MACROECONOMIC EFFECTS OF EUROPEAN SHALE GAS PRODUCTION

A report to the International Association of Oil and Gas Producers (OGP)

November 2013
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EXECUTIVE SUMMARY

The International Association of Oil and Gas Producers (OGP) has commissioned Pöyry Management Consulting (Pöyry) and Cambridge Econometrics (CE) to examine the impact of potential shale gas production on energy prices and macroeconomic indicators for the EU28 countries for the period 2020 to 2050.

The success of shale gas development and production in the US has led to significant benefits in terms of lower energy prices, improved security of supply, additional employment, a more competitive manufacturing base and foreign investment. Whilst the scale of the shale gas success story in the US may not be repeated to the same extent in other regions of the world including Europe, there may still be significant potential benefits in developing shale gas resources.

This study has been conducted independently by Pöyry and by Cambridge Econometrics without involvement of the OGP members. It reflects the views of Pöyry and Cambridge Econometrics on the possible impact on energy markets of potential shale gas developments.

Shale gas scenario development

This study has analysed a range of potential shale gas scenarios from ‘No Shale’ to ‘Some Shale’ to ‘Shale Boom’ production levels in the EU. The shale gas scenarios that have been developed are based on information from the Energy Information Administration (EIA) that has been supplemented by national geological surveys, where available, to produce total EU28 ‘risked’ resources in place of around 54 tcm (1,900 tcf)¹. The scenario approach allows us to compare the impacts of different levels of shale gas production in the EU28 countries.

The Some Shale Scenario assumes 15% of the risked resources in place are technically recoverable and represents a projection of shale gas production with sufficient levels of political and public support to enable developments to proceed. However, due to some restrictions remaining in place, not all shale gas can be produced due to environmental, technical and practical barriers.

The Shale Boom Scenario is a more optimistic projection of shale gas production that assumes 20% of the risked resources in place are technically recoverable and is based on the assumption that widespread public and political support can be achieved and that any barriers to production are minimised.

A series of discard factors (that vary by scenario) are then applied to the technically recoverable reserves to cover environmental, planning and practical constraints. This creates a maximum shale gas capacity that could be produced if all shale gas were economically recoverable. The maximum shale gas capacity is then separated into a number of cost tranches to reflect that there will be a range of costs across different shale plays. The capacity and cost tranches, when fed into the Pöyry Pegasus gas model produces the production profiles shown in Figure 1.

¹ The term ‘risked resources’ is used to define the shale gas resources in place that take in to account the shale play success probability factor (high enough flow rates) and the prospective area success factor (relating to geological complications that reduces availability).
Whilst there is still considerable uncertainty regarding the costs of shale gas production in Europe, we have based our estimates on the best available sources including the Oxford Institute of Energy Studies (OIES) and the EU Commission’s Joint Research Centre (JRC).

In order to achieve the level of production shown in the Shale Boom Scenario we have estimated that approximately between 33,500 and 67,000 wells (depending on well productivity) will need to be drilled until 2050 in EU28. Based on the assumption that each shale gas drilling rig is capable of drilling 12 wells annually, the requirement for rigs reaches a peak of between 148 and 295 (depending on well productivity) in 2035 in the Shale Boom Scenario.

**Impact on energy markets**

Utilising the Pöyry suite of models it has been possible to examine the impacts on wholesale energy prices, import dependency and electricity generation mix of the Some Shale and Shale Boom Scenarios as compared to the No Shale Scenario, in which no shale gas is produced in the EU.

The modelling has been based on the Pöyry standard central scenario in which we make key assumptions regarding gas and electricity supply and demand. The Pöyry central scenario has formed the basis of a number of studies that we have undertaken for regulators, government and market participants.

The key findings are that:

- Shale gas production in EU28 should result in lower gas and electricity wholesale prices when compared to a future with no shale gas production as shown in Figure 2.
- There is an average reduction in wholesale gas prices of 6% in the Some Shale Scenario and 14% in the Shale Boom Scenario, when compared to the No Shale Scenario, over the period resulting in average annual savings of €12bn and €28bn respectively. The maximum saving is €36bn in 2050 in the Some Shale scenario and €51bn in 2050 in the Shale Boom scenario.
- There is an average reduction in wholesale electricity prices of 3% in the Some Shale Scenario and 8% in the Shale Boom Scenario, when compared to the No Shale Scenario, over the period resulting in average annual savings of €12bn and €27bn.
respectively. The maximum saving is €28bn in 2050 in the Some Shale scenario and €42bn in 2039 in the Shale Boom scenario.

- Cumulatively, over the period of this study this sums to wholesale energy savings of €765bn in the Some Shale Scenario and €1.7tn in the Shale Boom Scenario, as compared to the No Shale Scenario.
- Household spending on energy costs by 2050 could be lower by up to 8% in the Some Shale Scenario and by up to 11% in the Shale Boom Scenario, when compared to the No Shale Scenario. Over the period 2020 - 2050 total cumulative savings could be €245bn in the Some Shale Scenario and €540bn in the Shale Boom Scenario.
- Gas import dependency could reduce from 89% in 2035 in the No Shale Scenario to 78% in the Some Shale and 62% in the Shale Boom Scenarios as shown in Figure 3. This results in total balance of trade benefits of €484bn in the Some Shale Scenario and €1.1tn in the Shale Boom Scenario, when compared to the No Shale Scenario.
- The production of shale gas in Europe does not affect the growth of renewables under either shale gas scenario, but it does reduce coal burn in electricity generation as shown in Figure 4.

Figure 2 – EU28 demand weighted average wholesale gas and electricity prices compared to the No Shale Scenario (No Shale = 100%)

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The increase in the percentage discount in 2049/50 is due to a higher priced marginal source of gas setting the price in the No Shale Scenario from this year.
Macroeconomic indicators

The macroeconomic impact of shale gas production in the No Shale, Some Shale and Shale Boom Scenarios was modelled by CE using E3ME, an input-output based model of the European economy and energy system.

Our key findings are that:

- GDP and net job creation increases in both Some Shale and Shale Boom scenarios driven by an increase in domestic gas production (and a corresponding reduction in imports) generating additional demand in the domestic supply chain and a relative reduction in gas prices benefiting consumers and industry. The impact on GDP is shown in Figure 5 and is made up of higher overall consumption, increased investment, lower imports and higher exports.

- In the Some Shale Scenario EU28 GDP increases by €57bn (0.3% increase) and €138bn (0.6% increase) in 2035 and 2050 respectively. In the Shale Boom Scenario,
GDP increases by €145bn (0.8% increase) in 2035 and €235bn (1.0% increase) in 2050.

- Cumulatively, GDP in EU28 could increase by €3.8tn in the Shale Boom Scenario and €1.7tn in the Some Shale Scenario in the period between 2020 and 2050.

- Tax revenues increase as a result of gas production, increased employment and GDP. In the Shale Boom Scenario, VAT receipts increase by €23bn in 2050, due to the large increase in consumption, and the creation of over 1 million jobs leads to a substantial increase in employment-related tax. This is shown in Figure 5.

- In the Some Shale Scenario, net employment increases by 0.4 million by 2035 and 0.6 million by 2050. In the Shale Boom Scenario, net employment increases by 0.8 million jobs by 2035 and 1.1 million jobs by 2050. This is shown along with the impact on the mining and quarrying sector in Figure 6.

- Industry in EU28 will attain cost savings as a result of relatively lower gas and electricity prices. The impact will be most significant in those industries that are energy intensive. Lower costs may be passed onto consumers and/or lead to additional net exports.

Figure 5 – Increases in EU28 GDP and tax revenues

Source: Cambridge Econometrics

Figure 6 – Net job creation in EU28 total and in mining and quarrying sector (incl. oil and gas industries)

Source: Cambridge Econometrics
Conclusions

The aim of this study has been to examine the potential impacts of a range of shale gas production cases in the EU28 countries.

If the levels of shale gas production shown in our scenarios can be achieved then the energy markets and the wider economies of the EU28 countries should see benefits. However the achievement of the levels of shale gas production that we have considered will require further exploration and appraisal of the shale resources, the development of an onshore rig manufacturing and drilling industry and both political and public support.

Whilst a US style reduction in prices is not expected, the production of European shale gas should result in wholesale gas prices that are lower than they otherwise would have been. This also has a beneficial impact not only on the gas markets, but also on the electricity markets, in terms of relatively lower wholesale prices and reducing the role of coal in the generation mix. Industrial competitiveness will improve, particularly in energy intensive industries. Household energy costs should reduce as the savings in wholesale energy costs are passed through to consumers.

As a result of increased domestic EU gas production and relatively lower energy prices, GDP and employment will increase as will investment and tax revenues. The benefits will be felt in a number of sectors of the economy.

The shale gas production scenarios in this study have been developed based on the best resource information available at the time and also on information from the US experience of development and production. However, it should be recognised that at the present time, no shale gas is being produced in EU28 countries and accordingly there is limited information available. Better information should become available as more test wells are drilled.

Achieving the levels of shale gas production presented in the scenarios will require development of the onshore gas industry in Europe and support from policy makers and local communities. Whilst the industry will build up over time in response to commercial incentives, strong political will is expected to be necessary in order to secure the level of support that will be required to achieve large scale production of shale gas in Europe.
1. BACKGROUND

1.1 Introduction

The International Association of Oil and Gas Producers (OGP) has commissioned Pöyry Management Consulting (Pöyry) and Cambridge Econometrics (CE) to examine the impact of potential shale gas production on energy prices and macroeconomic indicators for the EU28 countries for the period 2020 to 2050.

The development of the shale gas industry in the US has had a significant impact, not only on the gas market but also on the wider economy. The scale of shale gas production in the past few years has reduced gas prices and created significant employment and investment opportunities.

The US gas market has changed dramatically in a relatively short period of time. As recently as 2010 the Energy Information Administration (EIA) predicted a requirement for liquefied natural gas (LNG) imports into the US\(^3\). This forecast has not materialised and the requirement for LNG imports has been offset by the domestic production of shale gas. Indeed, the increase in shale gas production has been so substantial that it is now expected to support US exports of LNG.

A simple analysis of gas prices suggests that US exports of LNG would be commercially attractive as Henry Hub prices are now substantially lower than the prices in the European markets, and to an even greater extent, in the Asian market. This is shown in Figure 7 where it can be seen clearly how the US and European gas prices have diverged since the end of 2009. Many energy intensive industries in the US are currently enjoying a competitive advantage over their competitors located in other parts of the world due to the impact of shale gas in reducing their energy costs.

\(^3\) See Energy Outlook Reports, US imports of natural gas by source (Figure 92 in 2011 report).
The success of shale gas in the US has been due to a number of factors combining to create a competitive market that has encouraged investment and development of shale gas resources.

However, the US is not the only region that contains shale gas resources and attention has turned to other countries that show some shale gas potential.

Europe has significant shale gas resources that have been identified by various EIA reports and national geological surveys. There has, therefore, been considerable debate and various studies that have examined shale gas potential in Europe.

Many observers have concluded that shale gas in Europe will not reduce gas prices in the same manner that has been seen in the US. However there is much uncertainty concerning the economic production of shale gas - how much can be produced and at what price will it be commercially viable? There are significant barriers to shale gas development in Europe and overcoming these barriers will be a significant challenge for the shale gas industry and both national and European policy makers.

This study attempts to address these questions through the consideration of a range of potential shale gas production in Europe – the ‘No Shale’ the ‘Some Shale’ and ‘Shale Boom’ Scenarios.

The Some Shale Scenario represents a projection of shale gas production in EU28 with sufficient levels of political and public support to enable developments to proceed. However, due to some restrictions remaining in place, not all technically recoverable shale gas can be produced due to environmental, technical or practical barriers.
The Shale Boom Scenario is a more optimistic projection of shale gas production based on the assumption that widespread public and political support can be achieved and that any barriers to production are minimised due to this level of support.

We consider what impact these shale gas production scenarios could have on wholesale energy prices, security of supply and macroeconomic indicators and compare the findings to a third scenario (No Shale) in which no shale gas is produced in Europe.

The study was divided into two phases. The first phase (conducted by Pöyry) focussed on developing credible scenarios for shale gas production and examining the potential impact on EU energy markets including gas and electricity wholesale prices. The second phase has focussed on investigating the macroeconomic impacts (conducted by CE).

This study has been conducted independently by Pöyry and by Cambridge Econometrics without involvement of the OGP members. It reflects the views of Pöyry and Cambridge Econometrics on the possible impact on energy markets of potential shale gas developments.

1.2 Structure of this report

This report contains four main sections which follows the structure of the project itself:

- Section 2 – development of shale gas scenarios;
- Section 3 – impact on energy markets;
- Section 4 – macroeconomic impacts; and
- Section 5 – conclusions.

This report is written jointly by Pöyry and Cambridge Econometrics. Sections 1 to 3 were written by Pöyry. Section 4 was written by CE. The conclusions presented within the Executive Summary and Section 5 were written jointly.

To arrive at the results presented and discussed within this report, both Pöyry and CE engaged in detailed modelling. The approaches taken to the modelling are outlined in:

- Annex A – Pöyry’s modelling approach; and
- Annex B – Cambridge Econometrics’ modelling approach.

1.2.1 Conventions

- All monetary values quoted in this report are in euros (€) in real 2012 prices, unless otherwise stated.
- Volumes of gas are stated in trillions of cubic meters (tcm) or billions of cubic meters (bcm), unless otherwise stated.

1.2.2 Sources

Unless otherwise attributed, the source for all tables, figures and charts is Pöyry Management Consulting.
2. SHALE GAS SCENARIO DEVELOPMENT

2.1 Introduction

To assess the potential impact of shale gas in EU28, we first needed to develop feasible production scenarios. This has been based on estimates of the amount of the shale gas resources that could be recoverable, in real terms, on technical, environmental, practical, and commercial levels.

However, there are very significant uncertainties in each area of assessment that will impact directly on the level of shale gas production in Europe over the coming decades. For example, technical uncertainties require additional exploratory drilling to reveal the extent of technically recoverable resources, and provide clarity on production costs. Similarly, planning and environmental regulation for shale gas is still under development in Europe and it is not yet clear how these variables could impact, in real terms, on availability of what may be technically recoverable resources (and/or their production costs).

Finally, the specific responses of governments, regulators, and commercial players to the needs created by the emergence of a shale gas industry in Europe are, in most cases, yet to be defined. However, these responses could affect very significantly the pace of progress and shape of the European shale gas industry over the coming decades. Key uncertainties include – but are not limited to – the physical availability and access to suitable gas infrastructure; as well as ability of the services sector and labour market to meet demand stemming from the shale gas industry at affordable costs.

Against this backdrop, we have focussed on creating a transparent multi-layered methodology, aimed at reflecting the significant uncertainties on all these levels, whilst offering a realistic (but conservative) range of potential outcomes in EU28. We have accordingly developed 3 scenarios: the No Shale, the Some Shale and the Shale Boom Scenarios. In the No Shale Scenario, we simply assumed that there is no development of shale gas in Europe, whether due to technical, environmental, practical, and/or economic reasons. This case was then used as a benchmark in order to assess the benefits which shale gas production could bring to EU28.

Figure 8 below gives an overview of our methodology and key assumptions while Sections 2.2 onwards describe, in more detail, the approach that we have taken to develop our two scenarios, i.e. the Some Shale and our more optimistic Shale Boom Scenarios. These sections describe each of the discard factors we have applied including our specific assumptions for each scenario (and for each country where this impacts on the results), our rationale for each decision, and the data sources used.
2.2 Risked resources in place

Estimates of risked resources in place for EU28 form the basis on which our subsequent technical, environmental, practical, and commercial discard factors are applied. Such estimates of risked shale gas resources in Europe by country have been published by a small number of bodies; notably the US Energy Information Administration (EIA) in 2011.

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4 Risked shale gas resources in place are calculated on the basis of broader estimates of the total (unrisked) shale gas resources, which include both free and adsorbed natural gas. These estimates are then discarded for:

- **The play success probability factor:** this is the probability that appropriately high flow rates would in fact be possible in a given play to render its development likely. Indicatively, this could stand at between 30% and 100% of total resources in place.

- **The prospective area success factor:** this refers to the probability that there are no geological complications or problems in the prospective area that reduces available gas. Indicatively, this could stand at between 20% and 75% of total resources in place.


The aforementioned report by the EIA thus formed the basis of our assumptions regarding the size and country distribution of risked shale gas resources in place in EU28. However, our approach was also informed by estimates from individual national sources such as the German Federal Institute for Geosciences and Natural Resources and the Polish Geological Institute, where such information was more recent or deemed more reliable.

As non-EIA national estimates often referred to recoverable shale resources rather than to risked resources in place and in order to ensure consistency with our wider methodology, we back-calculated the level of risked shale gas resources in place by assuming that their reported technically recoverable estimates represented 15% of risked resources in place. The latter was in line with our assumptions concerning average technical recovery factors of risked shale gas resources in the EU as described in more detail in Section 2.3.1 below.

For example, the German Federal Institute for Geosciences and Natural Resources estimates availability of shale gas resources of between 6.8 tcm and 22.6 tcm for Germany (i.e. between 240 tcf and 800 tcf) - of which between 0.7 tcm to 2.3 tcm will be technically recoverable (i.e. between 25 tcf and 81 tcf).

We have accordingly assumed approximately 1.5 tcm (53 tcf) of technically recoverable shale gas in our Some Shale scenario, which we then back-calculated to 9.8 tcm (345 tcf) of risked resources in place in Germany. The recent EIA 2013 study estimates roughly 80 tcf of risked shale gas resources. However, this only assesses the potential of the Lower Saxony Basin.

Figure 9 shows the assumptions we have made with regard to risked shale gas resources in place in each relevant country in EU28. In the course of our work, the EIA published a new report with updated shale estimates. Though this update was too late to be used as the basis of our analysis, we have made a comparison of the 2011 figures with those in the 2013 report. This is shown in Figure 10.

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The EIA and national estimates we have used (and by extension our own estimates too) are inherently uncertain due to the early stage of exploration for European shale gas. However, by virtue of exclusion of some prospectivity they tend to be rather conservative. For example, they do not examine and/or offer estimates for all of the countries in EU28, or necessarily even assess all the potential formations within countries actually examined.

Our total estimate with reference to risked shale gas resources in place for EU28 stands at approximately 54 tcm (1,900 tcf). This represents roughly 40% of the most recent
estimates of EIA for risked resources in place in the US (~130 tcm or 4,600 tcf). Moreover, in its 2013 study, the EIA assumes the existence of as much as 139 tcm (4,900 tcf) of risked shale gas resources in place for Europe as a whole. However, this estimate includes countries such as Russia and Ukraine, both of which have significant shale gas resources. A more direct comparison for the EU28 countries shows that the EIA estimates around 68 tcm (2,404 tcf) as compared with our 54 tcm (1,900 tcf) estimate. Our estimates of risked shale gas resources in place are, therefore, more conservative than the latest EIA estimates.

2.3 Potential constraints to shale production (discard factors)

2.3.1 Technically recoverable resources

The term ‘technically recoverable shale gas resources’ refers to the share of the risked shale gas resources in place (see Section 2.2) which can be extracted on the basis of their shale mineralogy, reservoir properties, and geological complexities with current technologies.

The recovery factor for shale gas resources is typically assumed to range between some 15% and 40% (with the 20% to 30% range being more common), albeit it is not always immediately clear whether this is assumed to apply to unrisked or risked resources.

Given that risked resources represent only a fragment of unrisked resources in place, applying the recovery factor to them rather than considerably higher unrisked resources inescapably reduces the assumed technically recoverable resources.

In line with our focus on a realistic but generally conservative methodological approach, we adopted the lower range of these, i.e. 15% for Some Shale, 20% for Shale Boom. Moreover, we applied these recovery factors over our assumed risked shale gas resources in place for all countries with shale gas prospectivity in EU28.

Figure 11 below shows the impact of applying these differentiated discard factors on estimates of risked shale gas resources in EU28.

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This in turn yielded technically recoverable shale gas levels in EU28 countries of roughly 10.8 tcm (381 tcf) in the Shale Boom and 8.1 tcm (286 tcf) in the Some Shale Scenario. This range for EU28 represents only between 25% and 33% of the most recent available estimates of the EIA with reference to the recoverable shale gas resources in the US. Additionally, it is less than the technically recoverable shale gas resources that the EIA assumes for Europe as a whole, which includes significant non-EU28 resources such as the Ukraine and Russia, and which stand at almost 26 tcm (900 tcf).9

Figure 12 compares our estimates for technically recoverable resources in EU28 under our Some Shale and the optimistic Shale Boom Scenarios with the aforementioned estimates by the EIA for both Europe and the US.

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Environmental and planning constraints

The second discard factor we apply (on shale resources that are technically recoverable) is environmental and planning constraints, which are treated here as a single category. This discard factor seeks to reflect the controversy that shale gas has created in the EU and the level of opposition that has been seen in some countries.

Environmental opposition to shale gas mostly relates to fears of water contamination. However, it can also include opposition to what is perceived as obtrusive visual impacts; to the impact on geological stability (i.e. linking of hydraulic fracturing with earth tremors); the impact of shale gas well pads on the landscape; to the substantial use of what could be scarce water resources for drilling operations etc.

Planning opposition relates to such environmental opposition, albeit it could also include difficulties that have to do with securing planning permits from local or regional authorities. This will not be confined solely to the prospect of drilling for shale gas and are usually very different from one country to another (or even from one region to another).

Environmental/planning difficulties are likely to be more significant in Europe compared to the US and early experience from some EU countries indeed suggests this to be the case. This can be the result of a number of relevant factors, with a particular focus on:

- the significantly higher population density in EU countries compared to the US, which restricts land availability for drilling (as well as potentially driving costs up);
- the fact Europeans are much less used to or familiar with (even conventional) drilling operations – and therefore potentially more suspicious towards shale gas; and
- the more restrictive mineral ownership rights in Europe compared to the US, which result in owners having fewer incentives to lease land to shale developers.
We have taken a long-term view of environmental and planning constraints on shale gas development in EU28 across our reference period (i.e. 2020 - 2050) and have therefore not assumed any permanent bans on exploration and production.

However, we segmented our analysis and distinguished between different EU countries, to employ more realistic assumptions of what might be the impact of increased opposition.

For example, France has already seen strong opposition to shale development on both the social and the political level and a full ban on hydraulic fracturing still remains in force in the country. Against this background, we assumed that only half of technically recoverable resources in France will be in areas free from environmental and/or any other planning constraints and thus available to shale developers even under our optimistic Shale Boom Scenario; whilst only 30% of these shale resources are available under our Some Shale Scenario. Moreover, we have delayed first shale gas in France to 2024 to reflect current opposition.

For the other EU countries we assumed availability of prospective areas of 50% and 70% respectively under Some Shale and Shale Boom. This was in turn applied to our estimates of technically recoverable resources (which is different in the two scenarios). Furthermore, we have assumed that production for all EU28 countries except France starts before our 2020 reference period, albeit with some differentiation between them.

Figure 13 and Figure 14 offer a graphic representation of the impact of the application of environmental and planning constraints on our previously assumed technically recoverable resources under our Some Shale and Shale Boom Scenarios.
2.3.3 Potential practical issues affecting shale gas production

Alongside the aforementioned environmental and planning concerns, there are likely to be practical constraints which will restrict shale production in EU28. These factors include, inter alia, the availability of a suitable service sector (including drilling rigs) in Europe, trained and experienced staff, and physical and regulatory access to the pipeline network.

The implications and extent of these potential constraints remains uncertain in Europe. Hence, in order to be able to discard appropriately we took into consideration the level of drilling activity that various levels of shale gas production could imply in EU28. We then assessed on a high level that requirement against current capabilities in Europe and their potential evolution in the future under a conservative scenario.

Similarly, we took into account current imperfections in the European natural gas market, including both the availability of physical pipeline infrastructure and regulatory access to it. US shale experience suggests this can be an important parameter as it defines access for companies which may be able to make a meaningful contribution to shale development, but otherwise lack an established position in a given market.

Against this background, we have assumed availability of resources to shale gas developers of approximately 50%-55% under the Some Shale Scenario and 70% in Shale Boom. These figures stand at 30% and 50% respectively for France.

Twenty years after first shale gas for each EU28 country (i.e. between 2035 and 2044) we assume that market and regulatory conditions finally mature and practical constraints are thereby gradually lifted. The removal of these constraints reaches 75% over a 15-year period, in other words commercial constraints stand at 25% of those originally assumed by 2050, for most countries. In France this is reached later due to the delayed start date of shale gas production.

Figure 15 and Figure 16 describe the impact of the application of practical constraints on our estimates on resource availability in EU28 in the Some Shale and Shale Boom Scenarios (i.e. after having applied relevant technical and environmental and planning constraints). Figure 17 summarises the results of the application of our discard factors.
Figure 15 – Resource availability in EU28 after the application of practical constraints under the Some Shale Scenario

Available after environmental/planning constraints at Some Shale
Available after practical constraints at Some Shale

Figure 16 – Resource availability in EU28 after the application of practical constraints under the Shale Boom Scenario

Available after environmental/planning constraints at Shale Boom
Available after practical constraints at Shale Boom
2.4 Maximum annual shale gas production potential by scenario

Shale gas resources after application of all discard factors including practical constraints described in Section 2.3.3 (but at this stage still excluding costs) which would thus be available for development were then converted to annual gas production using a top-down approach. The specific assumptions employed in this framework are described below:

- Year 1 of production (“first shale gas”) is assumed to be 2015 for all EU countries, with the exception of Germany which starts in 2018 and France that starts in 2024. This is for the most part a theoretical production start point for modelling purposes.
- Shale gas wells are assumed to have a lifetime of 25 years. Available shale gas resources after the application of practical constraints are then divided by 25 (years) to help calculate possible annual shale gas production levels. This is considered to represent the peak annual production for this resource basis, and is assumed to be reached 20 years after Year 1 (i.e. between 2035 and 2044).
- There is a gradual build-up from Year 1 to peak shale gas production in Year 20, with EU28 production of shale gas accordingly declining from Year 21 onwards. This decline stands at roughly 50% of decline rates seen in the US Marcellus shale (excluding Year 1) to reflect multiple plays with different start years in this period.
- Practical constraints on shale gas resources are removed by 75% over a 15-year period after peak production and therefore release previously untapped production potential into the market from 2035 onwards (and thus arrest the overall decline).

The above assumptions and methodology imply neither flat shale gas production in EU28 nor that total available resources will be produced in our reference period of 2020-2050, as shale gas production in EU28 starts at a very low basis even before 2020 and gradually builds up to much more substantial levels, continuing in the 2050s and beyond.
Figure 18 reflects the impact of the above on our assumed aggregated maximum annual shale gas production in EU28 under both our Some Shale and Shale Boom Scenarios.

Importantly, these profiles show maximum annual shale gas production potential in EU28 under either scenario without yet taking into consideration production costs and EU wholesale gas prices. This key variable is included in our natural gas market optimisation modelling where shale gas production will compete with gas from other sources to ensure that EU demand is met at the lowest possible cost (and will accordingly not get produced if uneconomic to do so).

The potential production profiles have been 'sense checked' through estimating the number of wells that will need to be drilled, their implied productivity and rig requirements - including an assessment of European capabilities to deploy the assets thereby required - to produce such levels of shale gas in the 2020-2050 timeframe.

In this ‘sense-check’ analysis, we have assumed that approximately between 33,500 and 67,000 wells (depending on well productivity – either 2, 3 or 4 bcf) will need to be drilled until 2050 in EU28, in order to allow for the maximum theoretical production of our Shale Boom scenario (i.e. of the maximum production potential under that scenario prior to price and cost constraints).

Annual shale gas drilling in EU28 peaks in 2035 in this same framework, which accordingly sees between around 1,800 and 3,500 wells (again, depending on actual well productivity) drilled in that year.

By comparison, these figures are much lower compared to the approximately 150,000 shale gas wells drilled in the US in the last decade alone.

Based on the assumption that each shale gas drilling rig is capable of drilling 12 wells annually, the requirement for rigs reaches a peak of between 148 and 295 (depending on well productivity) in 2035. Currently it is estimated that the EU has a rig manufacturing capability of around 12-18 per year. We have assumed that European manufacturers construct a total 5 rigs that are suitable for shale gas drilling in 2020; 10 rigs in 2025; 14 in 2030; and 18 per annum by 2034/2035. Whilst Europe is able to build up a sizeable rig fleet over time it is possible that there may be a requirement for some imported rigs to be operational in the low well productivity scenarios.
2.5 Shale gas production costs in EU28

2.5.1 Introduction

Our next step is to add a specific commercial constraint on the aforementioned technical, environmental/planning and practical constraints. This was based on assumed long-run marginal costs pertaining to the production of shale gas in EU28.

We have excluded from our analysis the potential (favourable) impact of liquids credits on shale production, due to lack of adequate information to help reach realistic assumptions, as well as our conservative approach on methodology and application of discard factors.

The shale gas production cost variable was then included in our gas market optimisation modelling - where shale gas production competes with gas from other sources to ensure that demand is met at the lowest possible cost (and will accordingly not get produced if uneconomic to do so).

Hence, unlike the technical, environmental/planning and practical discard factors above, the proportion of shale gas resources in EU28 which is recovered after the application of the related commercial (i.e. cost) discard factor is not an input assumption into our model. Instead, this is an output of our models which is determined by how these assumed EU28 shale gas production costs compare with European wholesale gas prices in our reference period.

2.5.2 Cost assumptions and sources

We based our cost assumptions for shale gas production in EU28 on literature review. Our primary sources of information in this framework were a 2010 study from the Oxford Institute for Energy Studies (OIES), a recognised independent centre of the University of Oxford; and a number of other sources which were cited in the European Commission’s 2012 Joint Research Centre (JRC) scientific and policy report on unconventional gas. Among others, this included estimates from Rice University and energy companies E.ON (Germany) and Centrica (UK).

The OIES estimates a breakeven for shale gas production in some European countries that could stand at approximately USD 7.5 to 15.5 per mmbtu; whilst Rice assumes roughly USD 6 to 7 per mmbtu; E.ON about USD 6 to 10 per mmbtu; and Centrica (which recently invested in UK shale) between USD 7 and 10 per mmbtu.

Both the OIES and the JRC consider cost reductions of 50% to be realistic on shale gas drilling and completion costs in the EU. These reductions in drilling and completion costs

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10 This refers to condensate yields and natural gas liquids which are sometimes included in natural gas wells and have high commercial value, thereby reducing gas production costs.


12 Ibid.
may be achievable within a 5-10 year period and represent a major component of full-cycle costs (they stand at around 30% of full cycle costs). Furthermore, there may also be opportunities of reducing shale gas production costs as a result of a gradual emergence of efficient markets (e.g. service sector, labour market) and practices. At the same time though, most studies acknowledge the threat of EU28 cost escalation due to various technical, environmental, and practical constraints.

Against this backdrop, JRC’s meta-analysis suggests some USD 9.9 per mmbtu for 2010, approximately USD 7.2 per mmbtu for 2020, and also some USD 6.1 per mmbtu for 2030 as the more likely scenarios for these respective periods (-39% between now and 2030).13

2.5.3 Pöyry cost assumptions

2.5.3.1 Definitions and cost assumptions for 2020

Our EU28 shale gas breakeven assumptions are made on the basis of full-cycle costs and include finding and development costs, production costs, general and admin costs, and interest (they exclude transportation or other midstream infrastructure development). Furthermore, our estimates include an assumed nominal discount rate of 10%.

On the basis of the publicly available information mentioned above we have thus assumed that by 2020 shale gas can be developed in EU28 on a full-cycle basis at breakeven which ranges from as low as USD 5 to as high as USD 13 per mmbtu (with small outliers).

About 60% of this production is possible at breakeven between USD 8 and 11 per mmbtu, whilst the weighted average breakeven for EU28 in 2020 stands at USD 9.1 per mmbtu. This is more conservative compared to the cost estimates which were cited in Section 2.5.2. This is presented in graphical form in Figure 19.

![Figure 19 –Comparison of shale gas production costs in EU28](image)

Source: Pöyry with data from OIES and JRC

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13 This information comes from Table 6-1 on page 192, which however is cited as EUR per GJ. This was converted to USD per mmbtu assuming GJ = 0.95 mmbtu and EUR = USD 1.3
2.5.3.2 Downward and upward cost drivers to 2035

Additionally, we assumed two opposing cost drivers with regards to shale gas breakeven. The first is a downward cost driver relating to technological and efficiency gains which go beyond anticipated improvements in shale gas drilling and relevant well completion costs, and include more efficient markets (e.g. EU service sector, labour markets) and practices.

Under our Some Shale Scenario, these technological and efficiency gains put downward pressure on costs and reach cumulative savings 40% by 2035 (compared to 2020 levels). This is directly comparable with JRC’s 39% for 2030 which was mentioned in Section 2.5.2 above, and is equal to a Compound Annual Growth Rate (CAGR) of minus 3.3% for these costs. There are no departures in the EU shale gas cost structure from 2035 onwards on the assumption that technological gains and market efficiencies have already been captured.

Under Shale Boom, technology and efficiency gains put even more substantial downward pressure on costs, which by 2035 reach a cumulative 60% compared to our 2020 levels. This is higher compared to JRC’s 39% for 2030 which was referenced in Section 2.5.2, and is equal to a Compound Annual Growth Rate (CAGR) of minus 5.9% for these costs. As above, there are no changes in the cost basis from 2035 onwards on the assumption that all the major technological gains and market efficiencies have already been captured.

However, at the same time environmental protection measures and a gradual move away from sweet spots with high productivity shale gas wells towards less prolific shale areas work in the opposite direction and place upward pressure on shale gas costs for EU28. The above upward cost pressures result in a cumulative breakeven escalation by 2035 of 30% in our Some Shale Scenario (CAGR 1.8%) and 20% in Shale Boom (CAGR of 1.2%).

As above, there are no changes in the cost basis from 2035 onwards on the assumption that by then environmental costs have been successfully absorbed by the shale industry; whilst sweet spot well depletion does not cause any further upwards pressures on costs. Instead, this starts to be reflected on the tail-off of production in earlier sweet spot areas, albeit this is effectively neutralised by the freeing up of previously untapped potential due to the gradual removal of practical constraints from 2035 onwards (see Section 2.3.3 above).

2.5.3.3 EU28 shale gas breakeven between 2035 and 2050

As a result of these downwards and upwards cost drivers we see a net cumulative breakeven reduction of 10% in our Some Shale Scenario (i.e. 10% + 20% - 40%) and -40% under our Shale Boom Scenario (i.e. 0% + 20% - 60%).

Our assumed breakeven for shale gas production in EU28 between 2035 and 2050 thus stands between USD 4.5 and 11.7 per mmbtu (small outliers) in our Some Shale Scenario. Roughly 60% of this shale gas production can take place at a breakeven which stands between USD 7.2 and 9.9 per mmbtu and has a weighted average of USD 8.2 per mmbtu. This is more conservative and stands about 34% higher compared to JRC’s meta-analysis which suggests roughly USD 6.1 per mmbtu as the most likely breakeven for European shale gas in 2030 (see Section 2.5.2 above).

By the same token, our assumed EU28 shale gas breakeven under Shale Boom stands at between USD 3 and 7.8 per mmbtu (small outliers) in our Some Shale Scenario. Roughly 60% of this shale gas production can take place at a breakeven which stands between USD 4.8 and 6.6 per mmbtu and has a weighted average of USD 5.5 per mmbtu. In turn, this is about 10% lower compared to JRC’s USD 6.1 per mmbtu of Section 2.5.2.
Figure 20, Figure 21, Figure 22, Figure 23 and Figure 24 contextualise Pöyry’s long-term estimates against the JRC’s most likely scenario. Furthermore, they give a summary of our methodology, key assumptions, and assumed breakeven range under our Some Shale and Shale Boom Scenarios for our whole reference period of 2020-2050.

Figure 20 – Pöyry weighted average breakeven for shale gas production in EU28 compared to JRC most likely scenario for 2020 and 2030*

* Pöyry’s long-term estimate refers to 2035 as opposed to JRC’s 2030 time frame

Figure 21 – Opposing cost drivers and net benefit for EU28 shale gas in 2035 under Some Shale (left) and Shale Boom (right) scenarios
Figure 22 – Long run marginal costs of EU28 shale gas production in Some Shale Scenario

Source: Pöyry with information from JRC and OIES

Figure 23 – Long run marginal costs of EU28 shale gas production in Shale Boom Scenario

Source: Pöyry with information from JRC and OIES
2.6 Concluding remarks

Understandably, given the current stage of exploration of the shale gas industry in Europe, there is considerable uncertainty regarding production volumes and costs. There is no shale gas being produced on a commercial basis in Europe and this is expected to be the case for the next several years.

There is therefore, little reliable information available relating to the specifics of shale gas extraction in Europe. There is limited information available from the few exploratory wells that have been drilled. As the industry develops, such information will be valuable in informing estimates of production volumes, well production costs and likely depletion rates.

In the absence of such information, we have developed an approach based on a top-down view of potential shale gas production. This was chosen due to the lack of accurate and reliable information to enable us to make a detailed bottom-up estimate.

Where we have made an assumption, for example, regarding technically recoverable reserves we have tended to take a conservative view in order that the resulting production profiles are realistic.

In terms of the costs of production we have based our assumptions on the ranges of costs that we have observed from other estimates, in particular the OIES and JRC. Our view on production cost reductions in the Shale Boom Scenario may be viewed as optimistic.
(although they are based on JRC data) given that the US has already developed an efficient model of operation and Europe will be able to benefit from this. However, there are likely to be many more technical innovations in the next 10-15 years (and beyond) that could result in lower shale gas production costs.

Regardless of this, however, we do not consider that the potential production profiles will be adversely affected if the production cost reductions are not achieved to the extent we have assumed. This is because shale gas production will be economic if it can be produced below the market price of gas which we assume to be set by the marginal source. Under our scenarios, imported gas continues to be the marginal source of gas in Europe as is shown in the next section.

In this study we have assumed that the development of a shale gas industry in Europe is achievable. The specific responses of governments, regulators, and commercial players to the needs created by the emergence of a shale gas industry in Europe have yet to be defined. However, these responses could affect very significantly the pace of progress and shape of the European shale gas industry over the coming decades. Key uncertainties include – but are not limited to – the physical availability and access to suitable gas infrastructure; as well as ability of the services sector and labour market to meet demand stemming from the shale gas industry at affordable costs.
3. IMPACT ON ENERGY MARKETS

3.1 Introduction

To estimate the impact of shale gas production on the EU28 energy markets, the potential shale gas production profiles were included within the Pegasus gas model which schedules supply sources to meet demand at lowest cost. The resulting prices from Pegasus were then used as an input to the electricity market model Zephyr to assess the impact on the electricity generation sector. Further details on both Pegasus and Zephyr can be found in Annex A.

The modelling has been based on the Pöyry central scenario\(^{14}\) that contains a set of assumptions that include:

- gas production in North America according to those provided by the EIA;
- LNG availability for Europe faces increased competition from Asian gas markets in the medium-term, despite continued liquefaction capacity growth;
- Russia develops new gas fields, but some competition is introduced from other pipelines, notably TAP, from the Caspian region;
- Norway develops its gas sources, according to the most likely scenario from Norwegian Petroleum Directorate (NPD) reaching a peak supply in 2021;
- long-term contracts are priced, based on a mix of oil-indexed and LRMC prices, depending on the source and destination of gas; and
- new gas supply projects come online in a timely manner and gas trading hubs continue to develop.

Within the energy markets, we have assessed the impact of shale gas production on gas flows around Europe, the resulting wholesale gas prices and effects on the electricity markets. Our findings suggest that shale gas production will reduce gas imports, but will not remove import dependency entirely. Shale gas production in both the Some Shale and Shale Boom Scenarios should result in reductions in wholesale gas and electricity prices when compared to the No Shale Scenario.

\(^{14}\) The Pöyry central scenario has been used many times for numerous clients in public studies. For instance, see:

- ‘The Impact of Unconventional Gas on Europe’, Ofgem, June 2011
- ‘GB Gas Security of Supply and Options for Improvement’, DECC, March 2010
- ‘How will intermittency change Europe’s gas markets’, Multiclient, October 2012
3.2 Economic shale gas production

The potential shale gas production shown in Figure 18 excludes the impact of any gas which could not be produced commercially due to the long-run cost of extracting the gas exceeding the expected market revenue. This constraint is included within the Pegasus modelling, and so Figure 25 and Figure 26 show gas production profiles where only commercially viable gas is produced. The capacity line in these charts shows the total potential production capacity as established by the methodology described in Section 2.

Figure 25 – EU28 Shale gas production in Some Shale Scenario

In the Some Shale Scenario, shale gas production grows steadily to 60bcm by 2035, and thereafter grows more gradually to reach a peak of almost 80bcm in 2050, which represents 15% of total EU28 demand in that year.

Figure 26 – EU28 Shale gas production in Shale Boom Scenario
In the Shale Boom Scenario, shale gas production clearly grows more quickly than the Some Shale case, with production in 2035 two and a half times greater than the Some Shale case at 150bcm. Shale gas production reaches a peak of 167bcm in 2041; representing 30% of total EU28 demand by this point.

In both scenarios, shale gas could be produced economically by the start of the reference period in 2020. However, sources are not producing at the maximum capacity until the early-2030s in the Shale Boom Scenario and the mid-2030s in the Some Shale Scenario showing that only the cheaper tranches of shale gas production would be economic during these periods and that not all shale could be extracted economically at the prevailing market prices. Thereafter, shale gas is fully utilised as the costs of production decline, and the market prices increase, which then makes all tranches economically viable at the cost levels assumed.

Figure 27 puts the overall production in each scenario in context of the resources in place.

<table>
<thead>
<tr>
<th>Total shale production 2020-2050 (bcm)</th>
<th>% of total risked resources</th>
<th>% of technically recoverable resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some Shale</td>
<td>1,480</td>
<td>3%</td>
</tr>
<tr>
<td>Shale Boom</td>
<td>3,525</td>
<td>7%</td>
</tr>
</tbody>
</table>

### 3.3 Impact on gas markets

Shale gas production will have direct effects on the EU28 gas markets. In this section we explore the high level impacts on the prices and flows of gas for the EU28 as a whole.

#### 3.3.1 Impact on wholesale gas prices

One of the major factors to consider when assessing the impact of shale gas production in Europe is the extent to which it will affect gas prices. In this study we have utilised our Pegasus gas model to assess the impact of shale gas production under the different scenarios.

Our modelling shows that shale gas production should reduce wholesale gas prices in both the Some Shale and Shale Boom Scenarios in comparison to the No Shale Scenario. The change in demand weighted average wholesale gas prices compared to the reference No Shale prices is shown in Figure 28.
Wholesale gas prices in the Some Shale Scenario are only slightly lower than the No Shale prices until the mid-2030s after which there is a larger reduction in the price as shale gas production increases.

In the Shale Boom Scenario, prices diverge from the No Shale Scenario by the mid-2020s and remain substantially lower for the remainder of the reference period.

On average over the period from 2020 to 2050, shale gas production causes a reduction in gas prices of 6.2% in the Some Shale Scenario and 13.8% in the Shale Boom Scenario.

For the EU, this results in average annual savings of €12bn in the Some Shale Scenario and €28bn in the Shale Boom Scenario. The maximum saving is €36bn in 2050 in the Some Shale scenario and €51bn in 2050 in the Shale Boom scenario.

### 3.3.2 Household gas costs

Assuming that the wholesale gas savings are passed on to consumers then lower overall household costs for gas should follow. The Cambridge Econometrics model allows a comparison of EU28 average household gas costs and shows that in the Some Shale Scenario that household gas costs could reduce by 6% in 2035 and by 15% in 2050 when compared to the No Shale Scenario. In the Shale Boom Scenario, the reduction is greater and could be 16% in 2035 and 20% in 2050.

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15 Household gas costs have been calculated by distributing the total saving on the basis of total households in EU28. This is not the same as calculating the saving on the average EU28 gas bill.
This is equivalent to a €4.4bn saving in household gas costs in 2035 in the Some Shale Scenario and a €11bn saving in 2050 across EU28. In the Shale Boom Scenario, the savings could be €12bn in 2035 and €15bn in 2050.

### 3.3.3 Impact on gas demand

The relatively lower gas prices in the shale gas scenarios make gas generation more competitive compared to other thermal generation. As a result, the gas demand for power generation in the Some Shale and Shale Boom Scenarios will increase as compared to the No Shale Scenario as illustrated in Figure 29.

**Figure 29 – Impact of EU28 shale gas production on gas demand**

Within the scenarios, only the power generation sector is assumed to be responsive to gas prices, and so there is no demand growth in the industrial, commercial or domestic sectors. It is beyond the scope of this study to investigate the long-term relative competitiveness of fuels in these sectors, and so a simplifying assumption has been made that they are not responsive to price.

### 3.3.4 Impact on gas supply mix

Perhaps the strongest impact of shale gas in the scenarios assessed is the effect that it has on EU import dependency. In the No Shale Scenario, Europe’s ability to produce its own gas dwindles to approximately 6% by 2050, as shown in Figure 30.

In the Some Shale Scenario, the decline in indigenous European gas production is halted, with import dependency staying broadly stable at around 20%. When we consider the impact that this has on the balance of trade we see a reduction in the EU28’s expenditure on imported gas of €15.6bn p.a. on average and €484bn in total over the period. Instead of being imported, this gas is sourced from within EU28 resulting in a significant reduction in payments to gas importers located outside Europe.
In the Shale Boom Scenario, Europe is much less dependent on imported gas, with indigenously produced gas representing about a third of overall European demand – a reduction in the EU28’s expenditure on imported gas of €35.4bn p.a. on average and €1.1tn in total. The macro-economic effects of this change on the EU balance of trade will be explored in Section 4.

**Figure 30 – EU28 gas import dependency**

![EU28 gas import dependency](image)

### 3.3.4.1 EU28 gas supply mix

Overall, in the scenarios assessed, Europe is able to reduce its import dependency through the production of indigenous shale gas, but we have examined further which sources are most greatly affected. The overall supply mix to EU28 is shown in Figure 31.

**Figure 31 – EU28 supply mix in the scenarios**

![EU28 supply mix in the scenarios](image)

N.B – Supply exceeds 100% of EU28 demand since gas supplied to EU countries also contributes to supplies in non-EU28 nations (e.g. Switzerland and countries in South-East Europe)

In terms of percentage share of the supply mix, LNG imports are the most significantly affected; reducing 11% on average between the No Shale (24%) and the Shale Boom (13%) scenarios as shown in Figure 32.
LNG imports are displaced as soon as Europe starts to develop shale gas, and are significantly reduced from 2035 onwards in the Shale Boom case.

Russian exports appear more robust in the short term as shown in Figure 33. It is not until 2030 in either shale gas scenario that Russian exports are materially affected. The chart illustrates that the development of any shale gas would have a more significant effect on the volumes that Russia could expect to export in the long term. Even the relatively conservative Some Shale Scenario has a large effect on Russian exports, with the Shale Boom Scenario unsurprisingly reducing Russian export opportunities further.
Other sources (for example Norwegian supplies, North African imports) show smaller impacts than LNG and Russia. Norwegian production proves robust to increased shale gas production in the EU.

### 3.4 Impact on electricity markets

It was shown in Figure 29 that increasing shale gas production would have an impact on the gas demand for electricity generation. This section explores this impact further. Figure 34 illustrates that the generation mix across Europe is expected to change regardless of the impact of shale gas. The No Shale chart shows that the proportion of renewable generation is expected to grow, and that on a European level, generation from coal (including generation from lignite) is expected to decline as is generation from nuclear sources, based on the planned closure of nuclear plant in Germany from 2022 and new plant in GB and France failing to replace entirely the plant reaching the end of its operational lifetime.

Gas generation shows an increasing trend from 2020 to 2035 in all our scenarios – reflecting declining coal and nuclear generation – even though there is continuing growth in the renewable sector. In the period after 2025, the endurance of gas-fired generation is more sensitive to the price, with gas able to maintain its market share at the expense of coal in the Shale Boom Scenario. Both Some Shale and Shale Boom Scenarios show increased gas generation replacing coal when compared to No Shale. The increase in gas-fired generation is shown in the context of the electricity market in Figure 35.

![Figure 34 – EU28 generation mix](image-url)
Figure 35 – Proportion of total EU28 electricity generation from gas

Generation from gas is expected to increase in all the scenarios assessed. The scenarios start to diverge in the late 2020s, with the Shale Boom Scenario reaching a higher peak of 32% of all European electricity produced from gas, compared to peaks of c.28-29% in the other scenarios.

3.4.1 Impact on wholesale electricity prices

EU demand weighted wholesale electricity prices follow a similar trend to wholesale gas prices. Wholesale electricity prices are lower in the cases with shale gas production from the mid-2020s onwards and – similarly to wholesale gas prices – the Shale Boom Scenario shows an earlier and greater divergence from the No Shale Scenario.

Figure 36 compares wholesale electricity prices on an indexed basis (with No Shale representing 100%). In Some Shale the maximum impact is a reduction of 6% with the average reduction being 3%. Though this sounds a fairly modest impact, it nonetheless results in average annual savings of €12bn p.a. for the EU28. There is a greater impact in the Shale Boom Scenario with a maximum reduction of 16% and an average reduction of 8% (translating to average annual savings of €27bn). The maximum saving is €28bn in 2050 in the Some Shale scenario and €42bn in 2039 in the Shale Boom scenario.

The reductions in wholesale electricity prices are more muted than the reduction in wholesale gas prices (which as discussed in Section 3.2 averaged 6% for the Some Shale case and 14% for the Shale Boom case). This is because gas is only one element of several which determine wholesale electricity prices, for example the cost of carbon also needs to be taken into account, and because CCGTs will not be setting the marginal prices in all markets at all time we would not expect a percentage reduction in the wholesale gas price to transfer to an identical percentage reduction in the wholesale electricity price.
3.4.2 Household electricity costs

The analysis shows a reduction in wholesale electricity prices in the shale gas scenarios. Assuming that these savings are passed on to consumers the lower wholesale price should lead to lower overall household costs for electricity\(^\text{16}\). The Cambridge Econometrics model allows a comparison of EU28 average household electricity costs and shows that in the Some Shale Scenario that household electricity costs could reduce by 2% in 2035 and by 6% in 2050 when compared to the No Shale Scenario. In the Shale Boom Scenario, the reduction is greater and could be 6% by 2035 and 7% by 2050.

This is equivalent to a €3.3bn saving in household electricity costs in 2035 in the Some Shale Scenario and a €9bn saving in 2050. In the Shale Boom Scenario, the savings could be €11bn in 2035 and €14bn in 2050.

\(^{16}\) Household electricity costs have been calculated by distributing the total saving on the basis of total households in EU28. This is not the same as calculating the saving on the average EU28 electricity bill.
3.5 Concluding remarks

In summary, our key findings from the energy market analysis that we have undertaken are:

- Our analysis shows that shale gas production should result in lower gas and electricity wholesale prices when compared to a future with no shale gas production.

- We see an average reduction in wholesale gas prices of 6% in the Some Shale Scenario and 14% in the Shale Boom Scenario over the period resulting in average annual savings of €12bn and €28bn respectively.

- We see an average reduction in wholesale electricity prices of 3% in the Some Shale Scenario and 8% in the Shale Boom Scenario over the period resulting in average annual savings of €12bn and €27bn respectively.

- Over the period of this study this sums to energy wholesale savings of €765bn in the Some Shale Scenario and €1.7tn in the Shale Boom Scenario.

- Household spending on gas and electricity costs could reduce by up to 8% in the Some Shale Scenario and by up to 11% in the Shale Boom Scenario representing total cumulative savings over the period of €245bn in the Some Shale Scenario and €540bn in the Shale Boom Scenario.

- Gas import dependency could reduce from 89% in 2035 in the No Shale Scenario to 78% in the Some Shale and 62% in the Shale Boom Scenario. This could result in total balance of trade benefits of €484bn in the Some Shale Scenario and €1.1tn in the Shale Boom Scenario.

- The production of shale gas in Europe does not affect the growth of renewables under either shale gas scenario, but it does reduce coal burn in electricity generation.

If significant volumes of shale gas can be produced in Europe wholesale prices will be lower when compared to a future with no shale gas production. Security of supply will increase as import dependency is reduced. Shale gas development can be achieved alongside the development of renewables. The benefits of indigenous gas production over imported gas may only be achieved however, if there is support for shale gas development in Europe.

The analysis that we have carried out for this study has focussed on the development of European shale gas. We have based the analysis on the Pöyry standard central scenario assumptions. In each of the three scenarios considered, other inputs to the modelling have been kept constant. This allows us to determine that differences in the model output are due to the variations that we make in the inputs – in this case indigenous European shale gas production. The modelling exercise has shown that, in our central scenario that shale gas can be produced economically in Europe and can therefore contribute positively to the EU28 supply mix.

However, given that the gas market in Europe is linked, via LNG, to the US and Asian markets then the outcomes shown by the modelling exercise may be different in reality. Shale gas potential is also being examined in other regions of the world including China, India, South Africa, Australia and others and developments here will impact on the global LNG market. Potentially these developments, outside Europe, could reduce the costs of LNG imports into Europe in the future. Similarly, lower oil prices could also lower European gas prices through oil-linked gas contracts and/or we could also see a
weakening in the influence of oil linkage in European gas markets. Any or all of these developments could affect the European gas price and impact the commercial attractiveness and competitiveness of shale gas as compared with other sources of gas supply.
4. MACROECONOMIC INDICATORS

4.1 Introduction

The macroeconomic impact of unconventional shale gas production in the three scenarios was modelled using E3ME, an input-output based model of the European economy and energy system. This built on the technical analysis undertaken by Pöyry, which established, for each scenario, a series of E3ME model inputs in the form of annual projections for the years 2020-2050. This included the following:

- total gas production by EU28 member state;
- gas imports by EU28 member state;
- total extra-EU gas imports and extra-EU gas exports for the EU28;
- gas prices by EU28 member state;
- electricity prices by EU28 member state; and
- power sector gas and coal generation assumptions by EU28 member state.

Overall the results show that in the Some Shale Scenario, EU-wide GDP increases by around 0.3% by 2035 and 0.6% by 2050 compared to the No Shale baseline. In this scenario, an additional 0.4 million jobs are created across the EU economy by 2035, rising to 0.6 million jobs by 2050.

The Shale Boom scenario sees an increase in EU GDP of 0.8% and 1.0% in 2035 and 2050 respectively, and net EU job creation of 0.8 million by 2035 and 1.1 million by 2050.

Cumulatively, GDP in the EU28 could increase by €3.8tn in the Shale Boom Scenario and €1.7tn in the Some Shale Scenario in the period between 2020 and 2050.

The results in these scenarios are driven by two key factors:

- an increase in domestic gas production and reduction in net imports in the gas extraction sector which creates further demand in the associated domestic supply chain; and
- a reduction in wholesale energy prices which benefits consumers and industry.

This section of the report presents the macroeconomic results in the three scenarios:

- Section 4.2 and Section 4.3 expand on the economic intuition behind the model results by further examining the economic flows brought about by an increase in gas production and reduction in wholesale gas prices;
- Section 4.4 provides a summary of the macroeconomic modelling results in the three scenarios for the EU28, including analysis of output and employment; trade and competitiveness; tax revenues and greenhouse gas emissions; and
- Section 4.5 summarises the assumptions used in the economic analysis.
4.2 The economic impact of an increase in EU28 gas production

Currently, around 70% of total EU28 gas supply is met by extra-EU imports from Russia, Norway, North Africa and imports of LNG. In 2012, the costs of these imports amounted to a total of €57.6bn\(^1\) and, in the No Shale Scenario we expect these costs to increase. Reducing import dependency and improving security of supply are two key economic benefits of EU indigenous shale gas production.

As explained in Section 3, the shale gas scenarios show potential EU shale gas production that reduces import dependence from 89% in the No Shale Scenario to 78% in the Some Shale Scenario and 62% in the Shale Boom Scenario. Over the period 2020-2050 the average annual reduction in the cost of importing gas is €15.6bn in the Some Shale Scenario and €35.4bn in the Shale Boom Scenario.

This increase in output in the gas extraction sector will have a direct impact on GDP as a result of lower demand for gas imports, and a small increase in gas exports. It will also generate new jobs in the gas extraction industry; though, as this sector has a relatively low intensity of labour, the direct impact on employment will be small in absolute terms. The increase in domestic gas production will trigger an increase in demand for construction services and gas rig component parts, therefore filtering through to an increase in demand across the rest of the supply chain. Tier 1 industries that directly supply the gas extraction sector will see the greatest increase in demand, but benefits will flow through to higher-tier suppliers, and the increase in demand will eventually reach most sectors of the economy, driving an increase in indirect employment and higher GDP growth. As a result of this, tax receipts will increase (both directly from the royalty payments by the gas extraction industry, and indirectly through the increase in economy-wide employment and consumption).

4.3 The economic impact of a reduction in gas prices

The technical analysis for this project has identified different scenarios for EU28 shale gas extraction given varying technical, environmental, practical and commercial constraints. From this analysis, the Some Shale and Shale Boom Scenarios were constructed. These two scenarios therefore represent a state of the world by which shale gas production in the EU28 (as identified in the two shale scenarios) is economically viable, in the sense that the import price exceeds the domestic cost of extraction. Under this assumption, EU28 shale gas production takes place, reducing wholesale gas prices for EU28 consumers by displacing more expensive gas imports. The power sector, industry and households would all benefit from the reduction in wholesale gas prices; the behavioural response among these three groups in response to lower wholesale gas prices can be summarised as follows:

- **Power sector:** lower gas prices compared to the No Shale baseline would result in gas-fired power generation becoming a relatively more attractive power generation option. Consequently, in the long run, more gas-fired power plants will be built, displacing other power generation technologies, and resulting in an increase in demand for gas.

  The electricity market analysis outlined in Section 3.3, indicated that in most cases the increase in gas generation would replace coal-fired power generation. However,

\(^1\) European Commission (2013), COMEXT database.
as the ETS cap is fixed and the power sector is included within the EU ETS, we would expect any overall impact on traded sector emissions to be limited.

In the shale gas scenarios, we assume that lower costs of electricity production are passed onto industrial and domestic consumers in the form of lower electricity prices.

- **Industry**: lower gas and electricity prices will reduce production costs for industry which industries may retain as increases in profit, or pass on as cost savings to consumers. The extent to which industry lowers the prices of its goods depends on the market structure of each industry, and the degree of competition. Lower product prices will improve EU industry competitiveness, resulting in an increase in demand for exports and an improvement in the balance of trade. We would expect heavy industries to have the largest competitiveness gains, as gas and electricity make up a relatively large component of these industries’ total costs.

- **Households**: lower gas and electricity prices benefit households directly through lower energy bills, but also indirectly as a result of lower product prices. The fall in prices will increase real disposable income, driving an increase in consumption, and an increase in GDP.

The overall impact of lower gas and electricity prices is outlined in Figure 37 below:

**Figure 37 – The economic impact of lower gas and electricity prices**

![Diagram showing the economic impact of lower gas and electricity prices](source: Cambridge Econometrics)
### 4.4 Macroeconomic modelling results for the EU28

#### 4.4.1 Summary indicators

The scenario results for 2020, 2035 and 2050 are presented in Figure 38, Figure 39 and Figure 40 below.

#### Figure 38 – Summary of macroeconomic modelling results for the EU28, 2020

<table>
<thead>
<tr>
<th></th>
<th>No Shale (€ bn)</th>
<th>Some Shale (% difference)</th>
<th>Shale Boom (% difference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>14,742</td>
<td>0.02%</td>
<td>0.02%</td>
</tr>
<tr>
<td>Consumption</td>
<td>8,111</td>
<td>0.02%</td>
<td>0.02%</td>
</tr>
<tr>
<td>Investment</td>
<td>3,433</td>
<td>0.01%</td>
<td>0.02%</td>
</tr>
<tr>
<td>Exports</td>
<td>2,459</td>
<td>0.00%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Imports</td>
<td>2,448</td>
<td>-0.05%</td>
<td>-0.06%</td>
</tr>
</tbody>
</table>

Source: Cambridge Econometrics

#### Figure 39 – Summary of macroeconomic modelling results for the EU28, 2035

<table>
<thead>
<tr>
<th></th>
<th>No Shale (€ bn)</th>
<th>Some Shale (% difference)</th>
<th>Shale Boom (% difference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>18,517</td>
<td>0.31%</td>
<td>0.78%</td>
</tr>
<tr>
<td>Consumption</td>
<td>9,673</td>
<td>0.20%</td>
<td>0.56%</td>
</tr>
<tr>
<td>Investment</td>
<td>4,313</td>
<td>0.25%</td>
<td>0.60%</td>
</tr>
<tr>
<td>Exports</td>
<td>3,342</td>
<td>0.03%</td>
<td>0.17%</td>
</tr>
<tr>
<td>Imports</td>
<td>3,402</td>
<td>-0.74%</td>
<td>-1.72%</td>
</tr>
</tbody>
</table>

Source: Cambridge Econometrics

#### Figure 40 – Summary of macroeconomic modelling results for the EU28, 2050

<table>
<thead>
<tr>
<th></th>
<th>No Shale (€ bn)</th>
<th>Some Shale (% difference)</th>
<th>Shale Boom (% difference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>22,858</td>
<td>0.60%</td>
<td>1.02%</td>
</tr>
<tr>
<td>Consumption</td>
<td>11,391</td>
<td>0.56%</td>
<td>0.97%</td>
</tr>
<tr>
<td>Investment</td>
<td>5,306</td>
<td>0.43%</td>
<td>0.75%</td>
</tr>
<tr>
<td>Exports</td>
<td>4,357</td>
<td>0.15%</td>
<td>0.26%</td>
</tr>
<tr>
<td>Imports</td>
<td>4,406</td>
<td>-0.94%</td>
<td>-1.40%</td>
</tr>
</tbody>
</table>

Source: Cambridge Econometrics
GDP is defined as the sum of consumption, investment and stockbuilding, government spending and exports, minus total imports into the economy. It is also broadly equivalent to the total value added arising from each sector’s production. The percentage difference in GDP over time in the three scenarios is show in Figure 41.

**Figure 41 – Percentage difference in EU28 GDP**

In the Some Shale Scenario, annual GDP is €57bn higher than in the baseline scenario in 2035 and €138bn higher in 2050. The Shale Boom Scenario results in larger GDP gains of €145bn in 2035 and €235bn in 2050. Figure 42 shows that the main components driving the increase in GDP in the Shale Boom Scenario are an increase in consumption and a fall in imports, but exports and investment also increase in the shale gas scenarios.

- **Total consumption:** by 2035, annual total consumption is €20bn higher in the Some Shale Scenario and €54bn higher in the Shale Boom Scenario, compared to the No Shale baseline. By 2050 the positive impact on consumption increases to €64bn and €112bn in the Some Shale and Shale Boom Scenarios, respectively. This increase in consumption is driven by lower prices and increases in real disposable income. The multiplier effect increases the impact, as higher demand in the economy stimulates an increase in employment and further increases household incomes and expenditure.

- **Investment:** investment increases slightly, due to the direct capital investment required for shale gas production, and the higher level of GDP which stimulates further inward investment. By 2035, investment is €11bn higher in the Some Shale Scenario and €26bn higher in the Shale Boom Scenario, increasing to €23bn and €40bn respectively by 2050, compared to the No Shale baseline. By 2050, around 10% of this increase is due to capital investment in shale gas extraction and the remainder is due to increased profit expectations which are driven by higher demand in the economy.

- **Imports:** Compared to the No Shale baseline, total imports are €25bn lower in the Some Shale Scenario and €59bn lower in the Shale Boom Scenario, by 2035 and €42bn and €63bn lower in each scenario respectively by 2050. The fall in total imports is partly explained by the reduction in gas imports, and partly as a result of the competitiveness gains in domestic industries. However, the reduction in total
Import demand is partially offset by higher GDP in the two shale gas scenarios, which drives an increase in demand for imported (as well as domestically produced) goods.

- **Exports:** Higher exports are driven by small increases in gas exports and industry competitiveness gains. Exports increase by €1bn and €6bn respectively in the Some Shale and Shale Boom Scenarios, compared to the No Shale baseline in 2035 and by €6bn and €11bn in these two scenarios in 2050.

- **Employment:** The overall increase in production in the economy leads to an increase in employment. In the Some Shale scenario, net job creation compared to the No Shale baseline is 400,000 jobs by 2035 and 600,000 by 2050. In the Shale Boom scenario employment relative to the No Shale case increases by 800,000 by 2035, rising to over 1 million additional jobs by 2050. Net job creation in the shale gas scenarios is shown in Figure 43.

**Figure 42 – Increase in components of EU28 GDP in the Shale Boom Scenario, 2050**

![Diagram showing increase in components of EU28 GDP in the Shale Boom Scenario, 2050](source: Cambridge Econometrics)
4.4.2 Sector output and employment

In the broad NACE rev 2 data classification, the gas extraction sector is classified within the category, ‘Mining and Quarrying’. The scenarios are defined by the level of production in the gas extraction sector and so, in percentage terms, the Mining and Quarrying sector sees the largest increase in output and employment as shown in Figure 44 and Figure 45.
The ‘Mining and Quarrying’ sector, however, is relatively small when compared to the wider economy, accounting for just 0.3% of total output and jobs. Therefore, in absolute terms, it is the larger sectors that attain the greatest increase in output, and service sectors with high labour intensities, that see the largest increases in employment.

The sectors that see the largest overall benefit typically have one (or more) of the following characteristics:

- gas and electricity makes up a relatively high proportion of their total production costs e.g. heavy industry sectors such as Coke and Refined Petroleum, Non-metallic Minerals and Basic Metals (please refer to Section 4.4.3);
- they directly supply the gas extraction industry e.g. the Manufacturing and Construction sectors;
- they produce goods with a high price elasticity i.e. demand for the product is highly responsive to lower prices; and
- they produce goods with a high income elasticity i.e. demand for the product is highly responsive to higher incomes e.g. service sectors.

Net job creation by sector is shown in Figure 46 and Figure 47.

**Figure 46 – EU28 net job creation by sector in 2035**

Mining and Quarrying is capped here at 1% for presentational purposes. In The Some Shale Scenario, employment in this sector increases by 21% in 2035 and 24% in 2050. In the Shale Boom Scenario the increase is 31% in 2035 and 54% in 2050.
4.4.2.1 Sectors that benefit from capital investment in shale gas extraction

Figure 48 shows total annual capital investment in shale gas extraction in the three scenarios.

<table>
<thead>
<tr>
<th>Year</th>
<th>No Shale (€ bn)</th>
<th>Some Shale (€ bn)</th>
<th>Shale Boom (€ bn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>0.0</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>2035</td>
<td>0.0</td>
<td>5.7</td>
<td>9.7</td>
</tr>
<tr>
<td>2050</td>
<td>0.0</td>
<td>2.4</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Source: Cambridge Econometrics

The sectors that directly benefit from capital investment in the gas extraction sector are shown in Figure 49. Manufacturing and construction are the two largest components of the supply chain, each accounting for just over one third of the gas industry’s capital investment costs. These sectors see increases in demand as a direct result of the shale gas extraction. However, the overall impact on sector demand is to a much larger extent driven by increases in consumer demand due to lower gas and consumer goods prices.
4.4.3 Balance of trade and industrial competitiveness

As a result of lower gas and electricity prices in the shale gas scenarios, industries will attain cost savings. This will have greatest impact on industries in which gas and electricity makes up a relatively large component of their total costs, although at this level of detail it should be noted that, even in the energy-intensive sectors, gas costs account for less than 5% of total revenues. To some extent, these industries will pass lower costs onto consumers in the form of lower product prices, which improves their competitive position in international markets, stimulating an increase in international demand for the relatively cheaper goods they produce.

The six industries that attain the largest reduction in unit costs in the shale gas scenarios are shown in Figure 50. As E3ME models sectors at the 2 digit level of detail, these results only give an indication of the competitiveness gains, as in reality, subsectors within these categories may be more exposed to gas prices and therefore see larger benefits.

The boost to EU industry competitiveness leads to an improvement in the balance of trade, as cheaper EU goods become relatively attractive to international consumers, resulting in an increase in EU exports and a reduction in EU imports. This effect is evident in the model results, where, in the two shale gas scenarios, there is a small increase in exports, compared to the baseline.
4.4.4 Tax revenue

The economic modelling breaks down tax revenue into three component parts: income tax revenue, VAT receipts and social security payments\(^\text{19}\). Royalty payments by the gas extraction industry were calculated off-model and the methodology used is explained in more detail in Section 4.4.4.1.

The increase in tax receipts for the two shale gas scenarios is shown in Figure 51.

\(^{19}\) Taxes that do not fall within these groups, such as stamp duty payments and inheritance tax have not been modelled.
Although there is a substantial increase in tax paid directly by the gas extraction industry, the main increase in tax receipts is a result of the increase in GDP and employment. For example, in the Shale Boom Scenario, VAT receipts increase by €23bn by 2050, due to the large increase in consumption, and the creation of over 1 million jobs leads to a substantial increase in employment-related tax. By 2050, additional tax revenue in the Shale Boom Scenario is equivalent to reducing the 2012 EU (excl. Croatia) annual government deficit by 14%\(^{20}\).

### 4.4.4.1 Corporate tax

We have assessed, at a high level, what the effect of shale gas production would be on the corporate taxes paid by the developers. The following methodology was used:

- **corporate revenue** = market prices from our scenarios;
- **corporate cost** = supply-weighted average of production based on our LRMC assumptions (adjusted downward to remove the rate of return inherent in the cost estimates (assumed to be 12%));
- **net profit** = (revenue - cost) x shale gas volumes; and
- **tax revenue** = Net profit x assumed tax rate.

There is a wide range of corporate tax rates across Europe, and even greater variation in hydrocarbon taxation. We have therefore made a simplifying assumption that all profits across Europe will be taxed at 40% i.e. corporate tax and mineral taxes.

The resulting tax revenues are shown in Figure 52. The revenues under the Shale Boom Scenario are much greater than the Some Shale figures due primarily to the increased volume, but also by the lower costs in this scenario increasing the profit on each unit of energy produced.

\(^{20}\) Calculation based on E3ME model results and government deficit figures from Eurostat.
The tax revenues which result from shale gas production will, in reality, depend upon any tax incentive schemes proposed by the governments of Europe to encourage development of shale resources, and any additional taxes above the usual rates of corporate taxation as applicable to oil and gas production. For example, the UK government has issued a consultation which proposes to exempt shale gas producers from the supplementary charge of 32% on top of the usual 30% corporate tax rate\textsuperscript{21}. This exemption is proposed to apply to a proportion of the capital expenditure associated with each pad from which shale gas wells are drilled. After revenues exceed the allowed capital expenditure, the exemption would expire. If adopted, this regime would mean that shale gas producers would pay a lower rate than our assumed 40% rate in the early years of production from each pad, and a higher rate once the exemption expires.

### 4.4.5 Greenhouse gas emissions

The lower gas prices in the shale gas scenarios result in an increase in gas-fired power generation, but the overall impact on power sector greenhouse gas emissions is heavily dependent on the assumption we make about the structure of the power sector in the baseline by 2050. Due to the high level of uncertainty in the baseline power generation forecast, we do not present results for emissions in the power sector.

However, as the power sector is included in the ETS, and because emissions from the ETS are capped at a certain level, the net impact on traded sector emissions will be zero. A reduction in CO\textsubscript{2} emissions in the power sector would lead to a fall in the carbon price

and other industries that fall within the EU ETS regime would increase energy demand and emissions, to offset the reduction in the power sector.

4.5 Assumptions and sensitivity analysis

4.5.1 The baseline forecast

The ‘PRIMES’ reference case 2009 energy projections from the ‘EU Energy Trends to 2030’ publication\(^{22}\) is used as a basis for the No Shale baseline, and has been updated with economic projections from ‘The 2012 Ageing Report’, published by the European Commission (DG Ecfin)\(^{23}\). The baseline projections have been extrapolated to 2050 using the projected growth rates at the end of the projection period. For more information on the baseline, please refer to Annex B.

4.5.2 Modelling assumptions and limitations

The assumptions in the macroeconomic modelling are consistent with those applied to the technical analysis in Phase I. In addition to these, some further simplifying assumptions have been applied to the economic modelling. Details of these assumptions and reasons for their use are outlined in Table 1 below. In some cases, we have carried out sensitivity analysis for robustness. This is explained in more detail in Section 4.5.3.

---


Table 1 – Economic modelling assumptions

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household and industry gas and electricity demand is the same in all scenarios</td>
<td>Despite the lower gas and electricity prices in the shale gas scenarios, we have not included a demand response in the economic modelling. This was to keep the modelled scenarios consistent with the supply-side technical analysis carried out by Pöyry while avoiding a lengthy iterative process in balancing supply and demand.</td>
</tr>
<tr>
<td>Exchange rates are fixed between scenarios</td>
<td>We have not attempted to model the impact that a fall in net imports of gas would have on exchange rates, and therefore we ignore the potential for ‘Dutch Disease’, whereby increases in demand for exports (or a fall in imports) of a particular commodity push up exchange rates, making other export goods uncompetitive in the global market. As a result, our results may slightly overstate the improvement in the balance of trade.</td>
</tr>
<tr>
<td>Capital investment to fund the shale gas projects is available</td>
<td>In the shale gas scenarios, we have assumed that there are investors that are willing and able to undertake the required investment. This assumption is crucial for the scenarios to be valid. Recent shale gas projects in the US have reduced the associated risk and the technical analysis in Phase I of this study developed scenarios that only considered shale gas projects that would yield a satisfactory return to investors.</td>
</tr>
<tr>
<td>Investment in shale gas extraction does not ‘crowd out’ other forms of investment</td>
<td>We assume that the capital investment in drilling and constructing the wells does not displace other investment in the economy. Optimisation models often assume that investors have a sum of money to invest, and if they decide not to invest in shale gas extraction, they would use the money to invest in a different project. In our analysis, however, we assume that if investors do not invest in shale gas production, then they will not spend or invest this money elsewhere in the EU economy. This is based upon the premise that the majority of shale gas funding will come from international oil companies, who, if not investing in EU shale gas projects, are likely to instead invest this capital in similar projects outside of the EU. We carried out sensitivity analysis on this assumption, and as lower prices and reduced imports are the main drivers of the increase in GDP, this assumption does not have a large impact on our results.</td>
</tr>
</tbody>
</table>

24 The demand response would provide a rebound effect (typically estimated in the region of 20%) that could reduce the magnitude of the results, but not change the overall conclusions.
Assumption | Explanation
---|---
Capital investment in shale gas extraction uses the same industry sector suppliers as those used in a typical project in the oil and gas extraction industry | The input-output structure of E3ME, at the 2 digit NACE sector level of detail assumes that investment in the ‘Oil and Gas’ sector requires the same supply chain inputs as that in a typical oil and gas project. As shale gas rigs are similar in design to conventional gas rigs, this assumption seems valid. However, we undertook sensitivity analysis to test the extent to which a higher import content assumption would impact on our results, and found that the scale of the economic impact is negligible. For more information please refer to Section 4.5.3.
Land use change is not taken into account | As the size of the shale gas wells are extremely small compared to the total European land mass, we make the simplifying assumption that shale gas wells do not displace agricultural land or land used for any other productive activity.
The carbon price is fixed | We have assumed the carbon price is the same in all scenarios, however, in reality changes in power sector emissions would adjust the demand for allowances and cause the carbon price to similarly adjust. This would have further impacts on competitiveness.
Water requirements have not been modeled | We have not taken into account the macroeconomic impact of the significant volumes of water required for shale gas production.

Source: Cambridge Econometrics

4.5.3 Sensitivity Analysis

We undertook sensitivity analysis to test that our results were robust to:

- ‘crowding out’ investment; and
- higher import content assumptions for the manufacture of shale gas rigs.

4.5.3.1 ‘Crowding out’ investment

In our analysis, we have assumed that there are investors willing to finance shale gas projects, and that investment in shale gas does not displace investment taking place elsewhere in the EU economy. Furthermore, as shale gas extraction is likely to be financed by multinational corporations, it would not necessarily displace other European investment, and may instead crowd out investment taking place outside of the EU.

We undertook sensitivity analysis to test whether relaxing this assumption would have a significant impact on the results, and found that it only has a marginal impact on GDP (please refer to Figure 53). The reason for this is that the economic result is mainly driven by the benefits of lower gas and electricity prices. Compared to the other economic flows in the shale gas scenarios, the capital investment required in the shale gas scenarios is relatively small (around €6-8bn pa in the years 2020-2040, falling to €3.7bn pa by 2050 in Shale Boom).
4.5.3.2 Import content of shale gas rigs

Shale gas production is already well established in the US and there is an argument that specialized shale gas rig production facilities abroad have developed to such an extent, that if shale gas was extracted in the EU, the gas industry would, at least initially, import the rigs. The E3ME model however would treat this investment as typical investment for that sector, assuming the historical average import content in the manufacture of the rigs.

We undertook sensitivity analysis to test the significance of our assumption on the import content of the shale gas rigs. We compared our results to a case where we assumed that all of the shale gas rigs were manufactured abroad and found that the impact on the results is minimal. Capital investment in the Shale Boom Scenario in 2050 is €3.7bn. Of this, the cost of manufacturing the rigs amounts to around €0.5bn. Therefore, assuming 100% domestic content or 100% import content for the manufacture of the rigs will only alter the GDP result by around €0.5bn.

4.6 Concluding remarks

From the analysis that has been undertaken, it is clear that there are macroeconomic benefits to the development of shale gas in Europe. Compared to the baseline, the shale gas scenarios deliver lower energy prices while also reducing dependency on imported fuels, leading to increases in GDP, net employment and tax revenues.

The economic impact may appear relatively modest at around a 1% increase in GDP in 2050 in the Shale Boom Scenario. In comparison, the size of the entire Mining and Quarrying sector currently accounts for around 1% of total value added in the EU28 economy. Comparisons with other energy system interventions are perhaps more meaningful, but to compare economic impacts requires that a range of comparable alternative input scenarios could be constructed and tested, and there are no directly comparable studies.

Many policy-led interventions in the energy market involve pricing in negative externalities and as a result typically yield both positive and negative economic consequences. For example decarbonising the European economy typically requires investment in a more expensive technology, which has negative economic consequences for prices, but potentially positive consequences in terms of reducing dependency on imported fuels or through greater efficiency in the long term.
In contrast to this type of policy intervention, developing shale gas production yields only positive macroeconomic outcomes, it delivers lower energy prices while also reducing dependency on imported fuels, and as such it is perhaps more comparable to zero, or negative, cost energy efficiency investments.

If the gas produced in Europe simply displaces imported gas then there is also no negative impact on emissions, beyond those that arise directly from the shale gas extraction process. However, these emissions would have to displace other emissions within the EU ETS traded cap and as a result could likely lead to small increases in EU ETS allowance prices.
5. CONCLUSIONS

The analysis that we have undertaken for this study has demonstrated that if shale gas can be produced in Europe then there will be beneficial impacts in terms of relatively lower energy prices, increased security of supply, GDP and employment growth and increased tax revenues.

In terms of energy market benefits, the analysis has shown that:

- Shale gas production should result in lower gas and electricity wholesale prices when compared to a future with no shale gas production.
- We see an average reduction in wholesale gas prices of 6% in the Some Shale Scenario and 14% in the Shale Boom Scenario, when compared to the No Shale Scenario, over the period resulting in average annual savings of €12bn and €28bn respectively.
- We see an average reduction in wholesale electricity prices of 3% in the Some Shale Scenario and 8% in the Shale Boom Scenario, when compared to the No Shale Scenario, over the period resulting in average annual savings of €12bn and €27bn respectively.
- Over the period of this study this sums to wholesale energy savings of €765bn in the Some Shale Scenario and €1.7tn in the Shale Boom Scenario, when compared to the No Shale Scenario.
- Household spending on energy costs could reduce by up to 8% in the Some Shale Scenario and by up to 11% in the Shale Boom Scenario representing total cumulative savings over the period of €245bn in the Some Shale Scenario and €540bn in the Shale Boom Scenario.
- Gas import dependency will reduce from 89% in 2035 in the No Shale Scenario to 78% in the Some Shale and 62% in the Shale Boom Scenarios. This results in total balance of trade benefits of €484bn in the Some Shale Scenario and €1.1tn in the Shale Boom Scenario.
- The production of shale gas in Europe does not affect the growth of renewables under either shale gas scenario, but it does reduce coal burn in electricity generation.

If significant volumes of shale gas can be produced in Europe wholesale prices will be lower when compared to a future with no shale gas production. Security of supply will increase as import dependency is reduced. If gas is to remain a part of the European energy mix in the future then shale gas can play a role and deliver benefits in terms of relatively lower prices and increased security.

The macroeconomic impacts are also significant and the analysis shows that:

- GDP in the EU28 could increase, cumulatively by €3.8tn in the Shale Boom Scenario and €1.7tn in the Some Shale Scenario in the period between 2020 and 2050.
- Net employment could increase by 1.1 million in the Shale Boom Scenario and by 600,000 in the Some Shale Scenario in the period between 2020 and 2050.
- Tax revenues increase as a result of gas production, increased employment and GDP. In the Shale Boom Scenario, VAT receipts alone increase by €23bn in 2050, due to the large increase in consumption, and the creation of over 1 million jobs leads to a substantial increase in employment-related tax.
Industry in EU28 will attain cost savings as a result of relatively lower gas and electricity prices. The impact will be most significant in those industries that are energy intensive. Lower costs may be passed onto consumers and/or lead to additional net exports.

We must acknowledge however that there is still a significant level of uncertainty regarding the volumes of shale gas that can be economically extracted in Europe. A whole range of factors may influence this from the specific geology in each shale gas play to the costs of production and the prevailing wholesale gas price.

The uncertainty is not only due to the lack of detailed information on how much shale gas can be extracted from the shale formations in Europe, but also due to the political factors that have led to hydraulic fracturing bans in some countries and limited and cautious support in others.

The analysis that has fed into the development of our shale gas production scenarios represents a view on the range of production that might be possible if the potential constraints on development can be either mitigated or reduced and political support can be achieved.

Achieving the levels of shale gas production presented in our scenarios will require development of the onshore gas industry in Europe and support from policy makers and local communities. Whilst the industry will build up over time in response to commercial incentives, strong political will is expected to be required in order to secure the level of support that will be required to achieve large scale production of shale gas in Europe.
ANNEX A – PÖYRY’S MODELLING APPROACH

A fundamental market modelling approach was taken to assess the impact of shale gas on the European gas and electricity markets. To undertake the analysis, two market models were used – Pegasus and Zephyr. This annex describes the methodologies used within the two models.

A.1 Gas modelling methodology

Pegasus is a gas market fundamentals model, which aims to optimise flows of gas across the world in a way that replicates market behaviour. Pegasus has been developed to assess daily flows of gas in a world where gas demand is highly variable and uncertain.

The founding modelling principle of Pegasus is to optimise flows of gas in order to minimise the annual cost of meeting daily demand in every zone.

Pegasus optimises flows of gas from the major import pipelines, LNG terminals, indigenous production and gas storage.

In addition to meeting daily demand, the model takes into account a number of constraints that represent the physical constraints and contractual obligations of the market. Pegasus holds a database of capacities and costs for all the major pieces of infrastructure like LNG terminals, production fields at an aggregated level, gas storage volumes and dynamic capabilities.

Gas prices influence electricity prices directly as gas is, and will remain, a fuel commonly used for power generation in many European countries. The impact of shale gas on electricity market prices was included in the power generation sector through iterations of the gas and power market models.

The geographical coverage of Pegasus is shown in Figure 54. The countries of Europe are modelled in detail, alongside the market in North America. The model also includes LNG production and demand worldwide.
Examining daily demand and supply across these markets gives a high degree of resolution, allowing the model to examine in detail gas flows in and out of storage, weekday/weekend differences etc.

A.1.1 Description of Pegasus

Pegasus itself comprises of a series of modules. The main solving module is based in XPressMP, a powerful Linear Programming (LP) package, which optimises to find a least-cost solution to supply gas to the 23 zones in Pegasus over a gas year. The solution is subject to a series of constraints, such as pipeline or LNG terminal sizes, interconnector capacities and storage injection/withdrawal restrictions, as indicated in Figure 55.

The solving module takes input files generated by a series of Excel/VBA modules, which allow a variety of scenarios to be created by changing variables such as supply, demand, costs, storage and interconnectors. The outputs from the model (e.g. prices and gas flows) are sent to a database to allow easy extraction of data at a daily, monthly or annual resolution. Figure 55 depicts the structure of Pegasus including the major inputs and outputs.
A.1.2 Demand

The total gas demand (power and non-power) has a daily profile on a seasonal normal basis for each zone, based around a sinusoidal function derived from historical data (examples shown in Figure 56). The daily gas demand takes into account the difference in demand between weekdays, weekends, and the Christmas holiday period, again based on historical patterns.

Figure 56 – Selected demand profiles for Pegasus zones
A.1.3 Pipelines and interconnections

Pipeline imports and interconnections between the European demand zones are modelled in detail, alongside existing and proposed LNG terminals and their interaction with the global LNG market. We differentiate between a gas production source (e.g. a field or a LNG liquefaction plant) and a delivery point (e.g. a pipeline or a LNG terminal).

The interconnections between zones means that during certain periods, gas flows can switch back and forth between import and export based on costs. Flexibility can be transferred between markets if there is a surplus in one and a shortage in another alongside sufficient interconnection capacity.

A.1.4 LNG

Pegasus also models the worldwide LNG market. All existing and under construction, LNG liquefaction projects worldwide are included within the modelling, alongside likely projects further into the future. Similarly, all LNG re-gasification terminals are modelled. In Europe and the US each terminal is identified separately, except in the longer term when unspecified LNG terminal capacity may be included. The terminal capacity in the Far East, Canada and South America, and the rest of the world is grouped within zones.

Each LNG source can deliver to any LNG terminal, whilst gas fields can deliver via one or a few pipelines. As a result, LNG can be delivered to different destinations depending on which market is most profitable – for example, LNG will deliver preferentially to Montoir (France) or Zeebrugge (Belgium) when prices are higher in those markets than in GB. Thus European gas markets are linked not just through the interconnectors but also via LNG arbitrage. The interaction with the US and the rest of the world means that gas markets worldwide are linked based upon supply and demand for LNG.

A.1.5 Storage

Modelling storage accurately is important to understanding price formation, as it affects both summer and winter prices, along with weekday/weekend prices. The optimisation algorithm used not only means that gas is injected into storage during the summer and withdrawn during the winter as expected, but also that injection takes place for high cycle facilities during the winter weekends and Christmas periods due to lower demand, as seen in reality.

In Pegasus, storage facilities are grouped into a maximum of six tranches per country based on their withdrawal and injection rates. This level of detail is sufficient to arrive at a realistic result of the use of European storage. In Italy and Hungary we take account of the fact that some storage is designated as ‘strategic’ and in other countries is more difficult to access, which increases its cost.

A.1.6 Gas pricing

Oil has traditionally acted as a major driver of European and worldwide gas prices through the practice of indexing gas prices to the price of oil in the preceding 3 to 9 months. However, the continued liberalisation of European energy markets and the creation of relatively liquid hubs in North-West Europe, coupled with the situation of oversupply has, at times, weakened the link between oil and spot gas prices. The longevity of this pricing mechanism and the extent to which it may apply in the future remains uncertain. Within this study, several gas sources (for example gas from Russia) were assumed to maintain
this oil linkage, and other sources (for example indigenous gas including shale gas) were assumed to be priced based on the long-run marginal costs of production.

A.1.7 Feedback with power generation

As a core part of the modelling, we carried out iterations with our electricity model to understand how the demand for gas used in power generation will vary at different gas price levels. Iterating between the two models ensures that our assumptions on gas prices and gas demand remained realistic and reflected the elasticity of gas demand as gas prices declined due to the development of shale gas.

Figure 57 – Gas and electricity modelling and interaction with other fuels

A.2 Description of Zephyr

The Zephyr model is the platform we have developed to simulate markets with high levels of intermittent generation and flexibility; and has continuously evolved in scope since its introduction in 2008. The model has underpinned our ground-breaking studies quantifying:

- the impacts of intermittency in European electricity markets; and
- the role flexibility could play in meeting the challenges of intermittent generation.

Zephyr is an economic dispatch model based on optimisation. The model balances demand and supply by minimising the variable cost of electricity generation for a defined portfolio of generation capacity, given certain interconnection, demand side flexibility characteristics, plant dynamics and other specified constraints. There are a number of key modelling principles that underpin Zephyr:
- **Historical weather year approach.** The relationships between the weather (determining wind and solar generation) and demand for electricity are extremely complex and critical to accurate analysis. To ensure that these relationships are valid, the modelling in this study has used consistent sets of (very detailed) historical data patterns for wind, solar irradiation and demand.

- **Fully competitive market and marginal cost bidding.** All plants are assumed to bid cost reflectively and when operating they will fully cover their fuel, start-up and part-loading costs. This reflects a fully competitive market and leads to a least-cost solution. It is also assumed that new thermal plant will make high enough returns over their commercial lifetime to justify their investment, and existing plant will cover their fixed costs.

- **Value of capacity.** A value of capacity is included in the market price. In the modelling it represents the scarcity value of capacity and at any point in time is determined by the capacity margin in each market. It is needed to ensure that the plants required to maintain system security are able to recover their annual fixed costs, and, if new capacity is required, capital costs as well from the market.

- **Lights will stay on.** We generally assume that a minimum level of system security will be maintained in all scenarios and for modelled years i.e. ‘the lights will stay on’. However, this assumption is not essential. Zephyr reports statistics for system security, including expected energy unserved and number of hours of lost load; and on the basis of these statistics build decisions are varied.

- **Integrated hydro modelling.** A separate hydro model (BID) is used to calculate the water values of hydro generation that are used in the Zephyr dispatch. BID uses consistent input assumptions together with water inflow profiles to determine the water value for each period – dependent on the time of year and reservoir inventory levels. The water value quantifies the trade-off between using water to generate in the current period versus the value of keeping the water in storage for potential use later in the year.

### A.2.1 Model inputs

Accurate model inputs are key to ensure that the Zephyr model provides quantitative modelling and analysis of the highest quality.

- **Wind and solar data.** We have spent a great deal of time and effort to ensure a consistent set of input data to produce hourly profiles of intermittent generation. We use an extensive data set of wind speeds based on satellite data covering the whole of Europe, along with hourly solar irradiation data covering Europe so solar profiles are properly represented. In total we have analysed over 60 million records of wind and solar data to derive the consistent generation patterns of intermittent generation.

- **Hydro modelling.** A separate hydro model (BID) is used to calculate the water values of hydro generation that are used in the Zephyr dispatch model. BID uses consistent input assumptions together with water inflow profiles to determine the water value for each period – dependent on the time of year and reservoir inventory levels. The model employs water-value based hydro operation, using stochastic dynamic programming in order to calculate water-values. This model is used extensively in Scandinavia to model the power system.

- **Demand.** Hourly profiles of demand have been taken from relevant national organisations (e.g. TSO). By using historical demand data (suitably adjusted for
changes in GDP), we preserve the complex relationships between demand and weather.

- **Plant availability.** Zephyr can use either historical plant availability data on an hour-by-hour basis (where available), or a sophisticated availability module which optimises maintenance and adds randomised forced outages.

- **Value of capacity.** The value of capacity describes the mark-up on the variable cost of generation – also called the scarcity value. Zephyr models this mark-up in a sophisticated manner based on the system tightness in each hour.

- **Plant dynamics.** This includes scaling for different properties (maximum output, minimum on and off time, minimum stable generation, etc.) estimated from historical data.

- **Interconnection.** The model also takes account of interconnection between markets, so that flows between countries are optimised.

- **Zonal data.** Optionally the model can split the system into a number of zones which allows us to determine transmission flows and thus estimate the impact of transmission constraints.

- **Reserve and response data.** Optionally reserve and response constraints can be included. We assume that sufficient primary frequency response (full ramp-up within 30 seconds after unplanned outage) is provided in line with technical requirements for generation plants. For secondary frequency response (30 seconds to 30 minutes after an unplanned outage) and for reserve (30 minutes to 4 hours), we have used formulae to determine the ex-ante level of reserve required to be held by the system, which can be determined in a constrained run of the model, which looks at a number of factors such as the volume of capacity which is not generating but is still in a hot condition, headroom available for capacity which is generating, and OCGTs (which may be neither generating nor in a hot conditions but which can be started up quickly).

- **Flexible demand profiles.** The model includes profiles with respect to flexible demand-side units (in addition to flexible industrial demand) in three categories – residential non-heat, heating, and electric vehicles.

### A.2.2 Dispatch model

The model simulates the dispatch of each unit in the market for each hour of every day – a total of 8,760 hours per year, across chosen historical weather years. The unit dispatch is optimised across the market to give the least-cost solution of meeting demand. The least-cost solution means the model minimises the aggregate of fuel costs, the costs of starting plant and the costs of part-loading. For example, it may mean that the model will reduce the output of wind generation to avoid shutting down a nuclear plant and incur the cost of restarting it later.

There are a wide variety of constraints that the model must meet in order to ensure a feasible solution. These include:

- Constraints relating to plant availability/capacity.
- Demand must be met (though there is a load loss variable with an associated cost).
- MSG (Minimum Stable Generation).
- NTC (Net Transfer Capacity).
- Other interconnection related constraints – there are constraints relating to imports/exports to counties and flows between groups of countries.

- Plant operational constraints including: start up constraints; minimum on time (minimum number of hours a unit must stay on after starting); minimum off time (minimum hours a unit must stay off after shutting down); minimum/maximum generation constraints, where there are hourly limits on generation.

- Pumped storage and hydro constraints.
  - Pumped storage is optimised subject to a limit on the reservoir volume and capacities for pumping and generation. To reduce the foresight element we force pumped storage to be full at 6am on Monday mornings.

- Hydro has maximum output, minimum output, and maximum/minimum reservoir levels, which can vary with time. However the use of water-values largely ensures these constraints do not bind.

- Additional constraints relating to any demand side response.

Figure 58 gives a broad overview of Zephyr including all data input modules.

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**Figure 58 – Overview of Zephyr model framework**

- **Demand module**
- **Intermittent module**
- **Availability module**
- **Value of Capacity module**
- **External border module**

**New build of generation**

- **Commodity prices**
- **Plant data**
- **Zonal data**
- **Reserve data**

**Prices**
- **Load factors**
- **Interconnection**
- **Plant revenue**
- **Constraints**

- 8760 hours per year
- Historical weather patterns
- Plant dynamics
- Zonal analysis
ANNEX B – CAMBRIDGE ECONOMETRICS’ MODELLING APPROACH

B.1 E3ME description

E3ME is a computer-based model of Europe’s economies, energy systems, and the environment (hence the three Es); more recently it has been expanded to also include demand for physical materials. E3ME was originally developed through the European Commission’s research framework programmes and is now widely used in Europe for policy assessment, forecasting and research purposes.

Figure 59 provides an overview of the model structure.

Figure 59 – E3ME model overview

The economic structure of E3ME is based on the system of national accounts, as defined by ESA95 (European Commission 1996), with further linkages to energy demand and environmental emissions. The economic model includes a full set of macroeconomic feedbacks at the sectoral level that capture supply chain impacts and multiplier effects. The model contains a total of 33 sets of econometrically estimated equations, covering the individual components of GDP (consumption, investment, and international trade), prices, the labour market, energy demand and materials demand. Each equation set is disaggregated by country and by sector.

B.1.1 Model dimensions

The main dimensions of the version of the model used for this analysis are:

- 33 countries (EU28 member states, Norway, Switzerland and three candidate countries);
MACROECONOMIC EFFECTS OF EUROPEAN SHALE GAS PRODUCTION

- 69 economic sectors (2-digit NACE rev2 level), including a disaggregation of the energy sectors and 38 service sectors;
- 43 categories of household expenditure;
- 21 different users of 12 fuel types;
- 14 types of air-borne emissions including the six greenhouse gases monitored under the Kyoto protocol; and
- 13 types of household, including income quintiles and specific socio-economic groups.

**B.1.2 Comparison to CGE approaches**

E3ME is similar in many ways to a Computable General Equilibrium (CGE) model and produces a similar set of outputs. However, E3ME does not impose the assumptions about the nature of the economy that are typically incorporated in CGE models. Instead, E3ME follows a more empirical approach, with behavioural parameters estimated using historical data sets rather than imposed or calibrated to conform to neoclassical economic theory. Consequently, the model’s empirical validity does not depend on the validity of the assumptions common to CGE models, such as perfect competition or rational expectations, but it does mean that the model's validity depends on the quality of the data that are used to estimate the parameters.

**B.1.3 Key characteristics**

The key characteristics of E3ME for this exercise are thus:
- its coverage of the EU at Member State level;
- its two-way linkages between the economy and energy systems;
- its econometric specification, allowing for analysis of both short and long-term impacts; and
- its sectoral disaggregation, allowing detailed analysis of sectors of the economy that benefit most from shale gas production and lower gas prices.

**B.1.4 Modelling baseline**

**B.1.4.1 Overview of the baseline**

A forward-looking, **ex ante**, assessment requires a baseline forecast with which to compare the different policy scenarios. This is not necessarily presented as a forecast of future developments, but rather as a neutral viewpoint for the purposes of comparison, since many of the model-based results are presented as (percentage) difference from baseline. Nevertheless, the values in the baseline are important in themselves, since they provide, for example, an indication of prices and energy requirements over the next decade. It is therefore important that a robust and credible baseline should be established.

The baseline that was chosen for this study is the ‘PRIMES’ 2009 reference case from the ‘EU Energy Trends to 2030’ publication, which has been updated with the most recent economic forecast from ‘The 2012 Ageing Report’, published by the European Commission (2010), ‘EU Energy Trends to 2030’, available online http://ec.europa.eu/clima/policies/package/docs/trends_to_2030_update_2009_en.pdf
Commission (DG Ecfin). The baseline assumes that there is no shale gas production in the EU in the period up to 2050.

Figure 60 summarises the baseline economic and energy projections.

**Figure 60 – Summary of Modelling Baseline for the EU28**

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2035</th>
<th>2050</th>
<th>% pa growth (2010-2030)</th>
<th>% pa growth (2030-2050)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (000s)</td>
<td>504,121</td>
<td>528,063</td>
<td>528,548</td>
<td>0.19%</td>
<td>0.01%</td>
</tr>
<tr>
<td>GDP (€bn)</td>
<td>12,757</td>
<td>18,517</td>
<td>22,858</td>
<td>1.50%</td>
<td>1.41%</td>
</tr>
<tr>
<td>Employment (000s)</td>
<td>226,318</td>
<td>228,617</td>
<td>219,505</td>
<td>0.04%</td>
<td>-0.27%</td>
</tr>
<tr>
<td>Final energy demand (mtoe)</td>
<td>1,201</td>
<td>1,246</td>
<td>1,388</td>
<td>0.25%</td>
<td>0.72%</td>
</tr>
<tr>
<td>Greenhouse gas emissions (mtCO₂-eq)</td>
<td>4,423</td>
<td>3,695</td>
<td>3,438</td>
<td>-1.19%</td>
<td>-0.48%</td>
</tr>
</tbody>
</table>


**B.1.4.2 Additional processing**

Outputs from the PRIMES simulations and ‘The 2012 Ageing Report’ are incorporated into the E3ME solution. This includes the sectoral economic projections, energy and ETS prices, projections of energy demand by sector and by fuel, and sectoral CO₂ emissions. E3ME’s Energy Technology sub-model of electricity capacity and generation also makes use of some of the more detailed outputs.

However, in order to meet E3ME’s data requirements, it was necessary to carry out some additional expansion and processing.

- Classifications were converted – as E3ME and PRIMES use similar data sources, the classifications also tend to be quite similar. There are, however, some differences. For example, E3ME has more disaggregation of service sectors.
- Point estimates for occasional years were converted to annual time series – a simple interpolation method is used; short-term forecasts from the AMECO database are also used to take into account more recent data from the recession.
- Additional social and economic variables were estimated – only a small set of economic variables (GDP and the ones that are direct drivers of energy demand) are given in ‘The 2012 Ageing Report’ and PRIMES outputs. E3ME requires a complete specification of the national accounts so other variables must be estimated. The

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procedure followed to achieve this is described below (proxies for other economic indicators).

These additional steps were carried out using software algorithms based in the Ox programming language (Doornik, 2007). The result of this exercise is a set of baseline projections that is both consistent with the published figures and the integrated economy-energy-environment structure of E3ME.

B.1.4.3 Energy demand

The PRIMES figures include a comprehensive set of projections for Europe’s energy systems and the resulting emissions. Economic activity is provided as a driver of energy demand, but the figures tend to be provided only at an aggregate level (e.g. GDP, household spending or value added for some energy-intensive sectors). As the E3ME model is built around the complete structure of the national accounts, this means that the projections for other economic variables must be estimated.

B.1.4.4 Proxies for other economic indicators

This process was carried out using a methodology that is as consistent as possible between the economic variables, for example ensuring that the components of GDP sum to the correct total, and that similar indicators, such as gross and net output, follow the same patterns of growth. A set of software algorithms was used to carry out this exercise, written in the Ox software package.

The PRIMES datasets provide economic projections for GDP, gross value added (GVA) and household incomes in constant prices. It was necessary to estimate values for other variables. E3ME’s projections of GDP and GVA are set to match the published figures. Economic output (which is gross, defined as intermediate demand plus GVA) was set to grow at the same rate as GVA.

E3ME’s total consumer spending was set to grow at the same rate as the household income figures, following the standard economic assumption that, in the long run, all income is spent. Detailed consumer spending by spending categories was set to grow using historical trends and was then constrained to the total.

Other components of output (at sectoral level), mainly investment and trade, were also set to grow based on historical rolling averages and then constrained to the total output that was based on the GVA projections.

Prices for energy-related industries were set to be consistent with the PRIMES energy price assumptions. Prices for other industries were projected using historical trends.

B.2 Modelling approach

The technical analysis undertaken by Pöyry established, for each scenario, a series of E3ME model inputs in the form of annual projections for the years 2015-2050. This included the following:

- total gas production by EU member state;

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27 Gas prices, gas production and gas trade assumptions in the baseline were also adjusted to ensure consistency with the modelling results from Pöyry.
gas imports by EU member state;
- total extra-EU gas imports and extra-EU gas exports for the EU28;
- gas prices by EU member state;
- electricity prices by EU member state; and
- power sector gas and coal generation assumptions by EU member state.

These were processed using the Ox software package and read into the E3ME model as exogenous inputs.
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