IDDRI

SciencesPo.

STUDY

N°02/14 FEBRUARY 2014 | CLIMATE

Unconventional wisdom: an economic analysis of US shale gas and implications for the EU

Thomas Spencer, Oliver Sartor, Mathilde Mathieu (IDDRI)

THE UNCONVENTIONAL OIL AND GAS REVOLUTION: IMPACTS ON THE US ECONOMY

Despite very low and ultimately unsustainable short-term prices of natural gas, the unconventional oil and gas revolution has had a minimal impact on the US macro-economy. We provide an upper—optimistic—estimate of its long-term effect on the *level* of US GDP (not its long-term annual growth *rate*) at about 0.84% between 2012 and 2035. Compared to an annual growth rate of 1.4%, this long-term increase is small. And we estimate its short-term stimulus effects at 0.88% of GDP during the 2007/8 to 2012 downturn. The unconventional oil and gas revolution has also had a minimal impact on US manufacturing, confined to gas-intensive sectors, which we calculate as making up about 1.2% of US GDP. There is thus no evidence that shale gas is driving an overall manufacturing renaissance in the US.

THE UNCONVENTIONAL OIL AND GAS REVOLUTION: IMPACTS ON THE US ENERGY MIX

Absent further policies, the US shale revolution will not lead to a significant, sustained decarbonisation of the US energy mix nor will it assure US energy security. A reference scenario based on current policies sees US emissions stagnant at current levels out to 2040, clearly insufficient for a reasonable US contribution to global climate change mitigation. Oil imports continue to rise in monetary terms. While it can promote some coal to gas switching in the short term if additional policies are enacted, there is also the risk that the unconventional oil and gas revolution further locks the US into an energy- and emissions-intensive capital stock.

IMPLICATIONS FOR THE EU ECONOMY AND CLIMATE POLICIES

It is unlikely that the EU will repeat the US experience in terms of the scale of unconventional oil and gas production. Uncertainty exists around the exact size of exploitable EU shale gas reserves; a median scenario would see the EU producing about 3-10% of its gas demand from shale gas by 2030-2035. The EU's fossil fuel import dependency will therefore continue to increase and its fossil fuel prices will remain largely determined by international markets. Shale production would not have significant macroeconomic or competitiveness impacts for Europe in the period to 2030-2035. In terms of energy, climate and competitiveness challenges, shale gas could potentially be a complement to a broad EU energy strategy for some countries heavily dependent on coal or Russian gas, but it is certainly not a substitute for the current strategic orientations of EU energy policy.

www.iddri.org

Institut du développement durable
et des relations internationales
27, rue Saint-Guillaume
75337 Paris cedex 07 France

Citation: Spencer, T., Sartor, O., Mathieu, M. (2014). *Unconventional wisdom: an economic analysis of US shale gas and implications for the EU*, Studies N°02/14, IDDRI, Paris, France, 36 p.

☆☆☆

The authors would like to thank Richard Baron, Mourad Ayouz, and Michel Colombier for their comments on previous versions of this text.

☆☆☆

This article is based on research that has received a financial support from the French government in the framework of the programme « Investissements d'avenir », managed by ANR (French national agency for research) under the reference ANR-10-LABX-14-01.

☆☆☆

For more information about this document, please contact the authors:

Thomas Spencer – thomas.spencer@iddri.org
Oliver Sartor – oliver.sartor@iddri.org
Mathilde Mathieu – mathilde.mathieu@iddri.org

ISSN 2258-7535

Unconventional wisdom: an economic analysis of US shale gas and implications for the EU

Thomas Spencer, Oliver Sartor, Mathilde Mathieu (IDDRI)

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Context

Since approximately 2007/8, the United States has seen rapid growth in the domestic production of "unconventional" fuels, driven in particular by the exploitation of significant but previously inaccessible reserves of "shale" gas and "tight" oil. The new unconventional reserves are changing the landscape of domestic US energy markets. This development has triggered the interest of other countries in applying the technological breakthroughs that led to the US unconventional oil and gas revolution. This in turn could have impacts on global energy markets.

The perceived economic and energy security benefits of the US unconventional oil and gas revolution have sparked debate in Europe about whether EU energy and climate policy should be adapted. The EU is facing a number of challenges: rising electricity and gas prices;[1] concerns about declining EU gas production and the lack of diversification of supplies; and the slow speed of the EU economic recovery. These factors have all contributed to arguments that the EU should re-think its energy and climate strategy in light of the US shale gas boom. In particular, it is sometimes suggested that the EU's energy goals should be rebalanced in favour of competitiveness and affordability, and that exploiting shale gas would be a means to do so.[2] It is also argued that the US shale gas revolution demonstrates the potential to reduce carbon dioxide (CO_2) emissions quickly and cheaply.

1.2. Objectives and limits of the study

In this context, this study addresses two interrelated questions:

1. What are the current and projected economic, energy sector and emissions impacts of the shale revolution in the US?
2. Does the shale revolution in the US imply that the EU should fundamentally revise its energy and climate objectives, in so far as the domestic production of shale gas would allow the achievement of more affordable and secure energy? In other words, if the EU or EU Member States decided to go for shale, should this been seen as a complement or rather as a substitute to the current EU energy strategy which combines enhancing energy efficiency, completing the internal market, and de-carbonizing the energy system?

1. The European Commission notes that on average EU residential electricity prices have risen by 4% per year from 2008-12 while residential gas prices have risen 3% per year. For industry, the corresponding retail electricity and gas price increases have been 3.5% per year and 1% per year respectively. Wholesale electricity and gas prices have fallen by 35 to 45%, while wholesale gas prices have remain stagnant overall over the period 2008-2012. Cf. European Commission (2014), "Energy Prices and Costs in Europe", COM(2014)21.

2. An example is a 2013 Franco-German report overseen by Jean-Louis Beffa and Gerhard Cromme *Compétitivité et croissance en Europe [Competitiveness and growth in Europe]*, which argued that *« the growing costs of energy in Europe, most notably in Germany, are leading progressively to an off-shoring of energy-intensive industries, and, as a consequence, to the loss of the first link in the industrial value chain. This is one of the most important risks to growth and competitiveness for our countries. It is necessary to proceed with a radical revision of the entire set of objectives and the tools put in place to reach the goals envisaged for 2020 in terms of climate and energy."*

In addressing the vast topic of unconventional hydrocarbons, it is also important to set out openly the limits of the study:

1. The study does not address the local environmental impacts of shale gas exploitation, such as water pollution, water overuse, land degradation and so on. Interested readers are directed to the meta-study released by the European Commission on local environmental issues as well as that of the US EPA on water issues.[3]
2. Nor does the study address the complex and unresolved question of the life-cycle GHG emissions of shale gas. Interested readers are directed to the meta-study released by the European Commission on life-cycle emissions from shale gas.[4] Clearly, much research remains to be done regarding the gas system emissions and life-cycle emissions of shale gas.

While these issues are legitimate, the authors felt that current arguments for shale gas and a revision of EU energy and climate policy were being made largely on economic grounds. This is not surprising given the current difficult economic environment in the EU, the recent energy price divergence between the EU and the US, as well as growing security of supply concerns around natural gas in the EU. The objective of this study is thus not to enter into the debate on the trade-off between environmental and economic issues surrounding shale gas. *Rather, it aims only to assess the energy/economic side of the ledger*: are the energy and economic impacts of shale gas significant in the US? If the EU were to pursue shale gas, would the energy and economic outcome be significant?

Two other issues warrant clarification as to their place in the study:

1. Firstly, while it does discuss uncertainties and drivers behind long-term projections of shale gas production in the US, as well as projections in the EU, this study is not based on independent prospective analysis. The study relies on the projections of mainstream organizations like the International Energy Agency (IEA), the US Energy Information Agency (EIA), the European Commission, and companies such as BP.

2. Secondly, the study does not address in detail the global potential of unconventional gas and oil. In part three it discusses global projections for oil and gas supply and demand, and the projected potential impacts of unconventional sources. The objective here is to address the question of whether these projected impacts fundamentally change the energy security arguments for climate policy in major fuel importers, such as the EU.

2. THE UNCONVENTIONAL OIL AND GAS REVOLUTION IN THE UNITED STATES

2.1. What is the "unconventional oil and gas revolution"?

For the purposes of this paper, "unconventional oil and gas" refers to the large quantities of petroleum oil and natural gas, which are trapped inside geological formations which make them difficult to extract. Recent advances in two techniques in the US—namely High Volume Hydraulic Fracturing (HVHF or "fracking")[5] and horizontal drilling[6]—have made these previously inaccessible energy reserves economical to recover in large quantities.

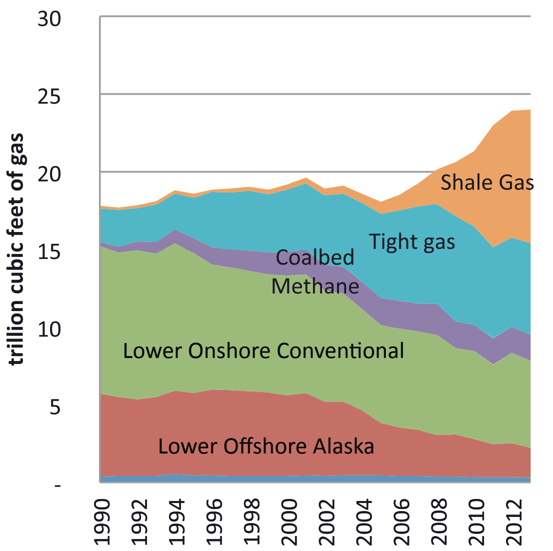
Unconventional natural gas is divided into three categories:

- shale gas, which is natural gas (either dry gas or liquids) recovered from shale rock;
- tight gas, which refers to natural gas recovered from other rocks of low permeability such as sandstone and limestone;
- coal-bed methane (also known as coal-seam gas), which is gas stored in coal beds.

The majority of the recent and forecast growth in US natural gas production is expected to come from shale and tight gas. For the purposes of this paper, unconventional oil refers mainly to so called "tight oil"—i.e. oil trapped in similar formations to shale or tight gas, although a number of other unconventional techniques, such as

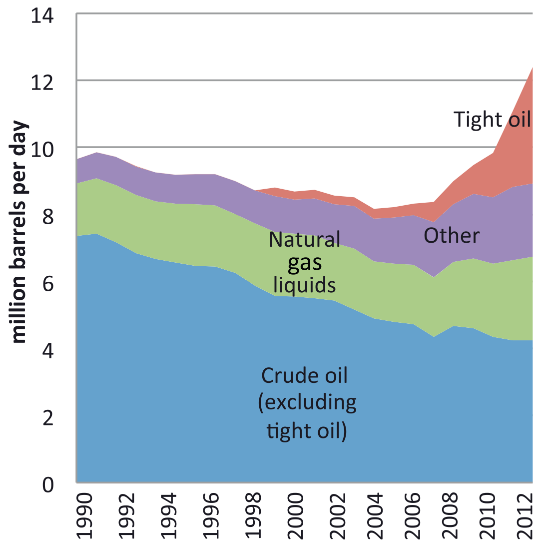
3. AEA (2012), "Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe", DG Environment. US EPA (2012), "Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources: PROGRESS REPORT".
4. AEA (2012), "Climate impact of potential shale gas production in the EU", DG Clima.
5. HVHF works by injecting large quantities of water, plus smaller quantities of other materials such as sand and other chemicals, at high pressure into underground rock formations containing the energy reserves. This process fractures the rock formations and facilitates the collection and extraction of the fuels trapped inside. The process requires in the order of approximately 19000m^3 of water per well
6. Horizontal drilling refers to a process whereby gas and oil wells are drilled not only vertically, but also horizontally over distances or several kilometers. It is often used to make HVHF more effective and economical by allowing for the fracking of a larger subterranean area, and thus a larger energy yield, from a single well pad.

Figure 1. US natural gas production by source (1990-2012)



Source: US EIA Energy Supply Statistics, 2013.

Figure 2. US liquid fuels production by source (1990-2013)



Source: US EIA Annual Energy Outlook 2014.

enhanced oil recovery (EOR), oil sands, etc. are also in use.

The growth in unconventional energy production in the United States can be considered revolutionary in terms of its scale and its speed. Thanks to unconventional gas—particularly shale gas—between 2005 and 2012 US natural gas production rose by more than 30%, from 511 billion cubic meters[7] (bcm) to 677 bcm in 2012[8] (see Figure 1). This has returned US natural gas production to its historical peak level of 681 bcm, which was last reached in 1973.

A similar picture is beginning to emerge for oil and liquid fuels production. Between 1970 and 2008, annual US crude oil production declined by 50%, from approximately 3.5 to 1.8 billion barrels per year. Rapid growth in tight oil production has led to a sharp reversal of this trend. Tight oil added an estimated 3.5 million barrels per day to average annual production in 2013, equivalent to 82% of conventional oil production. Nonetheless, in 2012 total crude oil production remained 13.5% below the 1970 peak of 10 million barrels per day. Growth in natural gas liquid fuels production associated with shale gas extraction and "other" sources (such as enhanced oil recovery) have also made a (smaller) contribution to the reversal of this trend (see Figure 2).

7. Throughout this paper cubic feet and cubic meters are used interchangeably as a measurement for natural gas volumes, the imperial measurement being used in the US, metric in the EU. 1 bcm = 0.035315 trillion cubic feet.

8. Cf. US Energy Information Administration (2013a).

2.2. Short-term impacts on US Energy Priorities

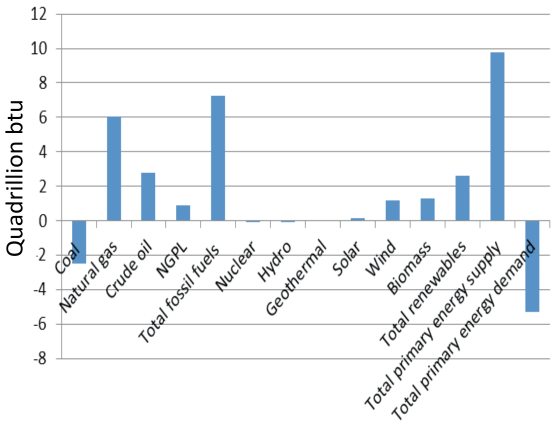
2.2.1. Energy security Energy security

For the purposes of this paper, energy security refers to the ability of energy users in an economy to have access to the energy services they need and to be able to do so at affordable prices. On this definition, there are therefore two aspects to energy security, both security of physical availability, which relates to issues such as import dependence, and costs, which relates to prices and end-use efficiency.

The gap between total US domestic energy production and consumption has declined significantly, from 30.85 Quadrillion Btu in 2005, when shale production was just beginning to take off, to 15.8 Quadrillion Btu in 2012. Shale gas has been the main driver of this, followed by an absolute decrease in energy consumption, then by the increase in crude oil production, and finally by the increase in renewables (see Figure 3). In percentage terms, renewables have grown fastest albeit from a low base. These changes have allowed the US to reduce its net imports of oil and gas (see Figure 4). Assuming present rates of production continue (uncertainties are discussed further below), the US is on track to become a net exporter of natural gas by 2018 (EIA, 2014).

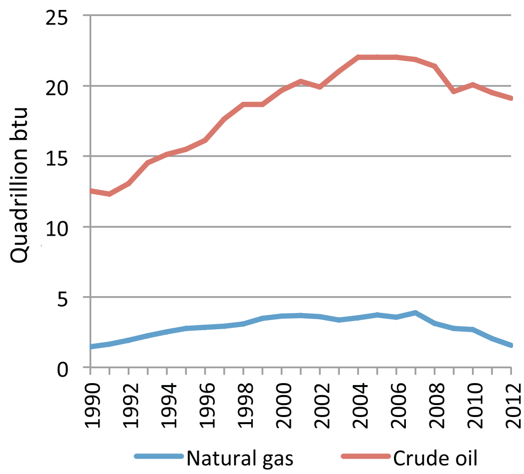
In the case of crude oil, however, the picture is quite different. The gap between domestic consumption and production has reduced by approximately 3 million barrels per day between 2010 and 2013, but a significant margin (around 8 million

Figure 3. Absolute change in primary energy supply and demand (2005-2012)



Source: US EIA Annual Energy Review 2013.

Figure 4. US net imports of oil and gas (1990-2012)



Source: US EIA Annual Energy Outlook 2013.

barrels per day) between domestic supply and demand remains. This margin is due to the US's large use of gasoline for transport fuel and more limited prospects for tight oil production. Thus, despite tight oil, there remains a strong case from an energy security perspective for the United States to continue energy efficiency policies in the transport sector, as illustrated by the Corporate Average Fuel Economy Standards (CAFE) program pursued by the Obama Administration since 2009 (elaborated further below).[9]

2.2.2. Impact on consumer energy prices

The unconventional energy revolution has also improved the affordability of energy for US consumers. Wellhead prices for US natural gas were trading at around 4 USD/Mbtu in late 2013, a sharp drop from 8 USD/Mbtu prior to 2008. It is important to note that prices of 4 USD/Mbtu are likely to be below the long-run marginal cost of shale gas supply, and due rather to the production of high value hydrocarbon liquids in association with shale gas production (so-called wet gas). The value of associated hydrocarbon liquids production has allowed shale gas to be marketed at low prices. As more profitable wet gas wells are exploited and focus shifts to dry gas in the coming couple of decades, prices will likely rise to reflect the marginal cost of dry shale gas production. Likewise, it is expected that, as the low-hanging fruit of the shale gas boom are exploited over the coming years, investors will demand higher US prices in order to keep investing in production and that this, along with more liquid LNG markets, should see US the gas price differential reduce relative to other regional markets over time.

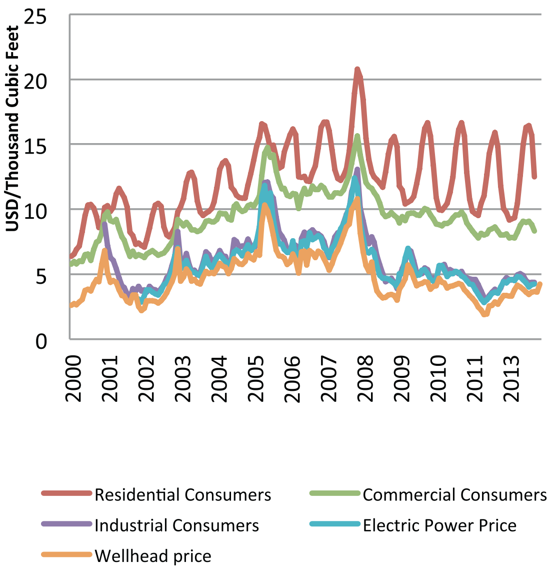
The fall in prices has been to the advantage of all US gas users, but it is instructive to investigate the extent to which different consumer types have received the benefits. For example, while the large fall in wellhead prices have benefitted industrial gas users (see Section 3), the benefits to commercial and residential consumers have been less dramatic. Figure 5 shows that peak season prices paid by residential consumers are largely consistent with those paid in 2005 and have not fallen to the same extent as industrial prices.

More importantly, however, natural gas represents a relatively small share of nominal energy consumption expenditure by US residential consumers—around 13% in 2010—with the lion's share being spent on petroleum products (59%) and electricity (30%).[10] From 2005 to 2012 residential electricity prices increased by 25%, while nominal gasoline prices increased by 52%. These

9. It is true that natural gas can be and is sometimes used as a substitute for oil in transport vehicles. However, implementing this on a sufficient scale to compensate for 6 million barrels of oil a day would require not only a reversal of the current narrowing of oil and gas spreads, but also large scale and costly investments in infrastructure to ensure availability throughout the country. This option therefore appears unlikely to happen in the foreseeable future.

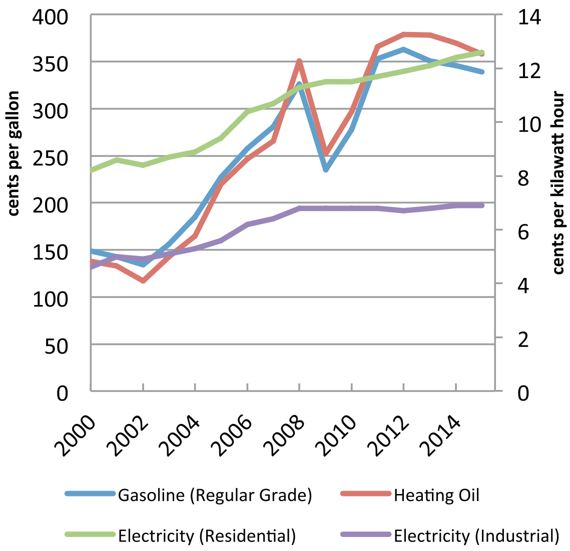
10. Cf. EIA Annual Energy Review 2012 (2012): Consumer Energy Expenditure Estimates by Source.

Figure 5. Evolution of natural gas prices by consumer type



Source: EIA Natural Gas Prices, Price history.

Figure 6. Evolution of key consumer Energy prices (forecast for 2014, 2015)



Source: EIA US Energy Prices (7 Jan, 2014).

effects outweighed any moderation of gas prices: a 20% fall in the price of gas is outweighed by even a 5% rise in the price of oil, or a 10% rise in the price of electricity. In other words, lower natural gas prices are not a panacea for the management of energy costs in the US. Nor would a significant fall in residential gas prices have the stimulus effect on aggregate economic demand that is sometimes assumed. Table 1 shows the change in average annual consumer spending per household for various energy sources, as well as a comparison to average annual income.

Table 1. Average annual household energy expenditure 2005 to 2012

	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.

The importance of gasoline and electricity prices for US consumers raises the question of the possible impact of the unconventional energy revolution on these energy sources. The evidence suggests that the price impact of unconventional energy production has been much more limited than for gas, even if prices of other energy types have been affected. For example, US motor gasoline and heating oil prices remain above their peak levels in 2008 (see Figure 6), despite recent growth in tight oil production, as the oil market is global and the US remains a net importer of around 8 million barrels/day[11] of crude oil from this market. In the end, US domestic WTI crude oil and motor gasoline prices still largely follow global fundamentals in the global oil market (Fatthou *et al.*, 2013).

There has also been an impact of shale gas production on US electricity prices, although the impact has been less dramatic than that which has occurred in the wholesale gas market for electricity generators (see Figure 6). This is because a number of factors affect electricity prices, including marginal price setting by different generation fuel types at different times (gas supplied 'only' 27% of US electricity generation in 2013), and at different locations,[12] the role of network infrastructure and reliability costs, taxes, grid transmission constraints, etc. Power bills

11. Cf. US Energy Information Administration (2013).
12. *Ibid.*

for residential and commercial consumers have continued their upward trend since the unconventional energy boom began and are forecast to rise further in the near future largely due to non-fuel related costs. Costs of electricity for US consumers are therefore determined by a range of factors, including but not exclusively determined by the price of natural gas.

A number of factors therefore affect energy prices across different energy sources and not all of these are affected to the same extent by an abundance of unconventional hydrocarbons. Moreover, there is also an important distinction to be made between energy *prices* and energy *bills*. The final impact of a change in the price of a given energy type depends also on the quantity of that energy type which is consumed, i.e. the energy intensity. This underscores the importance of a focus, in the US as in the EU, on minimizing *energy bills* for energy consumers, as opposed to focusing on individual factors determining *energy prices.* Additional policies that promote lower quantity of energy consumption across all fuel sources therefore remain important for policy makers seeking to lower energy bills for consumers.

2.2.3. CO2 emissions

As mentioned in the introduction, there is still uncertainty regarding life-cycle emissions from shale gas. It is beyond the scope of this study to address this question. The discussion on CO_2 emissions thus focuses on emissions in the transformation or final consumption sectors. Whether shale gas results in higher or lower methane emissions than conventional gas would worsen or improve the assessment of the shale gas contribution to US total greenhouse gas emissions.

Figure 7 shows the evolution of the share of natural gas versus coal-fired power generation and US natural gas price between 2011 and 2013. The share of gas-based generation increased by 10 to 12% between 2011 and 2012 at the expense of coal, as gas prices fell to very low levels in 2012. The share of coal in the power sector then began to bounce back and has remained at a steady level of around 40% of total generation since June 2012. The bounce-back in coal-fired generation contributed to the observed 2% rise in energy-related CO_2 emissions in 2013 compared to 2012.[13] This indicates that, even at very cheap gas prices, coal has remained competitive. This suggests that the impact on relative prices from the shale gas boom has not been sufficient on its own to undermine the economic case for coal-fired generation and to push existing coal plants out of the market, as would be required to significantly curb US CO_2 emissions in the short-term. The adoption of proposed CO_2 emissions performance standards for new and existing power plants will thus be an important lever to lower emissions in the future, and to promote gas in the US power fleet.

It is thus relevant to go beyond the analysis of short-term cyclical changes in the existing power fleet, to look at evidence of more structural changes, i.e. new capacities and retirements. Table 2 shows projected net capacity additions and retirements in the US power fleet over 2013 to 2017, with some retirement of coal capacity, alongside capacity additions in gas. These, however, remain modest in light of the size of the US generation fleet.

Table 2. Projected capacity additions and retirements

	2013-2017 (MW)	As a % of 2012 capacity
Coal	-24.40	-2.30
Gas	26.39	2.48
Wind	5.87	0.55
Solar	9.95	0.94

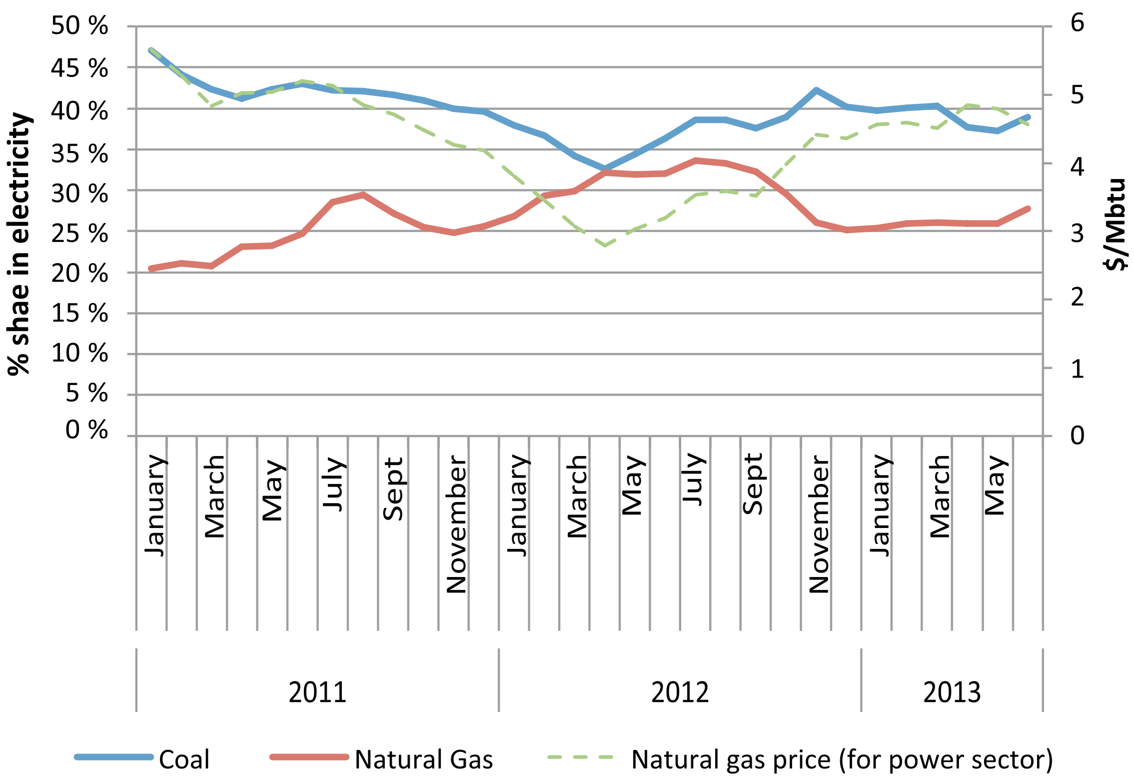
Source: EIA, Planned Generating Capacity Changes.

Another question relates to the contribution of the coal to gas switch to the overall 3.8% decline in energy-related CO_2 emissions in 2012 relative to 2011. A decomposition analysis (shown in Figure 8) reveals that in fact the CO_2 intensity of energy use (such as switching between coal and gas and greater use of wind power) contributed, by itself, around 1.4 percentage point of the overall reduction. Meanwhile around 5 percentage points of the decline came from lower energy use. These factors were in turn offset somewhat by population and economic growth, leaving a net reduction of 3.8%. The large decline in energy use was mainly due to a combination of a mild winter in that year, a steady penetration of vehicle fuel efficiency standards into the existing vehicle fleet and a reduction in mileage driven per household driven by higher gasoline prices.

Overall, the price effect of the shale gas boom has had a noticeable but nevertheless limited impact on US greenhouse gas emissions thus far; other factors have played a more significant role (the cyclical downturn in the manufacturing sector, improved efficiency and reduced activity in the transport sector). It also suggests that the unconventional energy revolution will not shift energy price incentives sufficiently to favour a swift and structural switch from coal to gas. Further policy would be required to deliver a sustained reduction in US emissions.

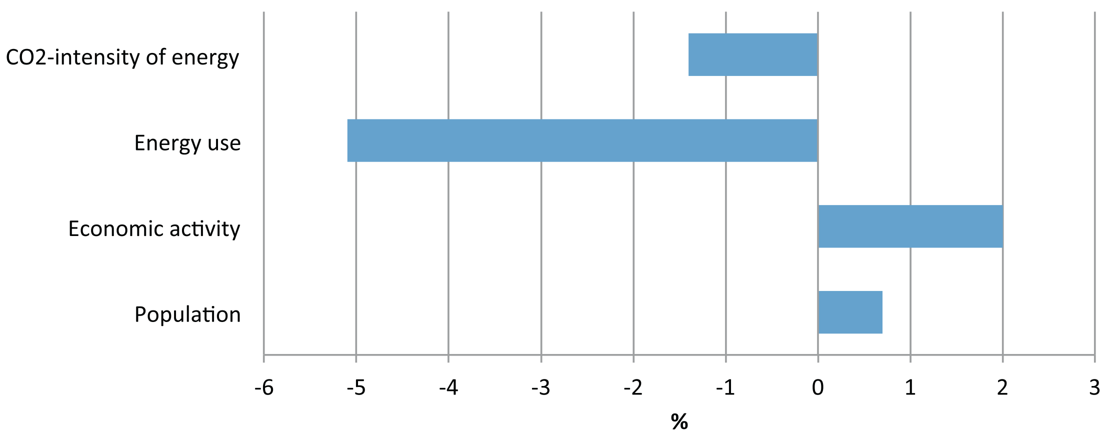
13. Cf. US Energy Information Administration (2014).

Figure 7. Share of gas versus coal in US power generation (2011-2013)



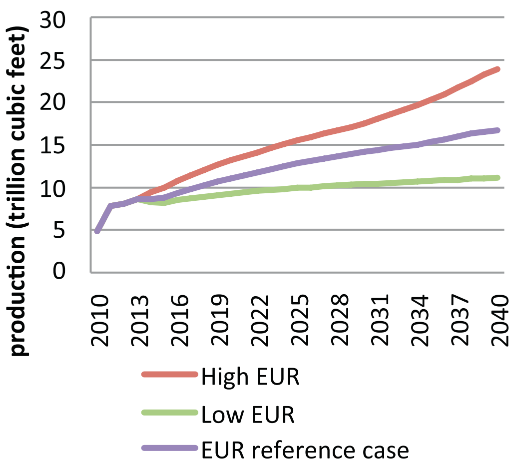
Source: EIA, 2013a, Net Generation by Fuel Type, Natural Gas Electric Power Prices.

Figure 8. Decomposition of factors contributing to the change in US energy-related carbon emissions in 2012



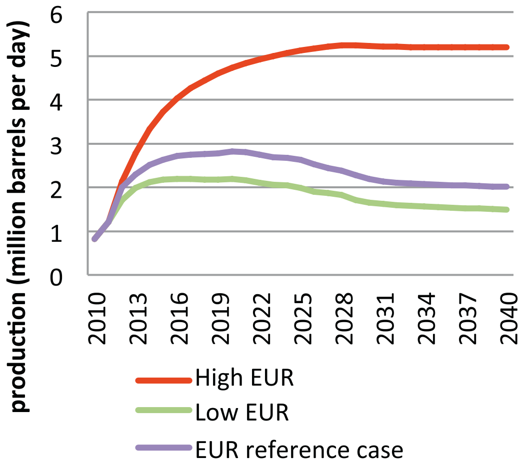
Source: EIA (2013b), "US Energy Related Carbon Dioxide Emissions, 2012".

Figure 9. Change in US shale gas production forecasts in response to differences in EUR assumptions



Source: EIA, AEO 2013.

Figure 10. Change in US tight oil production forecasts in response to differences in EUR assumptions



Source: EIA, AEO 2013.

Note: The "High EUR" case refers to a scenario when EUR rates are twice as high as currently forecast in the EIA's reference case scenario; while the "Low EUR" rates show the impact of a 50% decline in EUR rates in the reference case.

2.3. Longer-term impacts from the unconventional hydrocarbon revolution

The preceding discussion was largely backward looking. It is therefore necessary to analyse future projections and forecasts of the impact of unconventional hydrocarbons on US energy and climate goals, to glean a full understanding of the revolution's impact. A forward-looking analysis suggests that additional policy frameworks and economic incentives will become increasingly necessary to meet both CO_2 emissions and energy security objectives in the US.

2.3.1. Future production projections and uncertainties

The 2014 to 2040 reference scenarios published by the US Energy Information Administration in January 2014 forecast strong continued growth in US shale gas production over the next 27 years. Specifically, the EIA forecasts 2.6% average annual growth out to 2040, with production of shale gas reaching 20 trillion cubic feet (tcf) in that year. Tight oil production is expected to rise quickly but to peak much sooner, by the end of the decade, before declining gradually.[14] The EIA's reference case forecasts that tight oil production will rise to 2.5 billion barrels per year by 2016 and remain above 2.3 billion barrels out to 2040 (EIA, 2014).

Of course, significant uncertainties exist. As mentioned in the introduction, a comprehensive assessment of projection uncertainties is beyond the scope of this paper. Nevertheless, the literature relating to shale gas production highlights three main areas of uncertainty. The first concerns uncertainty about the size of unproven reserves.[15] The second area of uncertainty concerns estimated ultimate recovery (EUR) rates from shale wells.[16] Figure 9 and Figure 10 provide a sense of the importance of different assumptions about EUR rates for US shale gas and tight oil production forecasts. (Note that these are not estimates of actual confidence intervals for actual production.) The third area of uncertainty relates to the economics of shale gas and tight oil recovery. It remains to be seen whether the low price resulting from the recent gas glut is sufficient to sustain investment in the medium to long term, especially as the low hanging fruit of the unconventional resources is gradually picked. Other economic uncertainties relate to the impact of possible shale

14. Cf. IEA (2013), "World Energy Outlook", ff. 474.

15. For example, in 2011, the US EIA massively revised its estimates of the technically recoverable reserves available in the Marcellus shale gas play in the North-east of the country from 410 to 140 trillion cubic feet (EIA, 2012a). As drilling increases, however, uncertainty about unproven reserves should decline.

16. Shale gas wells usually exhibit high production rates in the first 1 to 4 years and decline rapidly. Since decline rates are unknown a priori, assumptions about future decline rates (and hence EUR rates) are based on an extrapolation from past experience at the well.

Figure 11. US Natural gas trade balance forecasts (in US$2011)

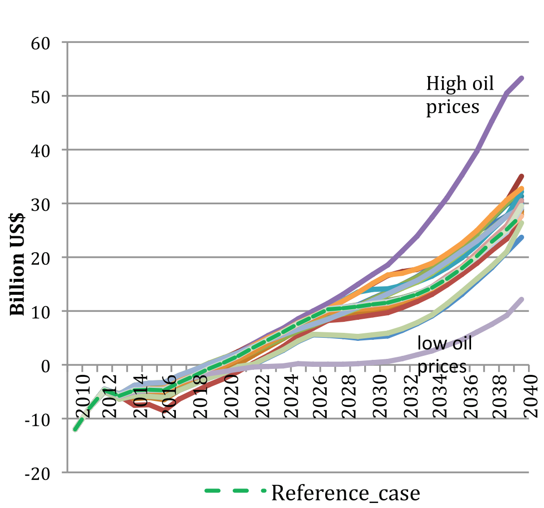
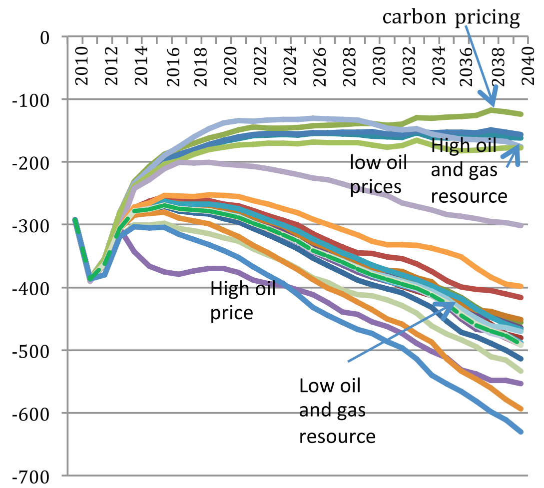


Figure 12. US crude oil trade balance forecasts (in US$2011)



Source: Authors' calculation based on US EIA Annual Energy Outlook 2013 data.

gas production in other parts of the world with large reserves, political opposition to local impacts of shale gas in places where more intensive drilling and denser well spacing is required (Richter, 2013), and the impact of US climate and energy efficiency policies on longer-term demand for oil and gas.[17]

2.3.2. Energy security projections

Figure 11 and Figure 12 provide the full range of US trade balance projections for both oil and gas made by the US EIA. The projections include scenarios with high and low oil and gas reserves compared to those currently estimated, high and low oil prices, high and low economic growth, current policies and future carbon pricing policies at different levels, as well as the current "reference case scenario" (depicted in hatched grey and green) which is based on current projections for economic growth, resource bases and production costs, and policies. These projections should not be taken as representing exact predictions of the future, but rather as indicating the range of factors that are uncertain and their relative importance with respect to current expectations of future trends.

The range of scenarios suggests that the US is well positioned to be self-sufficient in natural gas well into the foreseeable future and probably become a significant net exporter between 2018 and 2022. The major factor identified as uncertain here is the oil price. As a potential substitute fuel for gas, relative oil and gas prices will be important to the US demand for gas and therefore the degree of self-sufficiency and availability of gas for export.

Once again, however, oil production is a markedly different story. Figure 12 shows that in all scenarios, the United States will remain a significant oil importer in the future. In the reference case, imports stay above 11 quadrillion Btu/yr (equivalent to approximately 5.2 million barrels/day) and rise again as tight oil production declines and oil consumption increases. Interestingly, and to a much greater extent than in the case of gas, the figure shows a wide range of potential factors exhibiting a strong influence on US oil imports. This would suggest that greater uncertainty exists as to the degree to which the United States will be exposed to global oil prices in the future. The projections underscore the importance of energy efficiency in the transport sector, driven by robust policies, at reducing long run oil imports.

The quantitative importance of demand side policies can be highlighted through two examples. Firstly, some studies put the estimated fuel savings of recently strengthened 2009 Corporate Average Fuel Economy (CAFE) standards,[18] at around 330 billion liters between 2010 and 2020 (Cheah *et al.*, 2010).[19] This equates to 1.9 Quadrillion Btu per year on average,[20] which was about 2% of US

17. See Richter (2013) for a fuller discussion and literature survey.

18. Set by the Obama administration in 2009 to improve average vehicle fleet fuel economy by 20% by 2016.

19. These estimates relate only to fuel savings (not construction related energy cost savings).

20. Assuming a conversion rate of 33, 025 Btu per litre of gasoline.

total primary energy consumption in 2012. The standards have subsequently been updated in 2012. The 2009 standards required average fuel economy for the fleet of new vehicles sold in 2016 to be no less than 35.5 miles per gallon (mpg). The 2012 standards require a new vehicle fuel economy of 54.5 mpg to be achieved by 2025.

Secondly, Figure 13 gives an indication of the extent to which the US EIA believes that the trajectory of US energy use would be expected to change (compared the EIA's reference case) if the residential and commercial sectors were to switch to best available energy efficiency technology in their future purchase decisions and to double current rates of improvement of energy use in the existing building stock. These savings do not include a range of demand-side energy efficiency options (such as product substitution and energy conservation) and ignore supply-side potentials (such as distributed electricity generation, greater efficiency in industrial production). Even without these savings, energy efficiency gains could seriously improve the US energy supply/demand balance.

2.3.3. CO_2 emissions projections

The need for strong policies to guide the use of unconventional gas and other technologies towards a meaningful decarbonisation is also apparent when one considers the EIA's scenarios for carbon emissions beyond the current decade. For example, Figure 14 shows the historical and projected contribution of natural gas to US power generation out to 2040 under the full range of scenarios. As the wedges in the Figure indicate, these scenarios can be broadly divided into three categories: low gas prices (4-5 USD/Mbtu), high gas prices (7-11 USD/Mbtu), and new climate and energy policies, including carbon prices at different starting levels and growing by different amounts over time, renewable energy support and energy efficiency policies, etc. The Figure suggests that one requires relatively optimistic forecasts of low future gas prices for gas to become the dominant fuel source of power generation. As shale gas producers gradually move to more and more difficult plays over time, analysts generally expect that natural gas prices will be closer to the 7-11 USD/Mbtu range in the next decades. Indeed, such prices are included in the forecasts of made by the reference case (in green and grey), and which correspond to relatively low gasification of the US power sector, a higher share of coal than gas still being used in the mix, and stagnant or rising emissions for the energy sector as whole over time.

This scenario is in turn reflected in the "reference case" in Figure 15, which shows the corresponding CO_2 emissions for the US energy sector as a whole and which reflects emissions estimates that are based on current policies.[21] While CO_2 emissions do not rise between 2010 and 2040 in this scenario, they do not fall either. In the absence of a clear set of new policies, the EIA forecasts indicate that the energy system will not decarbonize. (Note that these projections predate the recent announcement of CO_2 efficiency standards for new power plants by the Obama Administration.)

These scenarios illustrate the critical importance of additional policy interventions and additional incentives to achieve a significant decarbonization of the US electricity system.

A final aspect of the climate mitigation impact of shale gas in the United States is its effect on the political economy of emissions reductions and climate change policy. On the one hand, there is evidence that the Obama Administration's 2013 announcement of new CO_2 efficiency standards on power plants—which render new coal fired power plants unprofitable unless they are fitted with carbon capture and storage technology (CCS)—was influenced by the shale gas boom and resulting changes in the power sector. For example, in its description of the economic impacts of the new power plant regulations, EPA notes:

> *"Natural gas prices have decreased dramatically and generally stabilized in recent years, as new drilling techniques have brought additional supply to the marketplace and greatly increased the domestic resource base. As a result, natural gas prices are expected to be competitive for the foreseeable future and EIA modelling and utility announcements confirm that utilities are likely to rely heavily on natural gas to meet new demand for electricity generation [...] Due to these factors, the EIA projections from the last several years show that natural gas is likely to be the most widely-used fossil fuel for new construction of electric generating capacity through 2020, along with renewable energy, nuclear power, and a limited amount of coal with CCS".*[22]

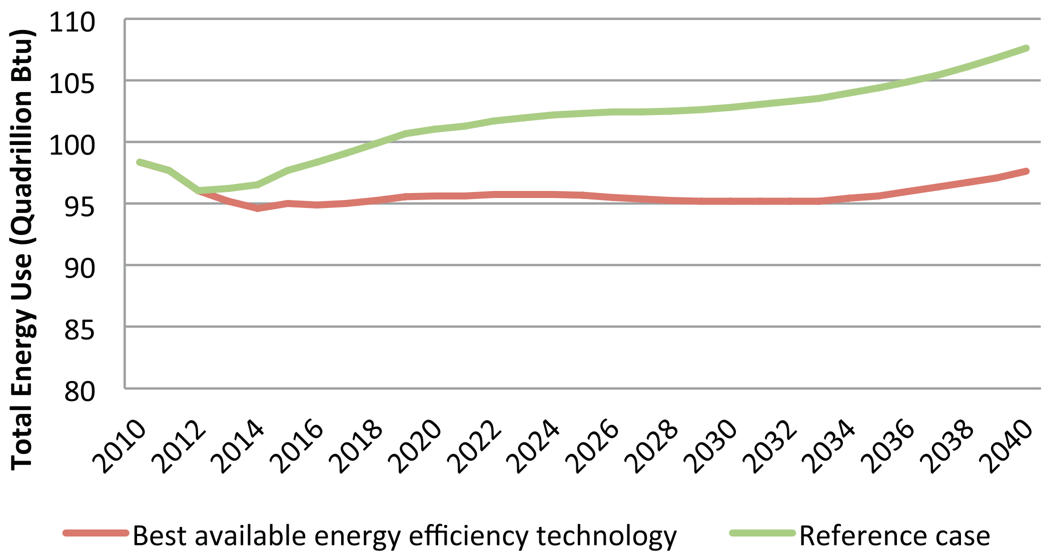
This confirms that shale gas has contributed to arguments for stronger moves to limit emissions from more carbon intensive alternatives (in this case coal without CCS) and has therefore improved the political economy of actions to reduce emissions.

On the other hand, in the absence of other policies to strongly support renewables and other

21. The reference case is also based on current energy price, economic and population growth and technological change forecasts.

22. Cf. US EPA (Sept. 2013) Standards of Performance for Greenhouse Gas Emissions from New Stationary Electric Utility Generating Units.

Figure 13. Impact on total US energy demand of switching to best available energy efficiency technology in the residential and commercial sectors



Source: EIA 2013 AEO Forecasts, Energy Consumption by Sector and Source, Reference and Best available energy technology (BAET) Scenarios. BAET Scenario assumes that future purchases on the demand side of the economy (residential and commercial) are made in best available technology in terms of energy efficiency. Residential building shells are assumed to use best available 2012 technology and existing building shells are assumed to improve efficiency at twice the rate of the reference case. Industrial and transport sector assumptions are the same as in the reference case.

Figure 14. Share of gas in US electricity generation (historical and forecast data post-2012)

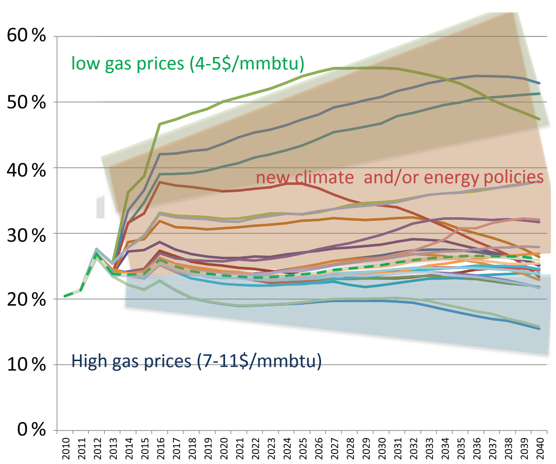
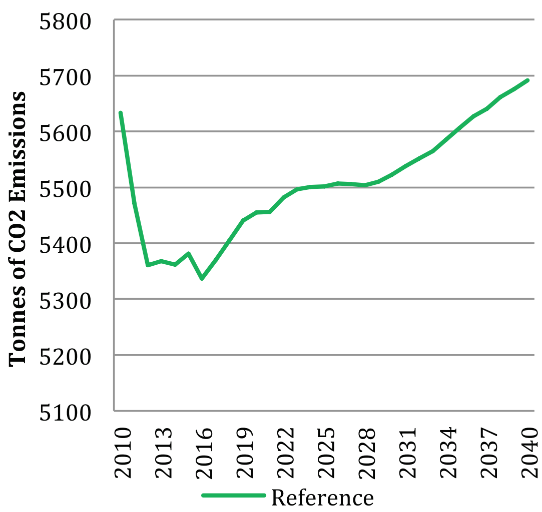


Figure 15. US energy-related CO_2 emissions forecast under the reference policy scenario



low-carbon power sources, one can ask whether these benefits do not risk to further lock-in political support for fossil fuels as well as the underlying capital infrastructure. This risk underlines the importance of accompanying policies and regulations to put in place a long-term strategy that circumscribes the role of unconventional energy reserves in decarbonization pathways.

3. IMPACTS ON GDP, EMPLOYMENT AND MANUFACTURING COMPETITIVENESS

The shale gas revolution has had impacts at both micro and macroeconomic levels in the United States. Microeconomic impacts refer to effects on individual markets, such as petrochemicals, fertilizers, etc. These impacts include increased profitability through lower gas prices and increased market share in international markets, through improved cost competitiveness. Macroeconomic impacts refer to impacts on GDP, employment and trade for the country as a whole. This Section begins with a discussion of the impacts on specific industries before "zooming out" first to consider impacts on US manufacturing and then on the US economy.

3.1. Impacts on US industrial competitiveness

A country's industrial competitiveness refers to the ability of its industrial producers to gain or maintain domestic and international market shares. Industrial competitiveness is affected by a lot of factors with differing importance depending on the product. Energy prices in general and gas prices in particular are therefore only one factor among many that affect industrial competitiveness.

To understand which kind of sectors could be affected by gas prices, this study presents a sectoral categorization of US manufacturing subsectors according to their gas price sensitivity. We divided energy-intensive sectors into three broad categories:

1. sectors that use natural gas and its derivatives (like LPG and NGL)[23] as a feedstock. Their ability to compete on international markets is highly dependent on regional gas price differences because of the importance of natural gas and its derivatives as a production input;
2. sectors consuming gas as a fuel;
3. the remaining sectors are largely not impacted by gas prices because, while energy intensive, they use other energy sources such as coal or electricity.

3.1.1. Energy intensive sectors using mainly gas as a feedstock

Four manufacturing sub-sectors are important consumers of gas (and its derivatives) as a feedstock. Table 3 introduces these four sectors and gives an idea of the importance of gas as feedstock in their energy consumption.

Table 3. Share of natural gas and LPG/GNL used as a feedstock in the energy consumption and in the sectoral value added

2010	Share of feedstock (natural gas and LPG/GNL) in total energy consumption	Share of feedstock expenditure in the sectoral value added
Petrochemicals	91%	26%
Nitrogenous fertilizers	55%	24%
Plastic materials and resins	62%	39%
Other basic organic chemicals	50%	27%

Source: EIA and Census Bureau (2011 Annual Survey of Manufactures).

Not surprisingly, petrochemicals are the main sector that has benefited from the fall of gas prices in the US relative to the rest of the world. Before natural gas is sold for use commercially, its impurities, which consist of non-methane hydrocarbons—such as ethane, butane, propane, and others, collectively known as natural gas liquids (NGL)—, need to be removed.[24] The natural gas glut has therefore triggered an ethane glut, lowering US ethane prices significantly (from 93 cents per gallon in 2008 to 41 cents per gallon in 2012 and 27 cents in 2013).

These prices have made the US an attractive destination for petrochemical industries at the

23. Examples of Liquefied Petroleum Gases (LPG) are ethane, ethylene, propane, propylene, normal butane, butylene, ethane-propane mixtures, propane-butane mixtures, and isobutene produced at refineries or natural gas processing plants, including plants that fractionate raw Natural Gas Liquids '(NGL).' The EIA classification does not distinguish LPG from NGL.

24. For example, a wet gas shale plays such as the Marcellus Shale gas play will produce roughly 75% methane, 16% ethane, 5% propane, and 1% butane, pentane, hexane, and other gases (Platts, 2013). These gases belong to the LPG/NGL (Liquid petroleum gas/natural gas liquids) group. Ethane, in particular, is used to produce ethylene, which is ubiquitously employed in the production of a wide range of polymers used to make plastic materials, solvents, detergents and other goods. US ethane cracker products are in competition with similar products in gas-rich states but also with naptha-cracker products (which is a petroleum derivative that producers use as a feedstock for ethylene production as well).

expense of other destinations and at the expense of European naptha producers, whose production costs remain linked to global oil prices.[25] Between 2012 and 2015, a number of companies have planned expansions or conversions of existing capacity equivalent to 2,760 kt of ethylene per year, with an additional 8,900 kt/yr of capacity planned for 2015 to 2017, estimated to be equivalent to a 30 to 40% increase in present US production capacity (Platts, 2013; PWC, 2012; IFRI, 2013). Moreover, as seen in Figure 16, the net exports of cyclic crudes and intermediates doubled between 2007 and 2012 and this sub-sector has seen a 50% increase of its value added over this timeframe.

As shown in the Table 4, the nitrogenous fertilizers sub-sector, which uses natural gas as a feedstock, also increased its value added fourfold between 2006 and 2011, and doubled the value of its shipments. This increase can be partly explained by the price fluctuation of fertilizers. According to US Department of Agriculture data, the price of nitrogenous fertilizers doubled between 2006 and 2011. However, the remaining 50% of the growth in value added appears to be explained by shale gas-driven cost reductions, and hence a higher volume of exports. Since fertilizer is a relatively easily traded product and its transport cheaper than that of LNG, lower imports and greater exports of US fertilizer may be expected in the medium term once global excess capacity comes back down.

Table 4. Progression between 2006 and 2011 of the number of employees and the added value of the four sub-sectors highly impacted by gas price variations

Index: 2006 = 100	Number of employees (2011)	Value added (2011)
Total Manufacturing	82.0	100.4
Petrochemical manufacturing	96.4	154.1
Other basic organic chemical manufacturing	105.7	97.6
Plastics material and resin manufacturing	106.7	97.5
Nitrogenous fertilizer manufacturing	136.7	380.5

Source: US Census Bureau, 2011 Annual Survey of Manufactures.

The impact of shale gas production on plastic materials and resins and on other basic organic chemicals is less clear based on present data. The value added of the sectors has decreased by 2-3% during the same period, a result most likely due to the recession and slow recovery of the US economy. The exports of plastics materials seems to have doubled since 2005, although to what extent this reflects the offloading of production due to excess capacity and inventories (as opposed to increased cost competitiveness due to cheaper gas prices and ethylene polymers) is difficult to determine. Exports of organic chemicals have fluctuated but slightly increased since 2005.

Two main factors can help to explain these results. Firstly, the full impact of shale gas on the cost-competitiveness of these sectors will take time to come to fruition: there is a delay between investment, production and the subsequent greater returns to the sector as a whole. Secondly, even for these sectors favorably impacted by low prices, the recession in the US and the global economic slowdown have so far overshadowed this cost advantage.

3.1.2. Energy intensive sectors using gas as a fuel

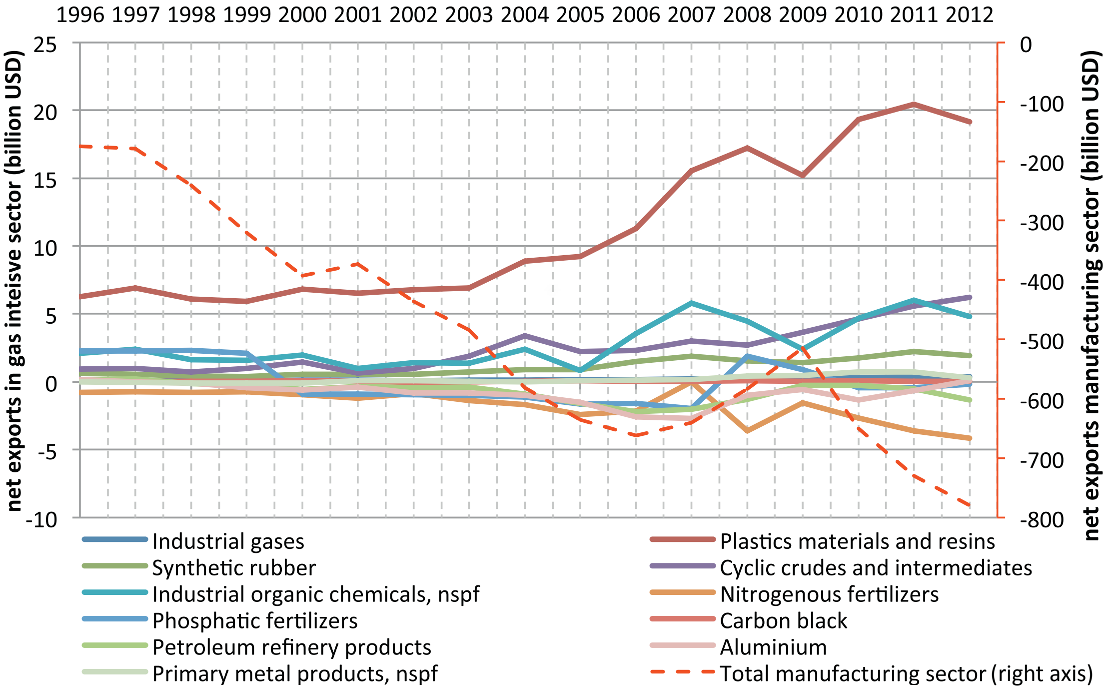
Sectors using gas as a fuel but not as a feedstock are also impacted by gas price variations. These are energy intensive sectors but gas is not their main energy input. Here we focus on just three of these sectors: alumina and aluminum production and processing (using mainly gas and electricity); iron and steel and ferroalloy manufacturing (in particular, plants using direct reduced iron (DRI) technology); and petroleum refineries. The energy bill of these sectors represents 25, 15 and 10% of the added value, respectively. Their gas bill is equivalent to 6% of their value added on average, but can be higher or lower for some specific sub-sectoral processes. These sectors will be less sensitive to shale gas prices, to the extent that their energy bill is largely made of other energy sources such as electricity whose price is mediated by a range of factors. Figure 16 shows the net exports of these sectors, and compares them with the overall US manufacturing trade deficit.

3.1.3. Energy-intensive sectors not directly impacted by gas prices

Finally, there are a number of sectors which are energy-intensive, but not necessarily likely to gain a significant advantage from low gas prices. For example, cement is one of the most energy intensive sectors. Its energy bill represents around 40% of its added value. However, only 5% of its energy

25. To some extent, naptha has a natural cost advantage over ethane which offsets its higher prices, in that other by-products can also be produced from it which give it a greater revenue to cost ratio per unit. However, this advantage is nevertheless undermined when gas prices divorce oil prices by a large enough margin, as has recently been the case. As of mid 2013, ethylene margins from ethane had increased by 30% compared to 2000 levels, while they have fallen by around 20% for naptha.

Figure 16. Net exports of gas intensive sectors (1996-2012)



Source : Comtrade.
Note: Axis on the left: sectoral net exports in billion US$/Axis on the right: Total manufacturing net exports in billion US$.

consumption is gas; its main energy source is coal, which still remains cheaper than gas in the US. Paperboard manufacturing also belongs to this category but its gas bill is still low (2% of added value approximately). Therefore, these sectors are not much impacted by the changes in gas price, as they tend to depend on coal or electricity whose prices are not strongly affected by the fall in the price of gas (see Section 2 above).

3.1.4. The impact of cheaper gas along the manufacturing value chain and for manufacturing as a whole

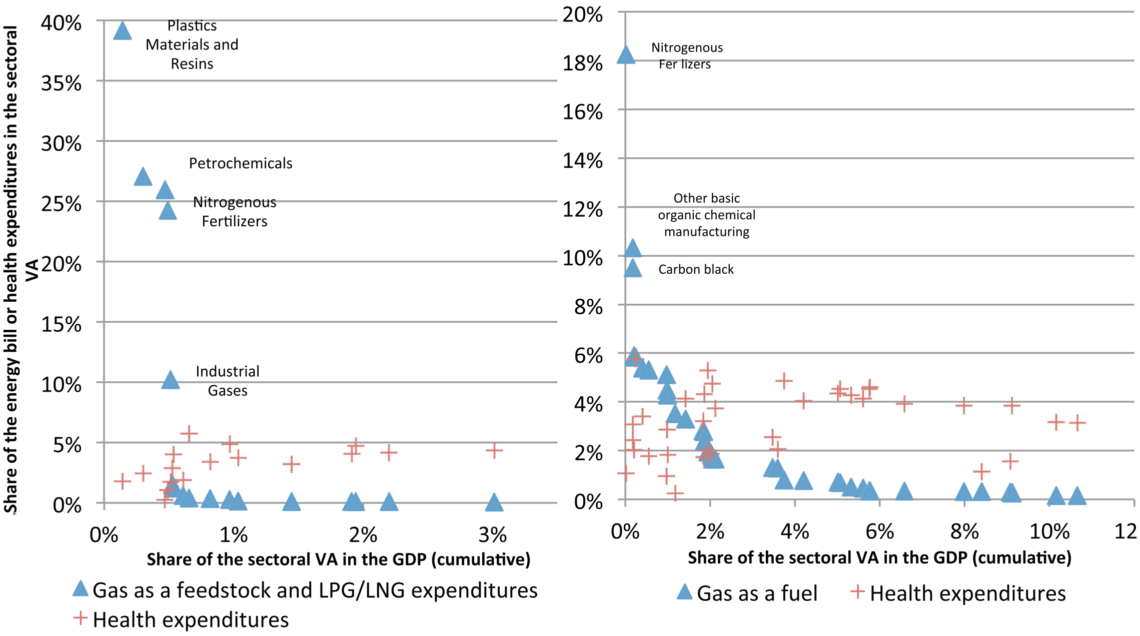
It is sometimes assumed that, as energy is a basic input into all goods, cheaper energy prices must automatically translate into improved competitiveness and productivity along the entire value chain in an economy. This largely over-estimates the importance of energy and energy-intensive products in the final value of many goods.

Sectors which benefit directly from the shale gas boom do not represent a large part the US economy. Figure 17 shows the share of the gas bill in the value added of all the manufacturing sub-sectors which use gas as a fuel or feedstock. The analysis in Figure 17 was used to define the sectors which are sensitive to gas in the sections above. Five manufacturing sub-sectors are important consumers of gas or LPG/NGL as a feedstock (noted above). These however represent less than 0.5% of US GDP and less than 5% of US manufacturing sector (in 2010, the entire manufacturing sector was 11.8% of the US GDP). A larger group of sectors have significant consumption of gas as a fuel; these represent slightly more than 1.16% of the US GDP and less than 8.7% of US manufacturing sector. There is some sectoral overlap between these two figures, but together these two categories make up a relatively small share of the US manufacturing sector, and only about 1.2% of US GDP. In order to put this in perspective, we compare sectoral gas bills with sectoral expenditure on employer-sponsored health care (red crosses). For all the other gas consuming sub-sectors where the red-cross is above the blue triangle, gas expenditure is lower than health care expenditure.

The impacts of lower gas prices on manufacturing as a whole are therefore limited to a relatively small group of sub-sectors. The conclusion that US manufacturing as a whole will receive a competitiveness boost from cheaper gas prices seems exaggerated.

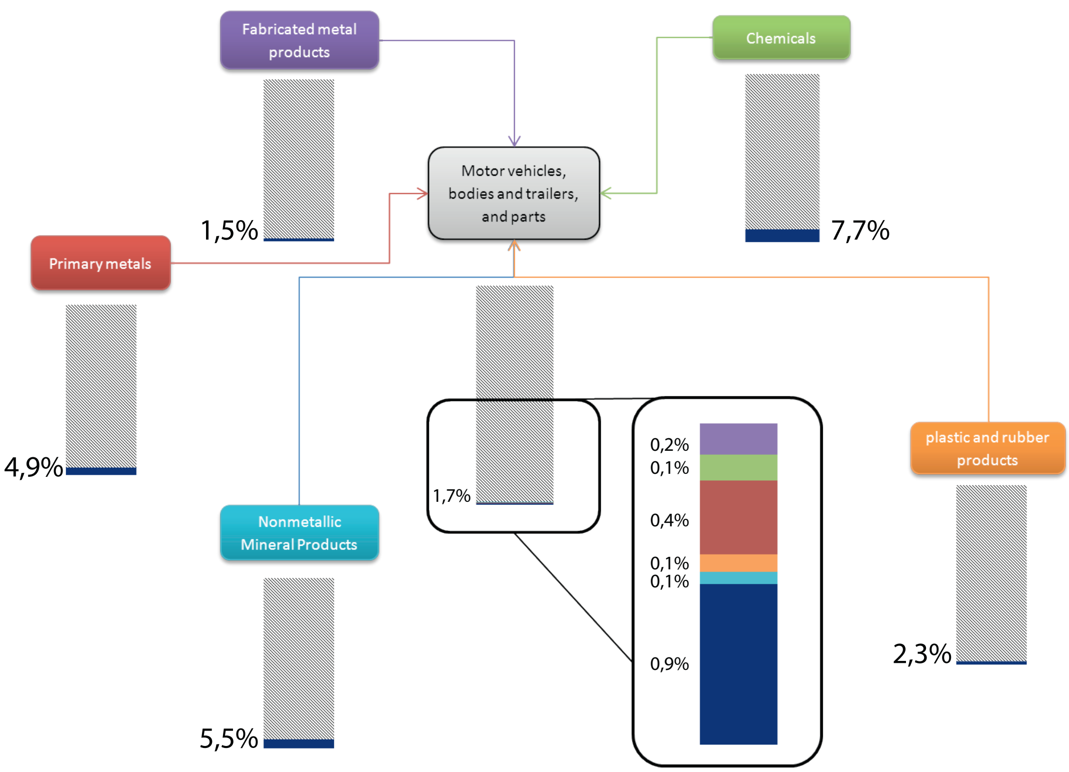
Moreover, it does not automatically follow that lower gas prices will lead to significant ripple effect along the value chain of US manufacturing. The example of a traditional manufacturing product—cars and transport vehicles—helps to illustrate this point. Figure 18 shows the direct and indirect cost

Figure 17. Gas and health expenditures in the manufacturing sectors (2010)



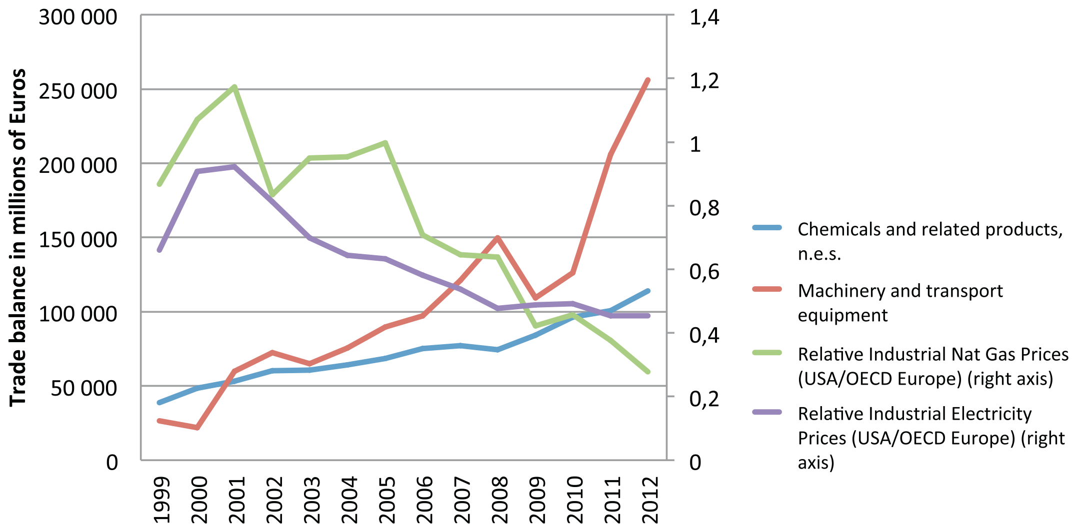
Source: EIA, US Census Bureau.

Figure 18. Direct and indirect cost of energy in the "Motor vehicles, bodies and trailers, and parts" sectors



Note: Dark blue represents the direct cost while the other colors are the indirect cost of energy attributed to energy intensive sectors upstream of the production process. Data source: Bureau of Economic Analysis, November 2012.

Figure 19. EU trade balance in chemicals and machinery and equipment (left axis) and European/USA relative energy prices (right axis)



Source: Authors, based on Eurostat and IEA data.

of energy in the Motor vehicles, bodies and trailers, and parts sector, which is a key sector in the automotive industry, and can be considered as a final product. It takes into account the energy intensive sectors upstream of the production process.

Figure 18 shows that the impact of oil and gas costs, and more generally energy costs, on the bottom line of many manufacturing products is quickly diluted as we move down the value chain. Indeed, the direct final energy cost of a car is about 0.9% of the production value. This cost is higher if we include indirect costs. As seen in the figure, if one adds the indirect "embodied" energy costs of the average energy content of five key energy-intensive inputs, the energy costs doubles to 1.7%. It will be slightly higher again if one includes the embodied energy in all products. However, in general the most energy intensive sectors make up the lion's share of indirect energy costs. Moreover, in some sectors, gas cost savings are not passed on down the value chain (for example in the electricity sector when coal remains the marginal unit of power generation and so lower gas costs do not change electricity costs). In any event, the US has remained a relatively stable net importer of motor vehicles and passenger car bodies since the shale gas boom.

The EU has among one of the lowest unit energy costs in the chemicals sector in the world, which reflects its high energy efficiency and focus on high-value added products.[26] Unit energy costs reflect the cost of energy required to make one unit of value added (i.e. it is analogous to unit labour costs). It is the product of three factors: firstly, energy prices in a given sector; secondly the efficiency of energy usage; third, the value added of the final product. Table 5 summarizes real unit energy costs in chemicals, and rubber and plastics in the EU27 and major economic competitors. The results suggest that the EU's energy efficiency and specialization in high-value added downstream sub-sectors has allowed these sectors to manage energy price increases while keeping in check their energy bill relative to value added.

Table 5. Real unit energy costs in chemicals and rubber and plastics

%	Chemicals		Rubber and plastics	
	2009	2011	2009	2011
EU27	33.2	36.2	13.4	14.1
US	22.1	23.1	10	6.8
Japan	44.1	47.3	13.3	13.7
Russia	74	77.9	36.6	42.1
China	84	92.6	17	17.9

Source: Cf. DG Ecfin (2014).

In summary, cheaper gas and gas-intensive inputs will probably give the US a competitive advantage in basic petro-chemical products like ethylene. Such products are inputs for a wide variety of downstream products. However, the absence of data prevents a detailed analysis of this downstream effect. The discussion above has shown that a number of factors such as the cost of other inputs, labour, transport, and clustering effects are likely to mitigate the downstream cost impact

26. Cf. DG Ecfin (2014).

of cheaper basic petrochemical inputs. In addition, specialization in high-value added chemical subsectors, as well as high energy efficiency, has helped to cushion the EU chemical sector from higher relative energy prices. Thus while the shale gas revolution may give the US a comparative advantage in basic petrochemicals, it seems unlikely to do so for the chemicals sector as a whole.

3.2. US Macro-economic performance

At the level of the US economy as a whole, there are two main channels by which increased domestic production of unconventional oil and gas can contribute to economic growth. Firstly, the existence of cheaper energy can improve the productivity of the economy. As energy is an input into the production of goods and services and is also a final service used directly by household consumers, a reduction in its costs effectively frees up additional resources which can in turn be used to produce and consume other goods and services. As explained in this section, this has essentially occurred in the US case *via* two "sub"-channels: firstly, by reducing the costs of domestic production of gas and thus its market prices for consumers. Secondly, by reducing imports of oil due to tight oil production and shifting that production into the domestic economy.

The second channel through which increased domestic production of unconventional oil and gas can contribute to the US economy is *via* short-term stimulus effects during the recent US recession. The resources spent by oil and gas companies in exploiting this new source of domestic energy are resources which almost certainly would not have been mobilized by the depressed US economy during this time. Consequently, they can be thought of as having had a small stimulus effect on the US economy and therefore as boosting employment and GDP in the short-run (but not the long-run).

The following analysis reveals that the shale gas boom does not have significant medium to long-term impacts on the US GDP and employment as a whole, and that short term effects are similarly small relative to the size of the short-run US output gap and unemployment rate.

3.2.1. Impacts on US productivity from lower energy costs

In order to quantify the effects lower energy costs on long run US GDP one must consider the expected longer term decline in energy costs for US energy consumption as a whole and compare this to the level of long run GDP. Data from the US Energy Information Administration shows that in 2013, US natural consumption was 71 billion cubic feet/day. Measures by the US Bureau of Economic Analysis of the size of the US economy put US GDP at roughly 17.1 trillion USD in 2013.

Next, to calculate the reduction in energy costs induced by shale gas a measure of the baseline for energy costs in the economy is needed had the shale gas revolution not occurred and had it not reduced prices. Constructing such a baseline is obviously difficult and requires making certain assumptions about a plausible US gas market scenario without shale gas. This study assumes that a reasonable baseline for US natural gas prices in the absence of shale gas would be current and

Box 1. Industries related to the petrochemicals sector

The wide range of uses of ethylene as an input into more complex chemicals and products has led some to predict a gradual shift of competitive advantage in chemicals production as a whole towards the United States (e.g. PWC, 2013). However, to our knowledge, no detailed quantitative analysis exists of the cost impact of cheaper primary petrochemical products such as ethylene along the chemical value chain. Given the complexity of the value chains involved and the lack of publically available data, this task is beyond the scope of this study. However, more generally, three important factors are relevant to the intermediate and downstream value chain impacts:

- *Firstly, transport costs at different points in the value chain.* For example, natural gas and anhydrous ammonia are more expensive to transport than nitrogen fertilier. Therefore it makes sense for fertiliser producers to produce close to the natural gas feedstock and then export rather than import LNG and then transform it to produce fertiliser. However, this may not be true for all products using ethane/ethylene as an input.
- *Secondly, the relative costs of ethane/naptha derivatives in intermediate and final products in the chemical industry.* Where the cost of intermediate inputs such as ethylene is not significant compared to the value added of the final product, cheaper intermediate inputs are unlikely to cause the relocation of the chemical value chain.
- *Thirdly, the impact of industrial clustering effects.* In some industrial sectors, chemicals in particular, agglomeration effects can occur whereby, over time, the fact of having a number of related production processes located in the same area can deliver economies of scale to businesses along the value chain. The extent to which this is important depends on the respective efficiency gains pushing suppliers and customers together (clustering effects), as opposed to those from international value chains (offshoring) which pull them apart. Clustering effects are likely to differ by sub-sector, but are generally large in the chemical sector. Thus, where a chemical industry cluster exists, it would tend to take a very high cost advantage to be able to compete with the complementarities of its components.

Aggregate data observations do not support the view that the chemical industry is shifting away from the EU, after now 8 years of the shale gas revolution. For example, the EU remains a significant and growing net exporter of chemicals, despite its energy price disadvantage relative to the US (Figure 19).

forecast European gas prices, since EU prices are likely to be only marginally impacted by shale gas exploration and US LNG imports in the near future. Obviously, such a calculation ignores other possible energy market interactions. However, for the purposes of this analysis, we believe that this simplified assumption is broadly reasonable as a baseline scenario. For example, US and EU prices have tended to move closely together prior to shale boom since they were both linked to similar global energy market fundamentals and could reasonably have been expected to do so in the future even more so due to growth in LNG market capacities.

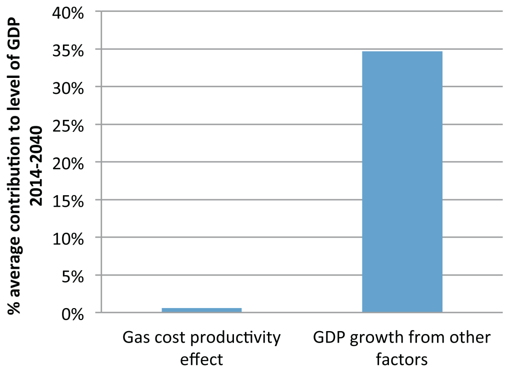
Current forecasts for average EU gas prices from the IEA's 2013 "New Policies Scenario" were used to obtain a baseline for US prices "in the absence of shale gas". This baseline would put US gas prices at 11.6 USD/Mbtu in 2015, 12.4 USD/Mbtu in 2020 and rising at 0.7% per annum to 14.26 USD/Mbtu by 2040. These figures are then compared with 2013 EIA forecasts of US industrial gas prices in the 2013 *Annual Energy Outlook*, in order to obtain the difference in gas costs between the baseline and the EIA forecast. Furthermore, the US forecasts from the EIA are adjusted post-2025 to reflect the fact that as the US begins exporting greater quantities of LNG, its domestic prices should gradually rise to reflect non-US prices (here assumed to be EU prices) minus the long run cost of gas liquificaton and transport, here assumed to be 4 USD/Mbtu. US prices are therefore assumed to be below the baseline by 7.2 USD/Mbtu in 2015, 6.85 USD/Mbtu in 2020, before narrowing to 4 USD/Mbtu below the baseline by 2026 and thereafter. Note that while in practice US prices may rise more slowly, they are broadly in line with expectations of rising breakeven costs of extraction. Also, changing these figures does not change the average long run effect of the calculation very much.

Furthermore, we estimate a long run GDP growth trajectory whereby GDP catches up to potential by 2020 (growing at 3% per annum to 2019) before slowing down to grow at 1.5% per annum on average out to 2040. Meanwhile natural gas consumption reference forecasts from the EIA are used, which suggest average annual growth of 0.6% per year. Finally, we assume that 90% of the decline in natural gas costs is passed on in lower product prices of intermediate and final goods. Strictly speaking, this implies that the productivity gain to the economy as a whole is 90% of the fall in natural gas costs compared to the baseline, not 100%. This factor is used to account for the fact that in practice US markets for goods and services are not perfectly competitive and therefore not all productivity gains are passed down the value chain in lower costs. The 90% figure is based on the mid-point of two estimates provided by Cowling and Mueller (1978) as the average deadweight loss of imperfect competition to the US economy. Altogether, these data simply show that the average increase in the level of GDP between 2014 and 2040 due to greater productivity from lower gas costs will be in the order of 0.575% of GDP. This would not be an increase in the growth rate of GDP, but rather simply the *level* of GDP. This figure is broadly consistent with the results of a recent modelling 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.[27] This is a small effect relative to the growth in GDP from other factors during this period, even assuming modest growth rates of 1.5% p.a. from 2020 onwards.

This estimate is of course somewhat simplified, since it basically takes account of the income effect on GDP from a fall in gas prices, but not the effects of relative price changes for other sectors due to greater gas production and lower prices (substitution effects). This simplification is done not to omit a potential channel through GDP could be increased, but rather for the purposes of methodological transparency (for example, to avoid the need for a "black-box" modelling exercise). We also believe that the substitution effects due to changes in relative prices are likely to be small relative to the income effects. For example, the vast majority of gas is consumed as a final good by consumers and represents a small share of US final expenditure. Also, as shown above, with the exception of all but a small handful of energy intensive sectors, the impact of lower gas prices on total production costs appears to be very small (and would not necessarily be passed on to consumers anyway). Furthermore, since the former sectors are not necessarily intensive inputs into many US goods and services, we believe the indirect effects on relative prices will be very limited. Note also that including this "prices" channel in our estimates would not necessarily increase the estimate of the GDP impact of shale gas, but might actually reduce it. Finally, other more sophisticated input-output based modelling studies of the ipact of US shale gas on GDP have broadly found similar results (E.g. Energy Modelling Forum, 2013, found total impacts of 0.45% of GDP). For these reasons we are confident that these estimates, althrough simplified, are the right order of magnitude.

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

Figure 20. Comparison of the contribution of cost productivity effects and other factors over the next 27 years



Source: Authors' calculation based on EIA (2013a) and US Congressional Budget Office data.

3.2.2. Impacts on US productivity from reduced oil imports.

A second channel through which the US economy could see its productivity increased would be *via* a reduction in oil imports due to tight oil production. As can be seen in Figure 21, increased production of oil and gas has lowered US imports, especially from 2010 onwards, as tight oil production began to replace oil imports. It is worth noting, however, that this impact has not yet been as significant as demand reduction due to the combination of: the recession of 2008/09, high oil prices which reduced consumption, and improved efficiency. These factors are largely responsible for the decline in imports prior to 2010.

The reduction in oil imports is beneficial to the US economy as it implies that the oil producer surplus (profits) have been transferred from non-US oil exporters to US oil producers and thereby into the US economy. Assuming a long run marginal production cost of around 70-80 USD/barrel for light tight oil[28] and a long run oil price of 114 USD/barrel from EIA projections, we estimate that the long run GDP effects of reduced oil imports would be equivalent to a about a 0.26% increase in the level of GDP in the period to 2035.[29] This may be offset slightly, but not entirely, by a small increase in the exchange rate and other crowding out effects in US capital and labour markets. However, it is nevertheless a net gain to US GDP, as it implies that resources are being deployed more productively (from a GDP perspective) than they would be if they were employed in other markets. As with the point above, this is a long-term increase in the level of GDP, not the growth rate.

Interestingly, Figure 21 also suggests that there has been no noticeable improvement in the US trade balance for non-petroleum products since the decline in gas prices which began in 2008/09. This would tend to suggest that the manufacturing competitiveness benefits have so far not been large enough to show up as a reduction in the size of the US trade deficit. This is consistent with the analysis provided above, which argued that only a small subset of manufacturing sectors were significantly affected by shale gas' impact on gas prices.

3.2.3. Short term "stimulus" effects on the US economy during the recession

The third main channel through which the US economy was likely to have been affected by the unconventional fuel revolution is more short term. It concerns the benefits of additional spending by oil and gas companies during the recent US recession. The main problem of the US economy in the years following the global financial crisis was a lack of aggregate demand and spending in the economy. This was due to simultaneous deleveraging by the private and public sector, which reduced spending throughout the economy. Moreover, monetary policy had already dropped interest rates to zero and could not easily stimulate the economy further, even though it remained depressed. In this context, any additional spending by either the public or private sector (i.e. spending that it would not have otherwise undertaken) during this period could therefore have a positive effect on GDP by boosting aggregate demand back towards "normal" levels, while the private sector deleverages. By coincidence, this was true of unconventional oil and gas companies, which began increasing spending to take advantage of the newly available resources in the unconventional energy sector.

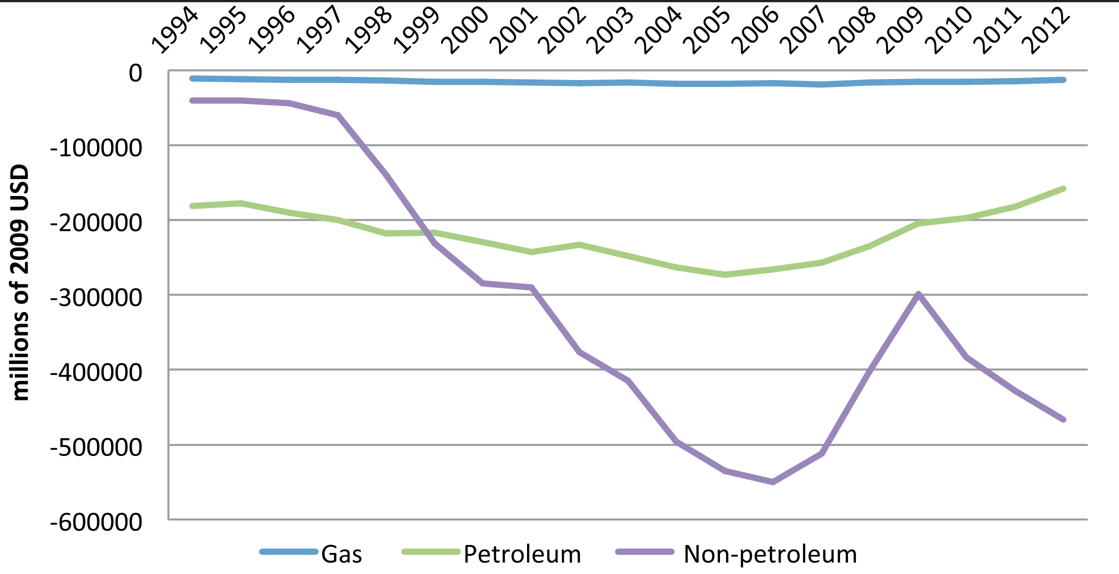
We posit that this effect is likely to have occurred principally by two main channels:

- *via* reductions in household spending on energy, which would have freed up income to spend on other goods and services. This concerns mainly gas purchases, but partly also *via* reductions in electricity costs due to lower peak electricity prices, which are set by natural gas plants;[30]
- *via* increases spending by oil and gas companies to produce oil and gas.

How big were these effects on GDP? To evaluate the impact of the first channel, we take the average

28. Cf. IEA (2013), *World Energy Outlook*, ff. 453.
29. Note that we ignore the impact of natural gas liquids here.
30. This is only likely to be true where gas plants set electricity generation costs by being the marginal unit of generation.

Figure 21. US real trade balance by product type, in millions of 2009 USD



Source: Authors' calculations, EIA net natural gas imports historical data, US Census Bureau Foreign Trade Statistics.

fall in natural gas expenditures for residential consumers from their peak in 2008 and 2012, which on average was approximately 20% of expenditure, or approximately 40 billion USD (EIA, 2013a). Dividing this by average US GDP during the period, which was approximately 15 trillion USD, and assuming all of this extra income was spent, we obtain a net expenditure increase of 0.267% of GDP. Using a generous GDP-multiplier estimate of 1.5, we arrive at a net short run increase in GDP of 0.4%.

To evaluate the impact of the second channel, we take data from the Bureau of Economic Analysis input-output tables on total expenditures on intermediate inputs and salaries by the oil and gas sector between 2009 and 2012. To compare these to a hypothetical spending baseline without shale gas, we calculated the ratio of the growth rate of oil and gas spending relative to overall manufacturing spending. We then multiplied this rate (which was 70%) by the net increase in spending from 2009 to 2012. Taking these spending numbers and once again assuming a high multiplier of 1.5 in the same fashion as above, we obtained estimates of a 0.48% impact on GDP.

In total, therefore, we estimate a maximum total short-term stimulus effect below 0.88% of GDP. Note that this is an estimate that is "conservatively large", since it is assumed that all of the increase in revenues is spent within the rest of the economy as opposed to saved, and large multipliers of 1.5 have been used. We also assume that a conservatively large share of the growth in spending from the oil and gas sector from 2009 to 2012 is shale gas and tight oil related.

While 0.88% of GDP is a non-trivial amount of output, this occurred in a context in which the US GDP output gap—which is the measure of the difference between where the economy would be if it weren't in recession and were it actually was—was conservatively estimated to average 4.6 to 5.5% of GDP during the period 2010 to 2013 (IMF, 2013).

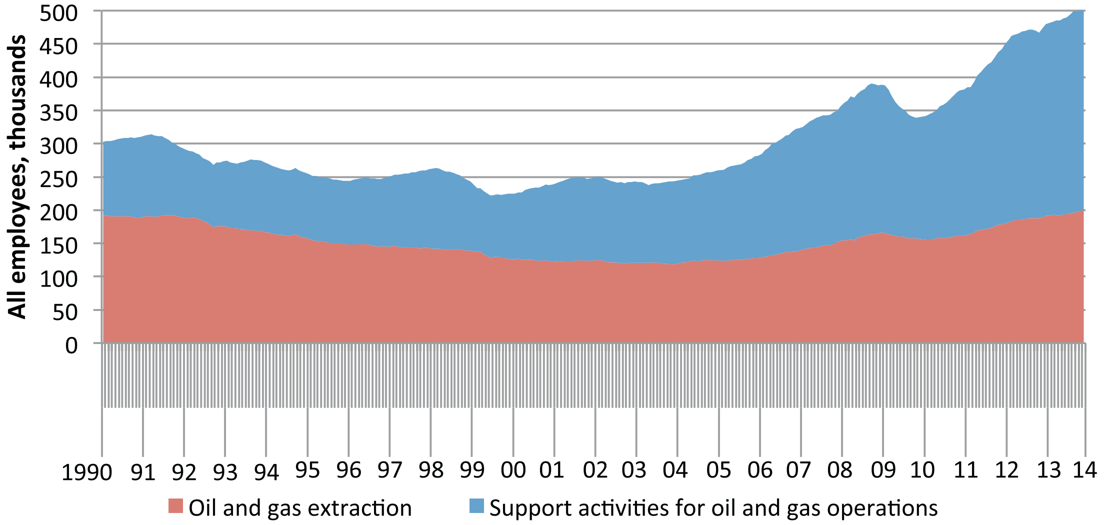
3.2.4. Short term effects on the US employment during the recession

In general, in the long run, an economy is at "full employment". This means that resources (labour and capital) are fully employed (the structural constraints of labor and capital markets notwithstanding). Therefore, in general, unemployment cannot be further reduced simply by adding new sectors to the economy. This means that, in normal circumstances, the unconventional energy sectors are not net job creators as is sometimes assumed. Rather, they tend to shift workers from one sector to another. In the short run this is different, as noted above. Therefore, the stimulus effects of unconventional energy production can have an impact on employment. How large were these "short term" employment effects?

As Figure 22 shows, employment in the oil and gas extraction sector and related support activities[31] has increased from just less than 400,000 em-

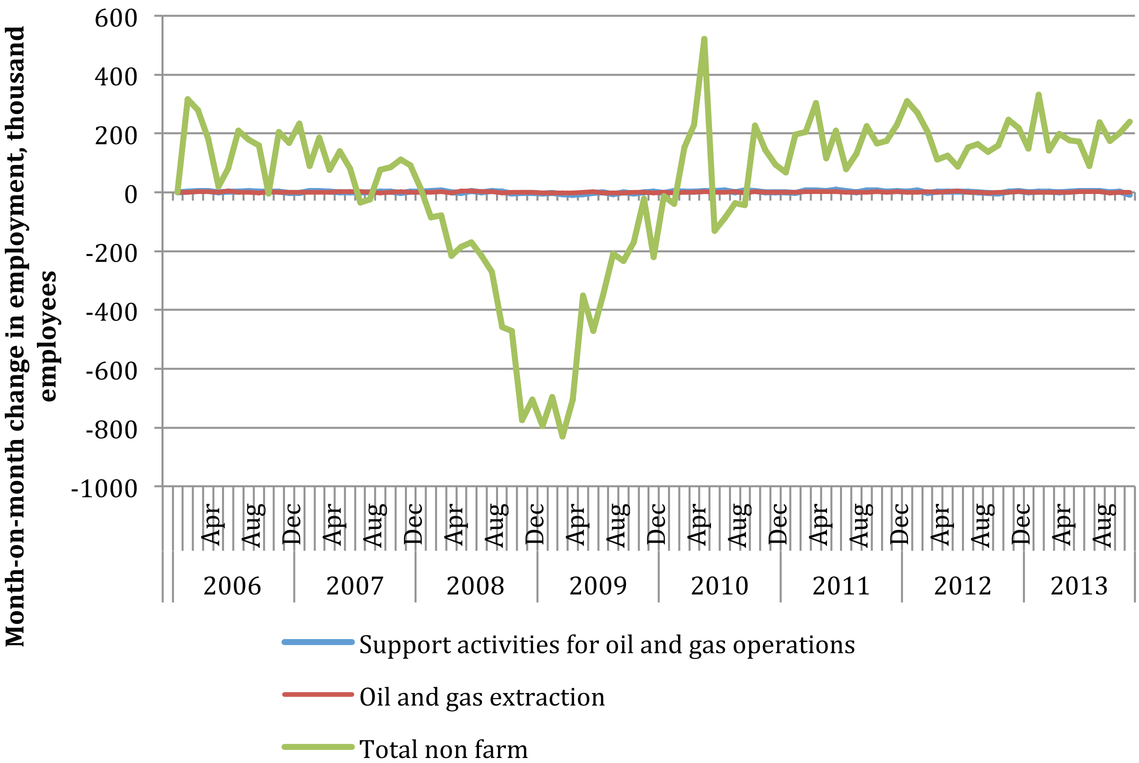
31. The US Census Bureau defines this sector as follows: This U.S. industry comprises establishments primarily engaged in performing oil and gas field services (except contract drilling) for others, on a contract or

Figure 22. Employment in the oil and gas sector



Source: www.econbrowser.com, Bureau of Labor Statistics.

Figure 23. Month-on-month change in employment in oil and gas extraction (red), in oil and gas support activities (blue), and in nonfarm payroll employment ex.-Census (green).



Source: www.econbrowser.com, Bureau of Labor Statistics.

ployees in 2008 to more than 500,000 by the end of 2013. The direct addition of 100,000 workers to the US economy is obviously non-negligible, but should be put in perspective. Figure 23 shows the monthly change in employment of non-farm employees in the US economy as a whole versus oil and gas extraction and related services. The picture therefore gives a good insight into the relative role of these two sectors in total job creation in the US labour market compared to other macroeconomic factors. It can be seen not only that the recession brought about by the US financial crisis and the subsequent recovery dominates these sectors by a large margin, but also that the impact of 100,000 jobs is ultimately extremely small in a labour force of 155 million workers. Indeed, even if one were to assume that the indirect jobs created by the oil and gas sector were a factor of three times those jobs directly supported by the oil and gas extraction boom, one would still arrive at a figure of 400,000 workers—the equivalent of 0.25% of the US labour force.

Calculating the indirect jobs created by greater expenditure of the oil and gas sector and its employees is difficult to do precisely given data constraints. However, a broader way to assess the combined effect of both the indirect and direct impact of the unconventional gas and oil exploitation boom on US employment is to compare the change in the unemployment rate across US states with differing levels of oil and gas production.

Figure 24 shows the annual growth of employment in producer (red) and non-producer (blue) states, where production is scaled by dividing the value of gas production by the size of the economy of each state. The data show that there is a high level of heterogeneity of employment growth both in producer and non-producer states. It can be seen that, while there is a—very weak—positive correlation between unconventional hydro-carbon production and employment growth, states with relatively high shale gas production incomes (located on the right side of the graph) do not witness a spectacular growth in employment. On the contrary, employment growth in these states does not seem correlated to shale gas production. The one exception to this is North Dakota, which is a major tight oil producer (along with Texas).[32]. Crude oil production in North Dakota rose from 100,000 bbl per day in 2006 to 660,000 bbl per day in July 2012[33] and as a smaller economy it has therefore seen a bigger impact on employment and GDP. This exception nevertheless proves the general rule: that even when one considers shale gas and tight oil production's direct and indirect effects together, one finds that the impacts have been limited in the aggregate except for specific cases with small economies and high production values.

The picture is similar for economic growth. States with significant shale gas production do record a slightly higher economic growth than non-producer states (these have a growth rate close to -0.5% on average over the period 2007-11). However, this difference is not large. With the exception of North Dakota where tight oil provides an additional source of income, the economic growth rates of producer states remain low or negative. After North Dakota, West Virginia has the highest rate of economic growth. The other significant producer states have an economic growth rate of between -0.5% and 0.

3.3. Conclusion

There has been an effect of the shale gas boom on the US economy. These effects can be categorized as long-term productivity effects *vs* short-term stimulative effects. The long-term effect on the US economy as a whole is small, in order of a one-off rise in GDP of 0.84%. These are "one-off" effects because they do not increase the annual growth rate of GDP. They are actually quite small in terms of long run growth in the level of GDP.

The short-term effects on GDP are slightly larger, but are not lasting. These include a one-off boost from a decline in gas prices for residential consumers (estimated at 0.4% of GDP), a similar boost from increased investment and employment in the oil and gas sector of around the same magnitude. These latter effects have nevertheless been short term and are non-replicable effects in economies at full employment. They also pale in comparison to the broader macroeconomic picture of the US economy and its 155 million workers and the broader challenges brought on the bursting of the US housing bubble and the slow recovery from recession.

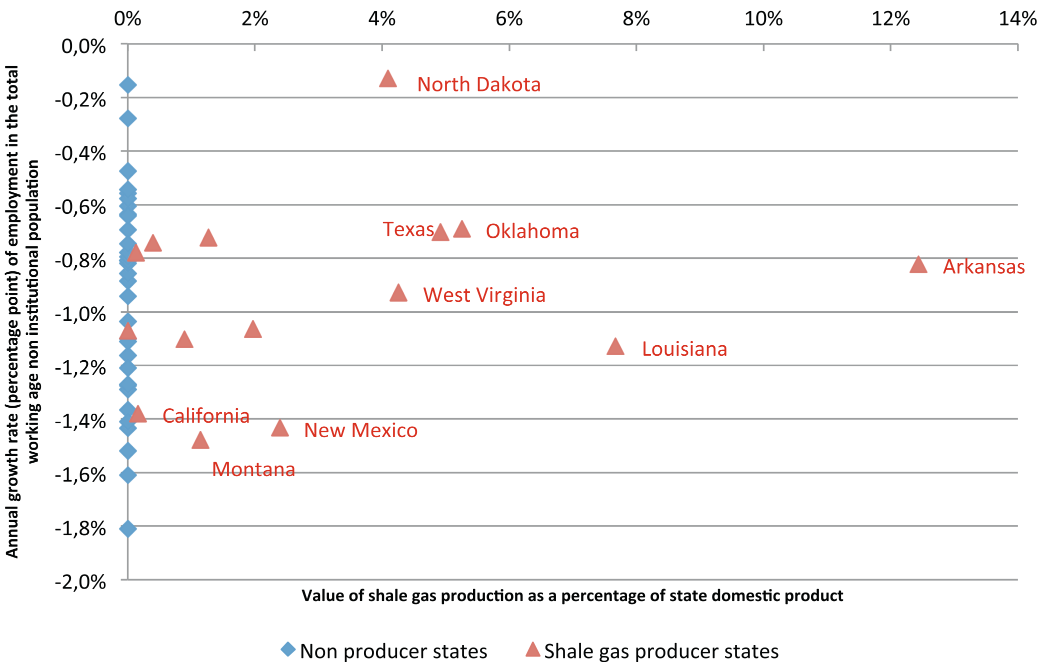
The most dramatic impacts of the shale gas revolution have therefore been local, in states such

fee basis. Services included are exploration (except geophysical surveying and mapping); excavating slush pits and cellars; grading and building foundations at well locations; well surveying; running, cutting, and pulling casings, tubes, and rods; cementing wells; shooting wells; perforating well casings; acidizing and chemically treating wells; and cleaning out, bailing, and swabbing wells.

32. The tight oil production is mainly located into three geological formations which are the Bakken in the Williston Basin (North Dakota) and the Eagle Ford shale formation and Permian Basins in Texas.

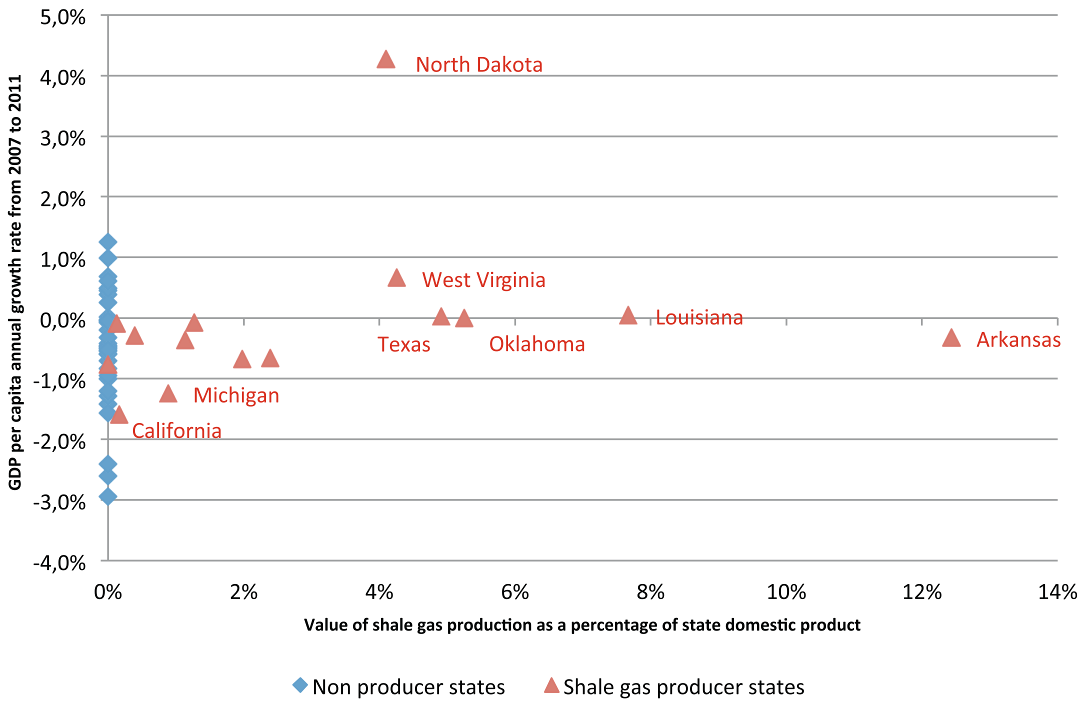
33. Tight oil represents 90% of North Dakota crude oil production.

Figure 24. Annual growth rate (percentage point) of employment in the total working age non-institutional population between 2007 and 2011 plotted against the value of shale gas production as a percentage of state domestic product



Sources: EIA, St Louis Federal Reserve Economic Data.

Figure 25. US Annual growth rate of GDP per capita of producer and non-producer states (between 2007 and 2011) ***vs*** the value of shale gas production as a percentage of state domestic product.



Sources: EIA, St Louis Federal Reserve Economic Data.

as North Dakota, with large production volumes relative to state domestic product, and on specific sectors such as petrochemicals which use gas as a feedstock. However, these sectors represent a very small share of US manufacturing, employment and trade, and as a consequence the US trade balance shows no signs of a large shift in competitiveness in non-petroleum and gas sectors. In short, the economic impacts of the US shale gas revolution have been modest, and largely sectoral and local. And yet the growth in US gas and oil production has been quite extraordinary, and, many argue, unlikely to be swiftly replicated elsewhere at such scale.

4. PROSPECTS AND IMPLICATIONS FOR THE EU

Having assessed the US case, the following sections turn to the EU. They address a number of questions. Firstly, what are shale gas production prospects in the EU? Secondly, would the most favorable scenarios imply a significant change in economic outcomes for the EU, in terms of energy prices, competitiveness and the EU macro-economy? As mentioned in the introduction, this study is not based on independent prospective analysis. Thus the objective of this section is to provide a broad strategic perspective on the potential importance of shale gas in Europe, given the trends suggested in the somewhat limited available literature.

4.1. European estimated resources

There is much uncertainty on EU shale gas resources. Only a small number of exploration wells have been drilled in Europe (around 50). To put this in perspective: between January 2005 and December 2010, the United States drilled on average 167 exploratory natural gas wells per month.[34] This means that resource estimates come from general geological data collected from core sampling, seismic measurements, and oil and gas log data from existing conventional onshore oil and gas production where applicable. Most European countries do not have significant onshore oil and gas production (in contrast to the United States) and therefore geological data are much scarcer (JRC, 2012). The US started estimating geological resources of unconventional hydrocarbons back in the 1980's, largely due to tax credit incentives from the Alternative Fuel Credit: the seemingly recent shale boom in the US came in fact on the back of several decades of exploration and assessment (Gény, 2010). It will take some time (5-10 years) for Europe to go through a similar process, and build a robust assessment of its resources and their commercial viability.

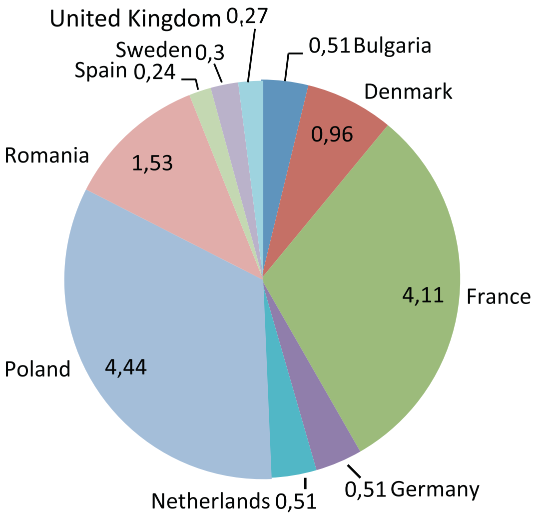
In the absence of such data as in Europe, two broad methods are used to assess shale resources. The first involves bottom-up assessment based on the relevant geological data. Moving from such bottom-up resource estimates to estimates of technically recoverable resources requires the use of an estimated recovery rate, based on geological parameters (total organic content, mineral content, thermal maturity, etc.). Estimated recovery rates are poorly constrained by existing data, given the short history of shale production. It is also difficult to extrapolate from one region to another without more detailed empirical geological assessment through exploration, given the large diversity of shale plays.

The second methodology involves extrapolation from production experience in existing shale plays to geologically analogous shale plays. This involves transposing estimates of well productivity (ultimate recoverable reserves/well, or URR/well) from an existing production play to an unexplored play. However, actual production rates can differ by several factors between neighboring wells, and by a factor of 10 within an entire shale play. Estimating an "analogous" ultimately recoverable resource per well (URR/well) is thus subject to significant uncertainties. The estimation of URR/well is also subject to uncertainties regarding the decline rate. At the beginning of operation, shale gas production declines rapidly, typically along a parabolic decline curve. As there is limited historical production experience, this decline curve is poorly constrained by existing data. Variations in the assumed decline curve can have significant impacts on the estimated URR/well and thus the cost of production and the overall recoverable reserves of the play. The uncertainty and controversy surrounding the decline rate will only be resolved with further years of production data.

The above introduction merely underscores the high uncertainty surrounding the estimates for technically recoverable reserves for Europe presented below—they should be treated with caution. A further issue relates to the translation of technically recoverable reserves into economically recoverable reserves, *i.e.* the share of technically recoverable reserves that could be extracted given current market conditions and technology. In the absence of actual exploration and production data, any translation of technically to economically recoverable reserves is fraught with significant uncertainties.

34. EIA (2013), Crude Oil and Natural Gas Exploratory and Development Wells.

Figure 26. Estimates of shale gas technically recoverable resources by country (tcm)



Source: EIA, 2013d.

Table 6 presents two recent estimates for European shale gas reserves, one from the literature review conducted by JRC (2012), the second from the recent comprehensive global assessment of the US EIA (2013). Estimates differ widely. To give an idea of magnitude: the EIA estimate of 14.1 tcm and the mean from the JRC of 8.9 tcm compare to the EIA estimate for the United States of 17 tcm. This latter figure for the US ought to be more robust given the extensive exploratory drilling activity that has taken place. Figure 26 gives estimated technically recoverable shale reserves by European country, taken from EIA (2013).

Table 6. Estimates of shale gas technically recoverable resources in Europe

Source	Estimated shale gas technically recoverable resources		
EIA, 2013	14.1 trillion cubic meters (tcm)		
JRC, 2012	Lowest	Mean	Highest
	2.3 tcm	8.9 tcm	17.6 tcm

Source: EIA 2013 and JRC 2012.

4.2. Qualitative assessment of factors behind production projections

The first point to underline is therefore the uncertainty surrounding resources and production projections in Europe. In the absence of hard drilling data from a significant number of wells, production projections are thus constrained by this fundamental uncertainty regarding technically recoverable resources and the technical and economic parameters of their eventual exploitation. However, a number of factors can be assessed to build a qualitative understanding of shale gas production prospects in Europe. These include subsurface geological conditions, as well as above-ground conditions.

Subsurface geological conditions: while extensive exploratory drilling is required in order to give a clear understanding of production potential, a number of geological factors can be assessed in order to develop an *a priori* assessment. These include the depth, extent, thickness, thermal maturity, organic content, brittleness (clayey shales fracture less well), pressure and porosity. It is difficult to give a general assessment of such conditions in European shale plays, given the extent of geological understanding and the difference between shale plays. However, some elements of a generalization can be given. European shales tend to be smaller, deeper, more highly pressurized (which makes fracturing more difficult) and higher in clay content.[35] While this does not preclude finding productive sweet-spots within shale plays, it does suggest that Europe would not be able to simply transpose US drilling techniques.

Service industry constraints: shale gas production is an intensive industrial activity, with a large amount of drilling required to achieve and maintain significant production. This can be seen in the US case, where the US averaged 1,087 active natural gas drilling rigs per year between 2005 and 2012.[36] This compares to the December 2013 natural gas rig count for Europe of 32.[37] A smaller fraction thereof would have horizontal drilling and fracking capabilities.[38] To produce around 30 bcm of shale gas per year (about 6% of EU demand in 2011) would require drilling about 700 to 1,000 wells per year over several decades. Taking Gény's assumption of 6 wells per year per rig, one would need between 110-170 active rigs with horizontal and fracking capacity. A further issue relates to labour costs and the availability of skilled personnel, where Europe is again likely to be at a disadvantage relative to the United States with a more extensive history of onshore oil and gas production. Significant expansion of the European natural gas service industry would be required to produce significant quantities of shale gas, and that this would take time to build up and would, in the meantime, pose a cost and scale constraint.

Land access: although the use of multiple wells

35. Gény, 2010 and IEA –Poland- (2013).
36. EIA, Crude oil and natural gas drilling activity. European Figure from JRC, pp. 76.
37. Baker Hughes international rig count 2014.
38. Gény pp. 95. (2010) put this number at 7 in 2010.

from single pads can reduce the intensity of land use, shale gas is widely viewed as more land intensive than onshore natural gas production. Land uses relate to the actual pads themselves, as well as road and utility access, refining and waste water treatment facilities and so on. Generally speaking, Europe is more densely populated than the United States, and European shale plays are generally located in densely populated areas. While this need does not necessarily pose a problem (some productive US plays are located in highly densely populated areas), local opposition is widely seen as a major obstacle to shale gas production in Europe. The European landscape is also more fragmented, with in particular smaller landholdings for farming. This implies higher transaction costs in terms of negotiation of land access. A further issue relates to economic incentives for land access. It is widely reported that the US regime of landholder ownership of sub-soil mineral rights has been an important factor in public acceptance of shale gas, as exploitation means royalties to landholders. In Europe, the situation is a not as clear-cut as often reported, but generally speaking landowners do not own sub-soil mineral rights, rather these are the property of the state. There is some diversity in this regard between EU Member States, however.

Environmental regulations: environmental regulations are generally much tougher in the EU. These can impact on the scale and cost of shale gas development. A notable element relating to land access are the Natura 2000 biodiversity reserve as well as Member State-level protected areas. Environmental regulations relating to the drilling procedures, well completion, waste water treatment and disposal, noise and light pollution are all relevant.

Generally speaking, such factors along with the fundamental immaturity of exploration in the EU are expected to result in slower and more costly production of shale gas in the EU in comparison with the US experience.[39]

4.3. Summary of projections and costs for shale production in Europe

This section presents a brief summary of projections for shale gas production in Europe. Again it should be underscored that the immaturity of European shale exploration efforts does not permit a detailed and robust modeling exercise, which ought to be based on existing production data and an understanding of below-ground reserves. Qualitative factors such as those discussed above further complicate a numerical, model-based assessment of production figures. Generally speaking these are integrated in modeling exercises *via* exogenous assumptions regarding maximum ramp up rates for drilling capacities, as well as in cost parameters such as the cost of gas produced. Table 7 summarizes the relevant parameters from a number of studies on EU shale gas production. It should not be seen as exhaustive.

Table 7. European shale production scenarios

Study	Cost assumption	Projected EU shale gas production in 2035	Natural gas import dependence 2035 (63% in 2011)
JRC 2012	5-12 USD/ Mbtu	1 to 2.1 tcm cumulatively in 2035 in the optimistic/ pessimistic scenarios	57% in the high shale scenario 72% in the low shale scenario
IEA WEO NPS 2013	Unclear	20 bcm in 2035	81%
Pöyry and Cambridge Econometrics study for International Association of Oil and Gas Producers (2013)	9 USD/Mbtu	60 bcm in 2035 in the low scenario 150 bcm in 2035 in the high scenario	80% in the low scenario 63% in the high scenario
BP WEO 2013	Unclear	37 bcm in 2035	Ca. 75%
EIA 2013	Unclear	79 bcm in 2035. N.B. figures are for OECD Europe, not the EU.	75%. N.B. figures are for OECD Europe not the EU

Source: JRC, 2012; IEA WEO 2013; IEA WEO 2011; Poryry and Cambridge Econometrics 2013; BP 2013; EIA 2013d.

Some general conclusions can be proposed from this qualitative and quantitative prospective literature on shale production in Europe.

1. Europe is at the very beginning of shale exploration; this process took several decades in the US, a factor which is often overlooked when considering the rapid expansion of US production after 2005. Between 2000 and 2010 the US drilled a total of 17,268 exploratory natural gas wells, at an average of 130 per month (by contrast, Poland is planning to drill 345 wells between by 2021).[40] This exploratory activity is necessary to find

39. Cf. the discussions in Geny 2010 and JRC 2013.

40. European Commission (2014), "Exploration and production of hydrocarbons (such as shale gas) using high volume hydraulic fracturing in the EU", COM, pp. 33.

the most productive areas within a shale play, and gain an understanding of overall productivity and cost. It would take time to replicate this in Europe, particularly given constraints on the service industry.

2. Generally speaking, the operating environment is seen to be less favorable in Europe than in the US. This is due to reportedly less favorable geology, greater perceived difficulties around land access and public acceptance, more stringent environmental regulations, and a less flexible, competitive, experienced and sizable service industry.
3. The literature on prospective scenarios for European shale production is limited and presents a wide range of results. Nonetheless, several common elements can be drawn. Firstly, the highest production scenarios see shale gas roughly compensating for declining domestic conventional production. In such scenarios, import dependencies remain at current levels, and prices are largely determined by international import prices. In lower production scenarios, domestic shale production is not sufficient to compensate the decline in domestic conventional production.
4. Prices are generally projected to be higher than the cost of domestic EU conventional production, and also relative to marginal supply costs from major exporters to Europe such as Russia and Algeria.[41] Thus it is difficult to see domestic shale production leading to a significant drop in EU gas prices in the coming decades.

4.4. Implications for EU energy and climate policy: European and international aspects

The above sections suggested that the EU is unlikely to be able to replicate the US shale revolution in the coming several decades in terms of the scale of production and price. A median estimate would see the EU producing perhaps several tens of bcm in 2030-2035, import dependence increasing from current levels to around 70-80%, and prices still determined largely by international markets.

This raises the question of what the expected energy market outcomes would be, and the implications for EU energy and climate policy. This question has two components, which will be dealt with sequentially. Firstly, the unconventional hydrocarbon revolution is a global phenomenon, and this raises this issue as to its impact on global markets and hence on the EU as an importer. For example, could unconventional hydrocarbons lead to a significant decrease in the EU's import prices such that concerns around the EU's import bill would be alleviated? Secondly, what would be the implications of the above scenario of some moderate shale gas production in the EU in terms of EU energy markets and climate policy?

One line of thinking sees the advent of unconventional hydrocarbons at a global level as significantly alleviating supply/demand concerns in global energy markets. In this scenario, significant incremental production is expected, lower prices compared to previous price projections, and reduced concerns about acute supply and demand imbalances. Another, perhaps more mainstream analysis, suggests a future in which oil and to a lesser extent gas prices will continue to rise in the long term due to growing demand from the developing world, declining marginal productivity of incremental supply, geopolitical barriers to supply, and imperfect markets leading to resource rents.

It is beyond the scope of this paper to address the substance of this debate. Nonetheless, we can address the implications of *either* scenario (resource optimistic/resource pessimistic) for the EU as a major importer of oil and gas importer going forward. Figure 27 shows a range of recent oil price projections to 2035, including several low price scenarios.

The IEA notes in its assessment of the low oil price case that there is sufficient production capacity in their estimated world oil supply curve to maintain prices at 80 USD/barrel until 2035. However, they discount the probability of this scenario, noting the geopolitical risks and/or project delivery risks in major future supplies such as Brazil, Iraq, and Kazakhstan, as well as the difficulty of replicating the US tight oil experience elsewhere. A major issue is also the market power of OPEC, which sees its revenues reduced by 500 billion USD cumulatively in the IEA low oil case versus the IEA New Policies Scenario. A price of 80 USD/barrel is also seen to be significantly below the fiscal break-even point for a number of OPEC producers. However, even at 80 USD/barrel, the EU oil import bill would be significant.

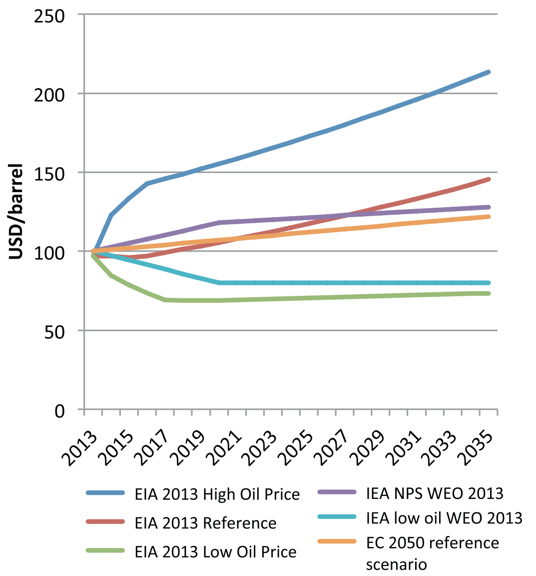
The more relevant impacts for the EU *via* international and EU markets may be related to natural gas. The EU currently imports about 67% of its natural gas consumption.[42] Russia (25%), Norway (23%), Algeria (10%) and Qatar (9%) make up the largest share of EU imports.[43] There are a number of Member States in the East that are highly

41. IEA WEO 2009, pp. 481-482.

42. Eurostat data, figure for 2011.

43. Eurostat.

Figure 27. Oil price projections to 2035



Source: EIA (2013), EC (2013), IEA (2013).

Table 8. Natural gas import dependency, share of Russia in imports, and share of gas in gross inland energy consumption

	Natural gas import dependency (%) N.B numbers above 100% indicate stock changes	Share of Russia in gross imports of gas (%)	Share of gas in gross inland energy consumption (%)
Bulgaria	86	100	14
Czech Republic	111	97	16
Estonia	100	100	8
Latvia	109	100	30
Lithuania	100	100	38
Hungary	66	65	37
Austria	103	63	23
Romania	22	86	31
Slovakia	105	100	27
Finland	100	100	9
Poland	75	69[1]	13

Source: Eurostat.

dependent on external gas supplies, among which Russia often accounts for 100% of imports (see Table 8). Eastern European countries are also among those with the more promising estimated shale gas reserves (Poland, Romania, Bulgaria, etc.). They also tend to be countries with a low penetration of gas in primary energy consumption.

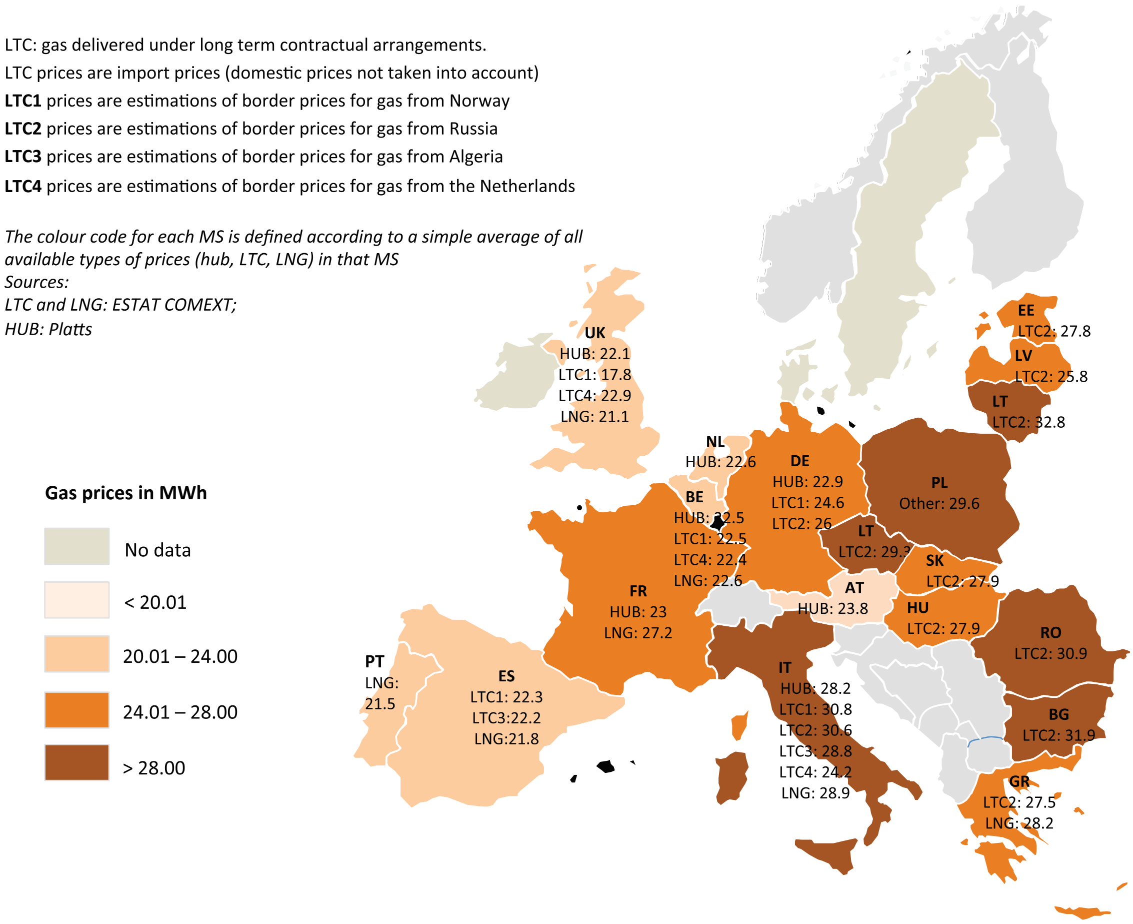
This high reliance on pipeline gas from Russia has led to a two-tiered pricing system. Pipeline gas is typically priced based on long-term oil-indexed contracts. These pricing arrangements have not felt the effects of the price impacts of the US shale revolution on global gas markets. Oil indexation and market power have generally allowed Russia to maintain higher prices for Eastern European customers than Western European consumers are paying at more liquid, internationally connected trading hubs. A comparison between wholesale gas prices across Europe underscores this point (Figure 28). For a number of reasons, analysts expect this use of oil-indexation to decline in Europe (JRC, 2012). It has already done so from about 80% in 2005 to under 60% of EU gas imports in 2010.[44]

How could shale gas fit in this picture? A number of conclusions can be drawn from this discussion. Firstly, the most significant impact of the shale revolution would likely be lower import prices from a less tight, more liquid international market. This can be seen in a comparison between the IEA's GAS scenario and its New Policies Scenario. In the GAS scenario EU import prices are about 20% lower on average from 2015 to 2035 than in the NPS scenario.[45] This, coupled with the necessary infrastructure build in Europe, could help favor the push to more liquid, internationally priced gas markets in Europe, particularly for those countries currently cut off from suppliers other than Russia. Secondly, some more shale production (a scenario of several tens of bcm by 2030-2035), combined with a stronger internal market and a lower LNG import price, may favor a stronger European market position in contractual negotiations with gas suppliers (in particular Russia in the case of Eastern Europe). Finally, the necessary infrastructure build out and the new location of shale gas supply could favor further physical market integration in Europe, and thus act as an impetus towards a strengthened EU gas market.

44. International Gas Union Data.

45. Cf. IEA WEO 2011.

Figure 28. Wholesale gas prices by supplier, contract type and Member State



4.5. Conclusion

This section has assessed the potential energy market implications of shale production in Europe. Several conclusions can be offered. Firstly, European shale exploration is in its infancy; exploring and scaling up any production will take time and effort, particularly as conditions seem less favorable than the US. Secondly, there is a wide diversity of production projections, but even under most optimistic assumptions, the EU will remain a net importer and thus its prices will depend on international markets. A scenario of several tens of bcm of production would seem to be a median scenario corridor by 2030-2035, which would cover in the order of 3-10% of projected EU demand. Thus, the energy market impacts would not seem to be significant based purely on shale gas production volume. Thus, the EU should not expect any manufacturing or macroeconomic benefits from shale production, small as these have been shown to be even in the US. Thirdly, however, the most important impact of the shale revolution is likely to be its impact on international gas markets and hence on the EU: supporting the current trend to increasingly liquid, interconnected and internationally-connected EU gas markets, based increasingly on gas-to-gas competition. This could assist the use of gas as transition fuel towards a low-carbon energy sector by 2050, in particular in Eastern European Member States currently largely cut off from the more liquid global markets. The pre-condition for such a scenario would be increased physical integration in EU gas markets. Finally, domestic production in the EU may have a marginal contribution to EU energy and climate strategy, if, combined with the necessary infrastructure and the necessary policies, it helps Eastern European Member States to shift away from coal and towards more flexible efficient gas-and-renewables based energy systems. Thus shale gas alone should not be seen as a panacea for the EU's security of supply and gas price competitiveness concerns, to the extent that the latter may be justified by the analysis presented of the US experience in sections 2 and 3.

5. CONCLUSION

By any standards, the US unconventional oil and gas revolution has been significant, with US production of oil and gas growing dramatically from 2005. However, the long run macroeconomic and competitiveness impacts appear small in the context of the overall US economy. Nor does the unconventional oil and gas revolution appear to be the answer to US concerns of energy security, the energy drag on household budgets, or US's significant GHG emissions. Absent further policy, the US will not be able to ensure a secure and sustainable energy sector. Indeed, although with further policies the availability of cheaper gas could facilitate some coal to gas switching, there is the real risk of lock-in to more emissions and energy intensive capital stock and consumption patterns.

In the EU, the US shale revolution has raised concerns about competitiveness and the direction of EU energy policy. We believe these to be unjustified overall. The shale-induced energy price differential between the US and EU is significant in only a handful of sectors, such as basic petrochemicals. For other more technologically complex, high value added manufactures, energy prices will not be a significant factor of competitive advantage. For the EU manufacturing sector, a much more significant concern is the general macroeconomic uncertainty and weakness, coupled with long-term structural trends to an economy based more on services.

The EU does, however, face a long-term energy challenge. Fuel imports represent 3.2% of GDP, and import dependency is projected to rise. Shale production faces a number of obstacles in the EU, not least the very early stage of EU exploration. A reasonable, median scenario would not see shale gas making a significant contribution reducing EU energy prices and dependence. The shale revolution may have a more significant contribution to more liquid, integrated and competitive EU gas markets, through lower cost international LNG imports and domestic production to a certain extent, particularly in Eastern Europe. Combined with the necessary infrastructure and favourable policies like higher carbon prices, this could facilitate the role of gas as a transition fuel in some coal intensive EU Member States. To the extent that gas is a necessary transition and balancing fuel, more integrated, liquid and competitive markets in the EU could be a contribution to EU climate policies. To this extent, shale should be seen as a complement to current EU energy policy priorities, and by no means as a substitute.

6. REFERENCES

Allen, D.T. et al. (2013). Measurements of methane emissions at natural gas production sites in the United States, Proceedings of the National Academy of Sciences of the USA, vol. 110 no. 4, pp. 17768–17773, doi: 10.1073/pnas.1304880110 http://www.pnas.org/cgi/doi/10.1073/pnas.1304880110

Beffa, J.and G. Cromme (2013). Competitiveness and Growth in Europe: Report of the franco-german working group, available at http://www.rapportbeffacromme.eu/

BP (2013). "BP Energy Oulook 2035"

Cheah, L., J. Haywood, R. Kirchain (2010). The Energy Impact of U.S. Passenger Vehicle Fuel Economy Standards, MIT Sloan School, http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/IEEE-ISSST-cheah.pdf

DG Energy (2013). "Green paper: A 2030 framework for climate and energy policies", European Commission, Brussels, 27.03.2013.

DG Energy (2012). "Energy Markets in the European Union".

DG Ecfin (2014). "Energy Economic Developments in Europe", European Economy 1.

EC (2013). "Trends to 2050, reference scenario 2013", http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2050_update_2013.pdf

EIA (2012a). Annual Energy Outlook, 2012, US Energy Information Administration, US Department of Energy, Washington DC, www.eia.gov/forecasts/aeo/

EIA (2012b). Annual Energy Review 2012, Consumer Energy Expenditure Estimates by Source http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0305

EIA (2013a). Annual Energy Outlook: with projections to 2040, US Energy Information Administration, US Department of Energy, Washington DC, http://www.eia.gov/oiaf/aeo/tablebrowser/

EIA (2013b). International Energy Outlook, US Energy Information Administration, US Department of Energy, Washington DC, http://www.eia.gov/forecasts/ieo/liquid_fuels.cfm

EIA (2013c). Energy Related Carbon Dioxide Emissions, 2012, US Energy Information Administration, US Department of Energy, Washington DC, http://www.eia.gov/environment/emissions/carbon/

EIA (2013d). "Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 ountries Outside the United States"

EIA (2014). Annual Energy Outlook (Early Release): with projections to 2040, US Energy Information Administration, US Department of Energy, Washington DC, http://www.eia.gov/oiaf/aeo/tablebrowser/

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

EPA (Sept. 2013). Standards of Performance for Greenhouse Gas Emissions from New Stationary Sources: Electric Utility Generating Units, US Environmental Protection Agency, http://www.regulations.gov/#%21documentDetail;D=EPA-HQ-OAR-2013-0495-0001

EPA (n.d.; accessed January 20th, 2014). Fuel Economy Regulations and Standards, US Environmental Protection Agency website http://www.epa.gov/fueleconomy/regulations.htm

"The Energy Collective" website (n.d.; accessed December 2013). "Friday Energy Facts: How much water does fracking shale gas consume?" http://theenergycollective.com/jessejenkins/205481/friday-energy-facts-how-much-water-does-fracking-shale-gas-consume)

Fatthou, B. and A. Sen (Sept. 2013). The Tight Oil Revolution in a Global Perspective, Oxford Energy Comment Paper, The Oxford Institute for Energy Studies.

Gény (2010), "Can unconventional gas be a game changer in European gas market?", Oxford Institute for Energy Studies, pp. 47.

Howarth, R. W., R. Santoro, and A. Ingraffea (2011). Methane and the greenhouse gas footprint of natural gas from shale formations. Climatic Change Letters, DOI: 10.1007/s10584-011-0061-5.

International Energy Agency (n.d.; accessed January 18th, 2014). IEA Online Statistics, IEA Projections, 2013, IEA/OECD, http://data.iea.org/ieastore/statslisting.asp

IEA (2012). World Energy Outlook 2012: Golden rules for a Golden Age of Gas, International Energy Agency, IEA/OECD, Paris http://www.iea.org/publications/freepublications/publication/WEO2012_GoldenRulesReport.pdf

IEA (2013). "World Energy Outlook 2013".

IHS (2012). *The economic and employment contributions of unconventional gas development in state economies* by IHS prepared for America's natural gas alliance.

IMF (2013). World Economic Outlook 2013, International Monetary Fund, Washington.

Pearson *et al.* (2012). "Unconventional Gas: Potential Energy Market Impacts in the European Union", JRC Scientific and Policy Reports.

Platts (2013). Can Shale Gas Save the Naptha Crackers? Platts Special Report, January 2013.

Pöyry Management Consulting and Cambridge Econometrics (2013). "Macroeconomic effects of european shale gas production. A report to the International Association of Oil and Gas Producers (OGP)".

Pwc (2012). "Shale gas : Reshaping the US chemicals industry".

Richter, P. (2013). From boom to bust? A critical look at US Shale gas projections, DIW Discussion Paper, DIW Berlin. http://www.diw.de/documents/publikationen/73/diw_01.c.432228.de/dp1338.pdf

World Economic Forum (2013). "The Global Competitveness Report 2013-2014".

Unconventional wisdom: an economic analysis of US shale gas and implications for the EU

Thomas Spencer, Oliver Sartor, Mathilde Mathieu (IDDRI)

IDDRI
SciencesPo.

IDDRI'S PUBLICATIONS

- Spencer, T., Colombier, M., Ribera, T. (2014). "Issues and options with regard to the renewables target in the context of the 2030 EU Climate and Energy Package", IDDRI, *Policy Briefs* N°04/14.
- Sartor, O., Colombier, M., Spencer, T. (2014). "Addressing industrial competitiveness concerns in the 2030 EU Climate and Energy Package", IDDRI, *Policy Briefs* N°03/14.
- Spencer, T., Colombier, M., Ribera, T. (2013). "The 2030 EU Climate and Energy Package: why and how?", IDDRI, *Policy Briefs* N°16/13.
- Spencer, T. (2013). "2B continued… The outcomes of the Warsaw Climate Conference and implications for Paris 2015", IDDRI, *Policy Briefs* N°15/13.
- Sartor, O., Spencer, T. (2013). "An Empirical Assessment of the Risk of Carbon Leakage in Poland", IDDRI, *Working Papers* N°08/13.
- Spencer, T., Stevenson, J. (2013). "EU Low-Carbon Investment and New Financial Sector Regulation: What Impacts and What Policy Response?", IDDRI, *Working Papers* N°05/13.

Publications available online at: www.iddri.org

www.iddri.org

The Institute for Sustainable Development and International Relations (IDDRI) is a Paris based non-profit policy research institute. Its objective is to develop and share key knowledge and tools for analysing and shedding light on the strategic issues of sustainable development from a global perspective.

Given the rising stakes of the issues posed by climate change and biodiversity loss, IDDRI provides stakeholders with input for their reflection on global governance, and also participates in work on reframing development pathways. A special effort has been made to develop a partnership network with emerging countries to better understand and share various perspectives on sustainable development issues and governance.

For more effective action, IDDRI operates with a network of partners from the private sector, academia, civil society and the public sector, not only in France and Europe but also internationally. As an independent policy research institute, IDDRI mobilises resources and expertise to disseminate the most relevant scientific ideas and research ahead of negotiations and decision-making processes. It applies a crosscutting approach to its work, which focuses on five threads: global governance, climate change, biodiversity, urban fabric, and agriculture.

IDDRI issues a range of own publications. With its *Working Papers* collection, it quickly circulates texts which are the responsibility of their authors; *Policy Briefs* summarize the ideas of scientific debates or issues under discussion in international forums and examine controversies; *Studies* go deeper into a specific topic. IDDRI also develops scientific and editorial partnerships: among others, *A Planet for Life. Sustainable Development in Action* is the result of collaboration with the French Development Agency (AFD) and The Energy and Resources Institute (TERI), and editorial partnership with Armand Colin for the French edition, *Regards sur la Terre.*

To learn more on IDDRI's publications and activities, visit www.iddri.org