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The UK's Global Gas Challenge

Research Report

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Research Report

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Executive Summary

Natural gas production in the UK peaked in 2000, and in 2004 it became a net importer. A decade later and the UK now imports about half of the natural gas that it consumes. The central thesis of the project on which this report is based is that as the UK's gas import dependence has grown, it has effectively been 'globalising' its gas security; consequently UK consumers are increasingly exposed to events in global gas markets.

Given the nature of the UK's gas balance, two arenas are of particular significance: developments in the Northwest European gas market (and the broader EU strategy of gas market integration) and developments in the global Liquefied Natural Gas (LNG) market. This report takes an interdisciplinary perspective, which marries energy security insights from politics and international relations, with detailed empirical understanding from energy studies and perspectives from economic geography that emphasise the spatial distribution of actors, networks and resource flows that comprise the global gas industry.

This report is divided into three sections. The first section reports on the development of a supply chain approach to global gas security; the second section reports on the findings of three case studies; and the final section deploys the supply chain approach to assess the challenges to UK gas security. The report concludes by considering the policy implications of our research and identifies areas for further research and monitoring.

The supply chain approach addresses the shortcomings of the current energy security literature that we consider to be fourfold: first, it tends to be too abstract and fails to engage with the specific characteristics of natural gas; second, it assumes that oil and gas are the same when it comes to assessing energy security; third, it is too state-centric and tends to ignore the crucial role of companies and other stakeholders involved in the gas markets; and fourth, it is overly concerned with upstream physical security of supply.

The supply chain approach addresses these failings by linking upstream concerns about security of supply to midstream issues relating to security of transportation (transit), processing and storage, and downstream concerns about security of gas demand.

Three case studies form the core of this project. They represent important issues that are likely to influence UK gas security over the short- to medium-term (5-15 years). The first case study examines the impact of US shale gas and considers both upstream security of supply impacts and downstream impacts. The case study reveals that without a single molecule of shale gas being exported from North America, the pace and scale of the US shale gas revolution is already having a significant impact on global gas markets.

The analysis identifies five stages over the past decade: first, the rapid increase in shale gas production in the US; second, the resulting loss of the US as a major destination for LNG imports; third, the redirection of US-bound LNG to European markets (in large part the UK) where it has increased competition, promoted hub-based trading and reduced the market share of Russian gas firm Gazprom; fourth, the subsequent re-routing of LNG away from Europe to Asian markets (principally Japan after the Fukushima nuclear incident); and fifth, most recently, the displacement of natural gas in Europe by cheaper coal imports – much of which has come from the US where coal consumption has fallen due to gas gaining market share in power generation.

The second case study looks at the UK's LNG supply chain and considers both upstream supply issues and midstream infrastructure issues. It was chosen because the expansion of LNG imports is one of the most significant aspects of the UK's newfound import dependence. The case study deploys a global production network (GPN) approach to examine the key networks and actors that shape and control the flow of LNG into the UK.



The research demonstrates how physical infrastructure for LNG supply has been developed in the UK. This infrastructure re-positions the UK with respect to established international trade in natural gas, extending the reach and diversity of UK gas supply beyond the North Sea and European continent to the Atlantic Basin and Middle East. It further shows how this infrastructure is embedded within international supply chains in ways that are significant for the security of supply.

The UK's LNG supply is dominated by Qatar, which means it is subject to the 'optimising' behaviour of Qatar Petroleum which places cargoes to ensure maximum income to the Qatari state. After an initial wave of supplies prompted by the loss of the US market, at present, only a modest amount of LNG is coming to the UK because of the surge in demand in Asia. However, there is the possibility that by the early 2020s there might be an over-supply of LNG and in such circumstances the UK is well placed to attract increased supplies. Whether or not it does so will depend on the price of gas on the European market.

The third case study explores the patterns of ownership and control over the European pipeline network. The research highlights the increasingly influential background role of the EU, in addition to the new layering of institutional actors as a result of expanding state regulation throughout the supply chain and the increasing concentration of power within a limited set of corporate bodies. At the same time, the nature of gas trading in the EU is moving away from long-term oil indexed contracts toward hub-based trading.

At present, the UK has its own hub – the National Balancing Point (NBP) – but as market integration gathers pace the UK gas market will increasingly be drawn into a larger Northwest European market. Thus, as the UK's domestic gas production continues to decline, it will be critical that we assess the implications of the evolution of a single European gas market for UK gas security.

The ongoing crisis in Ukraine and the associated gas dispute between Russia and Ukraine has once again heightened concern within the EU about its dependence on Russia. Although the UK does not directly import substantial amounts of Russian gas, Gazprom's trading activities in Europe are orchestrated from London and much of the gas that comes to the UK via the interconnectors is backfilled with supplies to Northwest Europe from Russia (largely through Nordstream).

In the light of the current situation in Ukraine, the European Commission and National Grid have conducted various stress tests to assess the likely impact of a shut down of Russian gas supplies for a prolonged period of time. These studies support the view that the UK has a resilient upstream supply situation and that, subject to market conditions, could draw additional supplies from Norway and the global LNG market. However, the latter would require a higher domestic gas price to attract LNG cargoes away from Asia. At the same time, the liberalised nature of the UK gas market means that in a gas supply emergency UK gas might flow to Europe if prices attracted it. Russia has reached an agreement to supply Ukraine through the winter of 2014/15, but in the longer term, the current crisis will have a lasting impact on European gas supply and demand.

The final substantive section of this report uses the supply chain approach to assess the UK's gas security. In the upstream there is the need for a more critical assessment of the future prospects of Norwegian gas supplies. There is a tendency to take the availability of Norwegian gas for granted, but as existing fields decline and the geography of production changes, so the accessibility of supplies will change and this may draw the UK into accessing Norwegian gas via the continental European market.

In recent years, the prospect of a UK shale gas revolution has been heralded as the solution to our security of supply concerns. However, given the current status of shale gas exploration, it is unlikely that domestic shale gas production will be a factor until the early 2020s and it is also unlikely to be of sufficient scale to significantly reduce the UK's import dependence or to have a significant impact on UK gas prices. In the midstream the focus is upon the need to ensure that the National Transmission System (NTS) is able to respond as the role of gas changes from base load to a back up for renewable intermittency. At the same time, should there be significant shale gas production this will require local connections to the NTS and may change the patterns of flow within the system.

The issue of gas storage remains the most controversial issue in the midstream. The UK only has 4.6 bcm of gas storage and total consumption in 2013 78 bcm. This is low by comparison with some other northern European countries that use significant amounts of gas. Planning approvals have been granted for a significant increase in storage capacity, but the industry maintains that there is no business case to invest and the current Government is adamant that it will not intervene. The unwillingness to invest in additional storage is symptomatic of a bigger problem in the downstream and that is the high level of uncertainty surrounding future gas demand in the UK.

The Government recognises the problem in its Gas Generation Strategy. The Electricity Market Reform capacity market is designed to ensure that sufficient new gas-fired generation is built; however, at present, existing Combined Cycle Gas Turbine (CCGT) stations are being mothballed and nobody is committing to new investment. This is a concern because if other areas of the UK's energy strategy are delayed (new nuclear) or fail to deliver (efficiency and demand reduction), then the UK may need more gas for longer than currently anticipated. As the Gas Generation Strategy illustrates, gas-fired power is also likely to be required to help balance an increasingly complex decarbonised electricity system, even if our legally binding emissions targets are met.

There is no doubting that UK gas security is now intimately linked to developments in both the European and global gas markets and that there is great uncertainty in both. Thus, what is required is a policy of 'gas by design' that plans now for the changing role of gas in the UK energy mix, thus ensuring future UK gas security.

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Introduction



Natural gas production on the UK Continental Shelf (UKCS) peaked in 2000, and in 2004 the UK¹ became a net importer. Since then the UK's import dependence has grown rapidly and in 2013 indigenous production was sufficient to meet only half of the UK's gas demand (DECC 2014). Thus, in less than a decade the UK has gone from being a net exporter of gas to importing half of its needs, and projections suggest that the level of import dependence will continue to increase unless there is a significant increase in indigenous production and/or a reduction in demand.

This report is based on the findings of a programme of research funded by UKERC Phase II, titled "The Geopolitical Economy of Global Gas Security and Governance: Implications for the UK". The central thesis of the project is that as the UK's gas import dependence has grown it has effectively been 'globalising' its gas security as UK consumers are increasingly exposed to events in global gas markets. The initial project had three aims: first, to develop a conceptual framework and methodology to analyse global gas security and governance; second, to identify the geopolitical drivers, actors, issues and risks shaping global gas security to the late 2020s; and, third, to assess the wider implications of our research findings for the UK's energy strategy and low carbon transition policy.

The project has been realised through five objectives, which were revised and became more focused as the research progressed:

- To develop a supply chain approach to global gas security
- To analyse the impact of US shale gas on UK gas security
- To analyse the development of the UK LNG supply chain
- To analyse the governance and control of the European pipeline network
- To assess the implications of our findings for UK energy strategy

This was always an ambitious project, but events in the global gas industry have made it all the more challenging. The original project proposal was submitted just days after the Great East Japan earthquake and the disaster at the Fukushima Daiichi nuclear power plant; and the project came to a conclusion just as the EU revisited its concerns about dependence on Russian gas imports in the light of Russia's annexation of Crimea. In between, the full significance of North American fossil abundance became apparent, as did related concerns about the impact of the cost of the low carbon energy transition on European economic competitiveness. In the UK, the possibility of domestic shale gas production has become a contentious issue, though there is very little prospect of significant commercial production until the 2020s. In all sorts of ways, these events have proved our central thesis that UK policy makers need to pay much greater attention to international developments, because in a globalising gas market events as far away as in Japan can have a major impact on how the UK sources its gas imports.

Just as there has been considerable movement in global gas markets during the project, the researchers themselves have all changed institutions. The project has been coordinated by Mike Bradshaw who started the project as Professor of Human Geography at the University of Leicester and ended it as Professor of Global Energy at Warwick Business School; the LNG elements of the project have been led by Gavin Bridge, who started the project at Manchester and ended it as Professor of Economic Geography at the University of Durham; the European gas pipeline governance elements of the project were led by Stefan Bouzarovski who started the project at Birmingham and ended it as Professor of Geography at Manchester; and finally, Jim Watson, who served as a consultant on the project, started it as Director of the Sussex Energy Group and ended it as Research Director at the UK Energy Research Director. The project's Research Assistant, Joseph Dutton is now a reporter on European Natural Gas with Argus Media.

¹ Although the term UK is used in this report, the focus of the project has been on GB; however, given that Northern Ireland is entirely dependent on GB for supplies of natural gas, the security challenges do relate to the wider UK. Furthermore, given that the Republic of Ireland obtains over 90 per cent of its natural gas from GB via two interconnectors, the project's findings have implications for the entire island.

The project also benefitted greatly from a partnership with the Gas Programme at the Oxford Institute of Energy Studies (OIES), and Professor Jonathan Stern and Howard Rogers have provided numerous valuable insights and a reality check when needed.

The project was divided into three phases. The first phase developed the supply chain approach. The second phase was organised around the completion of the three case studies. The final phase involved a consideration of the implications of our research findings for UK energy policy. The report employs the same structure as the project. After an initial examination of the changing status of UK gas security, the supply chain approach is presented. The following section reports on each of the three case studies. The final substantive section deploys the supply chain approach to assess the current status of UK gas security. The report concludes by considering the wider policy implications of our research.

The aim of this report is to present our work to a wide audience, during the project we organised two conferences, including a two-day conference last November on the 'UK's Global Gas Challenge' that was organised by The Meeting Place. The project has also contributed to UKERC's Flagship Project on Global Energy (Ekins and Watson 2014) and to the forthcoming book *Global Energy: Issues, Potentials and Policy Implications*, which will be published by Oxford University Press in 2014 (Ekins *et al.* 2014). Further academic articles are also in preparation and this report draws on all this material.

The UK's Global Gas Challenge



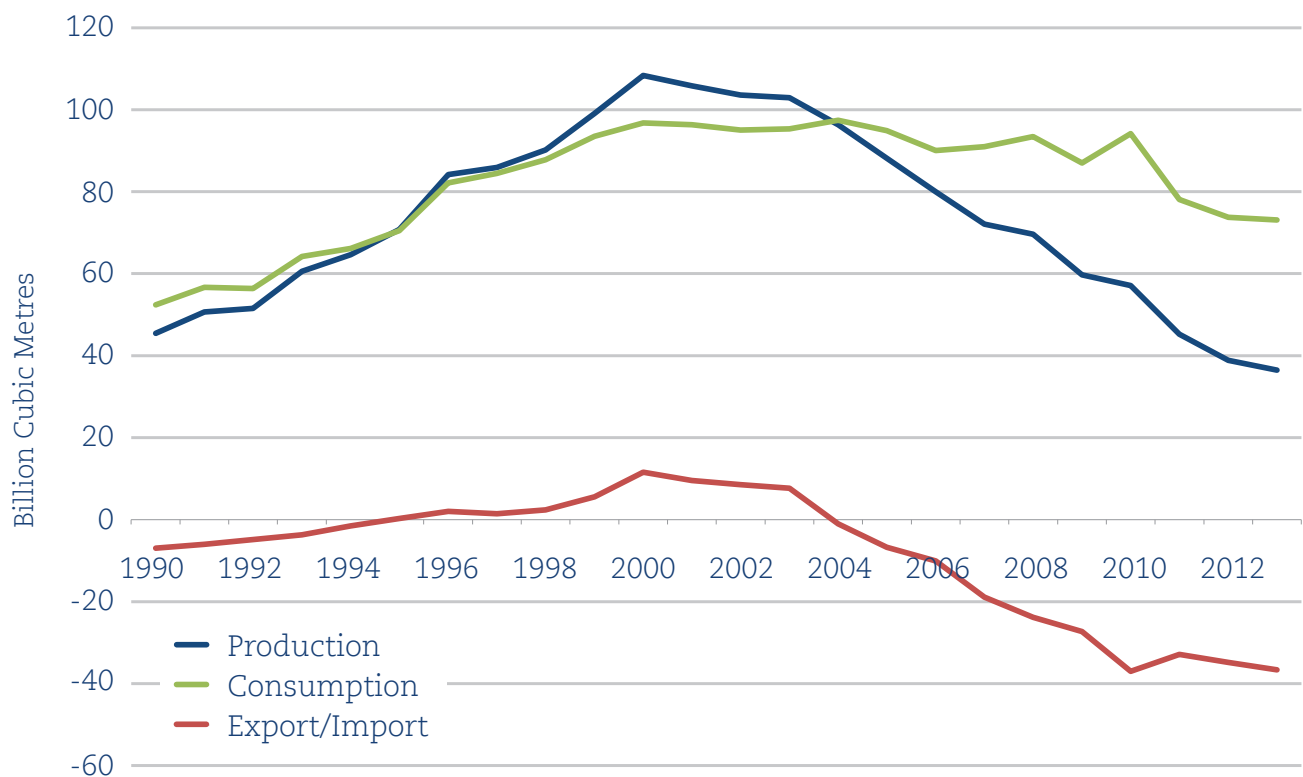
The story of the rise and fall of UK natural gas production is now familiar (this section draws on Bradshaw 2012). Prior to the discovery of natural gas offshore on the UK Continental Shelf (UKCS), gas in the UK was produced from coal and was known as 'town gas.' Offshore production of natural gas began in July 1967 and by 1972 it exceeded the supply of town gas.

In the 1970s and 1980s there was a nationwide conversion programme and expansion of the natural gas pipeline network and gas consumption grew rapidly in households and industry (a similar process of natural gas replacing town gas took place in Northern Ireland after the subsea interconnector from Scotland was commissioned in 1996). However, it was not until 1991 that it was permitted to use natural gas to generate electricity. The development of the Combined Cycle Gas Turbine (CCGT), combined with an abundant supply of natural gas from the North Sea, spurred a 'dash for gas' as gas power generation replaced coal- and oil-fired capacity (See Figure 1).

In 1970 coal accounted for 47.1 per cent of total primary energy consumption in the UK and gas 5.4 per cent, by 2010 the roles had reversed as coal had fallen to 14.8 per cent and gas had increased its share to 42.7 per cent. In recent years, the slow down of the economy has dampened demand for gas and there has been a relative resurgence in the role of coal in UK power generation at the expense of natural gas. Finally, the growth of renewable power generation is also impacting on gas demand.

In the UK natural gas consumption is divided fairly evenly between three sectors: power generation, industry and households. It is therefore important not to overstate the influence of the power generation sector on future gas demand. On an annual basis, the seasonality of natural gas demand is a result of its dominant role in space heating and UK gas demand is susceptible to significant year-on-year variation due to weather. At present, the gas industry in the UK must deal with a continuing decline in UKCS production and demand destruction from cheap coal and growing renewable generation.

Figure 1. UK Natural Gas Trends 1990-2012



Source: Data from BP 2014a

The UK's Gas Balance

The UK has a well-developed infrastructure that enables both the import and export of natural gas. The National Transmission System (NTS), that is owned and operated by National Grid, connects to pipelines that supply gas from both the UKCS and the Norwegian Continental Shelf (NCS) and there is one interconnector to Northern Ireland and two interconnectors that supply gas to Ireland (the Republic of Ireland and Northern Ireland are 93 per cent dependent on Great Britain for their gas supply). The Corrib gas field that is being developed by Shell offshore of the west coast of Ireland should come online in late 2014, after much delay. This could reduce Ireland's import dependence by as much as 30 per cent. DECC (2014) figures suggest that exports to the Republic of Ireland were 4.9 bcm (gas accounted for 49 per cent of power generation in Ireland in 2012). Longer term, further development of Ireland's offshore potential could change its role as an importer of UK gas. At present, the interconnectors have no physical reverse flow capacity.

There are two interconnectors to the continental European gas market. The Balgzand-Bacton Line (BBL) from the Netherlands that opened in December 2006 and has a capacity of 19.5 bcm and the Interconnector UK (IUK) from Belgium that started operations in 1998, a two-way pipeline with an import capacity to the UK of up to 26.9 bcm, or export capacity of up to 20bcm to Belgium (IEA 2014). Both pipelines provide physical flows from the continent to the UK, but only the IUK is physically reversible enabling gas to be exported from the UK to Europe. As a result of this capability, the UK has continued to export gas to Europe even as domestic production has declined.

As discussed below, in recent years there has been a substantial investment in LNG import capacity in the UK and there are now three operating LNG terminals: Isle of Grain in Essex (capacity 21 bcm) and South Hook LNG (capacity 21 bcm) and Dragon LNG (capacity 6 bcm) at Milford Haven in Wales. According to DECC and Ofgem's Statutory Security of Supply Report (2013), the UK has 54 bcm/y of import capacity from pipelines connecting to Norway; 46 bcm/y from capacity connected to continental Europe and 53 bcm/y from LNG terminals (this includes the Teesside Gasport that is not currently operational). This means that the UK total import capacity is 153 bcm, according to BP (2014) data; in 2013 total UK gas consumption was 73.1 bcm. This suggests a sizeable capacity

margin. However, there has been considerable variation in the load on that capacity and some elements of the infrastructure seem more prone to technical failure.

The final component in the UK's gas balance is storage, both in dedicated storage facilities and at LNG terminals. There are two types of dedicated storage: seasonal storage that is filled in summer (when gas is cheaper) and withdrawn when prices are higher in the winter (though the spread has declined, which has undermined the commercial case for investment in additional storage capacity). The Rough storage facility, which is a depleted offshore gas field, is an example of such storage. The other type of storage is fast-cycle storage that can be filled and refilled throughout the year in response to short-term market conditions. The UK currently has less than 5 bcm of storage capacity (DECC 2010) and the question as to whether or not the UK has sufficient storage and storage of the right kind is raised later in this report.

Table 1 shows the changing scale and geography of UK gas imports since 2000. The infrastructure described above supports three distinct 'vectors': pipeline imports from Norway, pipeline imports from continental Europe and LNG imports. The gas flows quantified here demonstrate how over a short period of time the UK has become increasingly drawn into both the continental European gas market and global LNG trade. In fact, the UK's gas security has been dominated by two trading relationships: pipeline gas from Norway and LNG from Qatar (see Table 1). More recently, Norwegian gas has re-established itself as the dominant source of supply. The reason for the decline in UK LNG imports is discussed later.

Gas imports via the two interconnectors are reported as coming from either the Netherlands (BBL) – which is a significant gas producer – or Belgium (IUK), which is not. There is no way of knowing where exactly that gas originated from, but it is back filled by imports from Norway, Russia and North Africa (Algeria and Libya). According to the European Commission (2014), in 2013 the EU imported 39 per cent of its gas by volume from Russia, 33 per cent from Norway and 22 per cent from North Africa. The vexed question of how much Russian gas the UK imports is difficult to answer. Gazprom's own data show an increasing amount of gas being exported to the UK, from 3.8 bcm in 2005 to an estimated 12.5 bcm in 2013; however, as Stern (2014) explains, most of this gas is exported from elsewhere rather than physically

Table 1. The Geography of UK Gas Imports: 2000-2013 (Million Cubic Metres)

Year	Pipeline Imports			Liquefied Natural Gas Imports		Total Gas Imports	Import Dependence
	Belgium	Netherlands	Norway	Qatar	Total LNG		
2000	270	-	1,031	-	-	1,301	1.4
2001	367	-	1,158	-	-	1,525	1.7
2002	611	-	3,392	-	-	4,003	3.9
2003	401	-	6,327	-	-	6,728	5.3
2004	2,339	-	8,460	-	-	10,799	9.1
2005	2,203	-	11,305	-	500	14,008	11.5
2006	2,788	840	14,003	71	3,442	21,073	17.2
2007	593	7,107	20,339	247	1,403	29,442	27.8
2008	1,127	8,440	25,528	-	820	35,915	34.3
2009	728	6,475	23,478	5,627	10,127	40,808	37.3
2010	1,245	8,164	25,026	14,565	18,578	53,012	47.6
2011	368	6,447	21,203	21,153	24,827	52,846	55.0
2012	1,310	7,297	26,832	13,335	13,667	49,105	56.4
2013	3,307	7,804	27,866	8,607	9,278	48,225	57.8
% Total Imports in 2013	6.9	16.2	57.7	17.8	19.2	100	n/a

The import dependence data are from National Grid and show the percentage of domestic demand that is met from imports. Note that the National Grid data report a higher level of import dependence than DECC, this maybe because they do not account for gas exports.

Source: Data from DECC 2014 and National Grid 2014a

sourced from Siberia as Gazprom actively trades on European markets (Gazprom Marketing & Trading is located in London). For example, Centrica signed a deal with Gazprom in 2012 to purchase 2.3 bcm of gas a year over a three-year period from late 2014, but even it does not know where that gas will come from. In any event, it is safe to assume, for the moment at least, that the UK is not dependent to any degree on Russian gas imports. In fact, we would argue that UK gas security has benefited from the construction of Nord Stream (which delivers directly from Russia to Germany via a subsea pipeline through the Baltic Sea) as this has increased the liquidity of the NW European gas market (see section 4.3).

Interconnection means that the UK is not immune to the impact of disruptions of Russian gas supplies to continental Europe and previous events triggered price increases in the UK. However, the 2009 gas crisis resulted in UK storage being emptied to sell gas in continental Europe. This highlights the fact that even in a gas emergency in the UK, the flow of gas is determined by the

price of gas in the UK relative to continental hub prices. For an assessment of the coming winter see National Grid's (2014b) winter outlook.

While the existing physical infrastructure clearly enables gas imports from a variety of sources, which is rightly considered a source of resilience; the open nature of the UK gas market means that it is exposed changes in both the NW European gas market and the global LNG market. Here it is useful to distinguish, as DECC (2012) does in its Energy Security Strategy, between physical security of supply and price security of supply. The diversity of the UK's gas balance suggests that physical security of supply should not be a challenge – though there is always the possibility of short-term technical disruptions – it is price security that presents the challenge. In short, the key question is will the UK gas market be able to attract sufficient gas to the UK at a price that is acceptable to UK consumers? The domestic UK gas price is determined by the National Balancing Point (NBP) and results from gas-to-gas competition in Europe's most liquid market (Heather 2010).

The NBP reflects UK market conditions, but that market is increasingly connected to markets in NW Europe, and in competition with other trading hubs, such as the Title Transfer Facility (TTF) in the Netherlands (Petrovich 2013). As a result of the EU's Third Internal Energy Market Package, there are major changes underway in European gas markets that will be accelerated by current events in Ukraine and that will have a significant impact on the status of the NBP and the way that gas is traded in the UK.

This research project paid particular attention to the development of the UK's LNG supply chain because it was new and increasingly significant. We did not examine the UK's relationship with Norway in any detail. Just as the UK's production has peaked and declined, so Norwegian production will inevitably fall. As existing fields decline, new production may not be in such close proximity to the UK and may require greater involvement in the NW European market to attract Norwegian gas. The rise of hub-based trading in NW Europe and Statoil's shift in favour of hub-based contracts will mean that in the future the destination of Norwegian gas will be determined by wider market conditions in NW Europe. Equally, if Norwegian production on the continental shelf were to decline more quickly than anticipated, this would require higher imports into the UK via the interconnectors, which would most likely originate in Russia. This suggests that a critical evaluation of the UK's dependence on Norwegian gas would be timely.

In sum, we would agree with DECC/OFGEM (2013, 8) in their assessment of gas security:

“Great Britain has the most liquid and one of the largest gas markets in Europe with extensive import infrastructure and a diverse range of gas supply sources. GB is therefore well placed to manage gas supply risks.

In 2012, around half of UK gas demand was supplied through UK production, and GB's import infrastructure has increased five-fold over the past decade, reflecting the predicted decline from domestic sources. As a result, GB has increased the diversity of supply sources and routes to market, and if necessary, could meet nearly double (189 per cent) its annual demand from imports alone. This flexibility means that if there is a problem with one source there are other sources to fall back on. It also allows gas suppliers to source gas from wherever is cheapest. Currently, GB can obtain gas from North Sea producers, via pipelines from Norway and the rest of Europe, via shipments of Liquefied Natural Gas (LNG) from further afield, or from gas storage.”

However, a more integrated approach is required to identify the key actors and interactions that govern the gas supply chain from upstream security of supply to downstream security of demand. Furthermore, there are limits and costs to the flexibility of supply that is described above and these need to be better understood. This is the purpose of our supply chain approach to gas security.

A Supply Chain Approach to Global Gas Security



This project develops a geopolitical economy approach to global gas security. This approach marries insights from politics and international relations in relation to energy security, to the detailed empirical understanding that can be found in energy studies – that is represented by the exemplary research of the Gas Programme at OIES – and the concerns of geography with the territoriality of energy infrastructures and the spatiality of actors, networks and flows that comprise the global gas industry.

The Failings of Existing Research

We have developed a supply chain approach to address the shortcomings of the energy security literature that we consider to be fourfold: first; the literature is often too abstract and fails to take account of the material specificities of natural gas production and trade. Because natural gas is a high volume, low value commodity and is difficult and costly to transport, there is no global gas market, but a complex network of interconnected regional and national markets, with different structures for pipeline and LNG trade (Stevens 2010). The nature of price discovery and contracting in natural gas is also far more complex than the oil sector (for an extensive analysis of pricing of internationally traded gas see Stern 2012). Second, as a result of the first failing, the literature tends to assume that oil and gas are the same when it comes to assessing energy security (in support of this criticism, see Shaffer 2013). A third failing is that the analysis of energy security tends to be too state-centric and pays insufficient attention to the role of companies and other stakeholders involved in gas governance. Though, it does seem the case that governments are more involved in the gas industry than other energy sectors, with the exception of nuclear power, and this has much to do with the capital intensity of the infrastructure and reliance on inflexible pipeline networks to transport gas and deliver it to consumers. In many cases states own or control national gas companies, but international trade in natural gas is largely orchestrated by companies and through market structures. It is not states that trade with one another, but companies through market structures that are regulated by states and other bodies such as the European Union. The fact that the trade data are reported by state means that it is all too easy to ignore the complex network of actors that participates in that trade. This project has sought to populate those networks with the companies involved in securing natural gas for the UK.

A final failing of the literature is that it is overly concerned with upstream security of supply as the major challenge to gas security. Furthermore, there is too much concern with the geopolitical manipulation of natural gas trade to support the foreign policy goals of exporting countries. This is not to down play the significance of geopolitics in Russian gas trade with Europe, but the fact is that the vast majority of disruptions to supply are technical in nature (Skea *et al.* 2012). For example, the most significant supply disruptions in the UK have come from the 2006 fire at the Rough storage facility and the Elgin gas leak in March 2012.

A Supply Chain Approach

An appreciation of the nature of the natural gas supply chain provides the starting point for our analysis. Figure 2 presents a simplified version of the natural gas supply chain, which also links the key stages in the supply chain – the upstream, midstream and downstream – with the energy security concerns of: security of supply, security of transportation (transit) and security of demand.

From a gas governance perspective, the supply chain approach also provides a framework for identifying the various actors and interactions that enable the material flow of gas from the wellhead to the consumer, be that industry, households or power generators. We would argue that for gas-importing countries an understanding of the multi-scalar and transnational nature of the supply chain is essential to assessing gas security. Furthermore, many of the measures that can be taken to improve the resilience of the supply chain are located in the midstream and downstream in the domestic market where national regulators and policy makers can make a difference, rather than in the upstream that is largely beyond the influence of gas importing countries (the EU's Third Package is just such a response).

Table 2 provides a generic framework to link the material and technical elements of the supply chain and the various dimensions and issues that influence gas security at both an international and national scale. At the global scale upstream issues relate to access to reserves and the availability of investment and technology to provide sufficient production to meet global demand (see Bradshaw *et al.* 2014a). It should be remembered that the majority of natural gas is still consumed within the country where it is produced. In 2013 only 30.6 per cent of global gas production was internationally traded and of that 68.6 per cent was as pipeline gas and 31.4 per cent as LNG (BP 2014a).

Figure 2. The Natural Gas Supply Chain

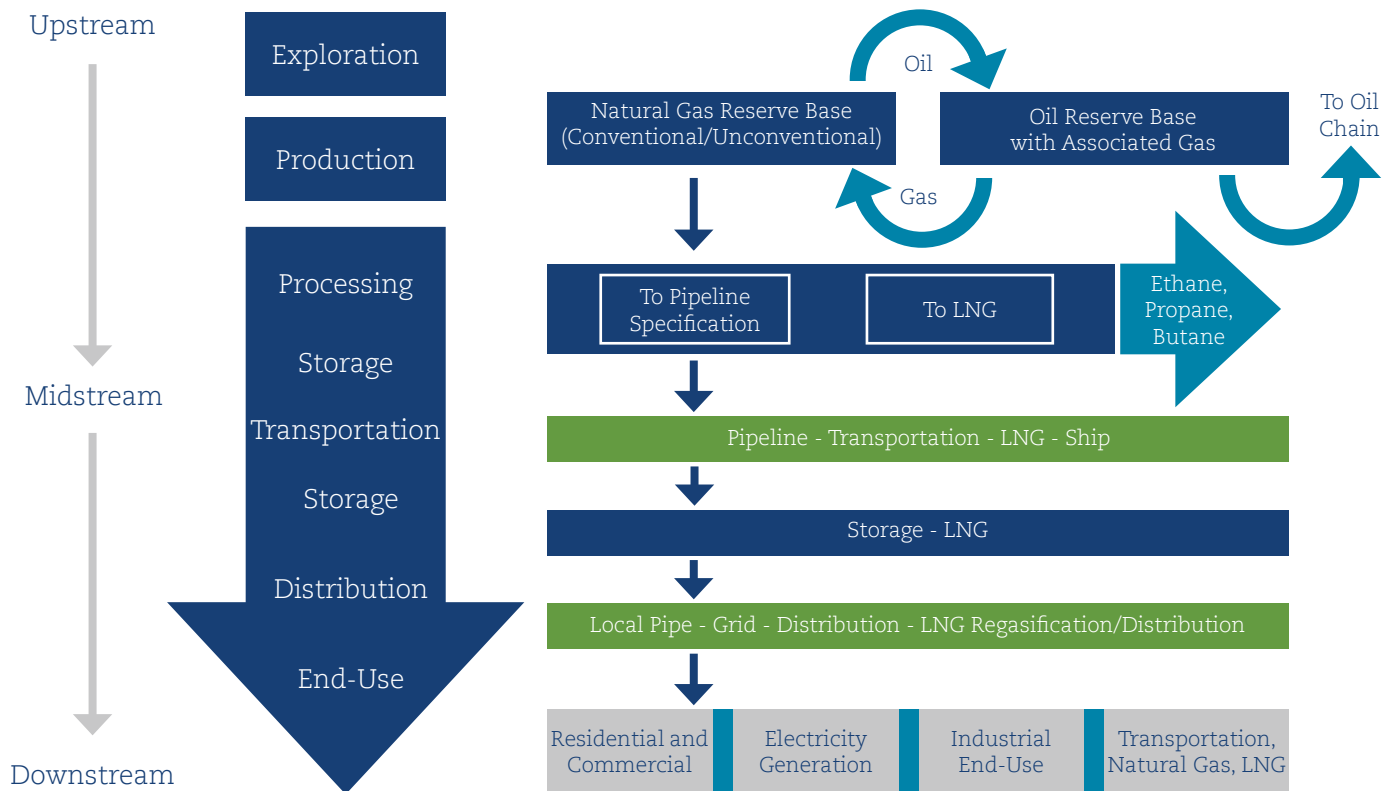


Table 2. A Supply Chain Approach to Gas Security

	Energy Security	Dimensions	Issues
Upstream	Security of Supply	<ul style="list-style-type: none"> Resource Base Technology Investment 	<ul style="list-style-type: none"> Extent of proven reserves Access to reserves for investors Access to investment to develop proven reserves Availability with existing technology and prevailing price
Midstream	Security of Transport (Transit)	<ul style="list-style-type: none"> Processing Transportation Storage 	<ul style="list-style-type: none"> Processing of associated gases Pipeline network Compressor stations Liquefaction facilities LNG Shipping Regasification facilities Storage Interconnectors
Downstream	Security of Demand	<ul style="list-style-type: none"> Power generation Industrial use Domestic use Transport 	<ul style="list-style-type: none"> Role of gas in the energy mix Price formation Price competitiveness Contract structure Energy policy Carbon tax/Cap & Trade Carbon Capture & Storage

For gas importing states security of supply issues relate to securing reliable access to gas at a price that is affordable to domestic customers. Issues in the midstream relate the processing, transporting and distributing natural gas.

Shaffer (2013) has conducted an analysis of the factors that affect the stability of supply of natural gas between states and concluded that: 'projects involving transit states are inherently less stable than those that are direct between supplier and consumer.' The analysis also shows that states 'usually curtail exports of gas when it entails shortages at home.' The issue of transit states is clearly a major concern for EU gas security, but the proposed 'Southern Corridor' will traverse more state boundaries than current Russian export pipelines, suggesting that it will do little to improve transit security. The analysis also demonstrates the logic of Gazprom constructing the Nordstream pipeline to Germany. In the downstream, concern is for security of demand. At a global scale this is a concern for gas-exporting countries that wish to receive a fair price for their resources and the certainty that there will be sufficient a market to warrant investing in production and export infrastructure.

The traditional LNG investment model requires that investors sign contacts with future customers often before they reach a final investment decision. Historically, this has served to constrain the construction of liquefaction capacity. Within national gas markets the concerns here relate to a sufficiency of demand to warrant investment in the midstream infrastructure and in power generating capacity. It should also be noted that for technical reasons the loss of domestic gas supply is much harder to recover from than an electricity outage. Stevens (2013) reports that in the early 1980s British Gas estimated that if the gas supply to Birmingham were cut off, it would take three years to reconnect all customers. This is because a gas engineer is required to reconnect each gas-burning appliance. Thus, a loss of supply to domestic customers is to be avoided at all costs. For this reason, many states use demand management – such as dual fuel contracts with large industrial customers and fuel switching in the power generation sector – to reduce demand when faced with a gas supply emergency. There is not the space here to consider all these issues in any detail; a later section of the report deploys the supply chain approach to assess the issues that are currently influencing UK gas security.

Case Studies



Three case studies form the core of this project. They were chosen as representing significant issues that would influence UK gas security over the short- to medium term (5-15 years). The first case study on the impact of US shale gas on UK gas security deals with both upstream security of supply concerns and security of demand concerns; the second case study of the UK's LNG supply chain considers both upstream supply issues and midstream infrastructure issues; the final case study on the governance and control of the European gas pipeline system focuses on a key issue that arises from the UK's increased integration into the continental European gas market and also illustrates how issues in the midstream impact on gas security.

Each of the case studies develops its own conceptual approach: the shale gas case study employs a more traditional energy studies approach and stresses the connected and unpredictable consequences of the rapid expansion of domestic unconventional gas production in the US; the LNG case study uses the Global Production Network (GPN) approach to examine the key networks and actors that shape and control the flow of LNG into the UK; the final case uses social network mapping techniques to chart the patterns of ownership and control over the European pipeline network.

4.1 The Impact of US Shale Gas on UK Gas Security

In less than a decade the United States (US) has gone from preparing for substantial LNG imports to planning for the development of LNG exports (this section draws on Bradshaw *et al.* 2014a). However, it is important to understand that the so-called 'US Shale Gas Revolution' has taken decades to develop. The industry in the US likes to proclaim the rapid development of unconventional oil and gas production as an exemplar of the role of small and medium-sized operators and the benefits of the free market system; but, this is only the recent part of the story and the reality is that the US Government played a key role in the 1970s and 1980s by supporting basic scientific research and the development of technologies for hydraulic fracturing, and also by providing tax incentives to promote development (Stevens 2012).

The key upstream technologies that facilitated the shale gas sector were a combination of those developed specifically for shale and others that were innovations for the oil and gas industry in



general and subsequently applied to shale plays. A 2001 National Research Council (2001) study listed the most significant technologies as horizontal drilling and hydraulic fracturing, with 3D seismic imaging making a general contribution to the upstream sector. Both horizontal drilling and hydraulic fracturing are proven technologies in the conventional oil and gas industry.

In the US it is commonplace to talk about high volume Hydraulic Fracturing (HVHF) in relation to shale gas to stress the high volumes of water used to produce shale gas. Mitchell Energy first drilled horizontal wells in the Barnett shale in Texas in 1991, and following a period of drilling process improvement, falling upstream costs and rising domestic gas prices, the number of horizontally drilled production wells in the Barnett grew from just 1 in 2000 to 2,091 in 2008. Mitchell Energy also developed hydraulic fracturing methods in the Barnett shale with 'frack zones' up to 1,500 ft. Devon Energy purchased Mitchell Energy in 2002 and the rest is history as a combination of conditions in the US enabled the rapid diffusion and deployment of these technologies to develop shale gas production. It was not our aim to examine the US shale gas revolution in detail (see Trembath *et al.* 2012), instead we are concerned with impact that the rapid and dramatic change of fortunes in the US is having on the global gas industry and in particular on gas security in the UK and Europe.

Even without a single molecule of shale gas being exported by North America (to include Canada and Mexico), the pace and scale of the US shale gas revolution is already having a significant impact on global gas markets. In our analysis we have identified five stages over the past decade: first, the rapid increase in shale gas production in the US; second, the resulting loss of the US as a major destination for LNG imports; third,

the redirection of US-bound LNG to European markets (in large part the UK) where it increased competition, promoted hub-based trading and reduced Gazprom's market share; fourth, post-Fukushima, the subsequent re-routing of LNG away from Europe to Asian markets (principally Japan); and fifth, most recently, the displacement of natural gas in Europe by cheaper coal imports – much of which has come from the US where coal consumption has fallen due to gas gaining market share in power generation.

However, the situation remains highly fluid and in 2013-14 the US power sector switched back to coal as a cold winter forced up gas prices and in the EU both gas and coal lost out to growing renewable generation in the power sector (Rühl 2014). The low price of carbon on the European Trading System (ETS) is also part of the story, as it is not penalising the higher carbon content of coal. The return of coal to Europe is likely to be short lived as both the Large Combustion Plant Directive (LCPD) and the Industrial Emissions Directive that will follow it will result in a large amount of coal-fired power generating capacity, and some oil and gas-fired capacity, having to close. The net result should be renewed demand for gas-fired power generation (some of which is currently mothballed), which in turn begs the question where will Europe source its gas from, should there be a recovery in demand?

Data for 2013 suggest that as LNG left Europe for Asia, Gazprom stepped into the gap and increased its market share (in the UK increased imports from Norway filled the gap). Gazprom's increase in market share was also because it bowed to consumer pressure and agreed discounts within many of its long-term supply contracts (Mitrova 2014). Most recently, the crisis in Ukraine has stiffened the EU's resolve to reduce its dependence on Russian pipeline gas imports, but the harsh reality is that there is very little that can be done in the short-term and the longer-term options, such as the Southern Corridor and LNG imports from North America may prove to be just as insecure and/or more costly. It is also the case that European companies are locked into long-term supply contracts with Gazprom that last well into the 2020s and beyond (Stern 2014). Furthermore, there is significant variation between member states in terms of their reliance on Russian gas, with the Baltic States and southeast Europe being particularly vulnerable, and the latter are particularly exposed to transit disruptions in Ukraine.

There are hopes that domestic unconventional gas production in the EU may provide an alternative source of supply. The crisis in Ukraine may result in a more positive attitude towards shale gas development in the EU, particularly in Poland and the UK; and the Ukraine itself has significant shale gas potential, though investors such as Shell and Chevron are understandably nervous about the investment environment. In June 2014, Shell was forced to suspend drilling activities over concerns about the safety of its staff. The bottom line is that for all sorts of reasons we are not going to see an US-style shale gas revolution in Europe and significant commercial production is unlikely until the 2020s and possibly into the 2030s.

The National Grid's (2014a) UK Future Energy Scenarios demonstrates both the high level of uncertainty and the degree of caution required in relation to future shale gas production in this UK. Their projections range from no successful production in their 'No Progression' Scenario to a peak of 32 bcm/year in the early 2030s in their 'Low Carbon Life' scenario. Whatever the eventual outcome, the reality is that for the remainder of this decade Europe will be unable to reduce its reliance on Russian gas imports, especially as indigenous production continues to decline and the global LNG market remains tight. This is a situation that will become even more challenging should European (and UK) gas demand rebound and start to grow again.

The US shale gas revolution has already had a significant impact on the pricing of internationally traded gas, again without any physical export capacity (this section is based on Bradshaw *et al.* 2014b). The pace and scale of change in the US is difficult to underestimate. A decade ago the US Energy Information Administration (EIA) was not reporting statistics on shale gas production and they were projecting that the US would account for 23 per cent of the global LNG market by 2010 with imports in excess of 169 bcm (EIA 2005). Instead, domestic shale gas production grew from 11 bcm in 2005 to 226 bcm by 2011 and in 2012 it reached 265 bcm – 39 per cent of all US gas production (EIA 2013a). According to the 2014 Annual Energy Outlook Reference Case, shale gas will account for 53 per cent of total gas production in 2040 with production more than double its current level at 554 bcm (EIA 2014). This has had a dramatic impact on the utilisation of US LNG import infrastructure.

In 2011 installed US LNG regasification capacity stood at 25 per cent of the country's natural gas demand, but only 13 per cent of that capacity was utilised, falling to 3 per cent in 2012. As recently as 2008 companies were still investing in LNG import terminals.

The North American gas market is currently an almost self-contained system where gas prices are determined by supply and demand. In recent years a combination of depressed demand due to economic recession and increased supply has resulted in falling prices for natural gas. The Henry-Hub wholesale price (the benchmark gas price in the US) fell from \$12.69 per million British thermal unit (MMBtu) in June 2008 to a 10-year low of \$1.82 MMBtu in April 2012. It rebounded to over \$3.72 MMBtu in 2013 and increased in early 2014 as a result of the very cold winter. Nonetheless, prices are expected to remain historically low for some time to come.

The EIA (2014) has developed five scenarios for the Henry-Hub price through to 2040 and four of the five show the price still below \$6.00 MMBtu in the late 2020s and the Reference Case suggests that the price will be below \$8.00 MMBtu in 2040, well below the highs of late last decade. The price at present is so low that only gas production that benefits from associated natural gas liquids (so-called wet gas) or that which is produced along with tight oil is profitable to produce on a full-cycle basis (i.e. all costs remunerated). A higher price is required for so-called 'dry gas' to come back into production. Here gas exports have a role to play, as they would allow production to increase because linking the North American market to global markets might increase domestic prices sufficiently to allow dry gas production to return.

Analysis of the impact of exports suggests that the resulting domestic price in the US would still be significantly lower than that paid in Europe and Asia, and would bring economic and balance-of-payments gains to the US economy (Ebinger *et al.* 2012). At present, the US government is considering 43 applications for LNG export licences totalling 304 mtpa of LNG (total LNG deliveries in 2013 were about 240mt), but only 6 have received approval to export to non-free trade agreement countries (which includes Japan and the EU) and four now have the necessary environmental approvals and one is under construction – Chermiere Energy's Sabine Pass project. Three others now have the necessary approvals to start constructions: the Freeport LNG Development project, Cameron LNG

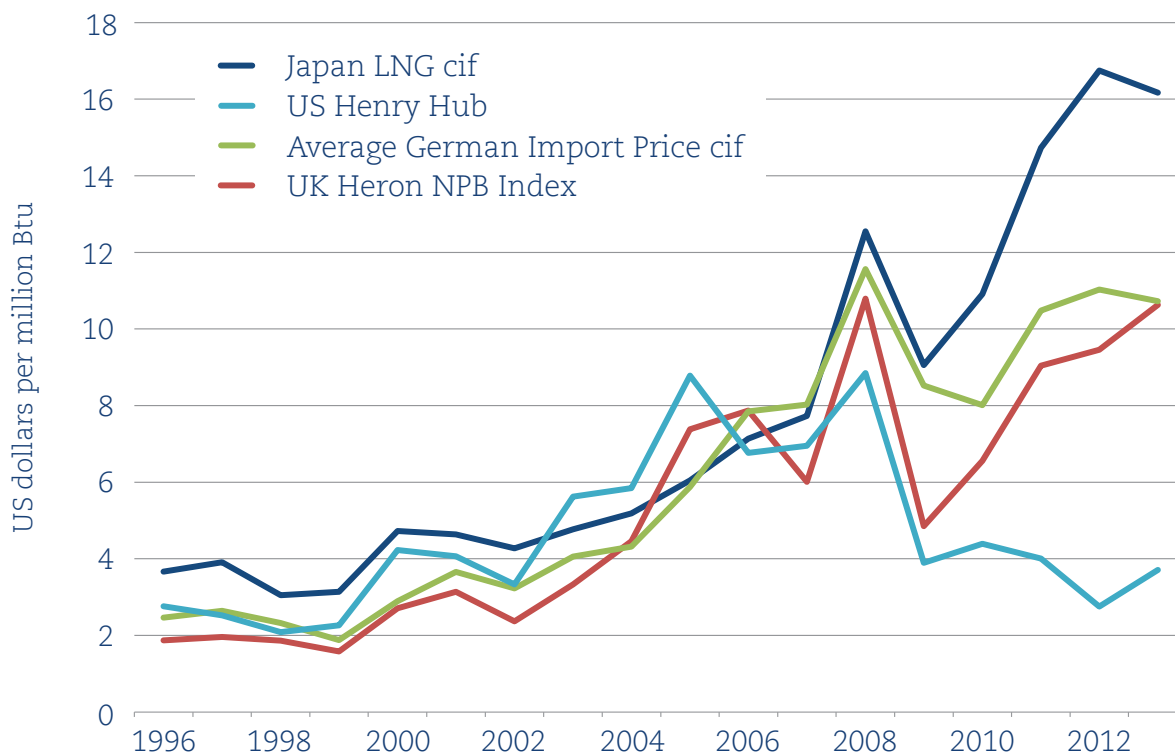
and Cove Point LNG. A further fourteen projects are pending approval, with more expected.

The US Department of Energy recently changed the process to require environmental approvals ahead of requesting an export licence. This move aims to raise the costs of applying for approval to stop speculative applications and speed up approvals; even then many approved projects will fail on financial and/or environmental grounds. Most recently the US House of Representatives passed a Bill that would require the Department of Energy to reach a final decision on a proposal within the 30 days after the Federal Energy Regulatory Commission (FERC) has completed its environmental analysis of an LNG project. The Bill has yet to be approved by the US Senate, but the concern now is that further delays may mean that US LNG projects will fail to secure buyers in an increasingly competitive market.

There is a further 100 mtpa plus of projects being considered in Canada. Just how much new LNG export capacity will be built in North America is impossible to know, but already the possibility of exports linked to Henry-Hub prices is impacting on the global LNG market. Figure 3 shows the recent dynamics of gas prices in the key regional markets – the US, Europe (UK and Germany) and Japan. The Post-2009 divergence reflects the different market conditions (and price formation structures) prevalent in the US, Europe and Japan. As discussed above, the US price is by far the lowest resulting from gas-to-gas competition in a more or less self-contained market that is over-supplied. Two European prices are shown, an average German import price that is dominated by the cost of oil-indexed pipeline supplies from Russia and North Africa and the NBP price in the UK that is linked to European and global LNG prices.

The Japanese price is an average of the price paid for LNG deliveries that are dominated by crude oil-indexed, long-term contracts. The impact of Fukushima is clear to see with Japan having to access additional short-term LNG cargoes post March 2011. The share of LNG in Japanese power generation increased from 29.3 per cent in 2010 to 42.5 per cent in 2012 (Okuya 2014); accordingly Japan's LNG imports increased 24 per cent between 2010 and 2012, reaching 119.0 bcm and falling slightly to 118.8 bcm in 2013 (BP 2014a). Imports have likely peaked for the moment as Japan's gas power generation is now operating at full capacity and there is the possibility that some nuclear power capacity will come back online.

Figure 3. Trends in Regional Gas Prices: 1996-2013 (\$MMBtu)



Source: BP 2014a

Japan has had to pay a high price to attract the necessary gas to meet demand and in 2012 alone spent \$68.98 billion on LNG imports making a major contribution to Japan's trade deficit. In such a context, it is not surprising that Japanese utility companies (and other LNG consumers in Asia) see the prospect of Henry-Hub based supply as a means of reducing prices. The IEA's Medium-Term Gas Market Report 2014 (IEA 2014) reports the gap between Asian and US gas prices as being \$12 MMBtu in 2013. The IEA talks of an 'Asian price stalemate' whereby Asian buyers no longer ready to pay record oil-linked prices are seeking more flexible contracts and pricing mechanisms.

To promote dialogue, the Japanese Government has hosted two LNG Producer-Consumer Conferences, with a third planned for November 2014. The problem is that investors report that future additions to LNG supply are likely to be increasingly expensive. Thus, LNG exporters are looking for a higher price and Asia importers are looking for a lower price. The current standoff is a result of the perception that US Henry-Hub projects might offer a cheaper alternative to oil indexation (Rogers and Stern 2014), prospective North American projects are also seeking long-term contracts to make them financially viable;

but they are all selling capacity on a tolling basis with customers buying the option to use the liquefaction facility. This suggests, the US LNG will introduce a degree of flexibility into the LNG market that will have wide-reaching implications.

As we move forward we will have four producing regions competing for the Asia LNG market: North America, Australia, Russia and East Africa. Thus, early next decade, there is the possibility of the current tight market being replaced by a significant supply-glut and lower LNG prices, but the number of projects reaching market will be constrained by the availability of firm buyers willing to sign contracts, unless there is an increased willingness for investors to build capacity aimed at the short-term market. These developments, in turn, could have significant consequences for European (and UK) gas security.

Post-Fukushima, LNG imports in Europe (and the UK) have fallen dramatically as that LNG has been re-directed to Asia (see Table 2 and section 4.2 for the case of the UK). This has not presented a supply threat to Europe or the UK because, as discussed earlier, gas demand has been falling and alternative supplies have come from Norway and Russia.

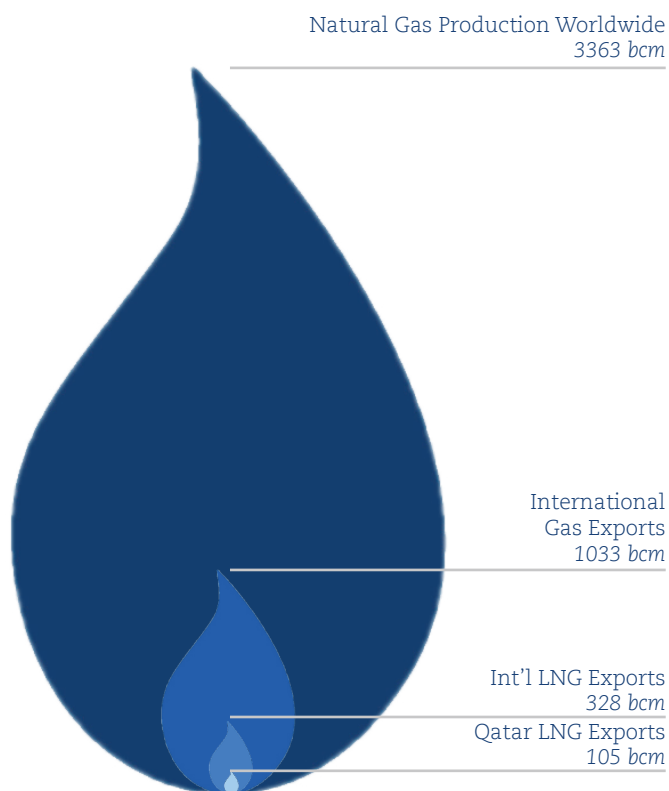


However, should gas demand recover and once again LNG become available at competitive prices, there is more than sufficient LNG import capacity in the UK and elsewhere in Europe to realise this opportunity once again (some LNG did return to the UK in summer 2014, a result of weaker demand in Asia). It is all a matter of price. The question then is how might Gazprom respond to this renewed competition? Its initial response last time was to defend price, but then it lost market share and offered discounts to regain it. Geopolitics notwithstanding, should that happen again the winner here could be the European consumer who would be paying less for their gas.

Furthermore, the possibility of perceived renewed competition from LNG could further reduce the role of oil-price indexation in European gas markets.

In sum, the significance of the US shale gas revolution to date lies not so much in the material difference it has made to UK and European gas markets; but rather in the impact that is having on global energy markets, initially through the knock-on effects of the loss of the US LNG market and increased coal exports, through to the possible consequences of Henry-Hub price-based LNG exports in the future. This example makes clear the need for UK policy makers to keep abreast of developments in an increasingly interconnected global gas market, particularly in relation to both shale gas and LNG.

Figure 4. Gas Production, Exports and LNG Compared (2013)

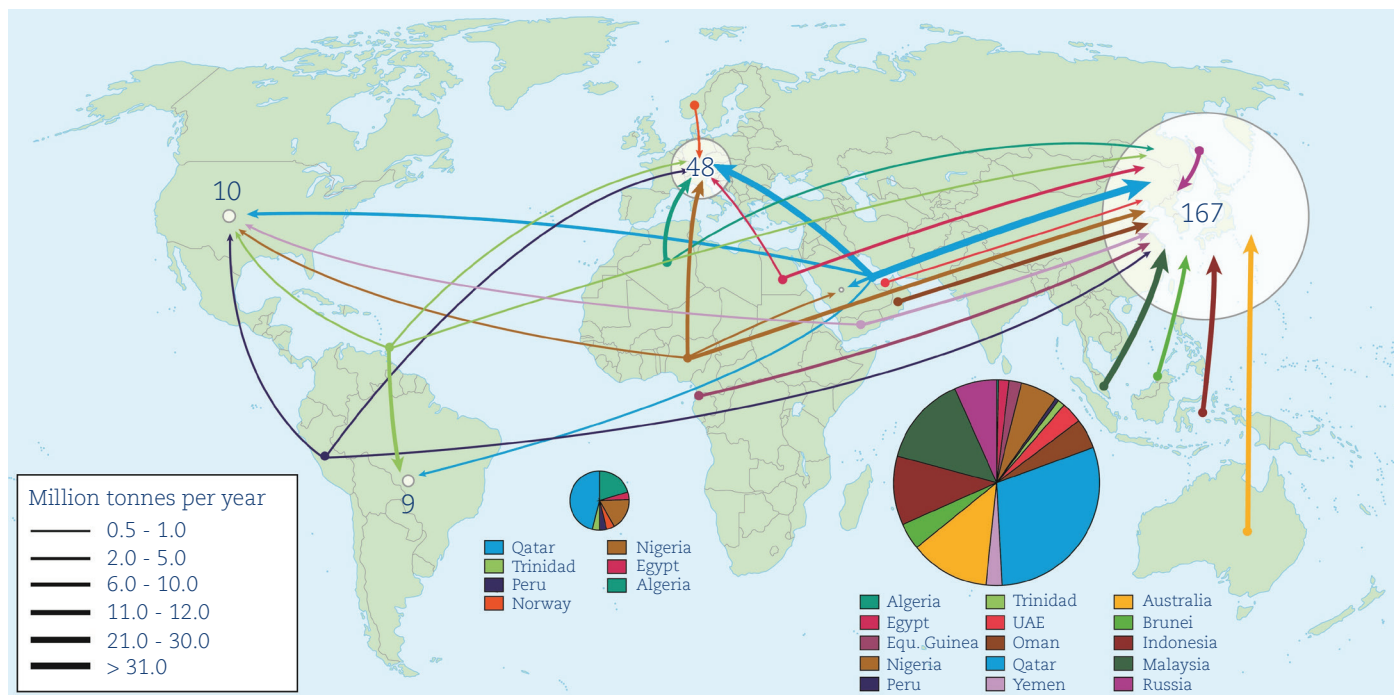


Source: Data from BP 2013

4.2 Following the Molecule: The UK's LNG Supply Chain

LNG is an established technology for handling and moving natural gas. Cooling natural gas to a liquid state reduces its volume 600-fold, making it economically possible to move gas beyond the limits of the pipeline network by road or ship. Ocean-borne LNG trade has doubled in the last decade and now accounts for a third of all internationally traded gas (BP 2014a). LNG enables gas producers to monetise historically 'stranded' gas reserves; creates opportunities for arbitrage between regional markets; and enables gas-importing countries to diversify sources of supply. By mobilising gas beyond the continental limits of pipelines, LNG is creating a more geographically complex and interconnected gas market. Understanding how LNG is re-shaping global gas markets is particularly important for the UK, where gas is a major component of the fuel mix and import dependency is growing. Our analysis has outlined the geographical structures and

Figure 5. Worldwide LNG Trade, 2012



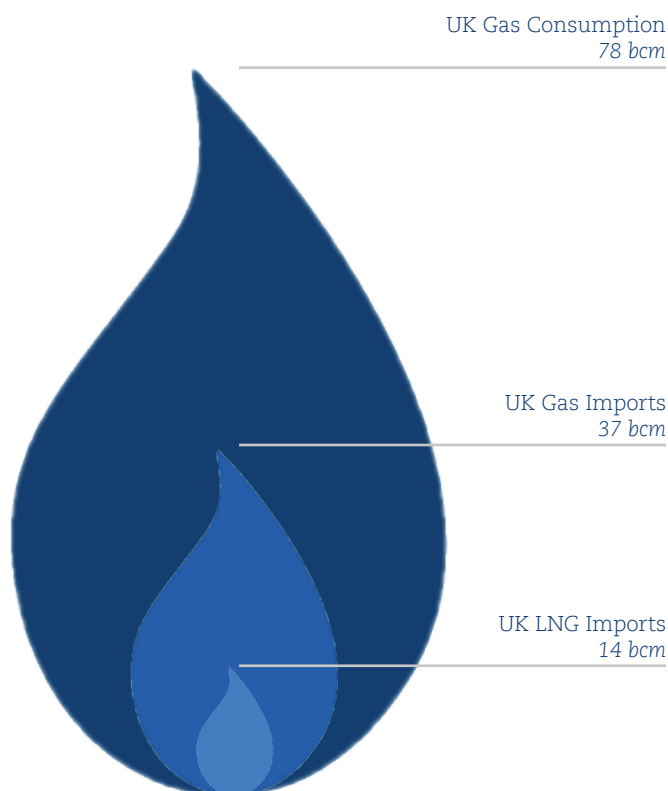
Flows <0.5 MTPA not shown. Source: Data from IGU 2012

trajectories of global LNG trade and examined how the UK's LNG supply chain is organised. Our case study involved desk research in the UK, industry interviews and site visits in the UK and Qatar.

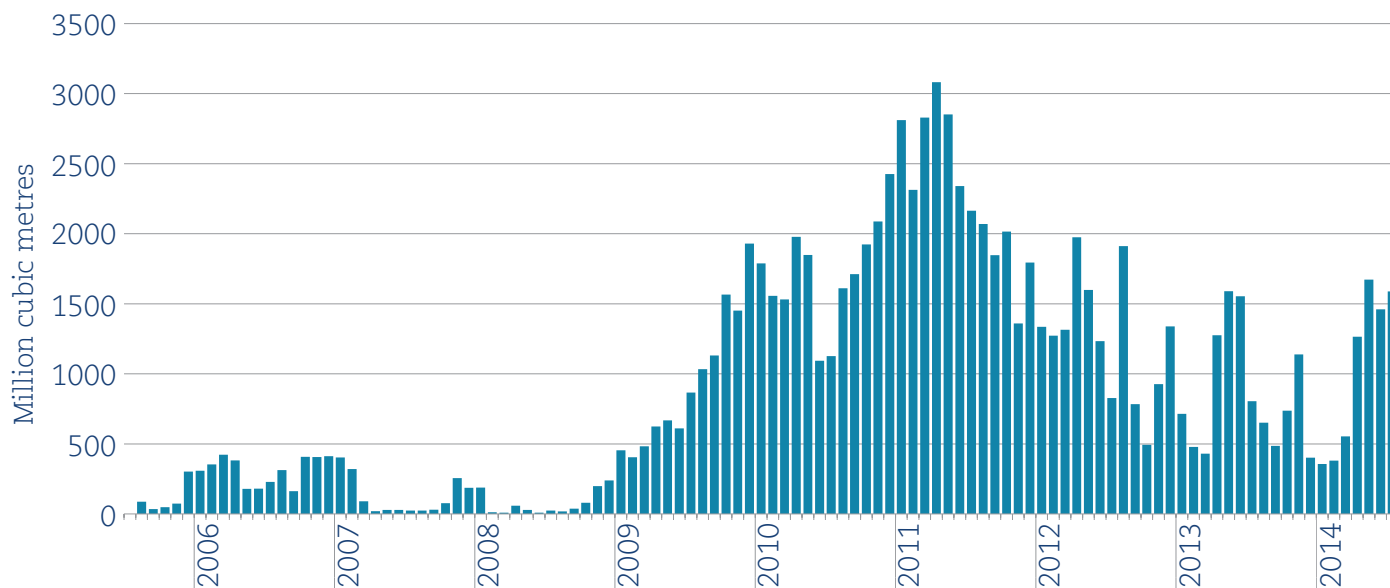
Expansion of Global LNG Trade

As noted previously, in comparison to oil, gas is geographically 'sticky': most of the gas produced worldwide is consumed in the country where it is produced, with only a third of global gas production internationally traded (Figure 4). Although this trade continues to be dominated by pipelines, as noted earlier, the volume of gas traded as LNG has doubled in the last decade. Historically, LNG has been a point-to-point trade structured by long-term contracts and, until the 1990s, was largely limited to flows into Japan and South Korea from SE Asia, and flows into Europe from North Africa. Trade in LNG has subsequently expanded in scale and become more complex in scope: the number of countries importing or exporting LNG has grown, Qatar has entered the market as a major new supplier eclipsing historic exporters (such as Indonesia and Algeria) in scale and reach, and extensive investment has been made in the infrastructure of LNG supply (liquefaction and regasification terminals, and tanker fleets). As the extent and intensity of LNG trade has grown it has eroded – although not replaced – the long-standing regional structure of LNG trade (Figure 5).

Figure 6. Contribution of LNG to UK Gas Imports and Consumption (2012)



Source: Data from BP 2013

Figure 7. UK LNG Imports, 2005 to 2014

Source: Data from DECC 2014

The UK's Position in Global LNG

The UK has seen significant investment in its infrastructure for importing LNG and it has become an important part of the UK's gas supply since 2005. In recent years LNG has accounted for between a third and a half of all imported gas so that, on average, LNG satisfies around a fifth of UK gas demand (Figure 6). The UK is now among the world's most significant LNG importers, vying with Spain as Europe's leading destination for LNG. The infrastructure developed in the UK over the last decade enables imports from a wide range of countries (including Trinidad, Algeria, Yemen and Norway) although since 2009 over 90 per cent of import volumes have originated from Qatar.

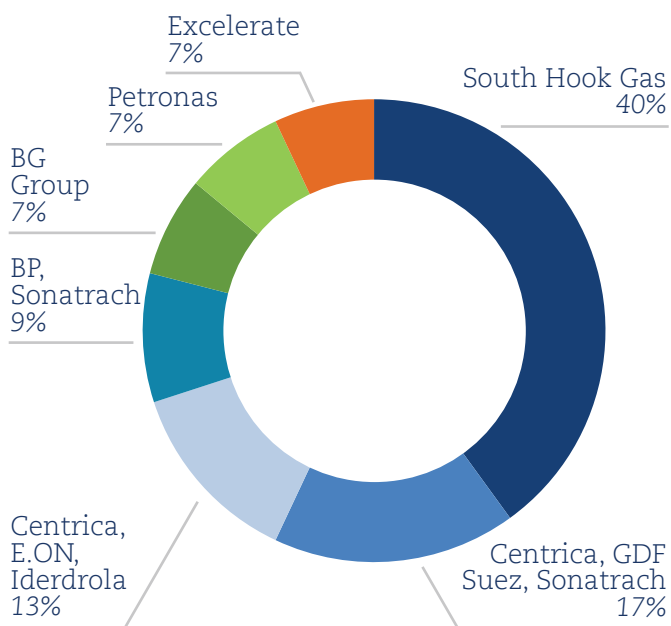
The UK has a deep and highly liquid gas market characterised by gas-on-gas competition. In such an environment LNG is essentially a 'price-taker'. Most of the LNG coming to the UK is not tied into long-term contracts that require physical delivery into the UK market. In fact, the only 'firm' LNG contracted to the UK is the agreement between Centrica and Qatargas to deliver gas to the Isle of Grain terminal. A new contract was signed in November 2013 to supply 3 mtpa (4.13 bcma) of LNG over a four and half year period, and this built on an earlier contract signed in 2011.

The vast majority of LNG comes to the UK under contract terms that enable gas to be diverted in response to market conditions and, as a result,

the rate at which LNG flows into the UK market largely depends on differences in price between here and elsewhere. Imports of LNG surged 20-fold to peak in the first half of 2011, as the UK absorbed LNG displaced by rapidly growing domestic gas production in the US (Figure 7). In the second half of 2011, however, LNG imports fell away rapidly as gas was diverted into the Japanese market following the shut down of significant nuclear electricity generation capacity in the wake of the tsunami. Imports of LNG to the UK have remained low since 2011, as the strength of Asian demand has expanded a long-standing price gap between Asian and UK/European markets and continued to pull available LNG eastwards.

Extensive investment in LNG import capacity, combined with the depth and liquidity of the UK gas market, has positioned the UK favourably within the evolving global LNG sector. Whether this import capacity is utilised, however, depends largely on the gap between prices in the UK and other markets (principally in Asia, but also seasonally in Latin America). Strong price signals elsewhere and contract terms that allow diversion of cargoes mean that, in a tight market, LNG does not flow to the UK. This means that LNG can be considered as a source of physical supply for the UK and the rest of Europe, but in a 'tight' market only if prices are sufficiently high to attract it from other competing markets. The corollary is that in a well (or 'over'-) supplied LNG market, the UK

Figure 8. Companies Holding UK Import Capacity



and the rest of Europe benefit from receiving LNG volumes surplus to Asian market requirements (with downward pressure on hub prices), as they did in 2010 and 2011.

Organisation of UK LNG supply chain

Most research on international gas analyses gas trade as a flow between exporting and importing states. However, it is firms – and the commercial arrangements concluded among them – that mobilise gas across national borders. Our analysis therefore focussed on the firms and corporate networks that organise and comprise the UK’s LNG supply chain. A key asset in the supply chain is access to import and re-gasification capacity, as this provides the physical gateway for LNG to enter the UK market. This import capacity exists at the three active terminals (Grain, Dragon, South Hook) that sit astride physical imports of LNG to the UK.

There are significant differences among the terminals, however, in how import capacity is owned and utilised: capacity at Grain is owned

by National Grid with access sold on commercial terms to a range of upstream gas producers and utilities; Dragon provides market access for its two owners, Petronas and BG; and South Hook provides dedicated access to the UK market for LNG from the Qatargas II project (a co-venture between Qatar Petroleum, ExxonMobil and Total, see Table 3) in Qatar’s North Field (Figure 8).

In practice the UK’s import capacity is embedded in international supply chain structures in different ways. While geographical variations in price between the UK and other markets are the primary driver of how much LNG flows to the UK, supply chain structures also influence the scale and timing of LNG imports. Some import capacity in the UK is held by upstream gas producers, such as BG, Sonatrach or Qatargas, providing them with dedicated access to the UK market. In each case, however, the capacity to import into the UK is part of a broader portfolio of international market access arrangements that allow these upstream producers to optimise the placement of gas into different markets. For example, although South Hook Gas was commissioned as part of an integrated supply chain connecting output from the Qatargas II mega-train to the UK market, the volume of gas placed into the UK via South Hook (and Grain) is determined by Qatargas’ global marketing strategy and there is no guarantee that LNG will be supplied.

Other UK import capacity is held by midstream gas players, such as E.ON and Centrica, providing supply diversification options for these significant actors in the UK gas market. Import capacity enables these consumers of gas to conclude agreements with LNG producers for delivery into the UK. These are essentially options on delivery, with pricing terms that reflect conditions under which cargoes can be subject to diversion. The prevailing price environment in the UK means that imports are not generally ‘locked in’ for UK delivery.

Implications

Growth in the availability of LNG initially led to predictions of a ‘global gas market’ similar to oil, in which an ocean-borne LNG trade connected historically separate continental markets, driving the convergence of regional gas prices and pricing mechanisms. This has proven premature.

As explained earlier, the rapid growth of domestic shale gas production initially eroded the US as a potentially major market for LNG, only

Table 3. Co-venturers in the Qatargas II Project

The Qatargas II Project consists of 2 LNG ‘mega-trains,’ each with a capacity of 7.8MMtpy

Train 4	Train 5
Qatar Petroleum 65% ExxonMobil 30%	Qatar Petroleum 65% ExxonMobil 18.3% Total 16.7%

to subsequently re-insert it as a potential gas exporter. Meanwhile policy decisions in Japan in the wake of Fukushima and continuing challenges with the nuclear fleet in South Korea have reproduced the long-standing primacy of Asian demand for LNG.

This combination since 2008, of lower prices in North America and rising prices in Asia, has enhanced regional price differentials, so that in the period 2011-13 they were greater than at any point in recent history. Because countries such as Japan and Korea currently have no gas supply alternative to LNG imports, they have little alternative than to pay higher prices than countries such as the UK with pipeline gas alternatives. But, as noted earlier, Asian buyers are now taking measures to drive down the price of LNG, and both Japan and South Korea are considering plans to bring Russian pipeline gas to their shores. The recent agreement between Russia and China to deliver 38 bcm of natural gas by pipeline from East Siberia – which could soon be increased to 68 bcm in total – will also have the impact of dampening LNG demand growth in China, as well as setting a new pricing benchmark in Northeast Asia.

Clearly, the factors affecting LNG are highly dynamic and confound general assertions of a 'global' gas market. It may be that expanding LNG is 'globalising' gas by increasing the connectivity of regional markets, but as it does so it also produces new uncertainties and potential vulnerabilities. Our research on the UK's LNG supply chain demonstrates how a physical infrastructure for LNG supply has been developed in the UK in a context of growing import dependency. This infrastructure re-positions the UK with respect to established international trade in natural gas, extending the reach and diversity of UK gas supply beyond the North Sea and European continent to the Atlantic Basin and Middle East. It further shows how this infrastructure is embedded within international supply chains in ways that are significant for the security of supply.

4.3 Governance and Control of the European Pipeline Network

As demonstrated by recent energy-related developments following the Ukraine crisis, the policy challenges surrounding the transmission of gas across national boundaries are the subject of high profile political and media attention. This situation can be attributed to the material and technical properties of gas: in addition to hydrocarbon flows, this resource also 'transports' relations of political and economic power across large geographical spaces. In the European context, the importance of gas transit is heightened by the European Union's longstanding efforts to implement policies of economic and regulatory liberalisation aimed at creating a common gas and electricity market. Also of significance in this context are the physical character of Europe's energy demand, resource endowment and spatial location, which mean that a large volume of the continent's natural gas needs are met via overland gas pipelines.

There is evidence to suggest that such processes are part of a global reconfiguration of the regulatory and corporate structures responsible for the production, transmission, distribution and consumption of natural gas. As far as Europe and the UK are concerned, however, the circulations of power and political agency that are associated with the emergent geopolitical reality of gas transit are poorly understood, especially when placed within the context of the wider systemic transformations stemming from the movement towards a low-carbon economy and society (Bouzarovski 2010; Bridge *et al.* 2013; Kama 2014).

In light of such knowledge gaps, and the policy context detailed above, our research has explored the different ways in which the transit of natural gas across and within national boundaries in the European Union allows for the rise of a specific regime of institutional and territorial organisation, extending beyond the traditional boundaries of the nation state. We have been uncovering the new political map of Europe constituted by the hybrid landscape of state authorities, corporate actors and transnational organisations involved in governing the material flow of natural gas within this geographical realm.

Drawing upon insights from network governance (Bulkeley 2005) and critical geopolitics (Dalby 2010), our analyses have explored how legal, policy and governmental institutions surrounding the transmission of gas reflect the geographical structure of the European energy sector. We have also sought to highlight the disconnect between public concerns over the security of supply, on the one hand, and the opportunities for free trade created by the emergence of common energy markets, on the other. As UKCS production falls, the UK is increasingly drawn in to trading in NW European markets to attract gas, this means that developments in continental Europe are of increasing significance to UK gas security.

Our work has been based on semi-structured 'expert' interviews with key informants in the European Commission, gas companies and non-governmental organisations, combined with a review of secondary documents. We have also undertaken social network analyses of contractual links between state and corporate actors in the European gas sector, derived from officially published reports. Our core analyses, as a whole, have been focused on i) the spatial and temporal underpinnings of natural gas in Europe, ii) the entrance of energy security in the policy agenda, iii) the rise of transnational governance networks of gas, and iv) the new geo-economic realities resulting from recent economic and political transformations.

The research has been anchored in current academic and policy debates on the notion of 'energy governance'. Here, we have emphasised the multiple meanings and uses of the 'governance' concept, which can be used to designate both the nature and typology of governing actors, as well as the roles and tasks that they undertake (Coutard 2002). The review has established the growing role of transnational bodies in this domain, accompanied by processes of neoliberalisation (Goldthau and Witte 2009). It has also underlined the need for focusing on the complex political processes behind energy policy-making, so as to move beyond one-dimensional analyses solely dedicated to markets or 'the state' as relevant actors. We have found that the fundamental geo-economic transformation currently underway in the European gas sector necessitates a movement away from the traditional emphasis on nation states that dominates mainstream understandings of the subject.

In exploring the geographical and historical issues surrounding the governance of the European gas sector, we have uncovered several distinctive features in the territorial architecture that underpins the socio-technical system for the transmission of this resource. Unlike other critical infrastructure networks, this system has increased incrementally from the bottom up over the last 150 years, starting from 'town gas networks' and moving towards a globally oriented regime involving a variety of transnational actors.

The resource base of the sector extends well into Asia and Africa, thus creating an array of economic, political and infrastructural interdependencies across a vast set of geographical realms. This transnational infrastructure produces a 'hidden integration' of Europe (Misa and Schot 2005) that does not easily conform to preconceived historical and political cleavages. In addition to being spatially diffuse, the physical boundaries of this space are highly interconnected with neighbouring realms, while being materially embedded in wider socio-technical systems for the provision of energy. The emergence of highly networked spaces (Germany, the Netherlands, and the UK) and infrastructural isolates (several Eastern European countries, the Baltic States and Scandinavia) is not explained by geographical factors alone – issues such as economic trust, cultural proximity and institutional reforms seem to have played a major role.

Our exploration of energy security and transnational control of gas transit has found that the sector is increasingly run in a manner that extends beyond the traditional domains of governance, involving organisational actors that do not easily lend themselves to conventional accountability mechanisms. In particular, the EU's increased involvement and interest in energy security issues reflects the broader consolidation of gas governance around a distinctive range of policy agendas. Possibly the most important of these can be found in the domain of gas liberalisation and the creation of a common energy market. In an effort largely led by the European Commission, a series of directives were implemented during the 1990s and 2000s, allowing for the separation and 'ownership unbundling' of trading, transportation and distribution activities, as well as the creation of independent regulatory bodies.



Of special significance here are the provisions of the Third Energy Package, involving two directives and three regulations for the ‘common internal markets’ in electricity and gas adopted in 2009. They have helped put in place a regime in which transmission network businesses have become regulated monopolies that are not always owned by the state (Stern 2013).

There is evidence that such developments have been decreasing the relevance of political tensions at the EU-Russia energy interface, by facilitating intra-regional co-operation among EU member states, and leading to further market opening and grid interconnectivity. The EU has been supporting them via the development of an institutional framework for co-operation with the wider European neighbourhood, exporting the market *acquis* to accession states via the Energy Community Treaty, and promoting efforts to secure gas from regions such as the Caspian and North Africa.

Academic research on the issue has emphasized that the EU is pursuing its aims through three models of energy co-operation: the community model (compliance and rule-based multilateralism), the partnership model (intergovernmentalism) and bilateral diplomacy (Padgett 2011). The fact that a wide range of geographic interests, energy priorities, and governance institutions has been employed to maintain such dynamics was also confirmed by two of our interviewees in the European Commission. The EU’s efforts in establishing the single gas market have been accompanied by the decline of oil-indexed long-term contracts (LTCs) – traditionally the main method of supplying gas to European markets.

The decline of oil-indexation and LTC’s is not only the result of the liberalisation and integration of the gas sector; the ‘virtual elimination of oil products from many stationary energy sectors in these markets’ (Stern and Rogers 2011) has also played a key role, in addition to the changing risk ownership structure in the gas value chain, in ‘which back-to-back selling at oil-linked prices is difficult’ (DNV KEMA Energy & Sustainability 2013). Such processes have precipitated the rise of wholesale gas spot and forward markets, creating a situation whereby midstream importing and wholesale companies have been ‘squeezed between gas bought upstream at oil-linked prices and gas sold downstream based on wholesale market prices’ (ibid).

Overall, the restructuring of the European gas markets has added a new layer of complexity and diversity to an already multi-faceted governance landscape. According to Stern (2013), this institutional tapestry involves a combination of upstream actors (national and international gas companies), network bodies (transmission and distribution owners and operators which are becoming legally ‘unbundled’ from other entities), downstream actors (shippers, retailers and marketers, subject to an additional layer of regulation) and ‘financial players’, where the regulation is of a financial nature.

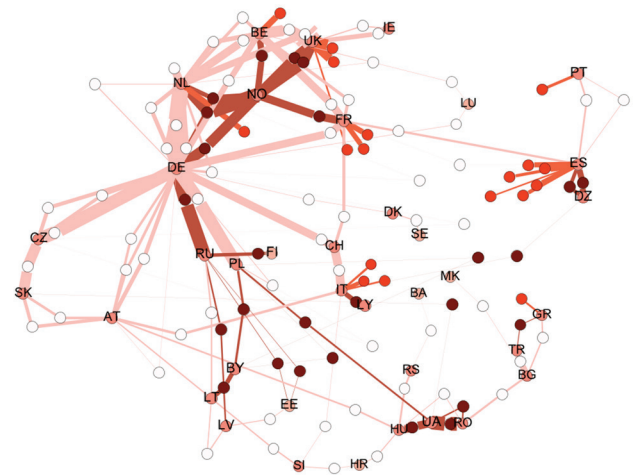
The organisational richness of the European natural gas architecture becomes even more evident when contractual relationships among transmission sector operators at cross-border trading points are analysed using network mapping techniques (Figure 9). In addition to the dense institutional linkages surrounding the two major exporters to Europe (the Russian Gazprom and Norwegian Gassco), the work that we undertook in this part of the study revealed the existence of a weaker set of relations in the Mediterranean, focused on the imports of Algerian gas. Also evident was the crucial role of the Nord Stream pipeline in helping bridge the transmission gap between the Gazprom and Gassco systems. Arguably, this link plays one of the most important roles towards the creation of a unified European network.

The network analyses also highlighted the key role that a limited set of companies – GDF Suez, Gasunie, E.ON, Wintershall, Fluxys and OpenGridEurope – play in facilitating transmission connections across the continent. This reflects findings by Stern (2013), who identifies these stakeholders, in addition to RWE, Enel, Endesa, Iberdrola and Vattenfall as being the main owners of a variety of gas assets across a number of European countries, thanks to a number of relatively recent mergers and acquisitions.

It is worth noting that the main basis of many such companies is in the electricity sector, which allows them to dominate the utility landscape as a whole. This has transpired despite the recent withdrawal of traditional utility companies from the gas sector in Eastern Europe, and their increasing replacement with financial investors (reflecting a broader trend across the continent, see Daborowski 2013).

In its entirety, our work has highlighted the increasingly influential background role of the EU, in addition to the new layering of institutional actors as a result of expanding state regulation throughout the supply chain and the increasing concentration of power within a limited set of corporate bodies. Consequently, as the UK's domestic gas production continues to decline, it will be critical that we assess the implications of the evolution of a single European gas market for UK gas security.

Figure 9. A Network Map of Capacities and Connections at Cross-Border Gas Transmission Points in the EU and Associated Countries



Note: Cross-border points within the EU are marked by white circles. Dark red circles represent non-EU import border points, and red circles indicate LNG terminals. Darker lines indicate connections between EU countries and non-EU gas transmission border points or LNG terminals.

Source: ENTSOG

A Supply Chain Analysis of UK Gas Security



Writing a decade ago, just as the UK became a net importer, Stern (2004) warned that it was time to get serious about UK gas security. At the time he identified four gas security issues:

- “Running out of gas” i.e. exhaustion of resources, from both a UK national and an indigenous European perspective.
- Increasing dependence on imports, particularly from distant, “non-European” sources.
- Whether liberalisation of gas markets adds to the risk of major investments and therefore the danger of failing to attract long-term supplies, and increases in price volatility.
- Contingency planning for events of low probability – e.g. severe weather, technical breakdown, terrorism – but potential market impact.

Over the last decade all of these issues have tested the UK’s gas security, domestic and European production continue to decline and imports now represent 70 per cent of the gas consumed in the European Union (European Commission 2014). In the case of the UK, new sources of supply have emerged in the form of LNG, predominantly from Qatar. When the UK was a net exporter of natural gas it was less exposed to physical security of supply concerns, but the open nature of the gas market meant that it was still exposed to price insecurity. However, the rise in import dependence has coincided with a period of uncertainty and volatility.

The resilience of the system has been tested in a number of occasions, mostly due to technical failings (Skea *et al.* 2012), but also the Russia-Ukraine gas disputes in 2006 and 2009, and also extreme weather events such as the long and cold winter of 2013.

In March 2013 a combination of events both climatic and technical prompted a gas emergency in the UK, but the resulting prices signals meant that additional gas was soon supplied to the UK market, largely from NW Europe via the interconnectors, but also in the form of LNG. However, as UK import dependency seems likely to increase in the coming years; DECC’s (2014a) latest gas production projections suggest 57 per cent import dependency in 2020, are there additional measures that need to be taken to improve UK gas security?

This final substantive section deploys the supply chain approach presented in section 3 to analyse the dimensions and issues that shape the UK’s gas security. The discussion is organised around the three stages in the gas supply chain – upstream, midstream and downstream – and identifies the key energy security issues and the measures that can be taken to increase resilience and mitigate risk (see Table 4).

Table 4. A Supply Chain Approach to Gas Security

	Geopolitics	Dimensions	Issues
Upstream	Security of Supply	<ul style="list-style-type: none"> • Resource Base • Technology • Investment 	<ul style="list-style-type: none"> • UKCS • NCS • Europe - Russia/North Africa • LNG Supply • Unconventional Gas
Midstream	Security of Transport (Transit)	<ul style="list-style-type: none"> • Processing • Transportation • Storage 	<ul style="list-style-type: none"> • LNG Terminals • Interconnectors and Third Package • National Transmission System • Storage • National Balancing Point/Hubs
Downstream	Security of Demand	<ul style="list-style-type: none"> • Power Generation • Industrial Use • Domestic Use 	<ul style="list-style-type: none"> • Role of Gas in UK energy strategy • Intermittency and Capacity Markets • Future Gas Demand • Carbon Floor Price & ETS • Carbon Capture & Storage

Upstream Security Issues

One of our concerns about the energy security literature is that it tends to focus too much on upstream physical security of supply issues. The IEA's (2014) latest report on the Energy Supply Security of member states says the following about the UK:

“UK natural gas imports amounted to 37 bcm in 2012 – around 47 per cent of its requirements. The Country's imports are relatively diversified, with significant imports from Norway (54 per cent of total imports), Qatar (26 per cent) and the Netherlands (15 per cent). It has also expanded and diversified its gas import infrastructure to compensate for the ongoing decline in domestic production.”

This is an accurate description of the current situation, but our analysis suggests that the figures belie a much more complex situation that stems from the fact that whether or not sufficient gas flows into the UK is determined by market actors and market conditions that are beyond the influence of the state. At any given time, a shortfall in the UK should be reflected in a higher NBP price that will attract imports, either by pipeline or LNG. As domestic production continues to fall, even more of the UK's demand is subject to those wider market conditions. Through the interconnectors, the NBP is already integrated into a wider European market as it increasingly draws on the same sources of gas to satisfy UK demand as continental traders. As noted earlier, any change in Norway's ability to supply European demand would have to be met by increased supplies from elsewhere, most likely Russia (see Dickel *et al.*, (2014) for an assessment of none Russia source of future gas supply). At the same time, as the global gas market becomes more connected, events as far away as Japan have an impact on market conditions in Europe and the UK in relation to the supply of LNG.

These observations sit well with National Grid's (2013a) notion of the 'Global Gas Markets' axiom whereby they identify a number of sources of uncertainty in relation for future UK gas supply:

- Development of new fields in the UKCS and Norway
- The development of UK shale gas reserves
- Further liberalisation of the European gas market and access to transmission and storage
- LNG market developments especially the extent and impact of Chinese demand.

The Development of UK Shale Gas Potential

Obviously, any future developments in the UKCS are significant in that they help to slow the decline in domestic production, but the projections suggests a continuing decline rate of 5 per cent a year. In that context, the UK Government has accepted the recommendations of the recent Wood Review: UKCS Maximising Recovery Review (Wood 2014). However, UK politicians are also placing great hopes on the development of onshore unconventional oil and gas to provide new sources of domestic supply. This project has not been about shale gas in the UK; however, we have paid close attention to the debate as it has raised concerns about UK gas security more generally. A proper assessment of UK shale gas production potential requires further research, but at present we would caution against assuming that domestic shale gas can make a contribution to UK gas security until well into the 2020s. The bottom line is that the industry in the UK is still in its infancy and a 2-3 year exploration programme is required before we can even begin to answer key questions about flow rates and prospects for commercial development at scale.

Commercial development will require a substantial supply chain that is not currently in place, and a so-called 'Social Licence to Operate.' At present, there is considerable public suspicion in relation to shale gas and the current 14th Licencing Round will serve as a litmus test of both investor interest in UK shale and public opinion about its development. There are various projections out there about how much gas might be produced from UK shale deposits, all of which should be treated with a high degree of caution.

The much-quoted Institute of Directors report (2013) suggests that: "A multi-year development of 100 shale gas pads of 40 laterals each could see peak production of 853 bcf (24.2 bcm) a year in the low scenario, 1,121 bcf (31.7 bcm) in the central scenario and 1,389 bcf (39.3 bcm) in the high scenario." Furthermore they estimate that: "Development of 100 10-well pads of 40 laterals could lower the import bill to £9.5 billion in 2030 in the low scenario, £7.5 billion in the central scenario and £5.6 billion in the high scenario. In 2030, in the low scenario, gas import dependency could be 46 per cent; in the central scenario, 37 per cent; and in the high scenario, gas import dependency could fall to 27 per cent."

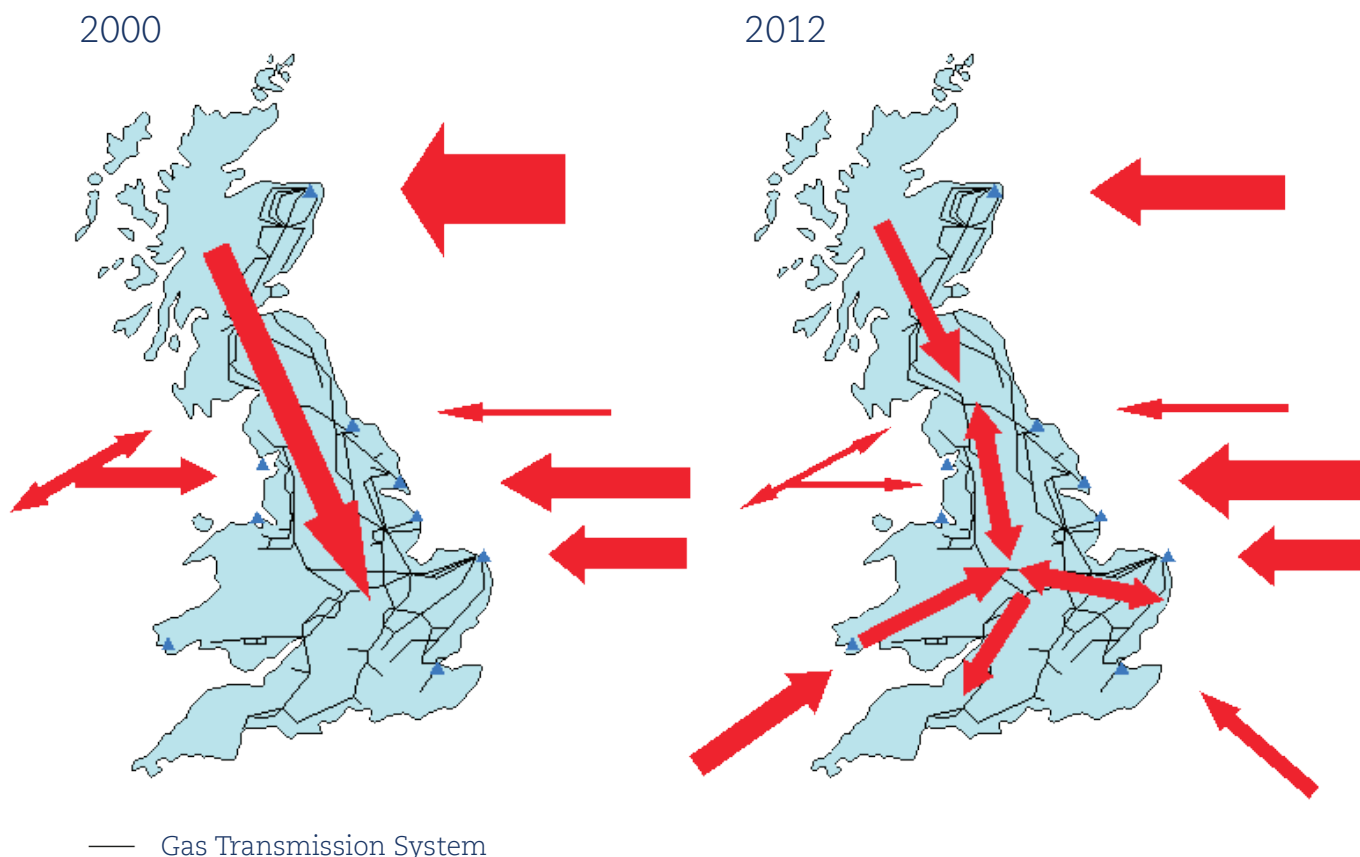
An alternative analysis by Rogers (2013) suggests that: “after 10 years a production level of 8 bcma is achieved by drilling 300 new wells each year (from 25 new pads per year, each with its own drilling rig).” As noted earlier, National Grid (2014a) has highlighted the high degree of uncertainty over the future contribution from shale gas in the UK. Amidst this uncertainty, three things are clear: first, that we simply do not know what future levels of shale gas production are likely to be; second, that significant levels of production are unlikely until the 2020s at the earliest; and third, that there is a high probability that the UK will continue to meet the majority of its gas demand through imports. Any talk of shale gas making the UK self-sufficient again, let alone allowing significant exports, is far fetched. Equally, in a wider European context progress in developing shale gas will be slow and both the IEA (2013) and BP (2014) see Europe producing less than 30 bcm from shale gas in the early 2030s. This means that during the second-half of this decade both UK and European gas import dependence will inevitably rise, unless demand is significantly constrained.

Midstream Security Issues

Table 4 identifies a number of issues in the midstream. The UK does not presently face any direct geopolitical transit security concerns. However, the two interconnectors and the various pipelines from the North Sea are subject to technical risks that often result in short-term price spikes on the NBP. The UK also benefits from having three operational LNG terminals, whose activities are closely monitored by gas traders. However, there are two sources of indirect transit security threat.

First, the interconnectors source gas from the continental European market and although these are recorded as coming from the Netherlands and Belgium these supplies are back-filled by supplies upstream. Thus, transit disruptions further upstream – be it problems between Russia and Ukraine or civil unrest in Libya – have implications for UK gas security. This tends to be reflected through price volatility. In fact, in the past when these interruptions have resulted in higher prices on continental markets, gas has flowed from the UK to Europe.

Figure 10. The Changing Geography of UK Gas Supply and Distribution



Second, the UK's dependence on Qatar for the vast majority of its LNG imports means that it is exposed to possible transit interruptions through the Straits of Hormuz and the Suez Canal (Emmerson and Stevens 2012). However, should there be such a disruption the UK is very much better placed to use alternative sources of supply than major LNG importers, such as Japan and South Korea. In any case given the importance of the Straits of Hormuz to global oil trade flows there would be many more powerful interests than the UK incentivised to rapidly resolve the situation.

The National Transmission System

The changing geography of gas supply into the UK has required National Grid, as the owner and operator of the National Transmission System (NTS), to make significant investments in the pipeline system. Figure 10, which is based on the National Grid's 2012 Ten Year Statement, illustrates the scale and direction of the changes. The initial system was based on the requirement to bring significant amount of gas onshore from both the UKCS and the NCS and move it to major consuming centres in the south. However, things have changed significantly since 2000 and there are more entry points into the system, including new pipelines from the North Sea, such as Langeled operated by Norway's Gassco, a second interconnector the BBL connecting to the Netherlands, and an additional interconnector to Ireland. Just as significantly, the commissioning of the three LNG terminals has also impacted on domestic gas flows. The construction of two terminals at Milford Haven required substantial investment (£700 million) in the so-called 'South Wales Gas Pipeline' to move gas from the Dragon and South Hook LNG terminals to the Midlands. The pipeline was controversial and any attempt to expand LNG import capacity at Milford Haven would probably again face strong resistance if it required additional pipeline construction (for an analysis of public acceptance of natural gas infrastructure in the UK see Marsden and Markusson 2011). At present, however, gas flows from the LNG terminal are modest. Falling production in the UKCS has also resulted in more gas having to flow north, requiring investment in reverse flow capacity. There are a number of future developments that will require additional investment in the NTS and DECC (2014b) reports that: "The total expenditure for gas transmission networks across GB between 2013 and 2021 is £5.5 billion."

As the role of gas changes from base load power generation to back up for intermittent renewables, so the scale and direction of flows in the NTS will change. On the supply side there are still a relatively small number of entry points into the NTS (9 terminals at present), however, should there be significant shale gas development in the UK this will change the geography of supply. Given the nature of shale gas production it will require producers to process their production and build pipeline connections to the NTS. The net result may be numerous smaller points of entry into the NTS, much like the impact of wind farms on the electricity grid. The UK shale gas industry considers the NTS a major advantage, but the costs and impacts of connection will need to be considered when assessing the prospects for shale gas in the UK.

Gas Storage

The UK has not invested a lot in building gas storage capacity; rather it has relied on: a) early discovered fields (pre-liberalisation) under long term contracts with high seasonal flexibility, however as these fields have declined this option has dwindled, b) from the mid 2000s pipeline imports from Norway and the Netherlands adopting a seasonal profile, mainly driven by the upstream suppliers to take advantage of higher winter NBP prices, and c) use of storage facilities at 'arms length' in France and Germany with seasonal flows via the interconnector and the continental grid. Now the UK finds itself with only 4.6 bcm of gas storage with total demand in 2013 at 78 bcm (DECC 2014). According to the recent IEA study (2014a), the UK has three types of gas storage: long-range storage at Rough that is a depleted offshore gasfield and accounts for three-quarters of total UK storage capacity, medium-term storage (in salt caverns such as Aldbrough in East Yorkshire that was opened in 2011 and depleted gas fields such as Hatfield Moor in South Yorkshire) and short-range storage (peak shaving LNG plants).

The economics of storage lies in the ability to purchase and store gas in the summer months and sell it when prices are higher in the winter. The industry in the UK maintains that the commercial case for gas storage is no longer convincing because the prices difference between summer and winter are not sufficient to make new storage profitable. Bros (2012) maintains that companies found it more attractive to invest in LNG terminals than storage facilities, with the



aim of benefitting from arbitrage opportunities (buying cheaper LNG and selling it onto the UK market for a higher price). This, together with the interconnectors, means that there are alternatives to traditional storage and explains why there are a lot of potential storage facilities with planning permission, but very little new capacity is actually under construction.

The key issue is; if it is needed, who should pay for increasing storage capacity? The answer probably lies in the fact that different types of storage address different problems. A key consideration being the speed with which they can fill and the rate at which gas can be withdrawn. They all need to retain a certain amount of 'cushion gas' to maintain the integrity of the facility (the same is true of LNG storage tanks) and provide a minimum operating pressure. As a result of an exhaustive analysis of all the issues, Le Fevre (2013) concludes that the need for storage in the UK is driven by two requirements:

- "The need for growing flexibility as a result of increased variability of demand for gas-fired power generation caused by the intermittency of wind-powered renewable energy;
- To underpin supply security in the event of an outage in a major supply source."

At present, existing storage, gas at LNG terminals and the interconnection accessing 'arms length' storage have provided sufficient resilience in the face of short-term technical disruptions; but large-scale geopolitical disruptions – in the distant upstream and transit choke points – present different challenges. Because the UK largely relies on short-term market access, rather than long-term contracts (particularly for LNG), the lack of storage will be reflected in vulnerability to price volatility as domestic shortages are manifested in a higher NBP price to attract gas to the UK.

However, new LNG cargoes can take a matter of weeks to arrive – the journey from Ras Laffan in Qatar to South Hook in Wales can take 18 days. Thus, to balance the market, storage is needed to provide a short-term cushion. A further consideration is that 75 per cent of the UK's storage is in a single facility at Rough, which experienced a fire in 2006. As the March 2013 episode suggests, technical failures can happen in parallel, when storage and LNG terminal inventories are low (and even then not all of the LNG terminals supplied gas at the time even though the NBP spiked). Equally, NW Europe often has a weather pattern in late winter that results in low temperatures and little or no wind, which means that wind power generation is negligible and gas demand for power generation high. At such a time, any technical failure in the UK gas supply system places significant demand on storage. The later in the winter season, the greater the likelihood that storage inventory will be low, as in March 2013.

Ofgem's Project Discovery (2010) raised concerns about UK gas security and Ofgem followed this up with a gas security of supply report (Ofgem, 2012) that concluded the UK system was sufficiently resilient and that only extreme circumstances would result in physical disruptions to supply. The UK Government subsequently commissioned another study, this time by Redpoint (2013) that examined the impact of gas market interventions on energy security. This complex report enabled the government, by selecting certain cases/scenarios, to conclude that there was no case for further intervention in the market; rather they would continue to rely on market signals to encourage private sector investment in additional storage – even though little has been forthcoming. However, Stern (2011) maintains that the market alone will not deliver the necessary level of storage – which he estimates is in the range of 12-14 bcm or three times current levels – instead: "rationing by price during periods of shortage will be the only available solution to gas security problems in the future, as it has been in the past."

It is not unreasonable to expect industry to invest in the storage capacity needed to ensure the effective operation of the market – including any obligations placed on them by the regulator to provide security of supply. However, given current concerns about Russian gas supplies to Europe and the UK’s increasing reliance on long-distance supply of LNG, there may be a case for what Stern (2011) calls ‘strategic storage’ that by definition would be held in reserve to deal with longer-term disruptions lasting weeks or even months.

It is noteworthy that six OECD countries – all in Europe – place gas stock obligations on domestic companies (IEA 2014a). Interruptible contracts and alternative fuel obligations to reduce demand are already part of the gas emergency response system in the UK, but they are insufficient to deal with such a longer-disruption of physical supply. LeFevre (2013) suggests that the Government and Ofgem need to monitor developments that might merit a re-appraisal of the case for intervention, these are:

- A major increase in forecast gas demand
- A material change in the geopolitics of LNG supply
- A reduction in the pace of liberalisation of the NW European gas market
- An appreciable widening of price spreads that did not stimulate new storage investments

We now seem stuck in a situation where the industry will not invest in additional capacity without government subsidy and the current government has set its face against providing such a subsidy. We would agree with LeFevre that, as a minimum, the issue needs to be monitored in the wider context of other challenges to UK gas security, in particular the ability of the UK to attract sufficient LNG when needed at prices that are affordable.

The National Balancing Point

The final element of the midstream that is usually overlooked in discussions of UK gas security is the NBP, the virtual market based on the physical infrastructure of the NTS that links suppliers with buyers, often through financial intermediaries. The NBP was not the focus of our research and we have found it difficult to fathom; but we accept the fact that the UK currently has a deep and liquid market based on gas-to-gas competition and the rules of supply and demand and that this is undoubtedly a source of security. However, for good or bad, it does significantly reduce the scope

for government intervention and mean that the UK must reply on price signals to attract gas to the UK market, just like any other commodity. It is therefore important to monitor the health of the market in terms of the number of players and the levels of trading activity (as well as its compliance with financial regulations). Equally, the emergence of strong gas trading hubs in continental Europe, such as the Netherlands’ TTF, has important implications for the future of NBP. In an integrating European gas market where hub-based trading is gaining prominence (it accounted for 50 per cent of gas sales in 2013), the NBP increasingly reflects wider European market conditions (witness the convergence between hub prices identified by Petrovich 2013). This is not necessarily a problem, rather it is the logical outcome of market integration; but it is important to monitor the development of hub-based trading in continental Europe and its impact on the functioning and status of the NBP.

Overall, we would argue that the status of the UK’s midstream is essential to maintaining gas security of supply and its status requires careful monitoring to ensure that there is sufficient capacity and flexibility to maintain a deep and liquid market. Storage remains a controversial issue, but this must be assessed against developments in a wider European and global context. There is no room for complacency given the increasing complexity of global gas geopolitics. One final observation is that we have used the term UK, but the status of the midstream has important implications for Ireland, which is dependent on the UK for its gas and for NW Europe as the UK still exports gas.

Upstream Security Concerns

For investors to continue to invest in upstream production and midstream capacity they must feel confident that there will be sufficient gas demand in Europe in the future to provide a return on their capital investment. In the UK, as in the rest of Europe, there is currently considerable uncertainty about the future role of gas in the energy mix and thus the level of future gas demand. The trajectory of the low-carbon transition will inevitably result in a significant fall in the demand for natural gas; however, the key issue at present is not ‘gas or no gas’, but ‘how much gas for how long?’ This is a whole systems question in that the role of gas and the scale of gas demand are dependent on the pace of decarbonisation of the whole system and on measures to reduce energy demand and increase energy efficiency (see also Bassi *et al.* 2013).

At present gas demand is split equally between three sectors – gas-power generation, industry and households. The UK's energy and climate strategy is based on the decarbonisation of power generation through a new generation of nuclear power stations and expansion of renewable energy (principally wind) and the electrification of the economy. In terms of gas demand, as noted earlier, this means that the role of gas in the power sector is changing from contributing to base load to backing-up renewable intermittency.

In households gas, which is currently the dominant fuel for space heating, will be replaced by electricity and other low carbon technologies. This is the theory and it is on this basis that official projections of future gas demand are based, as reflected in National Grid's 'Gone Green' scenario. It is only projections such as the National Grid's (2013) 'Slow Progression' that give us a sense of the possible alternative scenarios that result from policy failure manifested in a slowdown in the rate of decarbonisation. The latter may be caused by delays in implementing key infrastructures – such as a new fleet of nuclear power stations – or by a change in policy direction (such as revisions to the 4th Carbon Budget) or firm limits placed on total government financial support for renewables and capacity payments, Feed-in Tariffs (FITs) etc.

In short, uncertainty about the pace of progress with the UK's decarbonisation strategy is translating directly into uncertainty about the future of UK gas demand and this is already impacting on investment in upstream infrastructure, specifically new gas power generation (CCGT). The current Government's solution to the security of demand dilemma is the Gas Generation Strategy (DECC 2012b), which is part of the wider Electricity Market Reform. The aim of the strategy is to reduce the uncertainty around gas generation for investors. The specific challenge is to encourage new investment in CCGT power generating capacity when the load on that capacity will be lower than has traditionally been the case due to the increase in low carbon and renewable power generation.

There is already considerable volatility on the grid and DECC's (2012b) own numbers show average CCGT load factors falling from 71 per cent in 1996 to 48 per cent in 2011. This situation has been made worse by the return of cheap coal and some CCGT capacity in the UK is currently mothballed. In 2013 the share of coal in electricity supply fell from to 35 percent, down from 38 per cent the

previous year. However, the role of gas also fell by 1 per cent as renewables grew in significance (DECC 2014c). But, as coal capacity closes, and there is the likelihood of delays in new nuclear, the amount of gas power generation needed to meet capacity margins will increase. DECC (2012b) concludes: "Up to 2030, we will need significant new investment in CCGT's as existing capacity reaches the end of its life, potentially up to 26 GW including capacity that has recently been commissioned or is expected to be commission shortly."

The creation of a Capacity Market is the policy mechanism to ensure that this capacity is built. Under this scheme providers will be paid for providing reliable capacity, compensating for the fact that the load on that capacity will be lower than that traditionally required to make a business case for investment. According to the central scenario in the Gas Generation Strategy (DECC 2012b), "in 2020, CCGT's are estimated to have an average load factor of 25 per cent, rising to 38 per cent by 2025." In the late 2020s new nuclear generation and the availability of Carbon Capture and Storage (CCS) will impact on CCGT load factors and thus: "In 2030 it is projected that CCGT's will supply 88 TWh of electricity, representing 22 per cent of electricity generated that year the share is about 40 per cent at present. This is translated into an average load factor of 27 per cent for the CCGT fleet."

In simple terms, the strategy will pay industry to build more CCGT's and then compensate them to use them less, the net result being lower levels of gas demand, but with greater variability and uncertainty about that demand (which has implications for the NTS and storage). At present, there is no business case to support building new CCGT capacity – particularly with existing capacity mothballed or running at low load factors. The first Capacity Auction is scheduled for later this year, so we must wait and see.

Earlier in this report we cautioned against placing too much emphasis on the power generation sector as the sole arbiter of future gas demand. There is clearly a need to understand the nature of future gas demand in industry and in the household sector. Equally, there are possible new areas of gas demand, such as gas in transportation and LNG in marine bunkering. In short, it is important to understand the prospects for future UK gas demand beyond the power sector.

In the household sector the emphasis is on improving the energy efficiency of buildings and the developing alternatives to gas; but there is also a need to understand what this means for gas demand and its associated infrastructure (for an example of recent UKERC work in this area see Eyre and Pranab 2014). A significant reduction in household gas demand would have a major impact not just in terms of the volume of gas, but also the seasonality of demand. In other words, there is a need to work backwards from the future energy demand scenarios to understand what the low carbon transition means for gas demand outside of the power sector. Again, it is not just the consequences of policy implementation that matter, policy failures are equally important. For example, if households prove resistant to removing their old gas boilers and want to stick with their gas cookers, this has significant implications for future gas demand. From our perspective as social scientists working on energy security, industrial gas demand remains a black box and it is important to understand what gas is used for and how that demand is likely to change in the future.

In sum, the gas security literature has a strong security of supply bias, but the scale of future gas demand has a critical bearing on both the resilience of the system to supply side shocks and the adequacy of the midstream infrastructure (and the business models that support it), hence the need for a supply chain approach. In the UK energy research community there is an understandable focus on building the new low carbon system and promoting energy efficiency and demand reduction; but we also need to pay much greater attention to the consequences of fossil fuel demand destruction, particularly in relation to gas security. We need a much better understanding of the implications of the low carbon energy transition for gas demand.

Put another way, how much gas can we burn in the UK in the future (with or without CCS) and remain within our carbon budgets? At the same time, we also need to recognise that natural gas represents the fall back position for policy failure or slippage whereby a finite constraint is placed on financial support for decarbonisation. The net result may very well be that we will end up needing a lot more gas for longer – with or without CCS – and that will have significant implications for both our climate change strategy and energy security (understood as both physical security of supply and price security of supply).

Conclusions and Policy Implications



This project has sought to examine the implications of global gas security and governance for UK energy security. This final section considers these two issues and then turns to the specific policy implications of our research findings. The latter is organised around the supply structure that has shaped our analysis.

Global Gas Security

The starting proposition of our project is that UK has effectively been globalising its gas security as increasing import dependence has exposed consumers to global developments in gas markets. In this respect, our research suggests that there are three interrelated areas of concern for the UK that are a consequence of increased exposure to European gas market integration, on the one hand, and developments in the global LNG market, on the other hand.

- The first relates to the status of the NBP. As European gas market integration deepens and continental gas trading hubs continue to develop, the NBP may lose its pre-eminent status. But, provided that sufficient midstream infrastructure is in place to keep the NBP physically connected with continental hubs, this should be viewed as a positive and inevitable result of market integration.
- The second follows the first and relates to the Europe's current and continued reliance on Russian gas imports. Hub prices in Northwest Europe (including NBP by the action of arbitrage) are still strongly influenced both by the scale of Russian gas flows and their continued reliance on oil indexed pricing, and it will be some time before this influence is significantly reduced. This means that, as our import dependency increases, the UK needs to pay greater attention to developments in Russia-EU gas relations than it has in the past.
- The third relates to the reliance on LNG as part of the supply mix in the UK. In a 'tight' global market, such as at present, LNG exerts limited influence over UK gas prices. But in a well or oversupplied LNG market (when the NBP price is able to attract LNG cargoes) it can be beneficial for consumers in the UK and Europe as it constrains Russia's price ambitions.

Gas Governance

At the onset of this project, we criticised the existing literature for assuming that oil and gas were the same when it came to issues of energy security, for being too state-centric in its analysis of trade and for playing insufficient attention to the role of companies and other non-state actors. Our research has shown how the gas supply chain is subject to complex multi-scalar governance that involves transnational and national state actors – the EU and UK governments in our case – and a variety of companies with different ownership structures operating at national, international and global scales. At the same time, the material specificities of natural gas and its dependence on fixed infrastructures mean that ownership is often unbundled and markets regulated. In the UK, the National Grid plays a crucial role as the owner and operator of the NTS, Ofgem is the regulator and the Department of Energy and Climate Change is responsible for energy policy. As our case study of the European pipeline network reveals, the constellation of state authorities, regulators and companies varies greatly across Europe and adds considerable complexity to the challenge of market integration. Equally, our case study of the UK LNG supply chain demonstrates how in the upstream our dominant source of LNG supply is orchestrated as part of the global marketing strategy of Qatar Petroleum.

When it comes to downstream, the fate of future UK gas demand will be determined in large part by the investment strategies of companies in the power sector and by industrial consumers, as well as the preferences of individual households. Increasingly, the UK Government is intervening in the 'market' to drive forward its decarbonisation strategy and, as our discussion of security of demand illustrates, it is important to understand the implications of this strategy for the multitude of actors involved in the UK gas supply chain. Increasingly it seems that natural gas (methane) is treated more as part of the problem; rather than an essential part of the solution, especially when other things go wrong. The net result is that investors are uncertain about the future of gas demand and thus hesitant to invest in new infrastructure and generating capacity, which creates even greater uncertainty about the future role of gas.

Policy Implications

This final section considers the policy implications of the findings of our research by identifying issues for policy action and issues of policy significance that require monitoring or new research.

Upstream Implications

Our research has identified five critical issues to the future of UK gas security of supply:

- There is a need to monitor the status of the UKCS and the effectiveness of policy interventions (following the Wood Review) to support renewed investment to slow the rate of decline. This is because the rate of decline of indigenous offshore gas production is currently the most critical factor driving increased import dependency;
- There is a need to assess the prospects for the development of unconventional (shale) gas in the UK and in Europe more generally;
- There is a need to monitor the status of Norwegian gas production and its continued role in supplying a substantial portion of UK and NW European requirements;
- There is a need to monitor developments in the supply of Russian gas to European markets;
- There is a need to monitor developments in the global LNG market – particularly in relation to Asian demand growth and expansion of LNG export capacity – and assess their implications for future UK LNG supplies.

Midstream Implications

Here we identify three issues, but would also observe that it is technical failures in the midstream that are most often the source of short-term supply disruptions and these may become more frequent as the existing infrastructure ages.

- There is a need to ensure that the NTS has sufficient capacity and flexibility to respond to changing patterns of supply and demand related to supply diversification (including future shale gas production) and increased intermittency due to growing renewable power generation;
- There is a need to monitor the case for additional gas storage, both by the industry to ensure the functioning of the market in light

of increasing intermittency and by the state in support of 'strategic storage' to mitigate against major infrastructure failures or supply disruptions in the distant upstream that might result in longer-term supply problems.

- There is a need to monitor the liquidity and status of the NBP and to ensure its continued linkage to European hubs and the reliability of linking pipeline infrastructure.

Downstream Implications

We consider this to be an overlooked element of the assessment UK gas security and it is an area where it is necessary to integrate research focused on the gas sector with research on the system wide consequences of decarbonisation (UKERC's whole systems approach). We have identified five elements of the downstream gas demand dilemma that require further consideration.

- There is a need to monitor the consequences of the current 'return of coal' and the impact of the LCPD and Industrial Emissions Directive on the timing of coal-fired plant closures in the UK and their implications for gas demand.
- There is a need to monitor the impact of the failure of the EU's Emission Trading System and any attempts to reform it on EU and UK gas demand, alongside the impact of the UK's minimum carbon floor price.
- There is a need to monitor and understand the response of the power generation sector to the UK Government's Gas Generation Strategy and the implementation of the first auction under the Capacity Mechanism planned for later this year, as this will have a significant bearing on future gas demand.
- There is a need to consider the implications of the rate of progress on CCS for future gas demand in the UK. This is subject of research in UKERC, but the Government's assumptions about future UK gas demand and emissions have certain expectations about the availability of CCS and the room for unabated gas-fired power generation.
- There is a need to consider the impact of climate-policy induced gas demand destruction – particularly in the household and industrial sectors – on the integrity and commercial viability of the UK's gas supply chain.

Finally, there is a tendency to ignore the consequences of the low carbon energy transition for the incumbent fossil fuel sectors and this seems true of the gas sector in the UK. While it is recognised by politicians that gas has an important role to play in the UK's future energy mix, too often it is relegated to a default position and there is a degree of complacency and an assumption that secure and affordable supplies will always be available should they be needed.

We would advocate a 'gas by design' policy that plans now for the changing role of gas in the UK energy mix, thus ensuring future UK gas security. A blind belief that a future UK shale gas revolution will solve all our problems does not fit with this remit. It seems highly likely that the UK will end up needing more gas for longer than current policy predicts and a failure now to pay sufficient attention to the issues that influence UK gas security will mean that consumers may end up paying more to secure that gas.

References



- Bassi, S., Rydge, J., Khor, C.S., Fankhauser, S., Hirst, N. and Ward, B. (2013) A UK 'dash' for smart gas. Grantham Research Institute, LSE, Policy Brief. [Online]. Available from: www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2014/03/PB-uk-dash-for-smart-gas.pdf [Accessed 02 July 2014].
- Bouzarvoski, S. (2010) Post-socialist energy reforms in critical perspective: Entangle boundaries, scales and trajectories of change. *European Urban and Regional Studies*, 17, 167-182.
- Bradshaw, M., Dutton, J. and Bridge, G. (2014a) The geopolitical economy of a globalising gas market. In: Ekins, P., Bradshaw, M., & Watson, J. (eds.) *Global Energy: Issues, Potentials and Policy Implications* (forthcoming). Oxford University Press.
- Bradshaw, M Chindo, M., Dutton, J. and Kama, K. (2014b) Unconventional fossil fuels and technological change. In: Ekins, P., Bradshaw, M., & Watson, J. (eds.) *Global Energy: Issues, Potentials and Policy Implications* (forthcoming). Oxford University Press.
- Bradshaw, M (2012) Time to take our foot off the gas? The role of gas in UK energy security. *Friends of the Earth*: London. [Online]. Available from: www.foe.co.uk/sites/default/files/downloads/time_to_take_our_foot_off.pdf [Accessed 13 June 2014].
- Bridge, G., Bouzarovski, S., Bradshaw, M., and Eyre, N. (2013) Geographies of energy transition: Space, place and the low-carbon economy. *Energy Policy*, 53, 331-340.
- BP (2014) BP Energy Outlook 2035. London: BP. [Online]. Available from: www.bp.com/content/dam/bp/pdf/Energy-economics/Energy-Outlook/Energy_Outlook_2035_booklet.pdf [Accessed 15 August 2015].
- BP (2014a) BP Statistical Review of World Energy June 2014. London: BP. [Online]. Available from: www.bp.com/content/dam/bp/pdf/Energy-economics/statistical-review-2014/BP-statistical-review-of-world-energy-2014-full-report.pdf [Accessed 17 June 2014].
- BP (2013) BP Statistical Review of World Energy June 2013. [Online]. Available from: www.bp.com/content/dam/bp/pdf/statistical-review/statistical_review_of_world_energy_2013.pdf [Accessed 13 June 2014].
- Bros, T. (2012) *After the US Shale Gas Revolution*. Paris: Editions Technip.
- Bulkeley, H. (2005) Reconfiguring environmental governance: Towards a politics of scales and networks. *Political Geography*, 24, 875-902.
- Coutard, O. (2002) *The Governance of Large Technical Systems*. Taylor & Francis: London.
- Daborowski, T. (2013) New players on the Central European gas market. *Natural Gas Europe*. [Online]. Available from: www.osw.waw.pl/en/publikacje/analyses/2013-04-10/new-players-central-european-gas-market [Accessed 11 May 2014].
- Dalby, S. (2010) Recontextualising violence, power and nature: The next twenty years of critical geopolitics? *Political Geography*, 29, 280-288.
- DECC (2014) Energy trends section 4: Gas. [Online]. Available from: www.gov.uk/government/publications/gas-section-4-energy-trends [Accessed 13 June 2014].
- DECC (2014a) UKCS Oil and Gas Production Projections. London: Department of Energy and Climate Change. [Online]. Available from: www.gov.uk/government/uploads/system/uploads/attachment_data/file/287001/production_projections.pdf [Accessed 30 June 2014].
- DECC (2014b) Scotland analysis: energy. London: Department of Energy and Climate Change. [Online]. Available from: www.gov.uk/government/uploads/system/uploads/attachment_data/file/302784/2901910_Scotland_Energy_PRINT.pdf [Accessed 2 July 2014].
- DECC (2014c) UK Energy in Brief 2014. London: DECC. [Online]. Available from: www.gov.uk/government/statistics/uk-energy-in-brief-2014. [Accessed 15 August 2014].
- DECC (2012a) Energy Security Strategy. Department of Energy and Climate Change: London. [Online]. Available from: www.gov.uk/government/uploads/system/uploads/attachment_data/file/65643/7101-energy-security-strategy.pdf. [Accessed 13 June 2014].
- DECC (2012b) Gas Generation Strategy. [Online] Department of Energy and Climate Change: London. Available from: www.gov.uk/government/uploads/system/uploads/attachment_data/file/65654/7165-gas-generation-strategy.pdf. [Accessed 01 July 2014].
- DECC (2010) Gas Security of Supply: A policy statement from the Department of Energy and Climate Change. Department of Energy and Climate Change: London.

- DECC/OFGEM (2013) Statutory Security of Supply Report 2013. [Online] Department of Energy and Climate Change: London. Available from: www.gov.uk/government/uploads/system/uploads/attachment_data/file/261604/HC_675_updated_accessible.pdf [Accessed 13 June 2014].
- Dickel, R. et al. (2014) Reducing European Dependence on Russian Gas: distinguishing natural gas security from geopolitics. OIES & OUP: Oxford. Available from: www.oxfordenergy.org/wpcms/wp-content/uploads/2014/10/NG-92.pdf [Accessed 03 November 2014]
- DNV KEMA Energy & Sustainability (2013) Study on LT-ST Markets in Gas. KEMA Consulting GmbH: Bonn.
- Emmerson, C. and Stevens, P. (2012) Maritime Choke Points and the Global Energy System: Charting a Way Forward. Chatham House: London. [Online]. Available from: www.chathamhouse.org/sites/files/chathamhouse/public/Research/Energy,%20Environment%20and%20Development/bp0112_emmerson_stevens.pdf [Accessed 2 July 2014].
- EIA (Energy Information Administration) (2014) Annual Energy Outlook 2014. EIA: Washington D.C. [Online] Available from: [www.eia.gov/forecasts/aeo/pdf/0383\(2014\).pdf](http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf) [Accessed 17 June 2014].
- EIA (2013) North America leads the world in production of shale gas. *Today in Energy*, 23 October. EIA: Washington D.C. [Online]. Available from: www.eia.gov/todayinenergy/detail.cfm?id=13491 [Accessed 17 June 2014].
- Ebinger, C, Massy, K. and Avasarala, G. (2012) Liquid Markets: Assessing the Case for U.S. Exports of Liquefied Natural Gas. Policy Brief 12-01. Brookings Energy Security Initiative: Washington D.C. [Online] Available from: www.brookings.edu/~media/research/files/reports/2012/5/02%20lng%20exports%20ebinger/0502_lng_exports_ebinger.pdf [Accessed 17 June 2014].
- Ekins, P. and Watson, J. (eds.) (2014) UK Energy in a Global Context – Synthesis Report. UKERC: London.
- European Commission (2014) European Energy Security Strategy, COM 2014 330 final. European Commission: Brussels. [Online]. Available from: http://ec.europa.eu/energy/doc/20140528_energy_security_communication.pdf [Accessed 20 June 2014].
- Eyre, N. and Pranab, B. (2014) UK Energy Strategies Under Uncertainty: Uncertainty in Energy Demand in Residential Heating. UKERC Working Paper. UKERC: London. [Online]. Available from: www.ukerc.ac.uk/support/tiki-download_file.php?fileId=3660 [Accessed 15 August 2014].
- Goldthau, A. and Witte, J.M. (2009) Back to the future or forward to the past? Strengthening markets and rules for effective global energy governance. *International Affairs*, 85, 373-390.
- Heather, P. (2010) The Evolution and Functioning of the Traded Gas Market in the Britain. Working Paper NG 44. Oxford Institute for Energy Studies: Oxford. [Online]. Available from: www.oxfordenergy.org/2010/08/the-evolution-and-functioning-of-the-traded-gas-market-in-britain/ [Accessed 13 June 2014].
- IEA (International Energy Agency) (2014) Medium-Term Gas Report 2014. IEA: Paris. [Online]. Available from: www.iea.org/w/bookshop/add.aspx?id=473 [Accessed 17 June 2014].
- IEA (2014a) Energy Supply Security: Emergency Response of IEA Countries 2014. IEA: Paris. [Online]. Available from: www.iea.org/publications/freepublications/publication/name-113501-en.html. [Accessed 30 June 2014].
- IEA (2013) World Energy Outlook 2013. IEA: Paris.
- IGU (International Gas Union) (2013) World LNG Report 2013. [Online]. Available from: www.lngglobal.com/latest/international-gas-union-world-lng-report-2013.html [Accessed 17 June 2014].
- Institute of Directors (2013) Getting Shale Gas Working. Institute of Directors: London.
- Kama, K. (2014) On the borders of the market: EU emissions trading, energy security, and the technopolitics of “Carbon leakage,” *Geoforum*, 51, 202-212.
- Misa, T.J. and Schot, J. (2005) Introduction. *Inventing Europe: Technology and the hidden integration of Europe, History and Technology*, 21, 1-19.
- Le Fevre, C. (2013) Gas Storage in Great Britain. Working paper NG 72. Oxford Institute for Energy Studies: Oxford. [Online]. Available from: www.oxfordenergy.org/2013/01/gas-storage-in-great-britain-2/ [Accessed 1 July 2014].

- Marsden, N. and Markusson, W. (2011) Public acceptance of natural gas infrastructure development in the UK (2000-2011). UKERC: London. [Online]. Available from: www.ukerc.ac.uk/support/ES_RP_SystemsCCS [Accessed 15 August].
- Mitrova, T. (2014) *The Geopolitics of Russian Natural Gas*. Houston: Harvard University's Belfer Center and James A. Baker III Institution for Public Policy of Rice University. [Online]. Available at: http://bakerinstitute.org/media/files/research_document/cdfea656/CES-pub-GeoGasRussia-022114.pdf [Accessed 01 October 2014].
- National Grid (2014a) UK Future Energy Scenarios: UK gas and electricity transmission. National Grid plc: Warwick. [Online]. Available from: <http://www2.nationalgrid.com/uk/industry-information/future-of-energy/future-energy-scenarios/> [Accessed 15 August 2014].
- National Grid (2014b) Winter Outlook 2014/15. National Grid plc: Warwick. [Online]. Available from: <http://www2.nationalgrid.com/media/Resources/PDFs/reports/WinterOutlookReport2014.pdf> [Accessed 03 November 2014].
- National Grid (2013) Gas Ten-Year Statement 2013. National Grid plc: Warwick. [Online] Available from: <http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Gas-Ten-Year-Statement/> [Accessed 14 June 2014].
- National Grid (2013a) UK Future Energy Scenarios: UK gas and electricity transmission. National Grid plc: Warwick. [Online]. Available from: <http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Future-Energy-Scenarios/>. [Accessed 30 June 2014].
- National Research Council (2001) *Energy Research at DOE: Was it worth it? Energy Efficiency and Fossil Fuel Research 1978-2000*. National Academy Press: Washington D.C. [Online]. Available from: www.nap.edu/openbook.php?isbn=0309074487 [Accessed 17 June 2014].
- Ofgem (2012) Gas security of supply report. Ofgem: London. [Online]. Available from: www.ofgem.gov.uk/ofgem-publications/40204/gas-sos-report.pdf [Accessed 1 July 2014].
- Ofgem (2009) Project Discovery Options for delivering secure and sustainable energy supplies. Ofgem: London. [Online]. Available from: www.ofgem.gov.uk/ofgem-publications/40354/projectdiscoveryfebcondocfinal.pdf [Accessed 01 July 2014].
- Okuya, T. (2014) Energy Situation in Japan and its implications for European energy affairs from Japanese new energy strategy. Presentation to Chatham House, Fossil Fuels Expert Roundtable, 24 June.
- Padgett, S. (2011) Energy co-operation in the wider Europe: Institutionalizing interdependence. *JCMS: Journal of Common Market Studies*, 49, 1065-1087.
- Petrovich, B. (2013) European gas hubs-how strong a price correlation? Working Paper NG 79. Oxford Institute for Energy Studies: Oxford. [Online]. Available from: www.oxfordenergy.org/2013/10/european-gas-hubs-how-strong-is-price-correlation-2/ [Accessed 13 June 2014].
- Redpoint (2013) The impact of gas market interventions on energy security: A report for DECC from Redpoint Energy. [Online]. Available from: www.gov.uk/government/uploads/system/uploads/attachment_data/file/236757/DECC_FI_Final_report_09072013.pdf. [Accessed 01 July 2014].
- Rogers, H. (2013) UK Shale Gas-Hype, Reality and Difficult Questions. Oxford Energy Comments, July. [Online] Available from: www.oxfordenergy.org/2013/07/uk-shale-gas-hype-reality-and-difficult-questions/ [Accessed 30 June 2014].
- Rogers, H. and Stern, J. (2014) Challenges to JCC Pricing in Asian LNG Markets. Working Paper NG81. Oxford Institute for Energy Studies: Oxford. [Online] Available from: www.oxfordenergy.org/wpcms/wp-content/uploads/2014/02/NG-81.pdf [Accessed 22 June 2014].
- Rühl, C. (2014) BP Statistical Review Webcast. [Online]. Available from: www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html [Accessed 16 June 2014].
- Shaffer, B. (2013) Natural gas supply stability and foreign policy. *Energy Policy*, 56, 114-125.
- Skea, J., Modassar, C. and Wang, X. (2012) The role of gas infrastructure in promoting UK energy security, *Energy Policy*, 43, 202-213.
- Stern, J. (2014) Russian Responses to Commercial Change in European Gas Markets. In: Henderson, J. and Pirani, S. (eds.) *The Russian Gas Matrix: How Markets are Driving Change*. OIES & OUP: Oxford.
- Stern, J. (2013) The evolution of governance in European gas markets. Unpublished manuscript.
- Stern, J. (ed.) (2012) *The Pricing of Internationally Traded Gas*. OIES & OUP: Oxford.

Stern, J. (2011) Gas Storage: A Case of Market Failure. In: Rutledge, I and Wright, P. (eds.) UK Energy Policy and the End of Market Fundamentalism. OIES & OUP: Oxford.

Stern, J. (2004) UK gas security: time to get serious. *Energy Policy*, 32, 1967-79.

Stern, J. and Rogers, H. (2011) The Transition to hub-based gas pricing in continental Europe. Working Paper NG 49. Oxford Institute for Energy Studies: Oxford. [Online]. Available from: www.oxfordenergy.org/wpcms/wp-content/uploads/2011/03/NG49.pdf [Accessed 11 June 2014].

Steven, P. (2013) Gas Markets: Past, Present and Future. In: R. Fouquet (ed.) *Handbook on Energy and Climate Change*. Edward Elgar: Cheltenham.

Stevens, P. (2012) The 'Shale Gas Revolution': Developments and Change. Chatham House: London. [Online]. Available from: www.chathamhouse.org/publications/papers/view/185311 [Accessed 17 June 2014].

Stevens, P. (2010) The History of Natural Gas. POLINARES working paper n.5. [Online]. Available from: www.polinares.eu/docs/d1-1/polinares_wp1_history_gas.pdf [Accessed 01 October 2014].

Trembath, A., Jenkins, J., Nordhaus, T. and Shellenberger, M. (2012) Where the Shale Gas Revolution Came From. Breakthrough Institute for Energy & Climate Program: Oakland, California. [Online]. Available from: http://thebreakthrough.org/images/main_image/Where_the_Shale_Gas_Revolution_Came_From2.pdf [Accessed 17 June 2014].

Wood, I (2014) UKCS Maximising Recovery Review: Final Report. [Online]. Available from: www.woodreview.co.uk/documents/UKCS%20Maximising%20Recovery%20Review%20FINAL%2072pp%20locked.pdf [Accessed 02 July 2014].



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