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IMPACT OF TRENDS IN GLOBAL LNG SUPPLY AND DEMAND ON THE EUROPEAN GAS MARKET IN 2030

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ABSTRACT

The increased imports of liquefied natural gas (LNG) are one possible way for the EU to diversify its natural gas supply by 2030. However, as LNG is a globally traded commodity of limited abundance, other consumers' trends in LNG demand will impact the price and availability of LNG in Europe. This work couples a global LNG trade model to a high-resolution gas system model of the real European gas network to quantitatively assess the impact of possible different trends in global LNG supply and demand on the European gas market in 2030. It is found that by 2030, LNG from USA replaces Qatari LNG in the European gas market, while Qatari LNG supplies the increasing LNG demand in Asia. Due to the limited abundance of LNG supplies in 2030, the market penetration of Russian pipeline gas in Europe is found to increase by 50% compared to 2016. Further, it is found that the market share of LNG in the European gas market of 2030 is highly price sensitive, with a 10% reduction in LNG price leading to a doubling in market share. Such a 10% reduction in LNG prices is found to occur, if LNG demand in Asia is half that which is currently anticipated. This underlines the dependence of an LNG supply in Europe to trends in other markets of the world. Therefore contrary to general opinion, a strategy that relies on increased LNG imports is not necessarily politically less risky than a strategy that relies on increased imports of pipeline gas.

INTRODUCTION

Natural gas is planned to play a major role in Europe's transformation towards a more environmentally friendly energy supply by 2030. According to recent projections of the European Network of Transmission System Operators for Gas (ENTSO), the annual gas demand of the European Union will stay approximately constant until 2030 (ENTSO, 2017). At the same time, the domestic gas production of the two largest gas producers within the EU, which are the Netherlands and the UK, is expected to decline

by 50% (Netherlands) and 60% (UK) by 2030 (ENTSO, 2017). Therefore, by 2030 a shortfall of gas is anticipated in the EU, which means that additional gas will need to be sourced from alternative suppliers. One option to cover this shortfall is the increased import of liquefied natural gas (LNG), which can be sourced via tankers from over a dozen countries globally. This diversity of LNG suppliers is attractive for the EU, because it provides an alternative to pipeline gas from Russia, which the EU seeks to become more independent from (Medlock et al., 2014); (Richter and Holz, 2015). At the same time, the shift of gas imports from Russia to LNG implies a risk for the EU, because current LNG prices are higher than Russian pipeline gas prices, and could stay so in future (Wood, 2012).

The viability of covering the EU's shortfall in gas supply with LNG depends not only on the development of the energy sector in Europe. Because LNG is a globally traded commodity, the market trends in the rest of the world also impact LNG prices in Europe. East Asia (mainly China and India) is anticipated to have a significant increase in LNG demand in the upcoming decades, putting pressure on the global LNG market (Wood, 2012); (Vivoda, 2014). Additionally, the East Asian gas markets are projected to move from oil-indexed gas pricing to more market-oriented gas-on-gas pricing, which would further increase the competitiveness of the LNG market (Shi, 2016). Since East Asia and Europe are approximately geographically equidistant from the main LNG suppliers in the Middle East, both regions are expected to compete directly for LNG shipments from the Middle East (Nikhalat-Jahromi et al., 2016); (Choi and Heo, 2017). At the same time, USA is increasing its domestic production of shale gas, which enables it to be a net exporter of LNG in future (Medlock et al., 2014); (Moryadee et al., 2014). All of the aforementioned trends will impact the price at which LNG will be available in the EU, which is found to be a key determinant for LNG's future market share in the European gas market (Dorigoni et al., 2010). Therefore, it is crucial to model the global LNG

trading network to assess LNG's future role in the European gas market.

Several previous works have investigated global trends in LNG trade. Using a network model, Chen et al. find the global LNG market to become more competitive, since more suppliers have entered the market in recent years (Chen et al., 2016). By applying a Cournot model to the global LNG trade, Growitsch et al. investigate the impacts of short-term LNG disruptions on consumer prices in different LNG-importing countries (Growitsch et al., 2013). Dorigoni et al. find increased LNG imports to have a beneficial impact on European gas prices even when priced more expensively than Russian pipeline gas, because the LNG is found to reduce Russia's market power (Dorigoni et al., 2010). A similar impact of LNG on Russia's market power in Europe is found by Hartley and Medlock using an equilibrium model of the global LNG market (Hartley and Medlock, 2005).

Most of the aforementioned works do not model the physical European gas transmission network, and assume unlimited flow capacities among the EU countries. But as Lochner finds, the penetration of LNG in the European gas market is not only driven by its price and availability, but also by the ability of the gas transmission system to transport the regasified LNG to the demand across Europe (Lochner, 2010). This aspect is especially crucial for Europe, because an LNG-focused importation strategy represents a diametric reversal of the traditional pan-European gas flows: Instead of transporting gas via pipelines from north and north-east (from Norway and Russia) to south-west, LNG imports in Spain, France and Italy (which have the largest LNG regasification capacities in Europe today) would flow in the opposite direction. This implies additional challenges for the European gas transmission system, which would need to be upgraded in order to accommodate bidirectional gas flows on many pipelines. Ongoing projects show that the EU is preparing the European gas system to accommodate this bidirectionality (European Union, 2018).

To address these coupling effects between gas markets and gas infrastructure, a bottom-up simulation model of the European gas network is used in combination with a global LNG transportation model in this work. Compared to previous works, this novel approach enables new insights into the impacts of global LNG trends on the penetration of LNG in the European gas market, as well as subsequent effects on Europe's gas infrastructure and consumer prices.

METHODOLOGY

In this work we employ EnerPol, our in-house energy systems simulation framework. In EnerPol, the gas system is modelled in a two-step procedure: First, the global trade of LNG is simulated at weekly resolution for a full year. The results of the LNG trade model are used as boundary conditions in the gas system model, which simulates the operation of the European gas transmission system at hourly resolution for a full year. Both models and their feedback linkage are described in the following sections.

Global LNG trade model

Since LNG is a globally traded commodity, the LNG trade model covers the entire world. Both consumers and producers of LNG are regionally aggregated to the most significant market participants. The model comprises 12 LNG producers: Algeria, Asia-Pacific, Australia, Central Africa, Indonesia, Latin America & Caribbean, Malaysia, Middle East (excluding Qatar), North America, Norway, Qatar and Russia. On the consumption side, the model comprises the following 17 consumers: Asia-Pacific, Belgium, China, France, India, Italy, Japan, Latin America, Middle East, Netherlands, North America, Poland, Portugal, South Korea, Spain, Turkey and the UK. Each consumer and producer is represented as a geo-referenced node, as shown in Fig. 1. Between each consumer and each producer, a shipping route is followed. Using LNG shipping data from (IGU, 2017); (Stokes and Spinks, 2018), a cost of \$0.05/mmBtu per 1000 km and a shipping speed of 20 knots (which amounts to 900 km/day) are associated with each shipping route. For each consumer, the annual consumption of LNG is specified as boundary condition in the model. Using weekly gas consumption statistics for the European market from ENTSOG (ENTSOG, 2018), the annual consumption is disaggregated to weekly consumption values for each node. For the producers, the historical production, the installed liquefaction capacity and the price of LNG production are derived from public data sources (IGU, 2017); (Knoema, 2018) and are specified as boundary conditions in the model.

Figure 1 – Model of LNG production and consumption nodes and LNG trade routes

The mathematical description of the LNG trade model is summarized in equations (1) to (7). The subscripts used in the equations are c for consumer nodes, p for producer nodes, r for shipping routes and t for the weeks of the simulated year. Equation (1) describes the optimization objective: The simultaneous minimization of LNG prices at all consumer nodes. This minimization target assumes perfect market competition without unilateral market power by any market incumbent. This assumption is not perfectly accurate in today's LNG market, which still contains many long-term contracts and oil-indexed LNG pricing in Asia. But the assumption of perfect competition is more accurate for future years, because the LNG market is moving towards more competitive gas-on-gas markets with shorter-term contracts (Shi, 2016); (Chen et al., 2016). The weekly LNG

consumption at each consumer node is fulfilled with (2), where the duration of the shipping route is taken into account with the delay factor dur . Most countries seek to diversify their energy supplier portfolios to avoid the dependence on a single supplier. Data analysis from (IGU, 2017) shows that no major gas consuming country imports more than 30% of its annual gas consumption from a single source. Therefore, the amount of LNG that a consumer can source from one supplier is limited to 30% of the consumer's annual gas consumption with (3). The LNG transported on the shipping routes is linked to the LNG production with (4), and is limited not to exceed the producers' annual liquefaction limit with (5). The LNG production is limited annually rather than weekly, firstly because this enables LNG suppliers to shift their LNG production throughout a year, and also because annual limits enable a consistent implementation of all LNG suppliers' liquefaction capacities, which are generally available on an annual basis. The price at which each producer offers the LNG is increased from a reference LNG price with increasing LNG production (6). Hence equation (6) incorporates that the producers must tap into less economically recoverable gas deposits with increasing LNG production. The slope of the price increase is derived from (Bresciani et al., 2014). The mass-averaged price of LNG at the consumer nodes is the price of LNG at the producer nodes plus the distance-dependent price of shipping (7).

$$\min \sum_t \sum_c (landingprice_{t,c} \times LNGconsumption_{t,c}) \quad (1)$$

$$LNGconsumption_{t,c} = \sum_{r \rightarrow c} transport_{t-dur,r} \quad \forall t, c \quad (2)$$

$$\sum_t transport_{t,r} \leq 0.3 \times \sum_t gasconsumption_{t,r \rightarrow c} \quad \forall r \quad (3)$$

$$\sum_{r \rightarrow p} transport_{t,r} = LNGproduction_{t,p} \quad \forall t, p \quad (4)$$

$$\sum_t LNGproduction_{t,p} \leq LNGprodLimit_p \quad \forall p \quad (5)$$

$$LNGprice_{t,p} = refprice_{t,p} \times \left(1 + \frac{\sum_t LNGproduction_{t,p}}{LNGprodLimit_p} \right) \quad \forall t, p \quad (6)$$

$$landingprice_{t,c} = \frac{\sum_{r \rightarrow c} (transport_{t,r} \times (LNGprice_{t-dur,r \rightarrow p} + routeprice_r))}{\sum_{r \rightarrow c} transport_{t,r}} \quad \forall t, c \quad (7)$$

One of the key drivers in the LNG trade model is the reference price at which each producer offers its LNG. In a market situation with non-ideal competition, this reference price is the lever with which producers can exert market power on consumers. To increase the robustness of the simulation results with respect to the LNG reference price, a Monte Carlo approach is used. Specifically, the LNG trade model is run 100 times with stochastically varied reference prices for all producers. The average LNG trade and LNG prices of all 100 simulations are taken as risk-reduced result

of the LNG trade model. The model is implemented in the Python-based optimization modeling language Pyomo (Hart et al., 2012) and solved with the open-source nonlinear optimizer IPOPT (Wächter and Biegler, 2006).

Bottom-up modeling of the European gas system

To simulate the distribution of LNG from the regasification terminals to the gas consumers across Europe, a highly detailed bottom-up model is applied in this work. The European countries simulated in this work are Austria (AT), Belgium (BE), Switzerland (CH), the Czech Republic (CZ), Germany (DE), Spain (ES), France (FR), Great Britain (GB), Italy (IT), the Netherlands (NL), Poland (PL) and Portugal (PT). A geo-referenced database of the European gas transmission system, resolving the individual components of the real high-pressure gas network, is applied in this work. The model comprises 500 network nodes and 52'000 km of gas pipelines, as well as the 19 largest LNG regasification terminals in Europe, which collectively represent 94% of Europe's total regasification capacity. The gas system model is shown in Fig. 2. The gas demand is modeled at hourly resolution for the consumer sectors of households, industry, commerce and power generation and is allocated to the nodes of the gas network using the spatial distribution of each consumer sector. More information about the gas demand model can be found in (Eser et al., 2018).

Figure 2 – Model of gas pipelines, network nodes and LNG terminals used in this work

Using the above models, the sourcing of natural gas for Europe is financially optimized at hourly resolution for an entire year. The least-cost combination of gas imports, comprising pipeline imports from Algeria, Libya, Morocco, Norway and Russia as well as LNG imports at the LNG terminals shown in Fig. 2, is found. The optimization fulfils the hourly demand at each system node, while capturing the flow restrictions of each individual pipeline. Production cost functions, which determine at which price pipeline gas can be imported at the boundaries of the simulated European gas network, are derived for each pipeline gas supplier from

market data (PEGAS, 2018). The weekly prices of LNG at the LNG terminals are derived from the results of the LNG trade model. The weekly imports of LNG at European LNG terminals, derived from the LNG trade model, are uniformly allocated as boundary conditions across all hours of a given week in the European gas system model. With this approach, the gas system model represents the gas traders' behaviour in choosing between different import sources of natural gas. More detailed information about the gas system simulation framework can be found in (Eser et al., 2018).

Linkage of LNG model and gas system model

To determine the penetration of LNG in the European gas market, a feedback loop is implemented between the LNG trade model and the European gas system model, as illustrated in Fig. 3. From the LNG trade model, the price and availability of LNG at the European LNG terminals is derived at weekly resolution. These LNG prices and availabilities are used as boundary conditions for the gas system model, which determines the least-cost combination of pipeline and LNG imports to fulfil the European gas demand while safely operating the gas pipeline system. As one outcome, the gas system model determines, what share of the available LNG is actually imported into the European gas market. The usage of LNG is fed back into the LNG trade model, where the European countries' LNG demand is adjusted accordingly. For example: If less LNG is used in the European gas system model than was made available from the LNG trade model, it is an indication that the LNG is priced too expensively. Since less LNG is demanded in the next iteration of the LNG trade model, the LNG prices are reduced, subsequently leading to more penetration of LNG in the next iteration of the gas system model. Due to this implementation of a dynamic feedback loop, an equilibrium state between supply and demand of LNG is reached after several iterations. The prices of LNG at the landing nodes are used as termination criterion of the feedback loop between the LNG trade model and the European gas system model. These prices at the landing nodes are chosen as termination criterion, as they represent the economic linkage between the two models. The feedback loop generally convergences after five to ten iterations, with each iteration requiring a computational time of roughly six hours.

Figure 3 – Feedback loop implementation between LNG trade model and gas system model

Scenarios for Europe's gas system in 2030

The annual domestic gas demand for each of the simulated European countries in 2030 is derived from (ENTSOG, 2017). The demand predictions from ENTSOG's "slow progression" scenario are assumed in this work, which comprise a demand reduction of up to 10% for several European countries (Germany, Netherlands) while anticipating a demand increase of up to 45% for others (Poland, Portugal, Spain). The hourly gas load profiles for the year 2030 are derived from the historical 2016 gas load data by uniformly scaling up or down all hours' gas demand. The scaling factor is chosen such that the annual sum of each country's hourly gas loads equals ENTSOG's predicted demand for 2030. All pipeline expansion projects listed in (ENTSOG, 2017) with successful financial investment decision are assumed to be completed by 2030. Specifically the pipeline *Nord Stream 2*, which directly connects Russia and Germany through the Baltic Sea, is assumed to be operational by 2030. This means that significantly more Russian gas is available in central and western Europe by 2030, which increases the competitiveness of the European gas market for LNG exporters. The scenario assumptions for the 2030 European gas system are explained in more detail by the present authors in (Eser et al., 2018).

Global LNG trends until 2030

The year 2016 is chosen as reference year in this work. The annual LNG production and liquefaction capacity of each country for 2016 is derived from (IGU, 2017) and is shown in Table I. For 2030, the liquefaction capacities are determined as follows: From (IGU, 2017), a comprehensive list of ongoing and proposed liquefaction expansion projects is obtained. All projects with successful financial investment decision (FID) are expected to be completed by 2030. Of all liquefaction capacities in the pre-FID stage, 10% are assumed to be completed by 2030. Combining these liquefaction expansions, the liquefaction capacities shown in Table I are obtained.

Table I – LNG production and liquefaction capacities for 2016 and 2030

	LNG prod. [mton]	Liquefaction capacity [mton]		LNG production price [\$/mmBtu]	
	2016	2016	2030	2016	2030
Algeria	13	25	25	4.8	3.8
Asia-Pacific	14	14	16	10.0	8.0
Australia	44	57	90	5.8	4.6
Central Africa	22	31	37	4.8	3.8
Indonesia	18	25	31	7.3	5.8
Latin America & Caribbean	15	20	20	5.9	4.7
Malaysia	25	26	32	7.2	5.8
Middle East	14	24	24	3.3	2.6
North America	5	11	126	4.5	3.6
Norway	4	4	4	8.2	6.6
Qatar & Iran	77	77	89	3.7	3.0
Russia	11	11	35	3.8	3.0

It is evident, that the most pronounced capacity expansions are expected in Australia and North America. The reference prices for the production of LNG at each liquefaction node are obtained from (Wei, 2015). In accordance with (Hartley and Medlock, 2005), a decrease in LNG production prices of 20% between 2016 and 2030 is uniformly assumed for all producers, as shown in Table I.

The annual LNG demand values for 2016 are derived from (IGU, 2017). The LNG demand for 2030 is derived from the projected liquefaction capacities (Table I) rather than from the projected regasification capacities. This is, because the global regasification capacity in 2030 (1000 mton) is expected to be significantly higher than the global liquefaction capacity in 2030 (530 mton), hence causing the liquefaction capacity to be the bottleneck in global LNG trade (IGU, 2017). By using the increase in global liquefaction capacity between 2016 and 2030 as scaling factor for the demand, an increase in annual global LNG demand from 254 mton to 416 mton is predicted. The increase in LNG demand is allocated to the consumer nodes by using each consumer's increase in regasification capacity as scaling factor. With this approach, the LNG regasification and demand values shown in Table II are obtained for 2030. It is evident, that the most significant increase in LNG demand is projected for China, India and the Asia-Pacific region. Note that only the LNG demand for non-European consumers is predicted with this approach, while the LNG demand of the European countries will be endogenously determined by the feedback loop implementation described above.

Table II – LNG demand and regasification capacities for 2016 and 2030

	LNG demand [mton]		LNG regasification capacity [mton]	
	2016	2030	2016	2030
Asia-Pacific	21	53	24	60
China	27	89	49	120
India	19	87	27	105
Japan	83	83	197	197
Latin America	10	10	43	43
Middle East	17	17	17	17
North America	6	6	154	154
South Korea	34	34	101	101
Turkey	6	6	16	16

The scenario for 2030 described in Tables I and II is considered the reference scenario in this work, and is consequently termed 2030-REF in all results. The 2030-REF scenario incorporates all current noteworthy market trends until 2030: The projected significant increase in LNG demand in eastern Asia as well as the increased production capacities in USA and Australia. To quantify each market trend's isolated impact on the global LNG market, further sensitivities are investigated in this work:

- In the scenarios 2030-LOW-PRICE and 2030-HIGH-PRICE, a 10% decrease (respectively increase) of LNG production cost and LNG shipping cost is assumed. In comparison to 2030-REF, these low-price and high-price scenarios quantify the sensitivity of European LNG imports on global LNG prices.
- In the scenario 2030-LOW-ASIA, the increase in LNG demand in eastern Asia is half the increase assumed in 2030-REF. Therefore, this scenario covers a less aggressive increase of LNG demand in Asia.
- In the scenario 2030-LESS-US, the increase in US liquefaction capacity is half the increase assumed in 2030-REF. This scenario therefore represents a less aggressive US policy with regards to LNG exports.
- Similarly, the scenario 2030-LESS-AU assumes half the increase in liquefaction capacity in Australia compared to 2030-REF.
- The scenario 2030-HORMUZ assumes a politically induced blockage of the Strait of Hormuz, which cuts Qatar and Iran off from the global LNG market.

The quantified assumptions for all scenarios are shown in Tables III and IV. Data not specified in Tables III and IV are the same as in the 2030-REF scenario.

Table III – Assumed LNG liquefaction capacities for all 2030 scenarios [mton/year]

	2030-REF	2030-LESS-US	2030-LESS-AU	2030-HORMUZ
Australia	90	90	73	90
North America	126	68	126	126
Qatar & Iran	89	89	89	0

Table IV – Assumed LNG consumption for all 2030 scenarios [mton/year]

	2030-REF	2030-LOW-ASIA
China	89	58
India	87	53
Asia-Pacific	53	37

RESULTS AND DISCUSSION

Validation of LNG trade model for 2016

The novel LNG trade model is validated by comparing the simulation results of the reference year 2016 to historical data. The annual LNG trade between all global suppliers and consumers is taken from (IGU, 2017). In Fig. 4, the predicted annual LNG trade is compared to the historical data. For sake of legibility, only trade routes contributing more than 2% to the overall global LNG trade are shown in Fig. 4. It is evident, that the model correctly identifies the main trade routes, with 95% of the global trade routes predicted with less than 2.5 mton error (which is 1% of the annual global LNG trade volume of 254 mton). Several politically driven connections are underestimated, because the model assumes the market to be perfectly competitive. For example, the

trade between Australia and China, which have close political and economic ties, is underestimated by 5 mton. This causes more Australian LNG to be available for shipment to Japan.

Figure 4 – Simulated and measured annual LNG trade volumes in 2016

The error in annual LNG trade for the simulated European countries is specified more precisely in Table V. The error in Table V is defined as the average difference between the simulated and actual LNG trades on all trade routes to a specific country, relative to the country's overall annual imports. Averaged over all LNG trade routes to Europe, the trade of LNG along a specific route has an error of 9% relative to the receiving country's annual LNG import.

Table V – Relative error in route-specific annual LNG trade for European countries in 2016

Country	Error
Belgium	13%
France	5%
Italy	11%
Netherlands	9%
Poland	18%
Portugal	7%
Spain	2%
UK	3%

The validation of the LNG prices at the consumer nodes is shown in Fig. 5. Similarly to the trade volumes, the model correctly predicts the LNG prices. The average error in simulated LNG price is 5%. The only country showing a discrepancy in predicted LNG price of more than 20% is India, which can be explained by India's dependence on Qatar for its LNG shipments. Compared to other Asian consumers, India's LNG sourcing strategy is not very diversified (Vivoda, 2014). This leads to India overpaying for Qatari LNG due to disadvantageous long-term supply contracts, which are not captured by the present trade model.

Figure 5 – Simulated and measured annual average LNG prices in 2016

The global LNG market in 2030 compared to 2016

The comparison of the global LNG trade in 2016 and 2030 is shown in Fig. 6. The 2030 LNG trade is different from the 2016 trade in two distinct ways: First, due to the increase in LNG demand in Asia, more LNG from Middle East is transported to Asia. This has the effect, that LNG from Middle East, especially Qatar, is not available anymore for the European gas market. Second, USA is seen to enter the LNG market as a major supplier. Most of USA's LNG exports are directed westwards towards Japan and China, but USA is also found to replace Qatar as major supplier of LNG to Europe.

Figure 6 – Annual LNG trade in 2016 and in 2030 reference scenario

Since the increased LNG supplies from USA in 2030 are found to replace Qatari LNG instead of complementing it, the overall market penetration of LNG in the European LNG market is only moderately increased by 27% compared to 2016, as shown in Fig. 7. The main supplier covering Europe's shortfall in domestic gas production is Russia, which is increasing its 2030 market penetration by 50%

compared to 2016. This shows that the construction of Nord Stream 2 will increase Russia's market share in Europe's gas supply, unless the EU actively competes for LNG from Middle East against the growing consumption in Asia.

Figure 7 – European gas import sources in 2016 and 2030 reference scenario

Price sensitivity of European LNG imports in 2030

The sensitivity of European gas imports to the prices of LNG is shown in Fig. 8. It is evident, that the overall amount of LNG imported to Europe is highly sensitive to the LNG price: In case of a 10% increase (decrease) of LNG prices, the total amount of LNG imported to Europe is decreased by 40% (increased by 90%) compared to the reference case. This also has profound impacts on the competing gas suppliers: Both Norway and Russia lose 15-20% of their market share in the European gas market, if LNG is priced 10% below the reference case. This shows, that both Norway and Russia will struggle to keep their market shares in a more competitive global LNG market.

Figure 8 – Sensitivity of European gas imports to LNG prices

Figure 9 shows where the increased (decreased) LNG imports mainly take place in the case of decreased (increased) LNG prices. It is evident that the countries most

sensitive to the LNG price are Portugal and Spain, with total LNG imports to the Iberian Peninsula increased threefold compared to the reference case for the scenario of 10% decreased LNG prices. The reason for this trend is the fact, that a significant increase in gas demand is projected for both Spain and Portugal by 2030 (as described in the methodology), which requires substantial amounts of gas to be transported to the Iberian Peninsula via pipelines in the reference case, as shown in Fig. 10. This pipeline gas is relatively expensive for the consumers in Spain and Portugal, because it needs to be transported from Russia and Norway through most of continental Europe. In the case of reduced LNG prices, this expensive pipeline gas is replaced with cheaper LNG. This also reverses the pipeline gas flow at the Spanish-French border: Instead of importing expensive pipeline gas from northern Europe, Spain now exports LNG-imported gas to France, as shown in Fig. 11.

Figure 9 – Sensitivity of annual LNG imports per country to LNG prices

Figure 10 – Average pipeline gas flows in 2030 reference case

Figure 11 – Average pipeline gas flows in scenario with LNG prices reduced by 10%

This large-scale reversal of gas flows through Europe has profound impacts on the European pipeline infrastructure in two aspects. First, a large share of the European compressor stations needs to be upgraded to pump natural gas bi-directionally to enable the new south-to-north flow direction seen in Fig. 11. Second, the short-term operation of the compressor stations will need to be more flexible, because a relatively small change in LNG prices can trigger a reversal of gas flows throughout Europe. This more fluctuating operation will mean more wear and tear on the compressor stations, which historically were not designed to cycle frequently.

Impacts of lower LNG demand in Asia

The impact of less increased Asian LNG demand in 2030 on global LNG trade is shown in Fig. 12. It can be seen, that the lower LNG demand in China, India and Asia-Pacific frees up LNG supplies from several sources. More specifically, the LNG suppliers that are approximately equidistant between the competing Asian and European markets are observed to shift most due to the reduced Asian LNG demand: While Qatar exports 15 bcm less to India, the same amount is re-routed to Europe. Similarly, 15 bcm of North American LNG are shifted from Japan and China to Europe. On the contrary, LNG suppliers that are geographically tied to the Asian market, such as Australia and Russia's far eastern LNG facilities, are not found to export any significant LNG amounts to Europe irrespective of Asia's LNG demand.

Figure 12 – Annual LNG trade for 2030 reference scenario and lower Asian demand scenario

The impact of the reduced Asian LNG demand on the overall LNG prices is shown in Fig. 13. It is visible, that the decreased Asian demand leads to LNG price reductions of about 5-10% for all consumers uniformly. This price reduction is similar to the one discussed above in the LNG price sensitivity scenario; hence the changes in European gas imports, shown in Fig. 14, are similar to the changes discussed in Fig. 8 above. The overall LNG imports to Europe are increased by 110%, which causes Norway and Russia to lose 12% and 17% of their market share respectively. This shows, that Europe's gas importing strategy in 2030 will not only be determined by its bilateral trade agreements with LNG suppliers, but also the relationships of these suppliers to other major LNG consumers in the world. Since Europe has little to no political control over these third party trade agreements, a gas importation strategy that relies more on LNG entails political risks in this regard.

Figure 13 – Impact of reduced Asian LNG demand on LNG prices in 2030

Figure 14 – Change in European gas imports due to lower Asian LNG demand in 2030

Impacts of lower LNG supply in USA and Australia

The impact of less increased liquefaction capacity in Australia and USA on global LNG trade and European gas importation is shown in Figs. 15 and 16. It is visible that the trend in Australian liquefaction capacity does not affect the European gas market to a notable extent, because Europe and Australia are not found to trade significant amounts of LNG in the first place. The trend in US liquefaction capacity has more impact on the European gas market, with LNG imports being reduced by 9% in the scenario with less increased US liquefaction capacities. Yet compared to the scenario with reduced Asian demand (2030-LOW-ASIA), the sensitivity of European LNG imports to the trends in LNG supply is comparably low. This shows, that the European LNG imports in 2030 are driven more by the competition for supplies with Asia than by the trends in the LNG producing countries.

Figure 15 – Annual LNG trade for scenarios with less increased LNG production in Australia and US

Figure 16 – European gas imports for less increased LNG production in Australia and USA

Impacts of blockage of LNG from Qatar and Iran

The impact of a blockage of the Strait of Hormuz on the price and availability of LNG for the European market is shown in Figs. 17 and 18. It is visible, that the blockage of Qatari and Iranian LNG has profound impacts on the European gas market, with LNG imports to Europe reduced by 40% compared to the 2030 reference scenario. The shortage of LNG on the world market leads to an increase in LNG prices in Europe of 12% on average. These findings underline the geopolitical risks associated with an LNG-focused gas importing strategy for Europe 2030.

Figure 17 – LNG prices for scenario with blocked Qatari and Iranian LNG

Figure 18 – European gas imports for scenario with blocked Qatari and Iranian LNG

CONCLUSIONS

In this work, a global LNG transport model was coupled with a high-resolution gas system model to assess the impact of global trends in LNG supply and demand on the European gas market of 2030. The findings are as follows:

- The significant increase in LNG demand in Asia by 2030 is found to attract a large share of the LNG supplies from Middle East, which are therefore not available for the European gas market anymore. USA, entering the LNG market as large-scale supplier by 2030, is found to replace the LNG supply from Middle East for Europe. Because the increase in Asian LNG demand causes more global competition for LNG supplies, the overall European import of LNG in 2030 is increased by a moderate 27% compared to 2016. The main supplier covering the shortfall in European gas supply by 2030 is Russia, which increases its market penetration by 50%.
- The overall LNG imports to Europe in 2030 are found to be highly price-sensitive. A 10% reduction in LNG prices increases the amount of LNG imported to Europe by 90% relative to the reference scenario. Most of this increased import takes place in Portugal and Spain, which has profound impacts on the European gas pipeline infrastructure: The historically dominant north-to-south flow direction of natural gas is reversed at the French-Spanish border, with Spain exporting gas to France.
- A large-scale shift of LNG from Asia to Europe is seen, if the LNG demand increase in Asia by 2030 is only half of the projected increase. The shift is mainly induced by suppliers that are approximately equidistant between Europe and Asia, such as Qatar and the USA. LNG imports to Europe are increased by 110% compared to the reference scenario; the market shares of Norway and Russia in Europe's gas supply are consequently reduced by 12-17%.

This work has shown, that the market share of LNG in Europe's gas supply is highly price-sensitive. This is especially crucial, because the trends in LNG demand and supply in third-party markets such as Asia and the USA can have significant impacts on the European gas supply. Similarly to today, the global LNG market in 2030 will be more restricted by the availability of LNG liquefaction capacities than by LNG regasification capacities. This means, that the EU will find itself competing with other markets for limited LNG supplies in 2030. This competition is further enforced with the EU's political strategy to replace coal with natural gas in its energy supply. Therefore contrary to the general perception, a gas importation strategy that relies on increased LNG imports is not necessarily politically less risky than a strategy that relies on pipeline imports. While it is correct that the EU can choose from more suppliers in an LNG strategy, it must also compete with more consumers globally. One option to hedge the risk of competing globally for LNG supplies is to contract LNG deliveries through long-term contracts with fixed prices, which has the downside risk of overpaying for LNG supplies if the global LNG prices decrease over time. Another option is to proactively invest in new LNG liquefaction facilities in developing economies, which would tie certain annual LNG supplies to the European market. On the technical level, an increased LNG importing strategy is found to cause the reversal of gas flows from north-to-south to south-to-north in several countries, which means additional technical risks for Europe's gas infrastructure.

NOMENCLATURE

$gasconsumption_{t,c}$	Gas consumption of consumer c in week t [mton]
$landingprice_{t,c}$	Price of LNG at landing port [\$/mmBtu]
$LNGconsumption_{t,c}$	LNG consumption of consumer c in week t [mton]
$LNGprice_{t,p}$	Price of LNG production of producer p in week t [\$/mmBtu]
$LNGproduction_{t,p}^*$	LNG production of producer p in week t [mton]
$LNGprodLimit_p$	Maximum annual LNG production of producer p [mton]
$refprice_{t,p}$	Reference LNG price of producer p in week t [\$/mmBtu]
$routeprice_r$	Price of shipping for route r [\$/mmBtu]
$transport_{t,r}^*$	LNG transport on route r in week t [mton]

* Variables being optimized for

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