A model-based analysis of the implications of shale gas developments for the European gas market

Jeroen de Joode, Arjan Plomp, and Özge Özdemir

Abstract-- **Shale gas in Europe could potentially be a big thing, especially in particular regions. Whereas test drillings need to confirm the technical recoverability of deposits and further research is needed on the environmental and safety aspects of shale gas production, this paper illustrates that shale gas developments may have substantial implications for regional gas balances, gas flows, and infrastructure requirements throughout Europe in the next decades.**

***Index Terms*—Natural gas, supply and demand, Europe, modeling, economics**

I. Background

THE shale gas boom in the US in the past years has led to expectations and concerns in Europe: expectations with respect to the possible contribution shale gas deposits in Europe can contribute to European gas needs in the future and thereby ease Europe's security of supply concerns, and concerns with respect to the risks attached to European shale gas developments based on incidents in the US (e.g. local ground water pollution, safety hazards) and the sustainability of shale gas activities at large. In response, some European countries have imposed a de facto moratorium on shale gas developments (e.g. France) whereas others have welcomed a large number of test drillings for shale gas (e.g. Poland). Estimates on the presence of shale gas deposits in Europe are scarce and available estimates vary. Uncertainty also exists regarding the costs of bringing this gas to the market. The possible risks involved in producing shale gas deposits across Europe needs to be thoroughly assessed, and also the degree to which shale gas may be considered a sustainable energy source in comparison with alternatives needs to be analyzed. But irrespective of these issues, also the desirability (or: need) to develop shale gas resources from an economic perspective needs to be addressed if a proper full-range political assessment is to be made regarding pro's and con's. Without proper information on aspects related to, for example security of supply, policy maker's decisions on shale gas developments across Europe will be based on incomplete information.

Based on the scarce available information, and for the moment ignoring political decisions that are or may be made across different EU member states, this paper assesses the potential implications of shale gas developments in Europe for the EU gas market. How do shale gas developments contribute to security of supply in the EU and its member states in next decades? How may developments affect the sourcing of gas consumption across the EU? Finally, what are the implications for infrastructure use and investment requirements? These are the type of questions addressed in this contribution.

II. Methodology and Assumptions

In order to quantify the possible impact of future shale gas developments in the EU an economic equilibrium model is used that covers the EU gas market and its neighboring regions. The use of market models to simulate (future) gas market developments is not new, but an application to the potentially high-impact development of large-scale shale gas production has not been investigated thus far. Examples of other applications are an assessment of future costs of gas suppliers [1], an assessment of future gas infrastructure investment requirements [2], an assessment of the impact of gas supply interruptions [3], an assessment of the future need for seasonal gas storage [4], and an assessment of the impact of market power [5,6]. The thus far lacking of an application to the case of shale gas prospects may be explained by the scarce availability of commercially recoverable shale gas estimates and production cost data.

The adopted equilibrium model of the European gas market is called GASTALE[1] and is formulated as a mixed complementarity problem. [7] provides an overview of gas market models and the possible approaches with respect to problem formulation. The GASTALE model has been successfully applied in different contexts previously [2, 4 , 6].

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[1] GASTALE stands for Gas mArket System for Trade Analysis in a Liberalising Europe, and was originally developed to analyze the effects of gradual gas market liberalization on end-user prices and market shares of producers [6].

Particular features of the current version of the model that is adopted in this analysis are: endogenous investment decision-making, a distinction between different demand periods within a year, a timeframe until 2050, and the ability to reflect different degrees of upstream market power. The model endogenously determines required investment in new gas infrastructure over time using a net present value based rule. However, assumptions need to be made regarding investment in new gas production capacity over time. The model simulates market operations given available gas resources and gas demand nodes across Europe and provides optimal market outcomes by matching supply and demand at equilibrium gas market prices and optimal infrastructure levels. In doing so it also takes into account the fact that the natural gas market is not a fully competitive market: it allows gas suppliers a particular room for exercising market power. This leads to gas prices across Europe lying above the level of total costs of delivery.

In order to simulate future gas market developments various assumptions need to be made which reflect a probable future and may be referred to as a scenario. First of all, a scenario framework that has been developed in the European research project SUSPLAN provides a suitable context for assessing shale gas developments [8].[2] This project assessed the energy infrastructure implications of different energy transition paths to 2050. Most relevant aspect of this framework for the analysis on shale gas is the range of gas demand projections that has been constructed. The highest gas demand scenario shows a continuing increase in gas demand in Europe until 2050. In the low gas demand scenario gas demand peaks around 2020 and thereafter steeply declines until 2050.[3] With climate policy being one of the key drivers for the future role of gas in the energy mix it is important to mention here that long-term sustainability targets are not met in this particular high gas demand scenario, but are met in the low gas demand scenario. As will become clear, the impact of shale gas penetration in the markets is different for both scenarios. Figure 1 presents the two gas demand scenarios that have been taken from the SUSPLAN scenario framework and used in this analysis. [9] contains a full description of scenario assumptions and data input.

Second of all, assumptions on the availability of shale gas deposits, the rate of investment in shale gas production assets, and the cost of producing shale gas across Europe have been made. Firstly, the US Energy Information Agency (EIA) estimates for technically recoverable shale gas resources [10] have been used to identify the potential shale gas producing countries in Europe. Turkish and Ukrainian shale gas production has been excluded, since the used gas model covers only the gas consumption in the EU. Secondly, a non-linear rate of increase in shale gas production capacity, starting only in 2015 has been assumed based on estimates for 2020 and 2030 as put forward by [11]. The estimates may be qualified as optimistic, but not unrealistic, and hence suitable for the analysis in this paper. Total realized capacity is allocated to the countries using shale gas potentials as estimated by [10] on a pro-rata base.

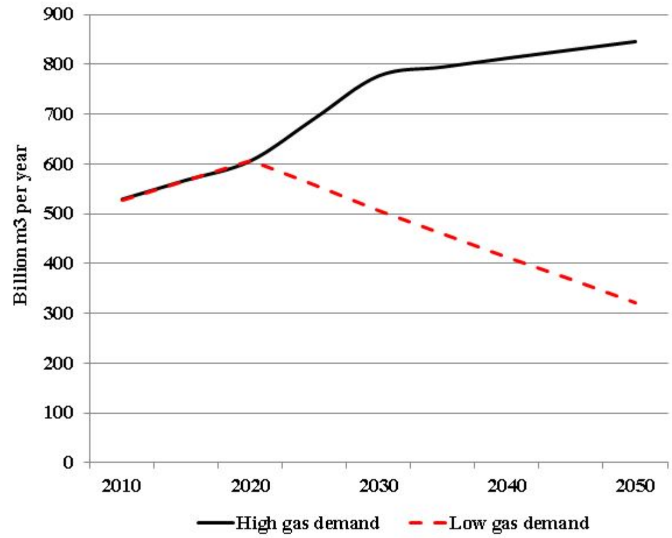

Fig. 1. Total demand for natural gas in the European Union (EU) until 2050 in two scenarios [9]. The high and low gas demand scenarios correspond to the 'Red' and 'Green' storylines from the SUSPLAN scenario framework (www.susplan.eu).

Figure 2 illustrates the shale gas production capacity that, for the purpose of this analysis, is assumed to come on stream over time in different EU countries that are currently estimated to have significant shale gas deposits in the underground [10]. The assumed development of shale gas production capacity is exogenously put into the simulation model.

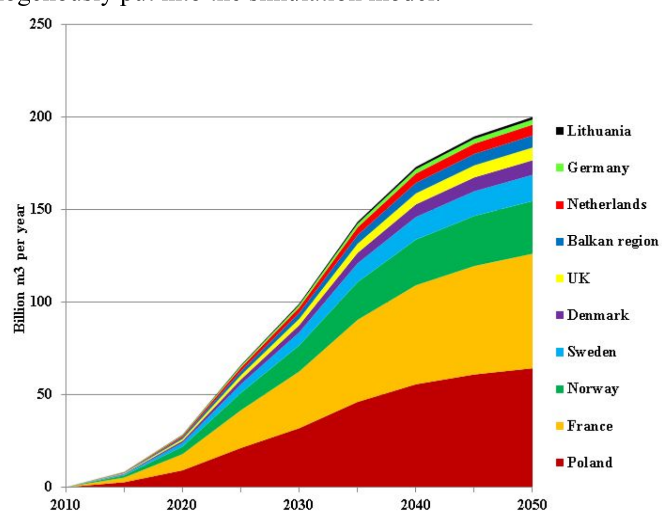

Fig. 2. Assumed installed shale gas production capacity in billion m^3 per year across the EU from 2010 to 2050 based on [10, 11].

Finally, the cost of producing shale gas is assumed to be in the range of 7-12 €-cent per m^3 [12], with the higher end of the range applicable to shale gas produced at maximum production capacity. These cost assumptions are uniform across countries and are generally about three to four times higher than the cost of conventional gas production [12].

[2] More information on the SUSPLAN project as well as publications from this project can be obtained via its website: www.susplan.eu.

[3] The high and low gas demand scenarios mentioned here correspond to respectively the 'Red' and 'Green' storylines defined in SUSPLAN.

Analytically, the total impact of shale gas developments on the gas market can be divided into two effects: a substitution-effect and a demand-side-effect. This is explained below. When a new gas supply source enters the existing portfolio of gas supply options, the confrontation of an expanded supply portfolio with a certain demand for gas, and given dispersion of both gas demand and supply sources and cost properties of different activities in the gas value chain may lead to changes in the deployment of gas supply sources. Whereas some resources were previously used to meet gas demand they may be utilized to lesser degree when new resources emerge that are considered more attractive based on location and cost properties. This effect may be referred to as the substitution effect. On the other hand, the increased availability of gas supply sources implies that from an economic perspective the commodity gas is less scarce, which may lead to lower gas prices. In turn, a lower price of gas may trigger new demand for gas. Compared with the former situation where there were less gas supplies available total demand may increase. This may be referred to as the demand-side-effect. A proper assessment of the demand-side effect in the case of shale gas requires a detailed modeling of different gas customers and in particular their investment decisions. This would for example require the modeling of the power generation sector (which is one of the largest gas demand categories in Europe) and the generation investment decisions therein. Whether a lower gas prices will result in additional investment in gas-fired power generation units and an increase in demand depends on the competitive position of gas in that sector versus other technologies such as coal-based power plants or wind power turbines. An interesting analysis of both the substitution and demand-side effects of increasing shale gas production in the US is provided by [13]. They observe that the demand-side effect for gas is highly dependent on both the impact of the increasing penetration of shale gas on the gas price and on climate policy. A strong or weak climate policy translates into a relatively higher or lower CO_2 price, which in turn affects the substitution of electricity generation technologies.

Since the current version of the adopted gas market model does not reflect into detail the different gas demand sectors (and investment decision-making therein) but rather includes these sectors in an aggregated manner the focus in this analysis is only on the substitution-effect of shale gas developments, and not on the demand-side-effect. In other words: while keeping gas demand fixed at the level of corresponding high and low gas demand scenarios, shifts on the supply-side are analyzed.

Finally, in addressing the mentioned research questions on the impact of potential shale gas activities in Europe it is important to explore how the production profile of specifically shale gas enters the analysis. This relates to the issue of flexibility in gas production. Whereas the demand for gas has a distinct pattern over time, for example throughout the year, gas production facilities are generally only capable of accommodating this pattern in a very limited manner [4]. Whereas the core analysis in this paper assumes that shale gas production is very flexible, a sensitivity analysis is performed that assumes the contrary.

To summarize, two different gas consumption scenarios have been used and are combined with an assumed development path for shale gas production capacity in the EU and associated costs of production in order to analyze the impact of potential shale gas developments on the supply side of the market (i.e. analysis of the substitution effect). The evaluation of results centers on the EU security of supply position, EU future gas flow patterns and gas infrastructure requirements and local gas demand and supply balances. Finally, a sensitivity analysis is performed regarding the production flexibility properties of shale gas production.

III. Results

This section highlights the results of the model-based analysis. The effect of the increasing shale gas production capacity throughout Europe can be derived from comparing model simulation results for the high and low gas demand storylines with and without the assumed trajectory of investment in shale gas production assets.

This section consecutively discusses the implications for EU imports and import dependency as a whole, the impact on regional gas flows and infrastructure requirements and the impact on specific countries within the EU. Finally, the impact of an assumption with respect to the production profile of shale gas producing facilities across seasons of the year is assessed. The latter assessment boils down to the question: what are the production flexibility properties of shale gas and how may this impact the gas market?

A. *Decrease of EU import dependency*

As may be expected, an increase in indigenous shale gas supplies replaces gas supplies previously contracted outside the EU and thereby reduce EU import dependency. Regardless of the gas demand scenario, the level of import dependency of the EU as a whole is reduced both in absolute import volumes as well as percentage wise. This result is illustrated by Figure 3. This observation can be explained by the fact that the gas supplies from outside the EU are generally more expensive than EU indigenous shale gas supplies when both the costs of production and transport (whether by pipeline or by LNG tanker) are included. The supply countries that experience a decline in gas exports to the EU as a result of increased shale gas production within the EU are Algeria, Nigeria, Egypt, Qatar and Russia. This is explained by a combination of higher production costs (for example in the case of LNG supplies from Egypt and Qatar) and relatively higher transport costs in comparison with the transport costs for shale gas deposits (for example in the case of Algeria and Russia).

What also emerges from the results is that the EU will continue to be largely import dependent on external gas suppliers in the future. A lower EU gas demand and increased shale gas availability may reduce the EU import gap in the next decades but is not likely to solve the EU import dependency problem altogether. In a low demand scenario and assuming an optimistic but not unrealistic development of shale gas production capacity the gap between EU gas demand and indigenous gas production in 2050 is about 300 billion m^3, corresponding to an import dependency of about 85%. In a high demand scenario the import gap in 2050 may still be about 700 billion m^3.

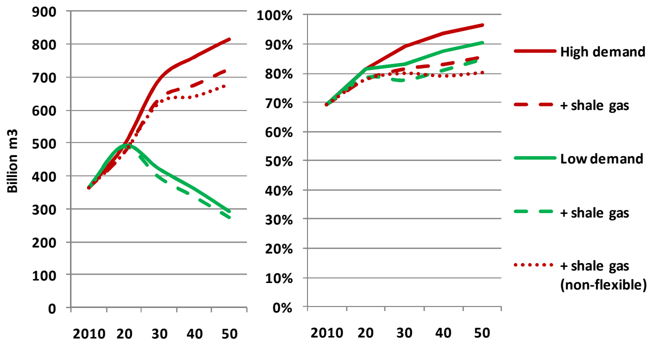

Fig. 3. Resulting EU import dependency in absolute terms (left) and relative terms (right) in the case of high and low gas demands and in the presence and absence of assumed shale gas production. Additionally, the figure shows the results in the case of a different assumption regarding the flexibility properties of shale gas production assets which is the central topic of discussion in Section III.D.

In the low gas demand scenario there is considerable less shale gas produced across the EU. This is explained by the fact that average gas prices in this scenario are lower than in the high demand scenario. As a result, there is also considerable less substitution of imported gas with indigenous shale gas. The lower gas demand and prices in this scenario already result relatively less supplies from more expensive suppliers.

Whereas the overall impact for the EU was discussed above the remainder of this section will zoom in on regional and country level implications of potential shale gas developments.

B. Significant changes in gas flow patterns in some parts of the EU

Since a large part of the European shale gas prospects are located in countries with previously little or no gas production, the increasing penetration of shale gas across the EU significantly affects EU internal gas flows as well as future infrastructure investment requirements. Figure 4 illustrates the impact of shale gas production in a high gas demand scenario in 2050 by depicting the incremental changes in net yearly gas flows compared with the situation with no shale gas production at all. Note that the incremental changes in gas flows may vary across seasons and that the figure only depicts net (changes in) flows over a year.

Changes in gas flow patterns either result directly from the penetration of shale gas production facilities in certain countries or indirectly from the substitution of relatively more expensive non-EU gas supplies for indigenous EU gas supplies. While increased production from shale gas deposits in the UK, the Netherlands and Norway partly compensate the declining conventional gas production, the large presence of shale gas in Poland and France gives rise to large changes in gas flow patterns to and from its direct neighbors. French shale gas is partly exported to Italy, Belgium and the Netherlands whereas Polish shale gas is exported to other central and eastern European countries that previously relied mostly on Russian gas imports. EU imports from Algeria via Spain/France or via Italy are reduced as a direct result of the production of shale gas in France. Transit routes on the East-West axis may lose in importance as a direct result of Polish and French shale gas production. Shale gas production in particularly in the UK and France lead to a large reduction in LNG imports in those countries.

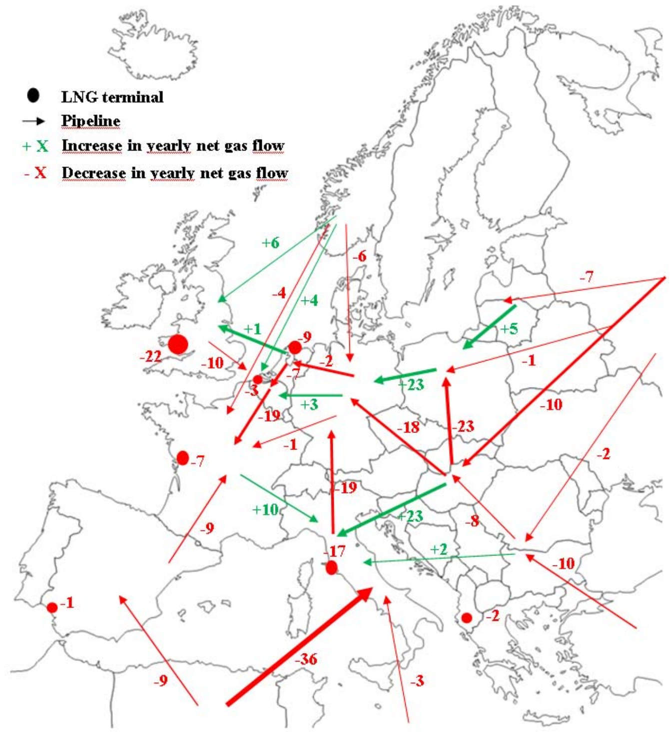

Fig. 4. Resulting incremental changes in yearly net gas flows in 2050 due to shale gas production in the high gas demand scenario (in billion m^3 per year). Gas flows in different seasons of the year (i.e. summer and winter) may vary, only the net effect is depicted here.

The above described changes in gas flow patterns have implications for future gas infrastructure investments. In order to accommodate gas flows from France to neighboring countries new gas pipeline investments are required for French interconnections with Italy and Germany, whereas less LNG import terminal investments are required in France, Belgium and the Netherlands. In Eastern Europe fewer investments are needed for the transit of gas from the South-East corner of Europe to Central Europe. Finally, investment in Algerian export pipelines to Italy and Spain that would be needed in a situation without development of shale gas resources becomes necessary. A lower volume of Algerian exports to southern Europe may reduce the utilization rate of existing pipeline capacity. Additional investment is however required in the pipeline connection between South-Eastern Europe and Italy. Given that Northeastern and Central Europe have less demand for gas supplies that enter Europe via its South-East corner, part of the gas flow is now re-routed to Italy, partly at the expense of Algerian imports into Italy.

In the low gas demand scenario, the little gas produced from shale gas deposits hardly affects infrastructure investment requirements since shale gas is predominantly consumed within the borders of the shale gas producing country.

The next section turns to discuss the gas supply and demand balance for a selection of EU countries, which may show quite different effects than the effects of potential shale gas developments for the EU as a whole.

C. Higher level of gas supply diversification and smaller import dependency on member state level

The presence of shale gas resources across Europe leads to new dynamics in European gas trade with new gas producers not solely producing for domestic consumers but also for neighboring countries: gas producing countries may at the same time import and export gas, just as observed in practice on the current gas market. The impact of the newly added shale gas production capacity depends significantly on the import dependency of countries – as measured by the gap between national gas demand and production – which varies largely across countries (see Figure 5).

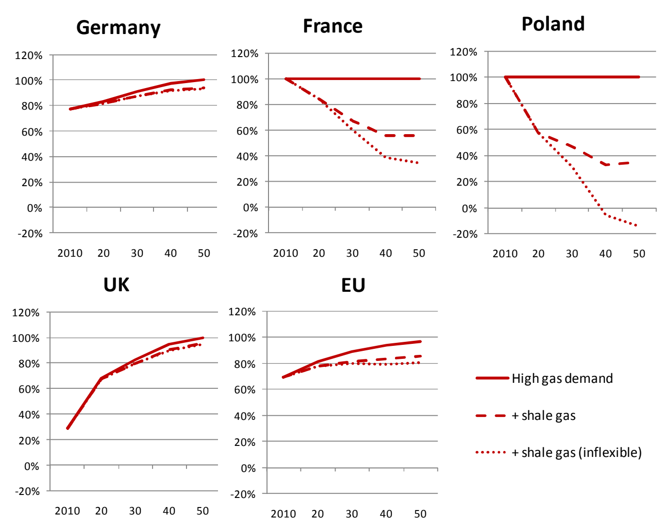

Fig. 5. Resulting import dependencies of a selection of EU member states and the whole EU. For Germany, UK and the whole EU, the import dependency increases over time. France and Poland remain, without shale gas production, entirely import dependent, while the development of shale gas decreases the import dependency.

Shale gas production in Germany reduces German import dependence somewhat while UK shale gas production is by no means capable of compensating the declining conventional UK gas production. However, shale gas production in Poland and France proves a 'game changer': Poland could become self-sufficient in the second half of the period until 2050 in a high gas demand scenario and France reduces its import dependency by more than 40%. In a low gas demand future the impact becomes negligible since the little gas demand that still needs to be served is accommodated by relatively cheaper conventional gas supplies from Norway or Russia. The general message that may be taken from these results is that the import dependency figures for the EU in total cannot tell the story for individual EU member states.

D. Assumptions on shale gas production flexibility matter for simulated market outcomes

Although the above results show a significant impact of shale gas developments on the gas demand / supply balance in the EU, it has been found that the total amount of shale gas produced over the years is less than what actually could be produced based on the assumed development of shale gas production assets over the same period. When simulating the impact of shale gas it turns out that in the low demand periods it is cheaper to import gas from outside Europe than to use available shale production capacity. This is explained by the higher level of production costs for shale gas, which is not sufficiently compensated by the relatively higher costs for transportation incurred when importing gas from outside the EU in low demand periods: i.e. no substitution of imported gas with shale gas in summer.

This obviously poses the question whether the investment in shale gas production capacity as assumed is economically viable and thus realistic. Generally, gas fields need to produce at a relatively constant rate throughout the year because the provision of high levels of (seasonal) flexibility is economically not viable (although perhaps technically possible). Some unique exceptions do exist such as the Dutch Groningen reservoir and, in the past, the UK Rough reservoir. Although the model is not capable of simulating endogenous investment in production assets, the impact of limiting production flexibility of shale gas has been assessed for the assumed shale gas production investments on the market. The assumption of an 80% minimum production level – which may still be considered quite flexible compared with conventional gas fields – results in a significant increase in the level of shale gas production. Also the distance to the market matters: the larger the distance between the reservoir and the demand centers, the higher the throughput requirement for long-distance transport pipelines.

The imposed assumption strengthens the substitution effects and has consequences for gas supply diversification and import dependency at the member state level as described above. The dotted lines in Figures 3 and 5 show how this imposed limitation affects results discussed in previous paragraphs. Figure 3 indicates that an 80% 'must-produce' constraint increases EU indigenous gas supplies with 30 to 50 billion m^3 per year (depending on the prevailing gas demand scenario). Figure 5 illustrates that shale gas producing countries France and Poland see a further improvement of their gas demand-supply balance, with Poland actually becoming self-sufficient from 2040 onwards.

IV. Concluding Remarks

Although the overall impact of possible shale gas developments on EU security of gas supply in terms of import dependency is positive, the performed modeling analysis shows that due to the particular distribution of presumed technically recoverable shale gas resources across EU member states the impact on the individual member state level can vary.

Results on the market impact of shale gas developments are to a large extent dependent on the overall level of gas demand and the gas demand trajectory towards 2050. Whereas a high demand trajectory allows for a significant penetration of shale gas in the market, a low gas demand trajectory gives rise to unfavorable position for shale gas due to the relatively stronger competition from 'cheap' supplies.

The fact that a considerable share of shale gas resources is located in countries that previously had little or no gas production may have large implications for gas flow patterns across Europe, especially in France and neighboring countries as well as Poland and Central and Eastern Europe. This has consequences for future gas infrastructure investment requirements on specific cross-border interconnections that would not generally attract attention in scenarios where shale gas resources are excluded. Moreover, since indigenous shale gas supplies partly replace gas supplies formerly contracted outside the EU in for example LNG producing countries such as Qatar and Egypt and in traditional supply countries like Algeria and Russia, there may be important implications for investors in new gas supply facilities as well. In addition to the uncertainty due to the uncertain pace of transition towards a sustainable energy system, also uncertainty about the real potential for shale gas may become an important factor in making large-scale gas infrastructure decisions.

Within the model analysis, it is assumed that necessary infrastructure investments such as cross-border pipeline connections are realized timely. In practice however, shale gas developments may be hampered by a lack of new pipeline investment as a consequence of the current regulatory framework within Europe. The particular problem of insufficient investment in infrastructure that is of pan-European interest is targeted by the recently proposed EU Energy Infrastructure Package [14]. The future will learn if the proposed regulation will solve the lack of investment problem.

An aspect that remains to be investigated further is the demand-effect of the potential large-scale availability of shale gas deposits. The availability of large volumes of shale gas may itself trigger more demand for gas and thus make a higher gas demand scenario more likely in the future. However, no conclusions can be drawn here since the analysis focused on the substitution effect of shale gas.

Furthermore, although non-economic issues such as environmental pollution, safety risks, sustainability features of shale gas and public acceptance at large have been abstracted from in this analysis it is acknowledged that these are crucial for the possible shale gas developments in Europe in the future. [11] compares the US and Europe on a number of these issues. How these issues will affect future supply of shale gas in Europe is at the moment difficult to predict. It is emphasized here that this analysis is based on very scarce information on shale gas resource availability and EU shale gas production cost estimates. Planned test drillings predominantly in Poland in the next years will need to provide more and better information that can then be used to analyze larger gas market implications. The political response towards shale gas drillings varies largely. Whereas France banned the technique required for shale gas drillings (fraccing), Poland has welcomed shale gas prospects as a way to reduce import dependency from Russia. We have refrained from modeling different scenarios where countries do or do not allow for shale gas production since it is not clear to what degree bans will be permanent. The Netherlands, for example, awaits further study on the potential impact of shale gas production before allowing or permanently disallowing shale gas drillings. Obviously, such decisions will both in model calculations and in practice change the gas flow pattern across Europe and associated infrastructure requirements.

Another issue that is of interest when discussing potential shale gas developments, but unfortunately cannot be sufficiently covered with the tools deployed in this analysis, is the role of long-term supply contracts – possibly linked to oil prices – in the European gas market. Whereas the share of spot market trade and long term contracts with spot market price linkages have been on the rise in recent years, it is uncertain whether this will continue in the next decades, and how shale gas developments may affect these dynamics.

V. Acknowledgment

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VII. Biographies

Jeroen de Joode was born in Gouda, the Netherlands on April 5, 1980. He graduated from the University of Tilburg in 2003 as an economist, with majors in environmental and resource economics and international economics. In 2002 he studied at the School of Management at the University of Bradford, UK. He was employed at the Dutch Bureau for Economic Policy Analysis in the Netherlands before joining the Energy research Centre of the Netherlands (ECN) in 2004. He was seconded to the Dutch Energy Council in 2004 to assist in preparing an advice on Dutch gas sector policy to the Ministry of Economic Affairs. Since 2005 he is affiliated with the Delft University of Technology where he pursues a PhD in economics on the topic of gas infrastructure regulation. First as researcher and later as gas coordinator he has contributed to and has been responsible for range of research projects for clients in both the public and private domain. His main fields of expertise are gas markets and infrastructure regulation.

Arjan Plomp was born in Zeist, the Netherlands, on July 18, 1980. He received his MSc degree in Chemistry in 2004 and his PhD degree in Heterogeneous Catalysis in 2009, both from Utrecht University, the Netherlands.

Since 2009 he joined the unit Policy Studies of ECN (Energy research Centre of the Netherlands) as a Researcher Energy and Environmental Policies. As a chemist, his focus area lies at industrial energy use and environmental emissions, in particular for oil and gas production and consumption. He is involved in and responsible for various research projects in which the energetic and environmental effects of technological developments are assessed and scenarios for future energy consumption are developed for the European Commission, the Dutch Ministries for Economic Affairs and Environment and third parties.

Özge Özdemir was born in Izmir, Turkey, on July 30, 1979. She received her B.Sc. degree in Industrial Engineering in 2001 from Bogaziçi University, İstanbul, Turkey and her MSc degree in Operations Research and Management in 2003 from Tilburg University, the Netherlands. From 2003 to 2008, she worked as a research assistant at the Department of Econometrics and Operations Research, Faculty of Economics and Business Administration, University of Tilburg. Her research interests are deterministic and stochastic optimization problems and equilibrium models, stochastic modeling techniques and simulation; applications in energy and environment. In 2008, she joined ECN Policy Studies as a scientific researcher in the Energy Production, Networks and Markets Group. She is responsible for coordination and development of modeling work on gas and electricity markets. She also contributes to various research projects on future developments in gas and electricity markets for the European Commission and the Dutch Ministries for Economic Affairs and Environment.