hand, shale gas detractors argue the EIA has generally been overstating fuel fossil production and they do so because they overstate TRR. They overestimate TRR because they disregard decline in production rate and overstate average recovery efficiency of shale gas (versus conventional gas). Their view is that US TRR are around (6.8 bcm) or 10 times 2011 production. Yet, they agree in situ resources are gigantic, but they believe the enthusiasts underestimate the economic (technology and price) and the Energy Return On Investment barrier (EROI - which encompass energy required, financial investment and environmental cost). The economic barrier is easy to understand, if you make no money or you technically cannot exploit a resource, then it is not recoverable. The concept behind the second barrier is a bit more complex. It takes energy to get energy and if the energy returned is lower then the energy invested, then it cannot be considered a source of energy and should rationally not be exploited. The EROI barriers include financial investment and environmental costs, which further raise the bar and reduce the TRR especially given shale gas specificities.

The key of this section, to determine whether shale gas should be considered an economic bonanza, was to determine when we would run out of shale gas. As we now better understand, we will never de facto run out of shale gas, but out of recoverable shale gas. Where the limit is depends on the EROI ratio, hence on the efforts that could reasonably be made to extract shale gas. In order to answer this question further studies are required. While it should be fairly simple to calculate the investment required, it will prove important to estimate the necessary energy required to extract shale gas. Moreover, it will also be key to fairly price the associated environmental costs. We believe this EROI discussion will prove the tipping point between the enthusiasts and the detractors.

Part 3: Shale Gas Economics in the EU

Shale gas in Europe, and within the European Union, is still at in infant stage. For comparison, as of February 2014, around 50 shale gas exploration wells had been drilled in Europe versus more than 12,000 in the US between January 2005 and December 2010. However shale gas interest spreads everyday a bit more into EU members, as governments and corporates become seduced by the idea of cheap energy. Many industrials feel squeezed between US competitors, which benefit from cheap shale gas, and plants in the Middle East, which benefit from their geographical proximity of high-growth Asian markets. What is more, concerns to reduce dependence on Russia energy (especially gas) have pushed many EU members to reconsider shale gas. For example, Germany's economy minister (Sigmar Gabriel) just wrote a letter to the parliament as a first step to lift fracking ban, the FT revealed in an article published June 4, 2014. On the same day, David Cameron (UK prime minister), announced there will be changes to fracking legislation to encourage shale gas exploitation. More generally, the EU's energy commissioner (Günther Oettinger) has urged European governments to allow fracking "demonstration projects" to diversify the continent's sources of energy. All in all, there is undoubtedly a strong interest in shale gas by EU members. In the first part of this section, we will compare the EU with the only resilient point of comparison regarding shale gas, the United States. We will start of by a very high economic comparison between the two zones. Then, we will discuss shale gas potential resources in the EU. Finally, we will then focus on the various other key differences between EU and the US, which could make EU shale gas development differ form the US one.

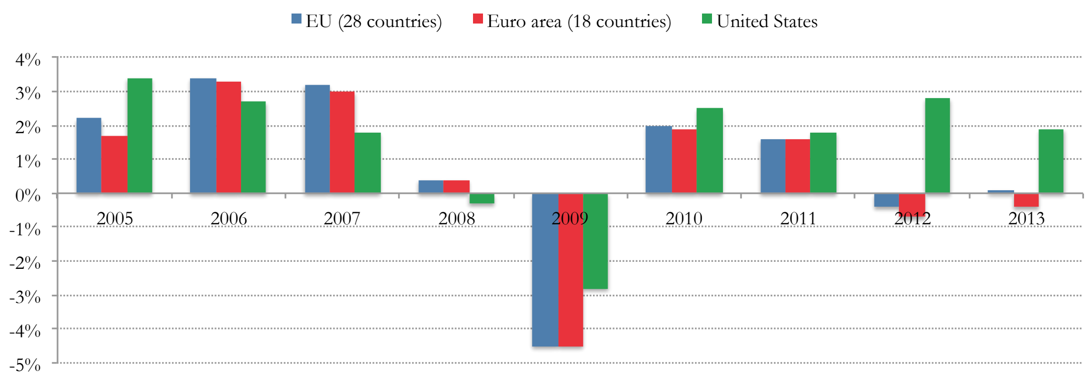
1. Current EU Situation versus the United States

a. Economic assessment

While the United States is (by far) the country with the largest economy in terms of GDP, with a '12 estimation by the world bank at $16.2 trillion (or €12.6[*] trillion). The European Union is the largest economic zone with a total output for its 28 members, estimated at €13.0 trillion by Eurostat for the same year. Nevertheless, as figure 31 below illustrates, the real GDP year-on-year changes in the EU[†] and Euro zone[‡] has been on average lower than in the US since 2005. Starting in '05 and ending in '12[§], real GDP grew by 6.7%, 7.9% and 12.4% for the Euro zone, the EU and the US, respectively. This effect is especially visible, after '09 onwards. Many argue shale gas played a major role in this better economic growth.

Figure 31: Real GDP Growth in the EU, Euro zone and US since 2005

Source: Eurostat.



We acknowledge the real growth in the US has been greater than in Europe, but we would like to already point out that demographics are very different too. The population growth over the same period was 2.6%, 2.2% and 7.2% for the Euro zone, the EU and the US, respectively. If we were to take out the population growth, the real growth in GDP per capita was in fact higher in the EU, than in the US.

What is also interesting to point out before we start our focused analysis on shale gas is the disparity in terms of economic power between the members and the citizens of the

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[*] As estimated by Eurostat, implying a '12 exchange rate of $1.29 for €1.
† EU numbers are based on the current 28 members, although some joined over the period.
‡ Euro zone numbers are based on the current 18 members, although some joined over the period.
§ We excluded '13 to compare with population data.

EU. Even expressed in purchasing power standards (i.e., PPS – eliminating the differences in price levels between countries), Bulgaria and Romania still have in '12 (though it improved much from '05) a GDP per capita of roughly half the EU average, while Luxembourg is first in class with roughly 2.6x the average EU GDP/ capita. Please have a look at Appendix 6 for full data. To finish this introduction we'd like to highlight one more thing from this table in Appendix. Although, the United States GDP/ capita in PPS was in '05 and is still in '12 much greater than the EU or Euro zone average. The spread in GDP per capita (in PPS) between the US and Europe actually went down over the '05 – '12 period, despite the shale gas revolution. Moreover, inequality (or at least as proxied by GDP/ capita in PPS) generally went down as all members that started below 80% of the average in '05 went up, most notably Lithuania, Romania and Slovakia. Interestingly countries decreased in relative terms by the greatest extent are the Greece and Ireland (as one would expect from their debt crisis) but foremost the UK. We will not say there is a causation – between the relative decline of the UK economy – and their eagerness to develop shale gas (despite relative low estimated resources – see later). However, there is a correlation, which could well be (or not be) a coincidence.

In any case, having an interest in developing shale gas is of use, only if there is something in the shale beneath your ground. In the next point, we will look at different estimates of potential technically recoverable resources in the European Union.

b. Potential shale gas resources in the EU

As discussed before, shale gas recoverable resources estimates in the US have been highly volatile, debated and contested recently. Although the US have been drilling and exploiting shale gas for decades and at larger-scale since circa '06, the EIA still had to cut its estimates for recoverable shale gas by c. 40% between '11 and '12. In comparison, the EU has put in place c. 50 explorative shale gas wells to date, while between January '05 and December '10, the US drilled more than 12 thousand exploratory wells (EIA – 2013). Even when rigs and wells are in place, few can accurately estimate the recoverable reserves of shale gas. Given this is not yet the case in the European Union, the data we present below is highly unreliable and somewhat speculative.

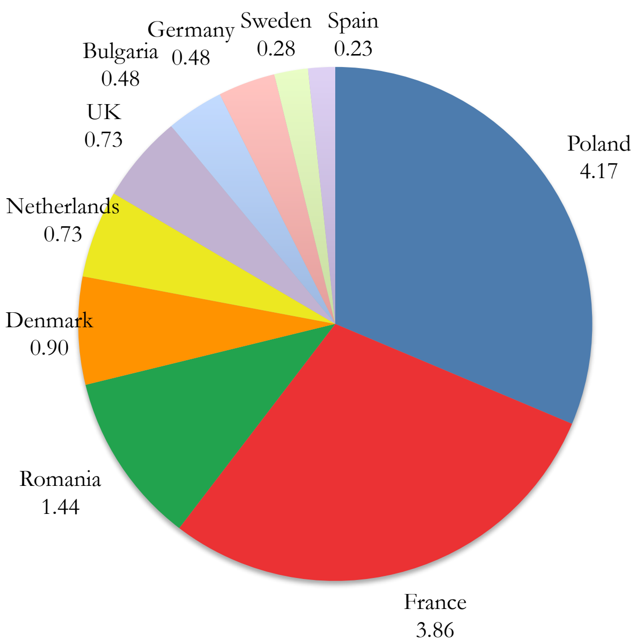
In order to provide some kind of estimates, geologists, scientists, academics and oil & gas professionals, mostly used two kinds of approach. Based on existing conventional oil and gas data, they – on the one hand – applied a "bottom-up approach" and – on the other hand – an "extrapolation approach". The first method starts from an estimation of the total resource available (the bottom of the pyramid is per Figure 28, and then tries to define the technically recoverable limit based on know geological parameters (e.g., total organic content or thermal maturity). The second approach uses data from existing shale plays, such as production rate per well and production decline rates, and transposes them to unexplored "geological similar" play. This highlights the speculative aspect of the method, as production rates and declining curve not only greatly varies between different play but also within the same play (e.g., sweetspot).

A report, from the Join Research Center (JRC) of the European Commission on unconventional gas, regroups estimates from different studies regarding shale gas technically recoverable resources (TRR) in the EU. While, studies pre 2010 ranged between 4 and 8 trillion cubic meters of shale gas TRR, studies post 2010 came up with larger estimates between 6 and 17.6 tcm. The upper limit came from a joint study (2011) of the ARI (Advance Resource International) – EIA estimate. In 2013, the EIA revised their numbers to 13.3 tcm, of which 60% is in Poland and France.

The Figure 32 below shows the distribution of shale gas TRR within the EU.

Figure 32: Shale Gas Technically Recoverable Resources in the EU (in tcm)

Source: EIA (2013) – "Technically Recoverable Shale Oil and Shale Gas Resources.



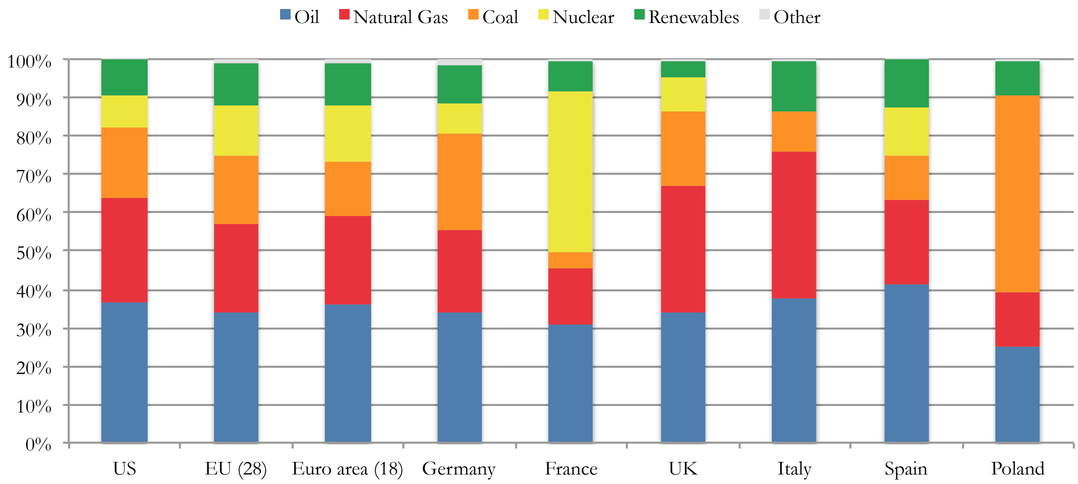
These numbers are not only significant for Poland and France but for the EU as a whole. To better understand them, one has to know the EU natural gas total production in 2011 was estimated at 185 bcm, for a total demand around 493 bcm (expected to remain stable till '20 by the IEA). This means the EU was (and is) the world's largest net buyer of natural gas, with Norway being it's number one supplier, followed by Russia and Algeria. To come back to the potential of the shale gas TRR, a 13.3 tcm would allow the Europe Union to fulfill its domestic demand for natural gas for 27 years at 2011 "consumption rate". This is massive, though highly speculative. We insist once more on the speculative aspects of theses numbers as Poland, for example, has (according to the EIA) Europe's largest TRR of shale gas with 4.17 tcm. On the other hand, the Polish Geological Institute (2012) in a report prepared with the US Geological Institute (USGS), estimates between 346 bcm to 768 bcm, an 80% to 90% haircut.

c. Europe fuel mix

In order to assess the impact shale gas could have on Europe, it is important to understand its current fuel mix. As we have seen before, a part of the decrease in CO_2 level in the US since 2007 is due to a switch from coal towards natural gas (driven by the shale gas revolution and resulting low gas prices). Figure 33 below illustrates the fuel mix of the US, compare to the EU, the Euro zone and the six largest energy consumers in the EU, which account for 70% of the total energy consumption of the EU.

Figure 33: Gross Energy Consumption per Fuel in 2012

Source: Eurostat and the EIA (for US).



First, it is interesting to notice that the EU on average is less reliant on the three fossil fuels (i.e., oil, gas and coal) than the US. Especially, for natural gas, which shows a 4.1% difference. On the other hand, the EU total consumptions is 5% more based on nuclear energy (mainly driven by France) than the US. However some countries, such as the UK – which was fuel-rich (see Part 1) – or Italy (with gas) and Poland (with coal) are relatively more fossil dependent than the US. To come back to the impact of a potential European shale gas revolution, which is (based on TRR) more likely to happen in Poland and France than elsewhere in Europe, one could hardly assess the impact on both prices and carbon intensity. Indeed, if shale gas were to replace (a part of) nuclear in France it would result in higher CO_2 emissions, while a switch away from coal in Poland would have the opposite effect. On prices, both nuclear and coal are widely considered the cheapest sources of energy and while a shale gas revolution could lower the price of natural gas in Europe, it is hard to assess whether or not it would become "cheaper" than nuclear and/ or coal.

2. Key Differences for Shale Gas Development in the EU vs the US

Whether or not shale gas development in Europe could be successful, may rely on few specific factors. For example, we have discussed shale gas uses great amount of water, requires significant technical knowledge and involves heavy capital investment. What is more, its profitability highly depends on the prices it can be sold at. As gas is hardly transportable but for pipelines (which are highly inflexible) and LNG installations (which require huge upfront investments), there is no real gas world market and prices can differ widely by location (see Figure 20). These are all parameters, which would influence a potential European shale gas development. In this section, we decided to group them by topic, starting with intrinsic geographical factors. Next, we will discuss the economics associated with shale gas, touching upon local prices and required investments. Third, we will assess the European capabilities in the unconventional oil & gas industry. Finally, we will evaluate the legal framework, which currently surrounds shale gas in the EU.

i. Geographical

Geography is probably the most obvious limiting factor. If there weren't any shale gas underneath the EU grounds, then we would not even been talking about it. Luckily (at least for the relevance of this paper), there is some. How much? That's hard to assess and comes back to our discussion over TRR above. Nevertheless, what appears clear is that there are shale gas plays in the EU and not all of them are created equal. Geological factors seem to greatly affect the production rate of the play but also its complexity, hence the required investment/ cost per-well. According to Gény (2010) and the EIA (2013), EU shale plays tend to be smaller, deeper, more highly pressurized and higher in clay content (which makes them more pliable), all these factors make them less apt to fracture. Nevertheless, this does not mean sweet spots won't be available within these plays, but it means it would likely be harder and more costly to find them, especially as techniques developed in the US could not simply be transposed (without major adaptations).

Second, shale gas is much more land intensive than conventional onshore natural gas production. Not only are the actual extraction site (with the rigs and wells) much larger but shale gas also requires "produced water" (i.e., flow backs) treatment facilities, refining, etc. This all requires space. Generally speaking, the density in Europe is roughly

3.5 times higher than the US ones. Moreover, many major EU shale plays are located in and/ or near urban areas. For example, 95% of the French shale TRR is supposedly located in the "Paris basin", which greatly expands outside "Paris intra-muros", but is still roughly centered below Paris. Nonetheless, this does not necessarily have to be a limiting factor if local landholders have sufficient (economic) incentives, which outweigh the cons. However, cultural differences towards risks and environment, landholder rights (see below), not to mention the risk of earthquakes, should probably outweigh the pros of developing shale gas in many densely populated areas.

Third, the European landscape is also more fragmented than the US. Especially, farmers own (in general) much smaller lands. Therefore, negotiations would be longer and transaction costs higher. Moreover, how to manage these multiple landowners is a key regulatory question that was addressed in the US with the "pooling and unitization" system (see legal framework below).

Last, water can be a limiting factor. Shale gas requires significant amount of water (see Part 2) and this could limit its development in some arid countries. Although this is more likely to happen in Saudi Arabia, Australia or even China, it might be a hurdle that Spain could have to overcome if they were to invest in shale gas production. In general, we have to admit that the availability of water is probably less of a limiting factor for the EU than for the US, where some of the largest plays are located in "dry-states" such as Texas.

ii. Shale Gas Economics

In part 2, we discussed in length the profitability of shale gas, including an example with ExxonMobil. We have identified that it heavily depends on production rate, declining curves and investment required (contingent on geological specificities) but foremost on selling prices. In 2012, when US gas prices was near a ten-year low point, shale gas exploitation seemed to generate (burnable) gas at a lower rate than it was burning cash. However, the situation already changed with Henry Hub Natural Gas Spot Prices currently (i.e., end of May 2014) trading 2.5x higher ($4.5 per MBtu) than their low $1.82 per MBtu of Avril 20, 2012 (EIA). Yet, these prices are nowhere near EU price, which range around $12 per MBtu (see Figure 20). In order to better grasp the difference in prices between the EU and the US but also within the EU, we have compiled Figure 34 based on data from Eurostat. The Figure below shows the average price of natural gas paid by the largest[*] industrial gas consumers in the EU[†] for the second semester of 2013. The left part of the table show data in € per GJ as provided by Eurostat and the right part in $ per MBtu as we are more accustomed to use. For both part, the left column shows the prices without taxes and levies, while the right column shows prices including all taxes (e.g., VAT) and levies.

Figure 34: EU Industrial Gas Prices for the second semester 2013

Source: Eurostat.

	(€/ Gigajoules) Excl. Taxes	All Taxes	% Taxes	($/ MBtu)** Excl. Taxes	All Taxes
European Union (28)	€ 8.0	€ 10.1	26%	$11.4	$14.4
Euro area (18)	8.2	10.3	25%	11.7	14.6
Austria	7.0	10.5	50%	10.0	15.0
Belgium	7.6	9.4	24%	10.8	13.3
Bulgaria	8.6	10.3	20%	12.2	14.7
Croatia	7.6	9.6	26%	10.8	13.6
Czech Republic	7.9	10.0	26%	11.3	14.2
Denmark*	8.9	23.3	161%	12.7	33.2
Estonia	9.2	11.2	23%	13.1	16.0
Finland	9.3	15.1	62%	13.3	21.6
France	8.1	9.3	16%	11.5	13.3
Germany	8.0	10.8	36%	11.4	15.4
Greece	9.1	10.8	19%	12.9	15.4
Hungary	9.7	12.8	33%	13.8	18.3
Ireland*	8.8	9.5	8%	12.5	13.5
Italy	8.8	9.6	9%	12.5	13.7
Latvia	9.0	11.4	27%	12.8	16.3
Lithuania*	10.5	12.5	19%	15.0	17.8
Luxembourg*	8.8	9.2	5%	12.5	13.1
Netherlands	7.7	9.5	25%	10.9	13.6
Poland	8.2	10.1	23%	11.7	14.4
Portugal	9.2	11.4	24%	13.1	16.2
Romania	5.0	7.7	54%	7.1	10.9
Slovakia	8.2	10.3	25%	11.7	14.6
Slovenia*	8.8	12.1	37%	12.6	17.2
Spain	8.9	10.9	23%	12.6	15.5
Sweden	10.3	23.4	127%	14.7	33.3
United Kingdom	7.4	9.1	22%	10.6	12.9

* Countries with no data for band I5 (very large consumer) - proxied with data from band I4
* Using an EU average: 9.4% discount when Excl. Taxes and 10.8% when Incl. Taxes
** €1 = $1.35 & 1GJ = 0.947817 Mbtu

[*] We selected the I5 band (annual consumption > 1 million GJ).
[†] Cyprus and Malta data not available.

The first thing we would like to draw from this table is that the approximation $12 per Mbtu in Europe is pretty close to the $11.4 estimated for the EU (excluding taxes). To compare (almost) apple to apple, the US average price for industrials excluding taxes over the same period was $4.4 per Mbtu, 62% less. Second, it is interesting to see how this table illustrates the differences in prices between countries for the same product (being excluding taxes or including taxes). Last point of interest is the disparity in level of taxation between "relative rich members[*]". On the one hand, Nordic countries (i.e., Denmark, Finland and Norway) impose very hefty taxes on average. While on the other hand, others – led by Luxembourg, Ireland and Italy– present an average total tax rate on gas below 10%.

To cut a long story short, natural gas prices (pre-tax) are much higher in the EU, hence the selling price for shale gas producer would be higher and this could be an edge for shale gas development in the EU. On the other hand, shale gas production costs are also projected to be higher in the EU (given factors discussed above and below, such as ownership fragmentation, geological specificities, relative lack of technology). Studied from the European Commission JRC (2012), estimated cost at $5 to 12 per MBtu, while another study made by Pöryry and Cambridge Econometrics (2013), estimated it around $9 per MBtu. Those estimates are generally higher than EU conventional production cost and also higher than those of major current exporters (including transportation costs) such as Norway, Russia or Algeria. So in case of falling EU gas prices, which is forecasted by the IEA in its gas price convergence case (see Figure 20), shale gas could be the first hit. In any case, given the potential relative small size of shale production in the EU in the coming decades, and its relative high cost of production, it is unlikely that it leads to a significant drop in EU gas prices.

Another economic point that raises concerns is the ability and willingness to raise capital to finance this heavy capex industry, which is shale gas. Indeed, while the US fracking boom was driven by many private companies willing to take on substantial financial risk fuelled by Wall Street, which hyped the prospects of a century's of cheap oil and gas. EU corporates and bankers might well not be ready to take on so much risk. Especially given

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[*] A member is considered "relatively rich" when its GDP per capita in PPS is above EU average (see Appendix 6)

the seemingly higher marginal cost, the risky legal landscape (see below) and the associated environmental concerns.

iii. Technological Capabilities

The US roughly has half of world's drilling rigs. They averaged 1,087 active natural gas drilling rigs per year between '05 and '12 (EIA data). This compares to the December '13 natural gas rig count for Europe of 32. Therefore, the US has also most of the world's oil services companies, pioneers in drilling innovation. Moreover, the bulk of petroleum geologists and engineers come from US universities. All in all, they benefit from economies of scale, learning economies and have the domestic know-how. It would hence require more time and effort to exploit, supposedly more complex, EU shale plays. Nevertheless, the EU has its local oil & gas champions such as Royal Dutch Shell, BP, Total or Eni, which could make the investments required to develop shale gas in the EU. However, this seems a long-shot. Recent examples point in the opposite direction, as Shell ex-CEO, Peter Voser recently (October 2013) announced he regretted Shell's huge (c. $24bn) bet on US shale (i.e., the company had to took a $3 bn impairment). He also believes US shale revolution being exported to other countries was "hyped", and that the rest of the world was in an early "exploration phase" which could yield "negative surprises". Furthermore, BP CEO, Bob Dudley, recently ruled out shale gas drilling in the UK as he fears BP would "attract the wrong kind of attention" after the Gulf of Mexico catastrophe.

iv. Legal framework

The legal framework is an essential part of to the development of shale gas. If a government forbids its exploitation, then there will be none till they decide to change the law. While, there is no such ban at the EU level, some members already decided to ban shale gas exploitation on their ground. Most notably, France (which could have the second largest technically recoverable resources of shale gas) under the precautionary principle (given the health and environmental risks) announced an outright ban in 2011. Bulgaria followed shortly after amid popular pressure. In 2012, Czech republic, Luxembourg and the Netherlands all passed a moratorium to prevent shale gas drilling before further studies are made. In Germany, situation is a bit unclear, it seems there is a "de facto ban" after Merkel's proposition to exploit shale gas raised so much protests, however they look set to lift the ban early 2015. In the UK, only Cuadrilla Resources was granted to exploit shale gas in 2011 (others received exploratory licenses). However, two minor earthquakes led to a suspension of the production for almost a year. After it was judged not cause by shale gas, and the development re-started under strict monitoring, among which only non-hazardous chemical may be used… Whether or not shale gas is found more economically profitable than environmentally destructive, will determine the evolution of these bans. Nevertheless, given current laws, some of the potential largest plays (e.g., in France) are inoperable and others could know the same faith. This regulation risk pills up risks on oil & gas operators and bankers, which would have to bet large amount on shale gas in the EU.

A second type of legal issue relates to land access. On the one hand, there is a potential economic incentive problem for the landowner and on the other hand, a difficulty to manage fragmented ownership and multiple owners.

First, it is often argue the US regime of landholder ownership of sub-soil mineral rights favors shale gas development. Indeed while in the EU the states often own the sub-surface right, in the US it is property of the landowner. Therefore, exploitation would yield royalties to landholders, which prove a strong economic incentive. However, the situation is in fact less black and white both in (and within) the EU and in the US. The heat of the discussion is in fact to what extent can landowner restrict access exploitation of their sub-soil. While the US tends to favor the mineral resource's owner, granting a compensation to the soil owner; the EU member's law vary in the extent to which landowner can purely refuse sub-soil exploitation.

Second, we have previously stated farms are typically smaller in the EU, making ownership more diffuse, while shale gas rigs and plants require typically lot of space. Developing the right regulation, which facilitates combining lands and managing several owners is thus key to shale gas development, just like the US have done with the "pooling and unitization" law. Such a regulation at the EU or the states level could prove essential in shale gas development.

Conclusion

One problem with finite resources, like shale gas (or time to write this paper), is that at one point, they run out. Nevertheless, finite resources can be managed sustainably. Indeed, the resource does not need to be passed on but rather the capacity to sustain the income stream from the finite resource, with for example a better-educated workforce (or young adult).

A second problem with fossil resources is that they can be hit by curses, namely the Natural Resource Curse and the Carbon Curse. In Part 1 – Section 3, we concluded that the Natural Resource Curse was not a valid reason to prevent the exploitation of shale gas in the EU. Although there are foreseeable economic risks, we believe EU members have the required institutions to empower governments and help them implementing the right policies, which would transform the curse into a blessing. On the other hand, we concluded the Carbon Curse would be harder to overcome, given emissions from fuel extraction (especially methane) and lower incentive to invest in energy efficiency, would likely result in a carbon intensification of the economy.

A third problem with unconventional fossil resources is that there are very complex. Not only are they complicated to define, but it is also a struggle to exploit them, to assess their impact on the economy (and on the environment), to measure their potential technically recoverable resources, not to mention trying to forecast their potential development.

One advantage of shale gas is that it greatly took off in the US almost ten years ago. So looking backwards, it is easier to draw a judgment. In Part 2 – Section 4, we argued that while shale gas has been a gigantic energy revolution for the US and domestic prices are indeed at very low level (historically and versus other regions), it did not have a gigantic impact on their economy. The shale gas revolution did have a significant impact on a very specific area of their manufacturing sector (i.e., gas intensive industry, such as fertilizers or petrochemicals) and a minor one on the household purchasing power (i.e., lower gas bills). All in all, without shale gas the unemployment rate could have been 0.25% higher and US GDP one 1% lower (maximum). Though significant, these numbers aren't those of an economic revolution. Further, the sustainability of shale gas economics, or more simply its profitability, are currently raising questions given strong decline rates and low selling gas prices. Moreover, many environmental concerns surround its development. While we acknowledge carbon dioxide emissions reduced by 9% between '07 and '13, we believe at least 80% of this decrease comes from a reduction in US energy consumption and a switch away from fossil fuel (towards renewables); and go further arguing cheap shale gas might have in fact played against this decrease. Besides, other environmental concerns (e.g., earthquakes and methane emissions) remain and the US legislation – via the "Halliburton loophole" in the "Safe Drinking Water Act" – frees up fracking from (environmental and regulation associated) costs they would otherwise face.

A fourth problem with complex matters is that educated people may have very different opinions, especially forward looking. While enthusiasts believe in decades of available technically recoverable resource (TRR) of shale gas, which would allow the US to become net gas exporter before 2020 and almost[*] energy independent by 2035 (net energy imports as % of production falling from 16% in ' to 3%). Detractors highlight steep decline in production rate and believe TRR are closer to 10 years of production. Although they agree resources are much larger, they highlight it makes no sense to extract a resource if the Energy Return on Investment (EROI[†]) is equal or below to one for one. Behind this point, the total investment (in energy, money and environment) is worth more than the energy recoverable; therefore the investment should not be made. Further studies would be required to estimate the energy cost and fairly price the environmental costs associated with shale gas production. Their results could prove key to define the EROI tipping point, beyond which, shale gas becomes a costly waste of time and energy.

Another advantage of complex matters, such as shale gas, is you don't have to come up with a Manichean answer. Especially given the fact that European shale gas is still at an infant stage. Indeed, while the US drilled more than 12,000 exploratory wells between '05 and '10, in the EU barely 50 explorative shale gas wells have been drilled to date. Knowing US Shale gas TRR estimates are still highly volatile, it is clear that European estimates are speculative, at best. Guesstimates (from the enthusiastic EIA) currently add

* Net energy imports as % of production falling from 16% in 2011 to 3% in 2035.
† EROI encompasses energy invested (EROEI), capital expenditure and environmental costs.

up to 13.3 trillion cubic meters of shale gas TRR in the EU (vs 19 tcm in the US), of which more than 60% is supposedly located in Poland and France. The total TRR estimated represents 27 years of supply at 2011 EU consumption level of natural gas. However, many believe these numbers are overly optimistic*. So to begin with, TRR are likely to be smaller but also EU plays are supposedly harder to exploit given geological factors. Second, shale gas requires space and the EU is on average 3.5x more densely populated and has a much more fragmented landscape, which would require specific regulation (such as the US "pooling and unitization" system). Third, the US has developed a technical edge regarding unconventional resource exploitation, implying higher EU production costs. Fourth, more stringent legal framework such as complete ban in France or temporary suspension in the Netherlands, could simply forbid shale gas development. While on the other side of the ocean, difference in landholder ownership and Halliburton loophole, make the US legal landscape generally more favorable to shale gas exploitation. Last, stronger environmental concerns and risks associated to oil & gas producers PR image could prevent European corporates to develop shale gas (e.g., BP feared to "attract the wrong kind of attention").

Given the specificities discussed here above, we believe it would not be possible for the EU to replicate the US shale gas boom. Moreover, despite this gigantic production boom, the revolution did not have a huge economic impact. The real GDP per capita grew, in fact, at a faster rate in the EU (than in the US) over the '05 – '12 period. Besides, would the energy required (for shale gas production) be accurately measured and environmental costs be fairly priced (e.g., abolishing the Halliburton loophole), shale gas real EROI could imply much smaller TRR (than expected), greatly reducing its future potential. What is more, other energy sources, which are carbon neutral and infinite, show – in opposition to fossil fuels – increasing trend in terms of EROI. By definition, renewables do not deplete, hence they are the only long-term way to become energy independent. While we acknowledge we are uncertain of shale gas potential in the US (and in EU), our recommendation would be not to consider shale gas development an economic priority for the EU members but rather focus on enhancing renewable development. On the one hand, would the shale gas actually happen to be a resource bonanza for the US, Europe will share a part of the benefits with cheaper gas prices given LNG development. Further, if scientists were to develop a clean efficient method

* For example, the Polish Geological Institute estimates its own TRR 80 to 90% below the EIA's numbers.

to exploit shale gas resources, EU TRR will not have vanished over the waiting time; we can keep this real option open. On the other hand, would shale gas prove uneconomic and environmentally dangerous, EU would have developed an edge in another source of energy that we know for sure yields increasing EROI and would have avoided a costly waste of time and energy.

In conclusion, we believe EU members should not (currently) consider shale gas an economic opportunity, despite rejecting the Natural Resource Curse. We acknowledge current US low gas prices might be luring European corporates, however we hope government will not listen to Oscar Wilde and *"resist then temptation by* not *succumbing*" to shale gas development. Indeed, money is not the prime mover of the economy; in fact it is energy that gets things done. On the long run, the only long-term way to provide profitable and environmental friendly sources of energy is to engage on the renewable path. We believe the earlier the better. Hence, our opinion is shale gas should not be considered an economic opportunity, but rather a real option, which might well remain unexercised.

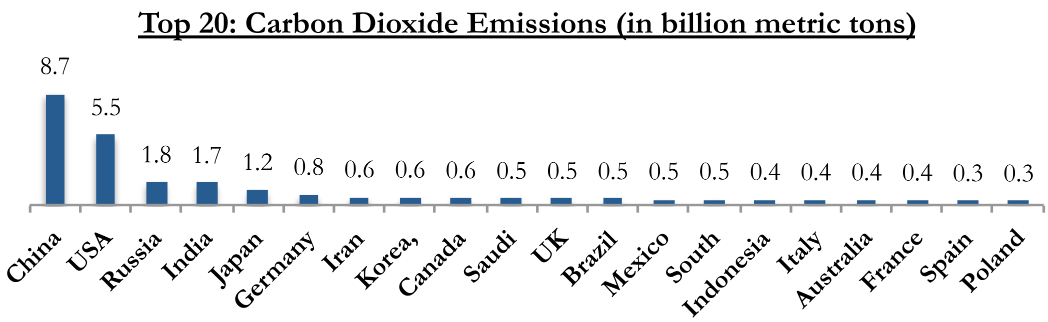
Appendices

1. Appendix 1: General Energy Data

In this section, we decided to display some valuable data for a better understanding of this paper. We provide the top 20 producers, net exporters and net importers of natural gas, crude oil and electricity. With regards to natural gas and crude oil, we also provide the countries with the largest proven reserves*. Regarding electricity, we also added the largest consumers. Finally, we considered the carbon dioxide emissions from consumption of energy.

Please note the data in this section comes from the Central Intelligent Agency website (www.cia.gov), as of end of April 2014 (hence, the vast majority of the data covers the year 2012 or 2013). We made three adjustments to the raw data. First, we eliminated the European Union as a country to avoid double counting. Second, we considered the single data point for Macedonia Oil imports as not available rather than the given value of 51.5 million barrels per day (which is more than the total of oil exports). Third, we computed net exportation (and net importation) as the difference between exportation and importation. Bear in mind that the data shows the total annual production, unless otherwise stated.

Carbon Dioxide†:



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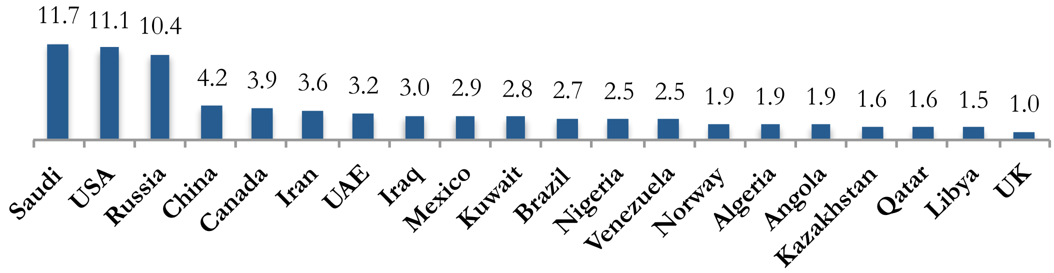
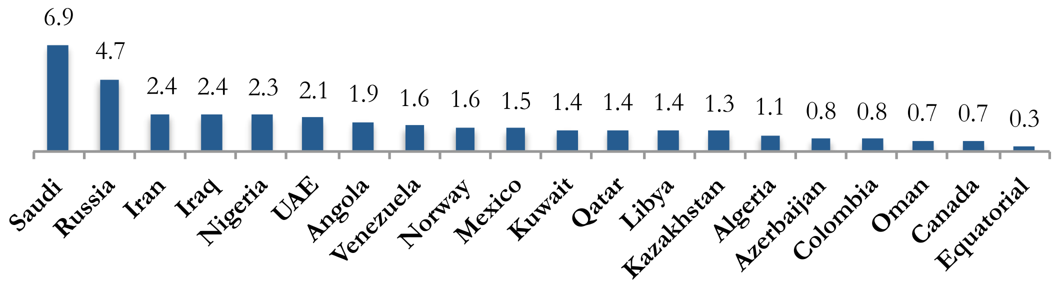
* Proved reserves are those quantities of petroleum (or gas) which, by analysis of geological and engineering data, can be estimated with a high degree of confidence to be commercially recoverable from a given date forward, from known reservoirs and under current economic conditions.
† This is the total amount of carbon dioxide released by burning fossil fuels in the process of producing and consuming energy.

Crude Oil:

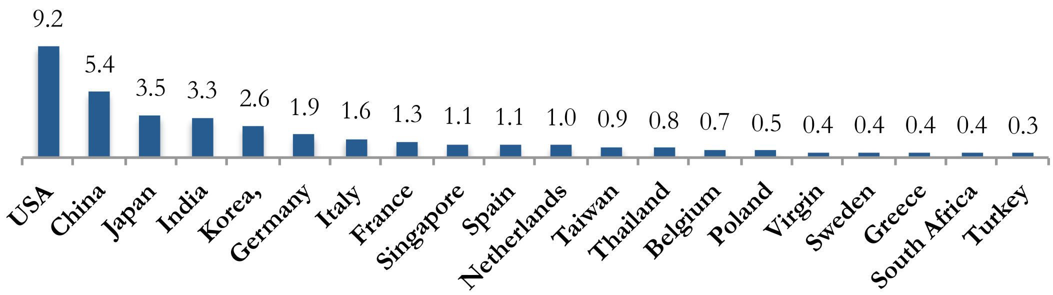
Top 20: Crude Oil Producers (in million barrels per day)



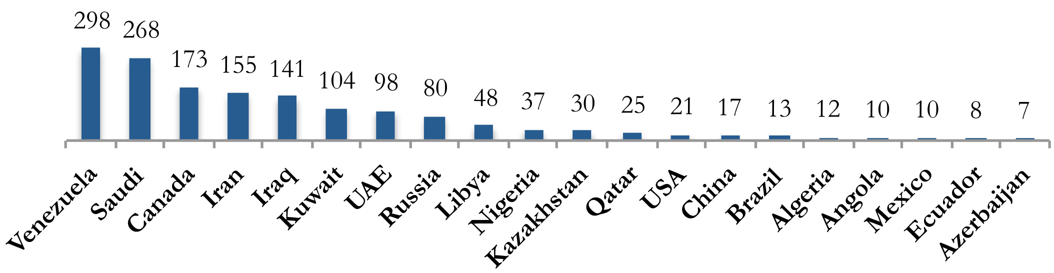
Top 20: Crude Oil Net Exporters (in million barrels per day)



Top 20: Crude Oil Net Importers (in million barrels per day)

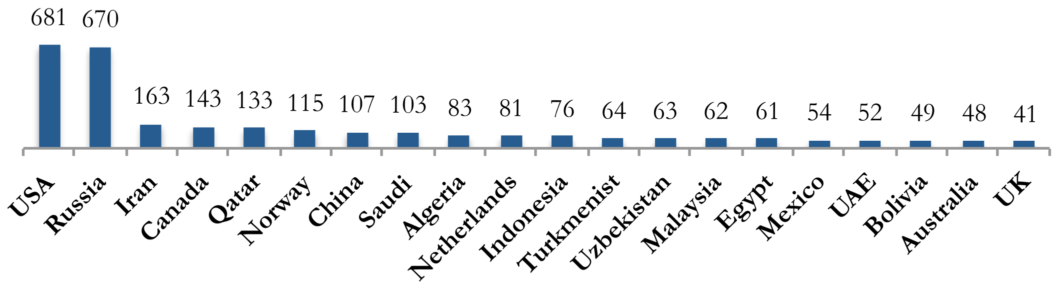


Top 20: Crude Oil Proved Reserves (in billion barrels)

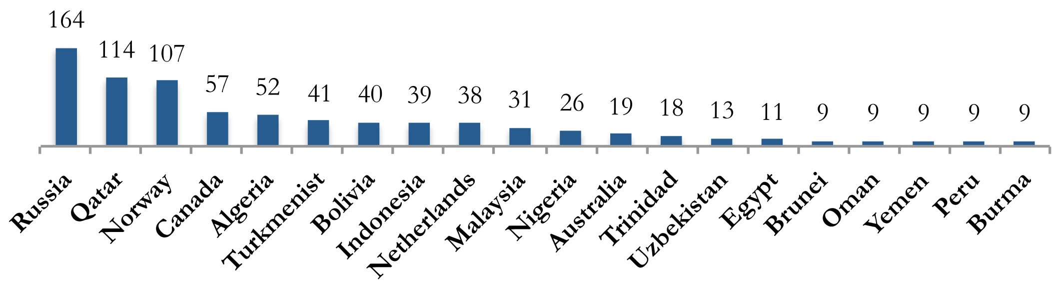


Natural Gas:

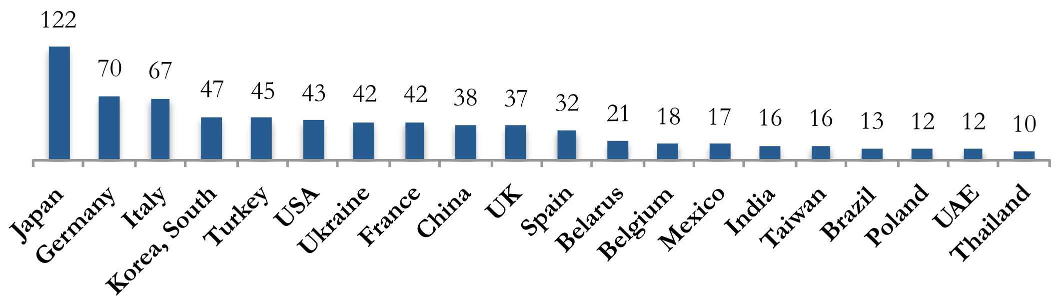
Top 20: Natural Gas Producers (in billion cubic meters)



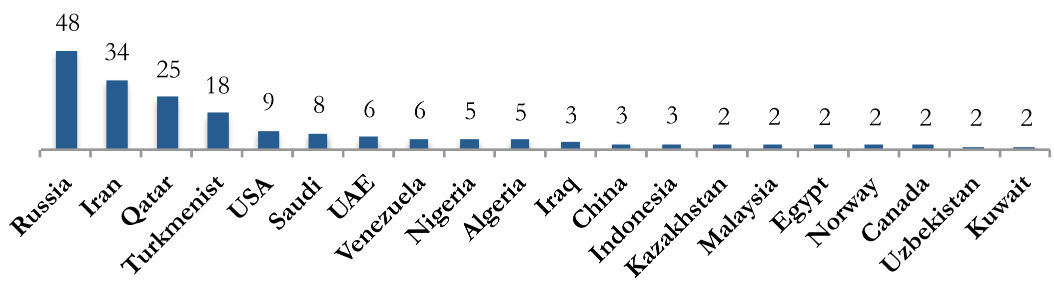
Top 20: Natural Gas Net Exporters (in billion cubic meters)



Top 20: Natural Gas Net Importers (in billion cubic meters)

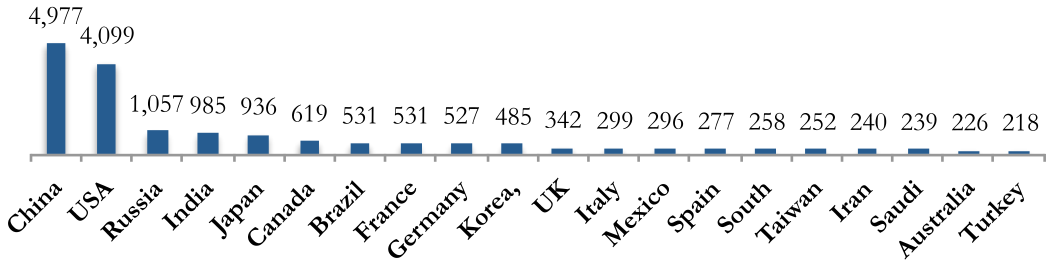


Top 20: Natural Gas Proved Reserves (in trillion cubic meters)

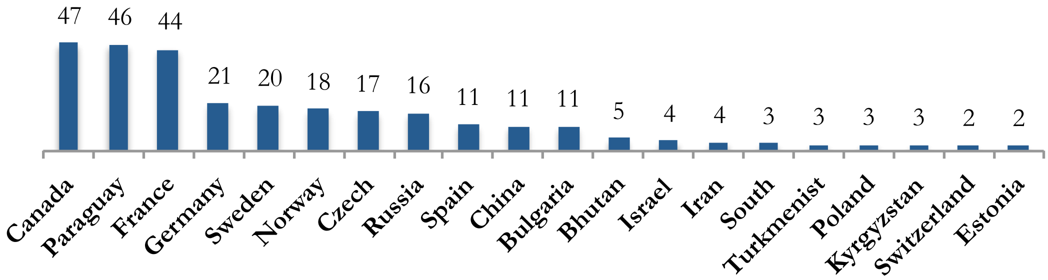


Electricity*:

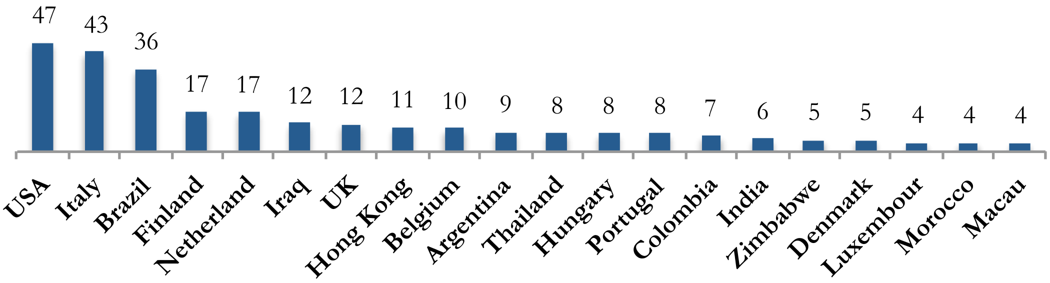
Top 20: Electricity Producers (in billion kilowatt-hours)



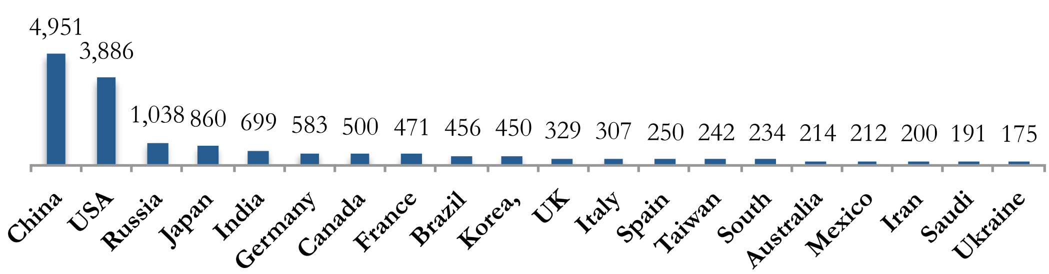
Top 20: Electricity Net Exporters (in billion kilowatt-hours)



Top 20: Electricity Net Importers (in billion kilowatt-hours)



Top 20: Electricity Consumers (in billion kilowatt-hours)



* Numbers might not add up due to electricity losses.

2. Appendix 2: Norway's selected Environmental Acts and Taxes

Selected Environmental Acts:

Source: Norway Ministry of Climate and Environment.

- Nature Diversity Act [19.06.2009]
- Greenhouse Gas Emission Trading Act [17.12.2004]
- Environmental Information Act [09.05.2003]
- Svalbard Environmental Protection Act [15.06.2001]
- Gene Technology Act [02.04.1993]
- Pollution Control Act [13.03.1981]
- Cultural Heritage Act [09.06.1978]
- Motor traffic on uncultivated land and in watercourses [10.06.1977]
- Product Control Act [11.06.1976]
- Outdoor Recreation Act [28.06.1957]

Environment taxes in Norway – main developments:

Source: Norway Ministry of Finance

1971	Sulphur tax on mineral oil
1974-1993	Tax on non-refillable beverage containers (replaced by broader taxation of beverage packaging)
1986-	Petrol tax differentiated according to lead content
1988-1998	Tax on nitrogen and phosphor in mineral fertilisers
1998-	Tax on pesticides, tax on lubricating oil
1990-1991	Tax on environment damaging batteries (replaced by regulation)
1991-	CO_2 tax on petrol, auto diesel oil, mineral oil (excl. fisheries etc.), and petroleum sector (only offshore activities)
1992-2002	CO_2 tax on coal and coke, except most industrial processes
1994-	Environment tax on beverage packaging differentiated according to return rate
1999-2001	Sulphur tax on coal, coke and oil refineries at a low rate (replaced by voluntary agreement)
1999-	Tax on final waste treatment. CO_2 tax includes domestic sea transport of goods (formerly only passenger transport) and the supply fleet
2000-	Tax on environment and health damaging chemical products (only two products so far), beverage packaging tax differentiated according to materials, auto diesel oil tax differentiated according to sulphur content, annual weight-based tax on heavy vehicles differentiated according to emission standards (EUROI–EUROIII)
2003-	Taxes on HFCs and PFCs

Note: Years fully or partly in operation. Source: Ministry of Finance.

3. Appendix 3: Are methane hydrates then next revolution-in-waiting?

Source: International Energy Agency - World Energy Outlook (2013) – Page 119 – Box 3.5.

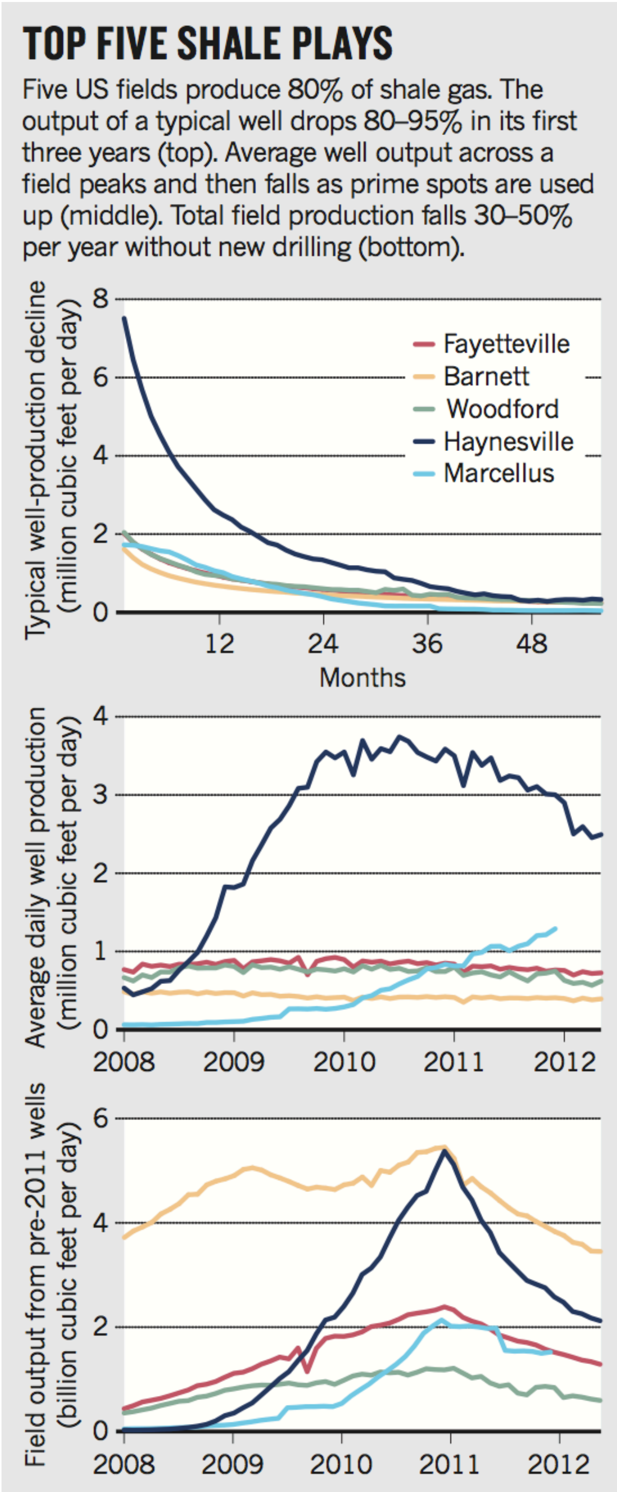
Methane hydrates are deposits of natural gas trapped together with water in a crystalline structure that forms at low temperatures and moderate pressures. They can be found either on the sea floor, in shallow sediments beneath the sea floor or underneath Arctic permafrost. Methane hydrates may offer a future means to further increase the supply of natural gas. Though quantitative estimates vary by several orders of magnitude, all agree that the resources in place are extremely large, with even the lower estimates giving resources larger than all other natural gas resources combined. Many estimates fall between 1 000 and 5 000 tcm, or between 300 and 1 500 years of production at current rates. The US Geological Survey estimates that gas hydrates worldwide are between 10 to 100 times as plentiful as US shale gas reserves.

Producing gas from methane hydrates poses huge technological challenges and the relevant extraction technology is in its infancy. So far there have been only small-scale experimental production projects: the Japanese Nankai Trough project has just achieved small-scale production and the Malik project in Canada produced for about three months from one well. The longer-term role of methane hydrates will depend on climate change policies as well as technological advances, as meeting ambitious goals to reduce emissions would require a reduction in demand from all fossil fuels, certainly in the longer term. In addition, methane released to the atmosphere from any source is a potent greenhouse gas and great care has to be taken to minimise such releases – a point highlighted in *Redrawing the Energy Climate Map*: *World Energy Outlook Special Report* (IEA, 2013b). One aim of the Japanese research programme is to develop production technology that achieves controlled release of the methane from the ice into the production well, minimising the risk of the methane escaping into the atmosphere. For countries like Japan that continue to rely on expensive imported energy, methane hydrates may be an attractive energy supply option. The Japanese government aims to achieve commercial production in ten to fifteen years, *i.e.* by the mid- to late-2020s.

4. Appendix 4: US Shale Gas Plays by D. Hughes

Top Five Shale Plays

Source: D. Hughes (2013): "A reality check on the shale revolution". Nature, Volume 494, 307-308.



Key statistics

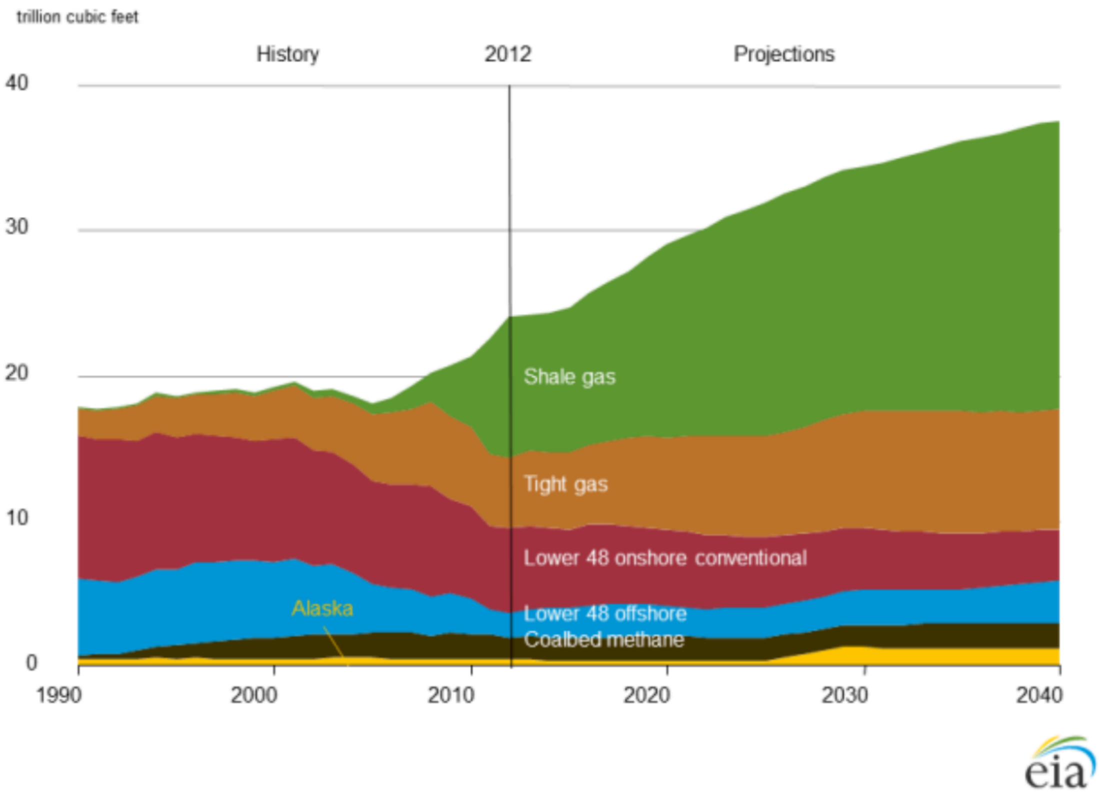
Source: D. Hughes (2013): "Drill, Baby, Drill". Table 1

Field	Rank	Production (bcf/d)	Month	Number of Operating Wells	Average Well Production (mcf/d)	Mean IP (mcf/d)	Median IP (mcf/d)	IP Trend	First year well decline (%)	Overall annual field decline pre-2011 (%)	Number of Wells needed annually to offset decline	Production Trend	Percent of Total Shale Gas Production
Haynesville	1	6.99	May-12	2802	2493	8201	7954	Declining	68	52	774	Declining	25.76
Barnett	2	5.85	May-12	14871	393	1619	1332	Flat	61	30	1507	Flat	21.56
Marcellus	3	4.96	Dec-11	3848	1290	1947	1133	Rising	47	29	561	Rising	18.28
Fayetteville	4	2.81	May-12	3873	818	2069	1985	Flat	58	36	707	Flat	10.36
Eagle Ford	5	2.14	Jun-12	3129	685	1920	1330	Declining	59	43	945	Rising	7.90
Woodford	6	1.13	May-12	1827	620	2292	1380	Declining	58	29	222	Declining	4.16
Granite Wash	7	0.95	Jun-12	3090	308	2080	1354	Declining	78	49	239	Declining	3.50
Bakken	8	0.60	May-12	4598	122	345	241	Rising	56	29	699	Rising	2.21
Niobrara	9	0.48	May-12	10811	45	162	123	Declining	56	26	1111	Flat	1.77
Antrim	10	0.29	May-12	9409	31	634	102	Flat	*	*	~400	Declining	1.07
Bossier	11	0.25	Jun-12	278	901	9116	3909	Declining	63	38	21	Declining	0.92
Bone Spring	12	0.23	May-12	1016	223	596	258	Flat	58	45	206	Rising	0.84
Austin Chalk	13	0.16	Jun-12	928	169	2109	370	Declining	72	35	127	Declining	0.59
Permian Del. Midland	14	0.088	Jun-12	1541	57	255	91	Rising	34	26	122	Flat	0.326
Lewis	15	0.0523	May-12	462	113	656	427	*	*	*	*	Declining	0.193
Mancos Hilliard Baxter	16	0.05	May-12	452	120	452	182	Declining	63	35	41	Flat	0.184
Spraberry	17	0.031	Jul-12	552	56	210	67	Flat	*	*	*	Rising	0.114
Miss. Lime	18	0.024	Apr-12	371	66	394	109	Rising	39	14	10	Flat	0.088
Bend	19	0.02	Jun-12	273	69	585	336	*	*	*	*	Declining	0.070
Pearsall	20	0.0060	Jun-12	17	309	*	*	*	*	*	*	Declining	0.022
Utica	21	0.006	Dec-11	13	467	478	34	*	*	*	*	Rising	0.022
Hermosa	22	0.0057	May-12	33	180	2549	1888	*	*	*	*	Declining	0.021
Pierre	23	0.004	Apr-12	193	20	126	105	*	*	*	*	Declining	0.015
Tuscaloosa	24	0.0025	May-12	23	110	1474	0	*	*	*	*	Declining	0.009
Manning	25	0.0018	May-12	45	41	903	246	*	*	*	*	Declining	0.007
New Albany	26	0.0017	Dec-09	28	62	101	18	*	*	*	*	Declining	0.006
Mulky	27	0.0015	May-12	120	12.4	50	34	*	*	*	*	Declining	0.006
Chattanooga	28	0.001	Dec-10	107	9	46	29	*	*	*	*	Declining	0.004
Mowry	29	0.0006	Jun-12	39	15	165	20	*	*	*	*	Declining	0.002
Cody	30	0.0004	Jun-12	11	40	334	0	*	*	*	*	Declining	0.002

5. Appendix 5: EIA forecasts for US Natural Gas Production

Source: EIA (2013) – Figure MT-44

Figure MT-44. U.S. natural gas production by source in the Reference case, 1990-2040



6. Appendix 6: Selected GDP per capita in PPS relative to EU (28)

Source: Eurostat.

Countries with a star* represent EU members that currently do not use the Euro.

	2005	2012	Δ '05 - '12
EU (28)	100	100	0
Euro area (18)	109	108	-1
United States	165	152	-13
Austria	125	130	5
Belgium	120	120	0
Bulgaria*	37	47	10
Croatia*	57	62	5
Cyprus	93	92	-1
Czech Republic*	79	81	2
Denmark*	124	126	2
Estonia	62	71	9
Finland	114	115	1
France	110	109	-1
Germany	116	123	7
Greece	91	75	-16
Hungary*	63	67	4
Ireland	144	129	-15
Italy	105	101	-4
Latvia	50	64	14
Lithuania*	55	72	17
Luxembourg	254	263	9
Malta	80	86	6
Netherlands	131	128	-3
Poland*	51	67	16
Portugal	80	76	-4
Romania*	35	50	15
Slovakia	60	76	16
Slovenia	87	84	-3
Spain	102	96	-6
Sweden*	122	126	4
United Kingdom*	124	106	-18
Iceland	130	115	-15
Norway	178	195	17
Switzerland	137	158	21

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