Model-based analysis of market integration and congestion in the European gas market

Stefan Lochner*[†], Caroline Dieckhoener[†], Dietmar Lindenberger[†]

Conference Paper submitted to the
9th Conference on Applied Infrastructure Research
8/9 October, 2010
TU Berlin

Abstract

In the light of potentially increasing investments requirements in the European natural gas supply infrastructure, a study by the Institute of Energy Economics at the University of Cologne (EWI) investigates physical market integration in the European gas market during the next decade. This paper presents the model and the methodological approach to investigating market integration applied in the study, as well as selected results. The identification of congestions is based on analyzing nodal prices, a large difference of which indicates impediments to trade. For Europe it is found that with all infrastructure projects planned in the next decade, the gas market is generally well integrated physically. Especially in Southeastern Europe, some severe congestion remains. If one of the large-scale infrastructure projects in the region, Nabucco or South Stream, is realized, market integration will greatly improve there as well.[1]

JEL: Q41, D41, L50, P42

Keywords: Natural gas, nodal prices, transport capacity, congestion

*Corresponding Author; *Email*: Stefan.Lochner@uni-koeln.de.

†Institute of Energy Economics at the University of Cologne (EWI), Vogelsanger Str. 321, 50827 Cologne, Germany.

[1]Methodological approach, scenario set-up and results presented in this paper are selected from the EWI Study *'Model-based Analysis of Infrastructure Projects and Market Integration in Europe with Special Focus on Security of Supply Scenarios'* (EWI, 2010a), which is a scientific study commissioned by the European Regulators' Group for Electricity and Gas (ERGEG) and seven national regulatory authorities. The contents of the EWI (2010a) Study and this paper are thereby the sole responsibility of the respective authors and do not necessarily represent the opinion of the commissioning entities.

1 Introduction

The European Union's rising import dependency on natural gas requires additional investments in import infrastructure and natural gas storages. At the same time, the Third Energy Package addresses, amongst other things, the strengthening of the single European market and the facilitation of cross-border energy trade which implies increased (and better coordinated) investments in gas transportation capacities between member states.

In this context, the Institute of Energy Economics at the University of Cologne (EWI) was commissioned by the European Regulators' Group for Electricity and Gas (ERGEG) to perform a model-based analysis of infrastructure projects and market integration including a focus on security of supply scenarios (EWI, 2010a). At the core of this investigation, methodology and selected results of which are presented in this paper, is the identification of congestion between European countries based on economic principles and the analysis of actual physical gas flows. Focus of the investigation is thereby the year 2019 to identify potential investments needs arising in the upcoming decade.

This paper outlines the methodological background, including the applied infrastructure model (and investigated scenarios), in the next section. Section 3 presents selected results of the study with a focus on the identification and valuation of (potential) bottlenecks in the European natural gas infrastructure system. Section 4 offers some concluding remarks.

2 Methodological Approach

2.1 Theoretical Background

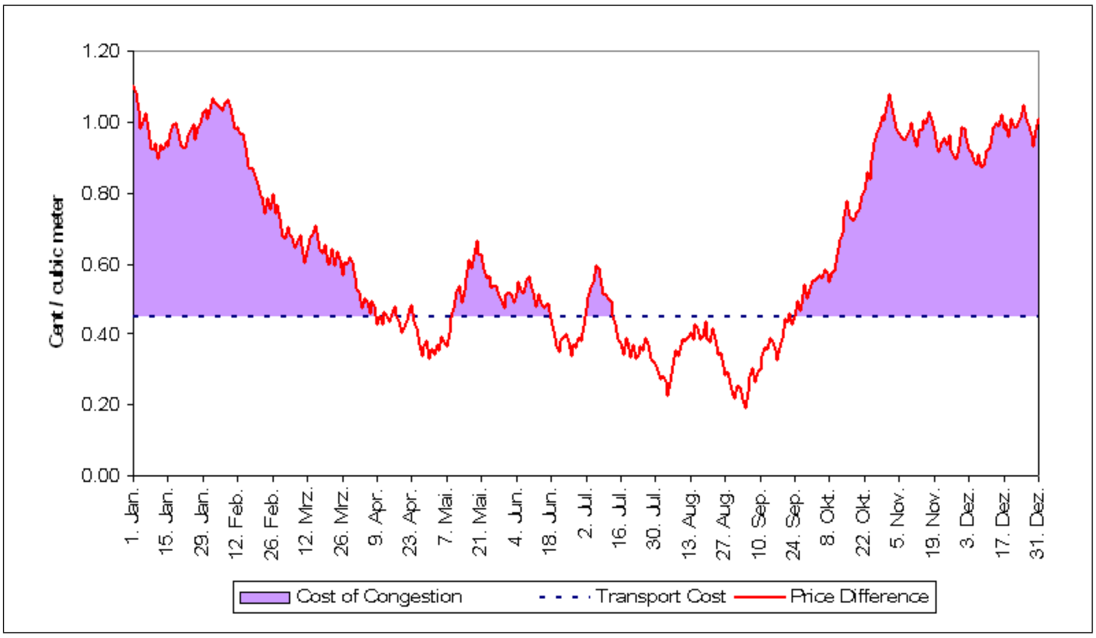
Generally, the value of a transportation service between two locations A and B is determined by the value the respective good has in B in excess to its value in A. As the value of natural gas in a market is determined by its price, the value of a transportation capacity between two locations is represented by the price difference between the two locations (Cremer et al., 2003), i.e. $(p_B - p_A)$. If these locations (markets) are separated geographically but connected by sufficient transport capacities, arbitrage takes places until the price difference is equal to (or less than) transaction costs from A to B (c_{AB}): $p_B - p_A \leq c_{AB}$. If there is no or insufficient capacity, prices will form in residual regional markets.

The background for these conclusions comes from the nodal pricing concept in electricity markets (Schweppe et al., 1988) which assigns each node (location) in a network an individual price as the allocative efficiency-maximizing equilibrium price may be different at each point if transport costs are greater than zero. For the application of these nodal prices to value congestion in electricity grids, see for instance Hogan (1998) or Stoft (2002); for a transfer of the general concept to natural gas markets, see Cremer and Laffont (2002), Cremer et al. (2003), Lochner (2009).

With respect to market integration, it can then be concluded that the two markets are considered to be integrated if the Law of One Price holds, i.e. the price difference between the two (or two representative nodes) does not exceed the parity bounds determined by transaction costs (Baulch, 1997). If it does, the two markets are not fully integrated physically and there is an infrastructure bottleneck (abstracting from other transaction costs and presuming the market works otherwise efficiently).

The shadow cost of this bottleneck (or the value of an additional infinitesimal unit of transport capacity) is then determined by the aggregated and discounted price difference in excess of transport costs over the considered time period. An illustration of these relationships is provided in Figure 1 where the shaded area represents the aggregated cost of the constraint from A to B over the period of one year (with the red and dotted blue lines representing the price difference ($p_B - p_A$) and the variable transport costs (c_{AB}) respectively).

Figure 1: Illustration of price difference, transport cost, and cost of congestion



2.2 Gas Infrastructure Modeling

In order to investigate physical market integration in 2019, we apply the European natural gas infrastructure and dispatch model TIGER (EWI, 2010b) in a scenario analysis. With a high temporal and areal granularity, the model-based approach takes into account intertemporal elements (gas storages) and interdependencies in the European gas market resulting from the interconnection of grids and transit flows. The linear optimization model minimizes the total cost of the gas dispatch given the restriction provided by the infrastructure, gas supply and the demand which has to be met. The modeling approach, hence, assumes that the European downstream market is working efficiently and that all efficient and possible gas swaps are realized. Considering different variations of demand, supply and infrastructure, we compute location-specific marginal supply costs for representative locations in each country. These can be interpreted as estimators for wholesale gas prices in a competitive market, or as nodal prices in an analysis of market integration as outlined in the previous paragraph.

Methodologically, TIGER is essentially a linear network flow model consisting of nodes and edges.[2]

Nodes represent locations in the European gas supply infrastructure where there are connections between pipelines, connections to storages, gas injections into the grid from gas production or LNG regasification facilities and withdrawals from consumers (locations of demand or off-take locations for local distribution networks).

The edges represent the pipelines in the European gas grid. They are assigned with the individual characteristics of each pipeline like geographic location, connection between specific nodes, technical capacity, length, directionality, availability.

Similarly, the individual characteristics of storages (working gas volumes, storage type, maximum injection and withdrawal rates and respective profiles) and LNG terminals (import, LNG storage and regasification capacity) are likewise included and assigned to the respective element located at the nearest geographic node.

Objective of the linear optimization is the minimization of the total costs of gas supply subject to the relevant constraints, i.e. meeting the location-specific demand and observing all technical restrictions of the infrastructure as well as on the supply side (availability of volumes). Intertemporal interdependencies, e.g concerning gas storage or annual production profiles, are also taken into account.

Costs in the optimization (objective function) include commodity, transportation and, where applicable, regasification and storage costs. With the model's focus on the dispatch of natural gas, the latter three cost factors essentially represent variable costs, the assumptions of which are based on different studies such as OME (2001) and United Nations (1999).

The inputs into the model can broadly be categorized into assumptions on natural gas supply, demand and infrastructure, the definition of which describes the scenarios (see Appendix A).

Decision variables for the model are the natural gas flows on each pipeline and the utilization of storages and LNG terminals. The linear cost minimization approach assumes that the transport of natural gas in the European Union is organized efficiently and that all possible swaps of natural gas are realized by transmission system operators.

[2]The remainder of the section is based on EWI (2010b). A mathematical formulation of the model can be retrieved from the appendix of Lochner (2009).

Figure 2: TIGER Model Regional Coverage

Results on the utilization of all the aforementioned infrastructure assets is one of the outputs of the model (gas flows on all pipelines, storage levels and injections/withdrawals, LNG imports at the different terminals). In their combination, they allow to derive an overall picture of gas flows and the supply situation (gas from what sources is physically being transport to which downstream markets) in the European gas market.

Apart from the endogenously optimized variables, the location-specific marginal costs of gas supply can be evaluated for each node. These represent the shadow costs on each node's balance constraint in the model (for each time period), which indicate marginal system costs for supplying one additional cubic meter of natural gas at this respective node and for the respective point in time.

Geographically, TIGER covers the European and the surrounding production countries (Algeria, Azerbaijan, Iran, Libya, Russia) as visible in Figure 2. Temporally, the forecasting horizon of TIGER with a monthly granularity is 15 years. Projections further into the future, however, do not seem very useful due to over time increasing degree of uncertainty attached to the input parameters. Temporal granularity can be varied. In this paper, we use a daily one, i.e. one time period represents one day.

3 Results

Based on assumptions on supply, demand and available infrastructure, the approach yielded the results with respect to physical market integration in Europe in 2019 which are outlined in this section.

Generally, the scenarios are set up to reflect a most-likely demand and supply situation for 2019. The same holds true for intra-European pipeline interconnections, where all planned expansions according to the Ten Year Network Development Plans of the individual transmission system operators (TSOs) are included.

The major infrastructure projects (Nord Stream, South Stream, Nabucco) as well as relative global LNG prices (high or low) are varied between scenarios to identify the impact of each of those factors on market integration. A detailed description of the scenarios can be retrieved from EWI (2010a); a brief qualitative summary is provided in Appendix A to this paper.

As the focus of the investigation is on cross-border congestion, the approach as outlined in Section 2 is applied to all European borders where gas interconnections exist or might exist in the course of the next decade.

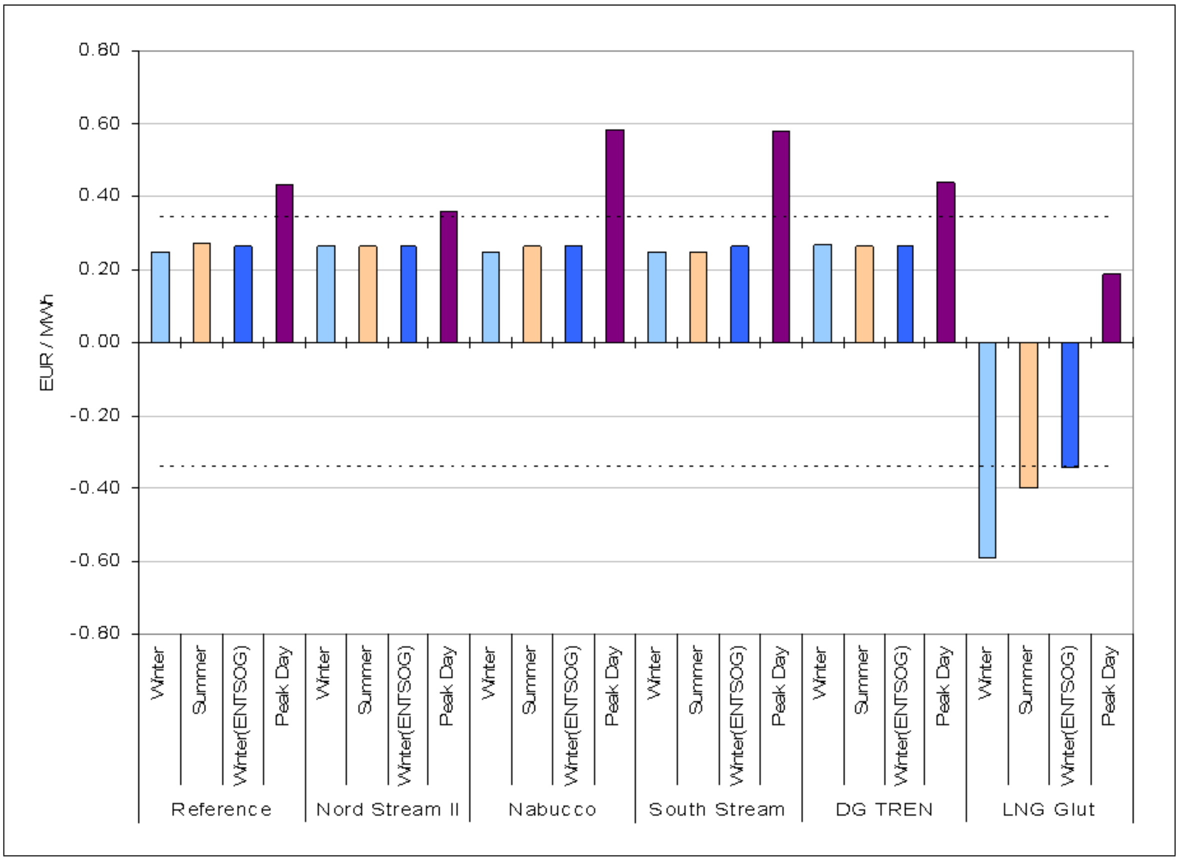
The general approach is outlined in Figure 3, which illustrates the comparison of price differences and transport costs for six scenarios and different types of days (summer day (yellow color), two winter days with higher (dark blue) and lower (light blue) demand, and the peak demand day (pink) as assumed by the TSOs ((ENTSOG, 2009))).

With respect to the methodological approach (Figure 1 on page 2), Germany equals country A, France country B and the dotted lines the variable transport costs c_{AB} and c_{BA} $(= -c_{AB})$ for physically moving gas between the two countries. The bars indicate the price difference $p_B - p_A$ on the respective day in the respective scenario.

For the Germany-France interconnection, we find that with the expansions planned until 2019, the market is well integrated as the price difference is simulated to be below the variable transport costs for all winter and summer days except on the peak demand day. Hence, there would be no demand for additional transport on these days as additional arbitrage is not profitable. On the peak demand day, prices in France are higher than in Germany with the price difference exceeding variable transport costs. Thus, if more capacity were available, additional gas flows would take place. Hence, additional capacity would have a value greater than zero.

However, by definition, the peak demand day does not occur very often, and the cost of congestions does not appear to be very high (below 0.30 EUR / MWh). Hence, it is not clear whether additional investment would actually be beneficially as investing is only efficient if the cost of investment is equal or smaller than the aggregated cost of the congestion. (An analysis of this in combination with investment costs is, however,

Figure 3: Congestion between Germany and France



Source: EWI (2010a).

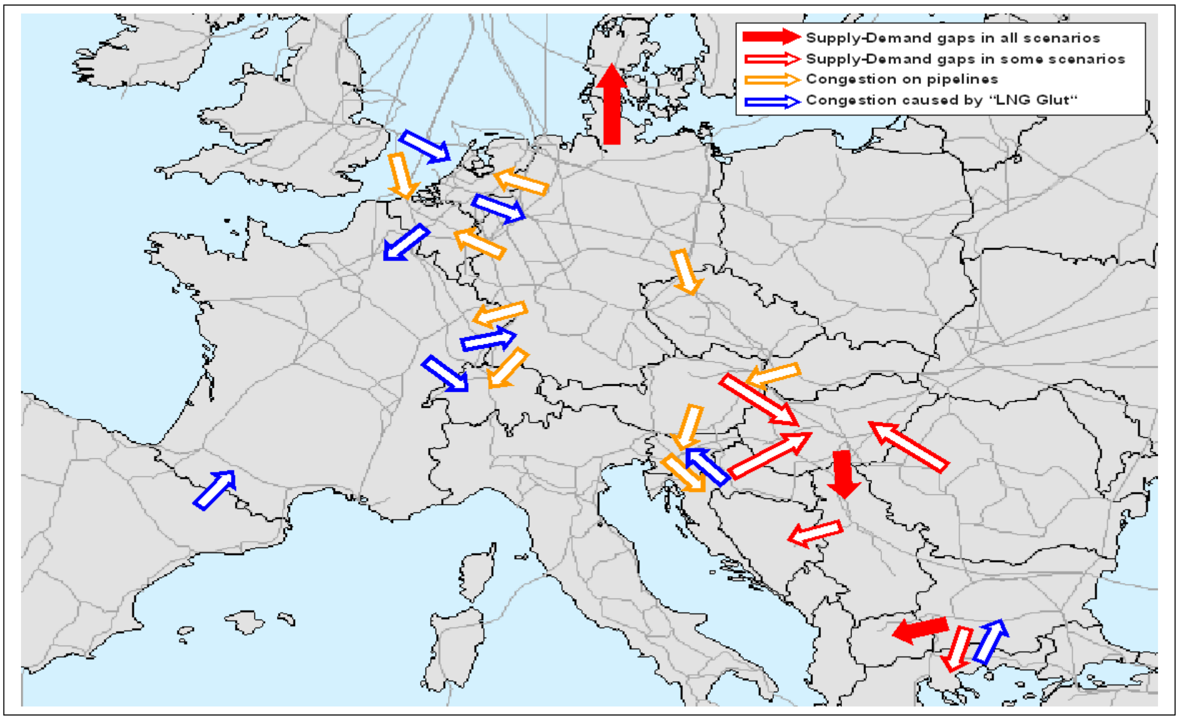
beyond the scope of this paper.)

Figure 3 further illustrates that the price difference between Germany and France may become negative (i.e. higher price in Germany than in France) when LNG availability is large. (This implies gas flows from France to Germany in this case.) On the normal winter days and the summer day, when this is the case, the absolute price difference even exceeds transport costs from France to Germany, i.e. implying congestion in this direction on the pipelines.

Applying the same approach to all relevant border connections in the European Union provided the results which are summarized by Figure 4 and Table 1.

In Figure 4, the arrows not only indicate the direction of congestion. Their colors also imply its respective cost and its likelihood of occurrence over scenarios: Significant costs of congestions (due to demand reductions to consumers becoming necessary) are labeled red; if this congestion does only occur in selected scenarios, the arrows are only red framed. Blue and orange framed arrows indicate costs of congestion greater than zero, which however only occur in selected scenarios or on selected days within the year (the blue color thereby indicates the LNG Glut scenario). A detailed list of congestion can be retrieved from the matrix in Table 1.

Figure 4: Overview of cross-border congestion in Europe



Source: EWI (2010a).

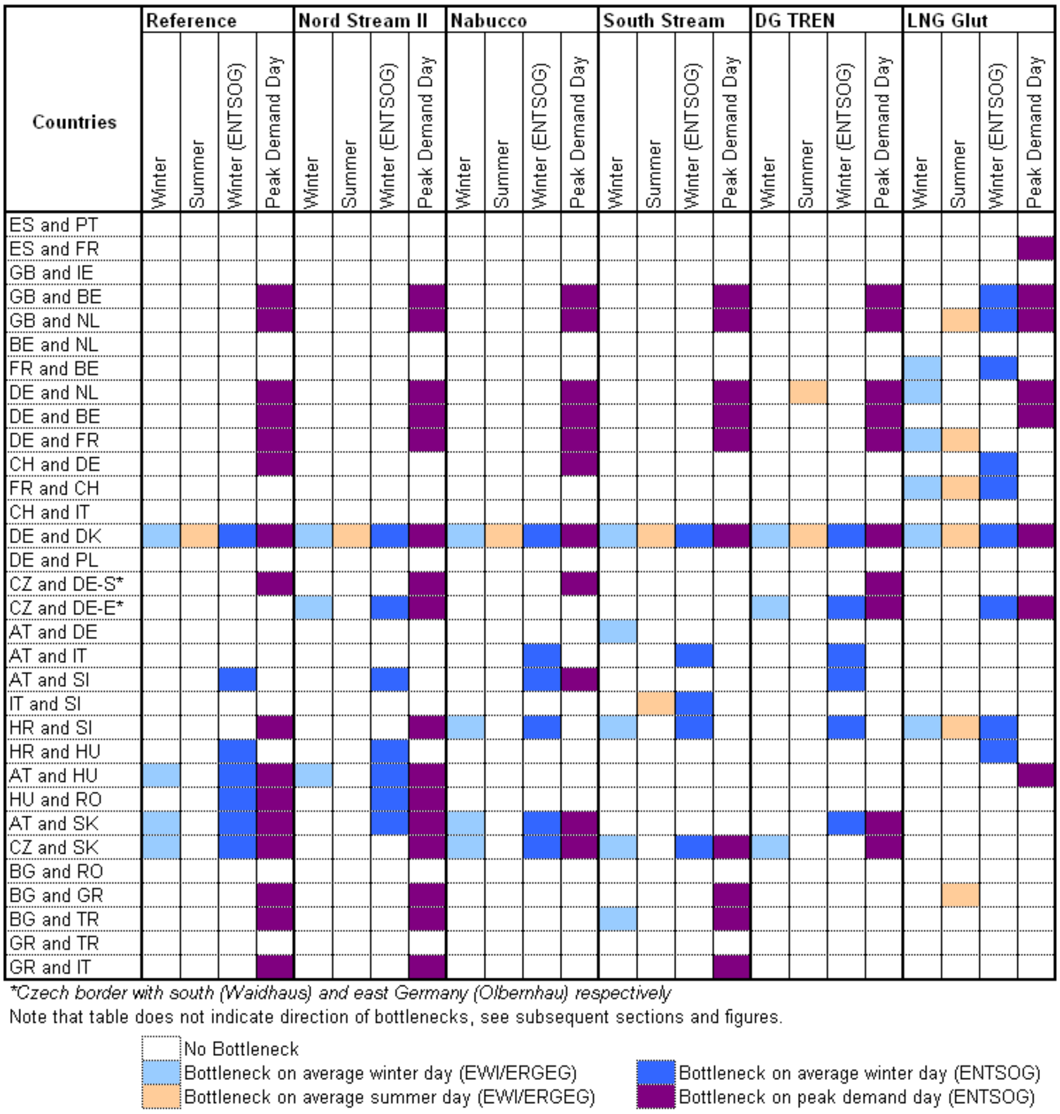
Summarizing congestion, supply-demand gaps are caused by the following bottlenecks:

- Between Germany and the region of Sweden and Denmark, if demand and supply in these two countries evolves as assumed. In this case, there is a definite need for investment.
- In eastern Europe, some bottlenecks are identified in the winter months. These mainly concern Hungary and the countries in the Balkans with a gas sector. However, the realization of one of the new major import pipeline projects (Nabucco or South Stream) helps to increase market integration in the region and to eliminate some of these bottlenecks.
- In addition, it is found that high demand in south-eastern Europe (including Turkey) might limit gas flows between Turkey and Greece opening a supply-demand gap in Greece (but only on days with very high demand in both countries).

Further congestion, which does not result in supply disruptions to consumers, but which may cause large price differences between markets and hamper competition in an integrated European gas market, exists:

- In western Europe, congestion is found to arise on the concurrent peak demand

Table 1: Overview of congestions across scenarios in 2019



Country abbreviations: ISO 3166 country codes (www.iso.org)
Source: EWI (2010a).

day (coldest winter day if it happens to be in each country on the same day) and in times of low LNG prices.

- The peak demand day bottleneck appears to be due to a relatively high availability of storages in central Europe and the UK relative to France, Belgium and the Netherlands (according to the assumed expansions of capacity). The latter group of countries also sees a relatively high peak day demand as a percentage of average daily demand compared to the EU average. Hence, congestion on such a peak day may be significant between Germany and France, Belgium and the Netherlands, and on the Interconnector between the UK and Belgium.
- In the case of temporarily low LNG prices, the model finds that more LNG could

be transported from the LNG import capacities in the west further to the east if more capacity were available. Congestion, for instance, arises between the UK and the continent, France and Germany and Switzerland, the Netherlands and Germany and between Spain and France on peak demand days.

As infrastructures designated in the context of the ten year network development plans are already included in the simulations, any bottlenecks identified are further limited to those not already addressed in these network expansion plans (ENTSOG, 2009). With these grid expansions, most European countries are generally found to be well integrated based on the simulation results, apart from the aforementioned exceptions.

Furthermore, it needs to be noted that the normative modelling approach only identifies congestion which would even occur in an efficiently working market. Additional (contractual) bottlenecks potentially arising from market inefficiencies are not be identified by the model.

4 Conclusion

The approach outline in this paper can be used to identify congestion in the European gas market between countries but also on transport infrastructures within countries. By computing and comparing locational marginal supply costs with transport costs, physical bottlenecks can be identified. Estimations of the congestion mark-ups allow evaluations of the values of additional capacities and the cost of the bottleneck.

The application in the context of a study on European gas market integration in 2019 has shown that, in the applied infrastructure, supply and demand scenarios, the market is generally well integrated from a physical point of view. Some exceptions, however, exist, especially in Eastern Europe and in times of very high demand or high LNG availability.

Areas for further research include the determination of efficient investments to remove bottlenecks, i.e. the full evaluation of congestion costs relative to the capital investments required to remove them, and the incentivisation of TSOs in a regulatory framework to perform these investments.

References

Baulch, B. (1997). Transfer Costs, Spatial Arbitrage, and Testing for Food Market Integration. *American Journal of Agricultural Economics*, 79(2):477–487.

Cremer, H., Gasmi, F., and Laffont, J.-J. (2003). Access to Pipelines in Competitive Gas Markets. *Journal of Regulatory Economics*, 24(1):5–33.

Cremer, H. and Laffont, J.-J. (2002). Competition in gas markets. *European Economic Review*, 46(4-5):928–935.

ENTSOG (2009). ENTSOG European Ten Year Network development Plan 2010 - 2019. European Network of Transmission System Operators for Gas, Ref. 09-ENTSOG-002, 23 Dec 2009, Brussels.

EWI (2010a). Model-based Analysis of Infrastructure Projects and Market Integration in Europe with Special Focus on Security of Supply Scenarios. Study initiated by ERGEG, Institute of Energy Economics at the University of Cologne, Cologne.

EWI (2010b). TIGER Infrastructure and Dispatch Model of the European Gas Market - Model Description. Institute of Energy Economics at the University of Cologne, Cologne.

Hogan, W. W. (1998). Nodes And Zones In Electricity Markets: Seeking Simplified Congestion Pricing. In Chao, H.-P., editor, *Designing Competitive Electricity Markets*, pages 33–62. Kluwer Academic Publishers.

Lochner, S. (2009). Nodal prices, capacity valuation and investments in natural gas markets - Overview and Analytical Framework. EWI Working Paper 09/2.

Lochner, S. and Bothe, D. (2009). The development of natural gas supply costs to Europe, the United States and Japan in a globalizing gas market - Model-based analysis until 2030. *Energy Policy*, 37(4):1518–1528.

OME (2001). Assesment of Internal and External Gas Supply Options for the EU, Evaluation of the Supply Costs of New Natural Gas Supply Projects to the EU and an Investigation of Related Financial Requirements and Tools. Chapter 3 - Assessment of Future Supply Costs to Europe. Observatoire Méditerranéen de l'Énergie (OME), June 2001. [Online] Available: <http://www.ome.org/ PDF/ Etudes/gas_study/documents/chapter_3.pdf> (accessed on January 22, 2008).

Schweppe, F. C., Caramanis, M. C., Tabors, R. D., and Bohn, R. E. (1988). *Spot Pricing of Electricity*. Kluwer.

Stoft, S. (2002). *Power System Economics: Designing Markets for Electricity*. IEEE / Wiley.

United Nations (1999). Study on Underground Gas Storage in Europe and Central Asia. UN Economic Commission for Europe - Working Party on Gas, New York City / Geneva.

Appendix

A Scenario set-up

In order to perform simulations of the European gas market and investigate physical market integration and congestion, the three framework parameters, supply, demand and available infrastructure, need to be defined. This subsection briefly describes the relevant assumptions, a full description and the individual numerical data can be retrieved from EWI (2010a).

As the focus of the investigation is the year 2019, all parameter definitions refer to this reference year.

A.1 Supply and Demand

- EU indigenous production declines to 126 billion cubic meters (bcm) annually (a 40 percent decline from 2008);
- Pipeline imports from outside the EU, at around 300 bcm in 2008, can increase up to around 400 bcm annually, with the largest additional volumes coming from Russia (+40), Norway (+20), Algeria (+18) and the Caspian Region (+15);
- LNG supplies are theoretically unlimited (of course constrained by import capacities), but are relatively more costly than pipeline gas in the long-term (see Lochner and Bothe (2009)).[3]
- With respect to demand, EWI (2010a) investigated two scenarios: one based on an adjusted version of the latest demand projection by the European Commission (European Energy and Transport - Trends to 2030, 2008 edition), the other on projections by the association of European TSOs (ENTSOG, 2009). While the former projects a rather small increase in demand until 2019 (+2.5 percent relative to 2008), the latter one foresees a larger rise (+12.1 percent). In addition, the scenarios include peak day demand projections by ENTSOG (2009).

A.2 Infrastructure

- Storages: 140 bcm capacity (working gas volume) in 2019, which equals expansions of 55 bcm compared to 2009.
- LNG import terminals: 280 bcm nominal annual import capacity in 2019 (+114 bcm relative to 2009).

[3] There is one scenario (*LNG Glut* Scenario) which assumes relatively lower LNG prices to mirror the situation of 2009/2010 with temporally lower LNG than pipeline contract prices.

- Infrastructure: Apart from intra-European projects and the expansion of capacities on existing import routes, the following major import pipelines are included in the Reference Scenario: Nord Stream I, GALSI, Medgaz.

(Again, detailed lists of the storage, LNG import and pipeline (capacity expansion) projects projects assumed to be realized until 2019 can be found in EWI (2010a).)

A.3 Scenario Variations

The aforementioned infrastructure and supply and demand assumptions essentially make up the Reference case. The study then added further large-scale infrastructure projects which are currently discussed in separate scenarios. The resulting investigated scenarios are depicted in Table 2.[4]

Table 2: Investigate Infrastructure Scenarios

Scenario Name	Infrastructure
Reference	see text
Nord Stream II	*Reference* plus Nord Stream II pipeline
Nabucco	*Reference* plus Nabucco pipeline
SouthStream	*Reference* plus SouthStream pipeline
DG TREN	*Reference* plus Nord Stream II and Nabucco pipelines
LNG Glut	*DG TREN* with low LNG prices

[4]Some of the scenarios include further alterations to the Reference case which are not explicitly listed in the table. These include changes in intra-European projects, partially related to the connection of the large-scale projects with the grid, and availability of gas volumes from specific sources (e.g. additional gas being available for a Southern Corridor project like Nabucco). Full scenario definition, see EWI (2010a).