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Supply Security of Europe in a Numerical Model of the World Natural Gas Market
- Impacts from the World Gas Model[1]

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For this report, we have used a numerical partial equilibrium model of the European and world natural gas market, called the “World Gas Model” (WGM) and simulated several development scenarios of the global natural gas market until 2030. The World Gas Model is an extension of previous modeling efforts such as the GASMOD and the European Gas Model. The WGM includes a global database, including not only the data of the European pipeline and LNG market but also pipeline markets on all other continents and LNG supply and demand on a global scale. In addition, the WGM includes endogenous investment decisions in transport and storage infrastructure in a multi-period time horizon until 2030. The previous modeling efforts were static models without investments. Because of the model improvements that allow us to investigate supply security in the long term, we use the WGM instead of the GASMOD in this study.

The scenarios presented in this report highlight the European supply security with natural gas until 2030, and they also put it into perspective relative to other large consumption regions in North America and Asia. Across all scenarios we find a remarkable similarity of European natural gas consumption over time, meaning that the European consumers will be able to find their supplies even in adverse scenario cases (e.g. disruption of Russian and Caspian exports). A diversified import portfolio with pipeline supplies from several production regions (Norway, North Africa, Middle East, Russia and Caspian) but also with LNG from a large number of producers ensures the security of European natural gas supplies.

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[1] This report results of a cooperation on modeling the global natural gas markets with Steven A. Gabriel and Ruud Egging (both University of Maryland) and Franziska Holz and Daniel Huppmann (both DIW Berlin).

1. Introduction

The world natural gas industry is in turmoil. On one side, skyrocketing prices and the increasingly tight environmental constraints have destroyed the perspectives of natural gas to become the “transition” energy source on the way to a low-carbon world (e.g. hydrogen economy). Thus, a large part of the gas-fired power plants forecasted around the turn of the decade have been shelved because they turned out to be economically unviable (Stern, 2007). But on the other side, natural gas still spurs various concerns about future reliable supplies, industry concentration, and supply security (Stern, 2007; Victor, Jaffe and Hayes, 2006). It comes as no surprise to see diverging forecasts for natural gas supply, demand and prices even for the short-term future. Thus, the official forecast for natural gas demand in Europe, based on the Primes model, has been significantly reduced (European Commission, 2007). Along these lines, the forecasts from the POLES model seem to be overoptimistic (European Commission, 2006). The Energy Information Agency has also corrected its figures for US natural gas demand downwards (Energy Information Agency, 2007). The crystal ball is highly non-transparent.

In this report, we provide a balanced discussion about the perspective of the world natural gas industry until 2030. We specify a “base case” which defines the business-as-usual assumptions based on forecasts of the world energy markets. We then investigate the sensitivity of the market by simulating a number of scenarios that all have a positive probability to occur. The simulation results from the scenario runs can give us more insights into trends, sensitivities as well as resiliency in the global natural gas market until 2030. The scenarios can be distinguished into global and regional ones. On a global scale, we implement: i) tightly constrained reserves, and ii) a CO_2-constraint and the emergence of a competing environment-friendly “backstop technology”. Another set of scenarios focuses on regional trends: we simulate iii) the full halt of Russian and Caspian exports towards Western Europe, iv) sharply constrained production and export activities in the Arab Gulf, v) heavily increasing demand for natural gas in China and India, and finally vi) constraints on infrastructure development in the Western US. Our results show significant changes in production, consumption, traded volumes and prices. Investments in pipelines, LNG terminals and storage are strongly affected. However, overall the world natural gas industry is resilient to local disturbances and can compensate local supply disruptions with natural gas from other sources. Long-term supply security does not seem to be at risk.

The report is structured in the following way: the next section describes our analytical tool, the World Gas Model (WGM) and the data upon which our analysis relies. We then sketch out the base case, that we have calibrated such as to follow the Primes and Poles forecasts for Europe and the world, respectively, as close as possible (Section 3). Sections 4 to 6 each describe one scenario in detail: a production reduction due to constrained reserves, the advent of a climate friendly, carbon-constraining policy and Russia diverting trade to the East (i.e. Asia) and to North America instead of supplying Europe. Section 7 gives an overview of the results of other scenarios; these focus on a supply shock in the Middle East, China and India with exploding natural gas consumption, and NIMBY-policies pursued in California vis-à-vis LNG imports. For each scenario, we identify the effect on prices, quantities produced, traded, and consumed - both at a general level and at the level of individual countries and regions. These key results are summarized in Section 8. In Section 9 we conclude that medium- and long-term supply security should not be of major concern, though local effects are significant.

2. Model and Data

The World Gas Model

The World Gas Model (WGM) is a simulation model of the global natural gas market covering the next three decades. It includes more than 80 countries and over 95% of global natural gas production and consumption. The WGM allows for endogenous investment in pipelines and storage as well as expansion of regasification and liquefaction capacities and considers demand growth, production capacity expansions and price and production cost increase. Taking into account the game-theoretic aspects of the natural gas market, the model also includes market power *à la* Nash-Cournot for some players participating in natural gas trade, the traders and regasifiers. See Egging et al. (2008) for a detailed description of the one-period model.

Players in the model are producers, traders, liquefiers, regasifiers, storage operators, marketers (implicitly) and consumers in three sectors, namely residential/commercial, industrial, and power generation. The consumers are taken into account via their aggregate inverse demand function. All other players are modeled via their respective profit maximization problems under some specific operational or technical constraints. There is usually one producer and one trader per country; only the US, Canada, and Russia are divided into several regions due to their geographic scope and importance in the world market. Pipelines, liquefiers and regasifiers are included as of today, but there is ample leeway in the model for new pipelines and LNG capacities to be built when the model considers them economically viable.

While the role of producers, liquefiers, regasifiers and storage is intuitive, the traders are more specific: they act as marketing arm of „their“ producer via the pipeline grid. Modeling producers and traders as separate entities allows to distinguish between production and trade aspects, and it is also in line with recent political initiatives, namely the „unbundling“ of vertically integrated energy companies. Examples of traders in this sense in today’s natural gas marketplace include Gazexport for Gazprom (Russia) or GasTerra for NAM (The Netherlands). Depending on their origin and point of operation, traders may have market power; this means that they are in a position to withhold supplies in a respective market and thereby increase prices and maximize their profits.

In addition to the possibility to export by pipeline, producers can export the natural gas as LNG. To this end, the producer sells the natural gas to a liquefier (in the same country node) who can sell it to any regasifier. The LNG market today is characterized by a large amount of contracted sales, that imply that liquefiers have committed to sell a minimum amount of natural gas while possibly already fixing the regasifier.[2] In the WGM we include LNG contracts known as of today (2008) as the minimum amount sold by each liquefier to a regasifier. Assuming that the LNG spot market will develop further over the next decades and given the limited knowledge of contracts signed in the future, LNG contracts are gradually phased out in the model. Regasifiers, while buying supplies from the liquefiers in a perfectly competitive market, are modeled as Nash-Cournot players vis-à-vis the storage operators and end consumers, in much the same way as traders are.

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[2] Similarly, pipeline in Europe are to a large extent contracted for several decades. However, we do not dispose of a data base to include these contracts in the model.

Storage operators act as arbitrageurs between the three seasons in the model, considering the high fluctuation of natural gas consumption. Pipeline operators are not owners of the gas sent through their pipeline but only charge a regulated price to the respective trader for the service. A congestion fee ensures that the pipeline capacities are allocated in an economically optimal way. The base year of the WGM is 2005; investment projects already under construction at the time of writing are considered. The simulation of the global natural gas trade runs until 2040 in five year intervals, but results are only reported up to 2030.

Mixed complementarity problems and investments

The mixed complementarity problem (MCP) formulation is often used when investigating market equilibrium (Facchinei and Pang, 2003). Each of the players is represented by a profit maximization problem subject to engineering or operational constraints. Taking together all the Karush-Kuhn-Tucker (KKT) optimality conditions for the players, combined with appropriate market-clearing conditions, gives rise to an MCP (Gabriel et al., 2005ab; Egging and Gabriel, 2006; Egging, Gabriel, Holz, Zhuang, 2008).

Typically, MCPs for computing market equilibria do not include investments as decision variables. Investments are usually discrete choices corresponding for example to “build or not build”-decisions or integer levels of the investment. If the integrality restrictions are taken into account at the same time as the MCP, the resulting problem is difficult to solve and in some cases there may be no solution. A second reason that investments are not always combined with MCPs lies in the sequential nature of the problem. Typically, investment decisions are made first, for example corresponding to long-term planning. Then, the market is considered with a fixed set of investments or a static network. This usually leads to a two-level problem which can be computationally more challenging than an MCP. In practice, researchers often either fix the level of investments exogenously or take a continuous relaxation of the integer restrictions but mostly in the context of solving an optimization problem and not an MCP. In the World Gas Model we have adopted the latter relaxation approach and solve for investment simultaneously with all other decisions. Lise et al. (2008) adopt a similar approach but with less detail for the market players.

Data and calibration

The model has been calibrated to projections of the future energy markets, namely PRIMES forecasts for Europe (European Commission, 2007) and POLES forecasts for the rest of the world (European Commission, 2006). These sources are used to determine the (exogenous) production capacities and the reference consumption quantities and prices of the demand function. POLES projections reflect a worldwide increase in natural gas production and consumption of 70% in 2030 relative to 2005. Generally, demand stagnates or even declines in some countries in the projections after 2025.

While the PRIMES and POLES forecasts have the advantage of being officially approved forecasts, we have not been able to verify some of the underlying assumptions. In particular, it seems that reserve estimates and their forecasts of natural gas production are optimistic. For this reason, the WGM base case (Chapter 3) does not include reserve horizons for the producers. We examine the effects of reserve constraints on the global gas trade in one scenario presented here and compare the results to the base case („In the ground“ scenario, Section 4).

The calibrated worldwide base case consumption (production)[3] in 2005 is 2368 (2435), and 3757 (3905) bcm in 2030, and an average wholesale price of \$375 per 1000 m³. We assumed an average yearly price increase of 3%, in accordance with POLES projections. For infrastructure capacities (pipelines, LNG liquefaction and regasification terminals, storage), project and company information from various sources has been employed (e.g., Oil and Gas Journal, GSE database at www.gte.be). This information was used to include existing additional capacities since 2005 and also considered when assessing the maximum allowable capacity expansions per period for the base case.

3. Base Case

The base case follows general assumptions provided by the literature on the development of the natural gas market. Simulation results show, as can be seen in Figure 1, a steady increase of natural gas production over the whole forecasting period

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[3] WGM model accounts for losses in liquefaction, regasification, storage and pipelines. Consumption in WGM is corrected for ‘own consumption’ in the energy sector, IEA: www.iea.org/Textbase/stats/prodresult.asp?PRODUCT=Natural%20Gas

up to a level of about 3,900 bcm/y (3700 bcm/y of consumption after the subtraction of losses) in 2030.

We assume a yearly price increase of 3% (in 2005 US-Dollars). LNG trade grows until 2020 and then reaches a plateau close to 600 bcm/y. At that moment, LNG will account for approximately 15% of total natural gas production. The amount of natural gas consumed in its production countries drops from 60% to about 50% of total consumption over the time horizon, while the share of natural gas exported by pipeline remains relatively stable (30%). In other words, the international trade of natural gas and the share of LNG in the trade volumes will increase.

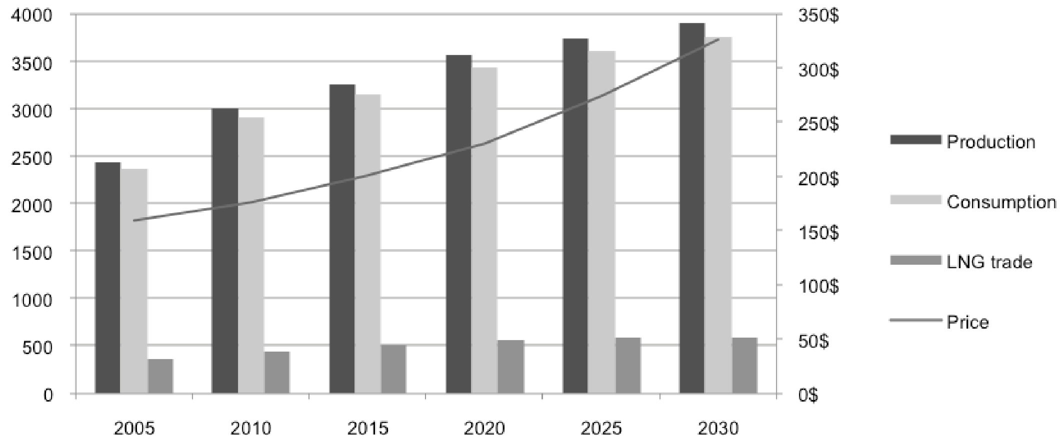

Figure 1: World consumption and production and world average wholesale price; in bcm/y and $/kcm

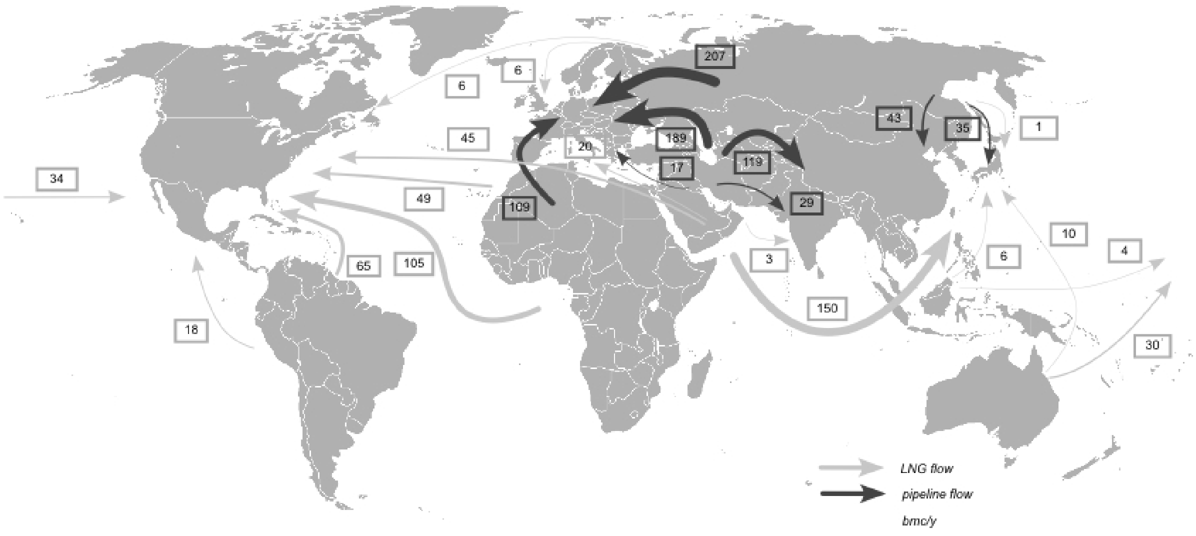

Figure 2: Natural gas flows in 2030 by region; in bcm/y, base case

Figure 2 shows globally traded volumes in 2030. The Middle East, Russia and the Caspian region split their sales between Europe and Asia, with small amounts sold via LNG to North America. Total consumption in Europe in 2030 amounts to 667 bcm/y; of this, 27 bcm/y are supplied in the form of LNG, which accounts for 4% of total consumption, and 200 bcm/y are produced domestically. The lion’s share of consumption, however, is imported from Russia and the Caspian region.

In the base case, Asia consumes almost 850 bcm/y in 2030. Looking at the country level reveals a differentiated picture: while Japan and Taiwan continue to rely heavily on LNG imports, to a large extent from the Middle East, China and India each produce half of their consumption domestically and import another 40% by pipeline from Russia, Burma, and the Caspian region. North America produces about 60% of its consumption domestically with the remaining 40% satisfied by LNG imports.[4]

Investments in liquefaction and regasification capacities are compared in Figure 3. While liquefaction capacities increase from 242 to 652 bcm/y, regasification capacities expand from 491 to 945 bcm/y. There are certain spare volumes in order to meet seasonal demand or to benefit from the option of importing additional volumes of liquefied natural gas. Investment is strongest at the beginning of the time horizon and again in 2020; after that, investments decrease due to the assumption of demand stagnation in many developed markets.

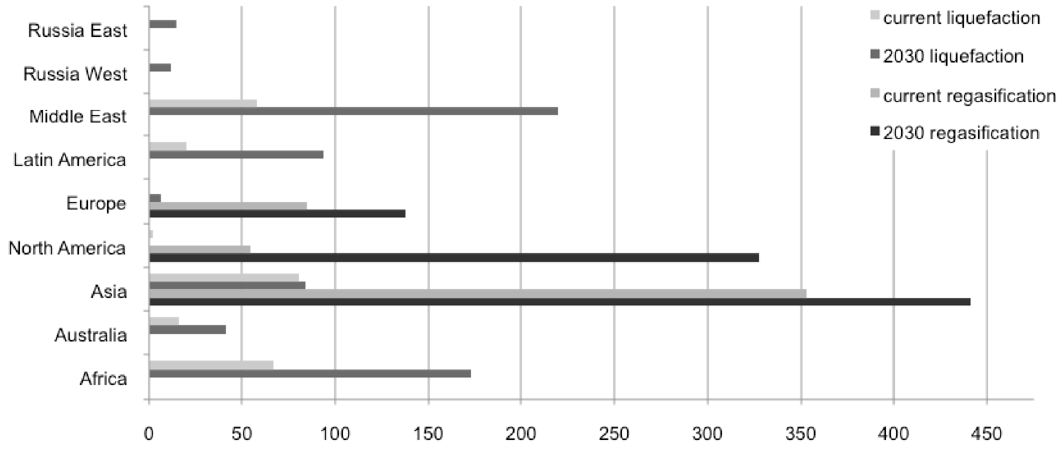

Figure 3: Investments in liquefaction and regasification capacities; in bcm/y, base case

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[4] While there has been much discussion about shale gas in the U.S. recently, no reliable data on reserves and production capacities of shale gas were available at the time of the model simulation runs. If shale gas is produced in the large amounts and at the low costs that are predicted by some sources, the share of LNG in the North American supplies is likely to be much lower than indicated by our results.

4. „In the ground“

This first scenario is an extension of the WGM base case including exogenously determined limited reserve horizons for all producers. The scenario simulates a considerably reduced reserve base: no further exploration takes place and only the reserves proved today, i.e. those that can be produced economically today, are exploited. The data is taken from BP (BP, 2008) and the Energy Information Administration (EIA, 2008). The constraint leads to the characteristic Hubbert production curve (Hubbert, 1956) for those countries which have a reserves-to-production ratio within the time horizon under investigation and which are still expanding their capacities. Countries with highly developed production but limited reserves show decreasing production over the next decades.

As shown in Figure 4, both North and Latin America considerably reduce their production levels in this scenario, whereas the Middle East is the only region that expands its production when compared to the base case. This reflects the large available reserves in countries such as Iran, Qatar, or Saudi Arabia. At the end of 2007, the Middle East was endowed with 41% of the total proven reserves in the world.

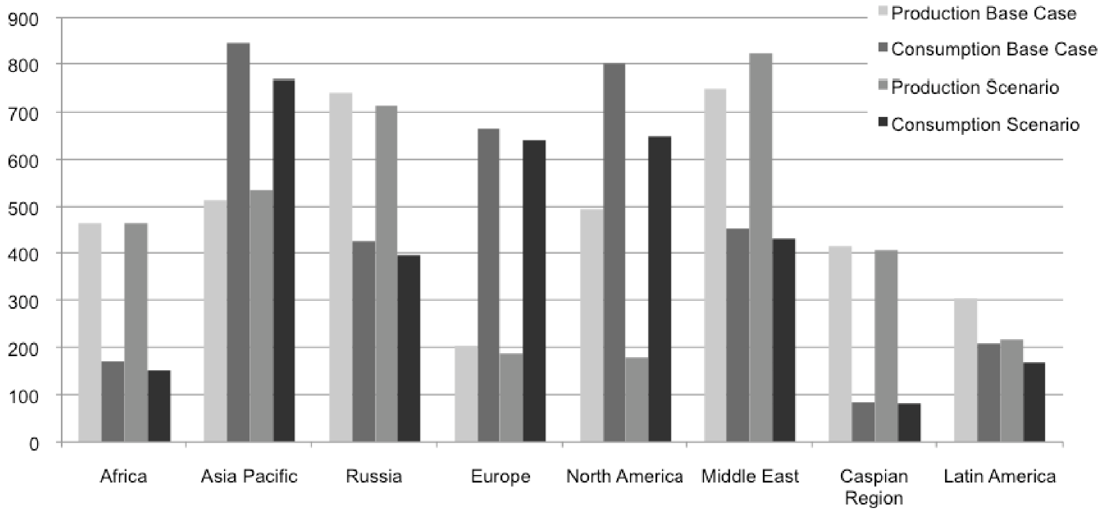

Figure 4: Production and consumption in 2030; in bcm/y, "in the ground" scenario

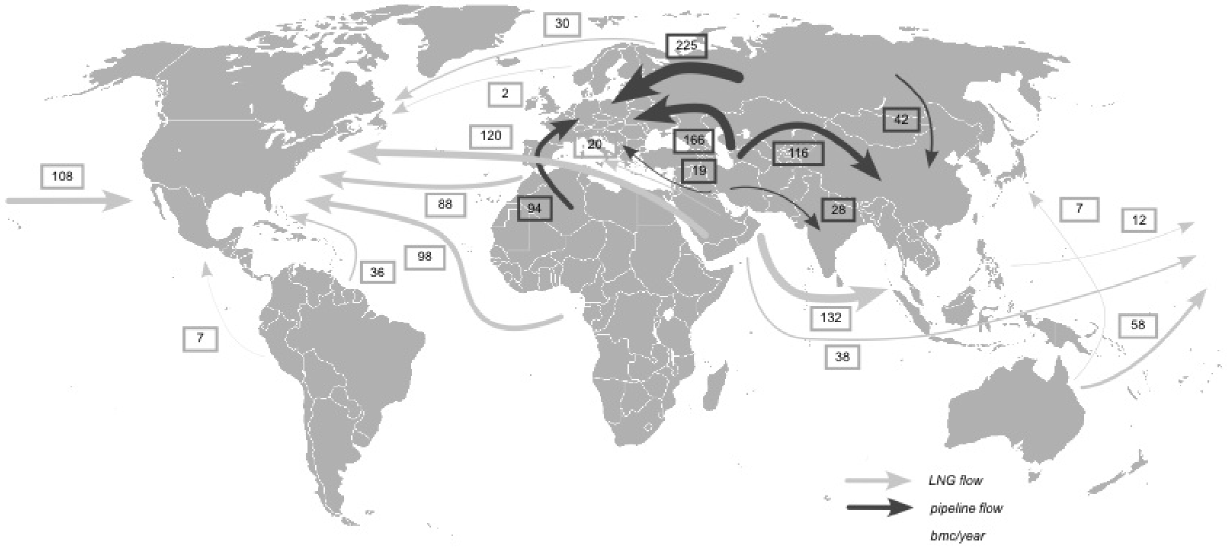

Figure 5: Natural gas flows in 2030 by region; in bcm/y, „in the ground“ scenario

The scenario leads to some rerouting of LNG flows compared to the base case, most notably from the Middle East and Africa to North America substituting domestic consumption and shipments to Europe (Figure 5). However, the Middle East with its huge reserves is at the same time expanding its pipeline deliveries to Europe compared to the base case. Thus, the Middle East expands its role as a central player in the world natural gas market with virtually all importers relying on it to some extent. An interesting detail is the observation that the Middle East even starts to deliver to the North American West Coast via the Indian Ocean and the Pacific basin.

Prices are generally higher in the scenario than in the base case. While average wholesale prices are approximately 10% higher in Europe in the year 2030 compared to the base case, they increase about 14% in Asia and almost 40% in Russia and North America.

The simulation results also show the large share of imports in the Europe consumption in 2030. Both North America and Europe satisfy less than 30% of their consumption from domestic production, but both rely on a wide array of external suppliers. North America’s imports are primarily LNG from different producers. Europe, on the other hand, continues to rely largely on pipeline imports, that is complemented by LNG imports.

5. „Post Bali planet“

In this scenario, we examine the advent of an alternative, more climate-friendly energy source and its effects on the natural gas market. It does not matter, for the sake of our study, whether the backstop energy source is wind, solar, biomass or any other. The important characteristic is rather that the cost of using the alternative energy source is too high at the moment to substitute for natural gas, but is assumed to become economically feasible over the next decades. We also assume that the backstop technology can substitute for all applications of natural gas, including heating and transportation.

Figure 6 compares the development of wholesale prices in several world regions to the costs of an equivalent amount of energy from the backstop technology. All production costs in the WGM are subject to an annual increase of 3%; wholesale prices subsequently rise by approximately the same rate, influenced by relative surplus or scarcity of supply. The cost of the backstop technology, on the other hand, is assumed to increase by only 1% per year, representing technological progress in this area and, possibly, economies of scale as the implementation of this technology is advancing. We assume the backstop technology to be available at a marginal cost price (i.e., no strategic behavior by the backstop technology supplier).

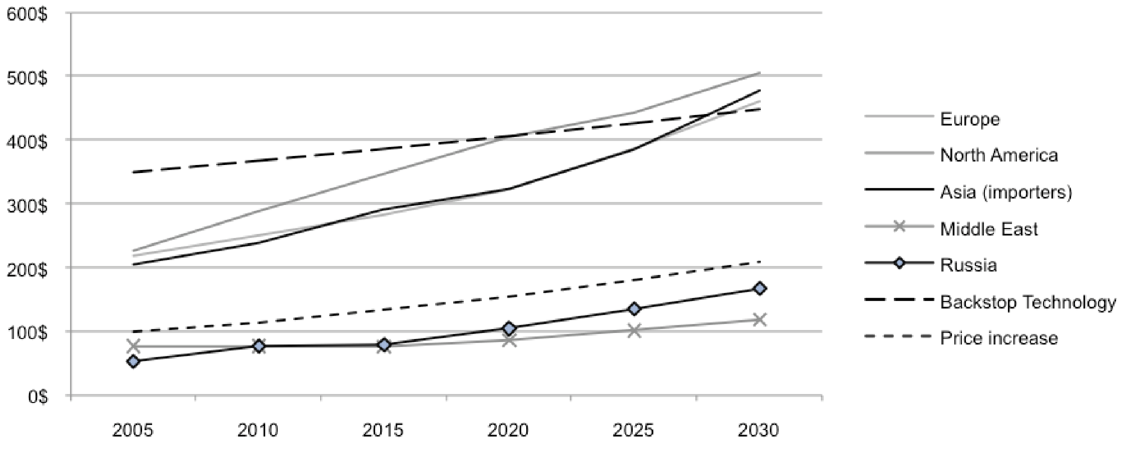

Figure 6: Average wholesale prices (base case), backstop technology costs (post Bali scenario); in $/kcm

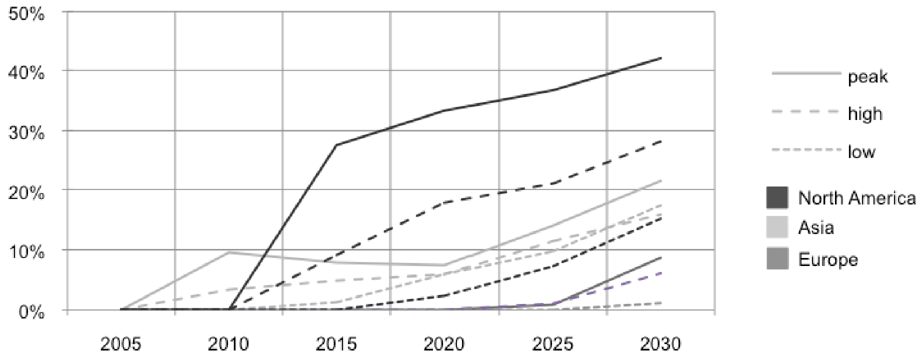

Figure 7: Backstop technology in energy consumption by season, post Bali scenario

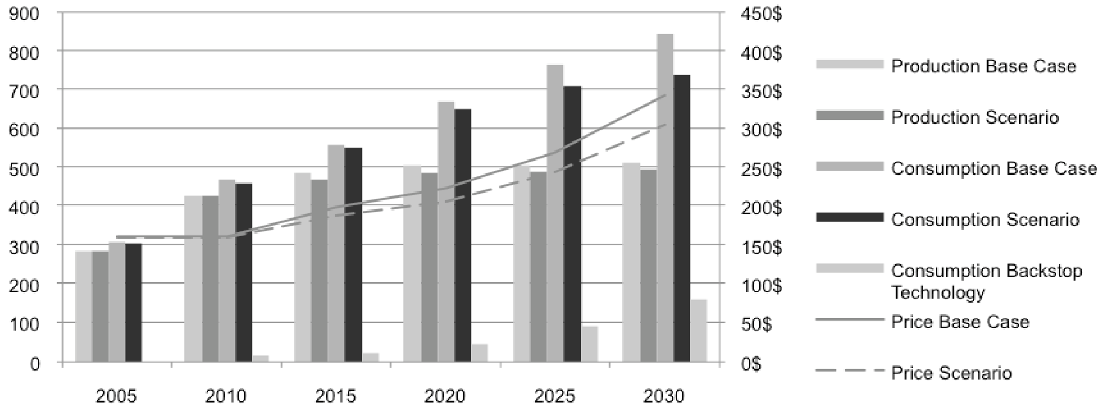

Figure 8: Volumes and average wholesale prices in Asia; in bcm/y and $/kcm, post Bali scenario

As one would expect, the backstop technology is first introduced in those regions where wholesale prices are highest, namely North America and parts of Asia. This reduces total demand for natural gas and, hence, leads to lower prices. Europe has some more own production and benefits from reduced prices in the LNG markets, which induces countries like Algeria to revert to pipeline export to Europe instead of selling LNG to North America. As a consequence, Europe only starts to use the backstop technology relatively late, in spite of its large consumption and high dependency on natural gas (see Figure 7). In the scenario, the backstop technology accounts for 15% of energy consumption in 2030 in those sectors which traditionally rely on natural gas.

Figure 8 shows that the introduction of a backstop technology leads to a noteworthy decline of wholesale prices compared to the base case (we show the example of Asia, trends in other regions being similar). At the same time the level of energy use, meaning natural gas consumption plus backstop technology, is well above the consumption levels in the base case. The backstop technology therefore leads to a substantial improvement of consumer surplus, both because of lower prices and due to more available energy sources.

6. “Eastern promises”

This scenario investigates the effects of a politically motivated move by Russia to halt all exports to Europe - both its own sales and those of other countries passing through Russian territory (e.g., from the Caspian region). The interruption is assumed to take place in 2015. In this scenario, Ukraine is treated as part of Europe, unlike Belarus. We want to investigate the adjustment strategies by the European importers to the supply stop from the East.

European countries are hit by the supply disturbance in the short term, with a 40% price spike in 2015 compared to the base case. Consumption is reduced by more than 12% (521 bcm/y instead of 596 bcm/y). Since Finland and the Baltic states would not receive any natural gas imports after 2010, we allow for the construction of two new pipelines from Sweden to these countries (a pipeline from Norway to Sweden is already allowed in the base case). These pipelines are constructed in 2015 with a capacity of 7 bcm/y to the Baltic states and 4 bcm/y to Finland. Still, the price impact of the Russian export stop is significant in both countries, with prices almost twice as high as compared to the base case.

However, after the first shock, European natural gas demand picks up again (Figure 9) and a broad diversification of imports can be observed. Holz et al. (2009) have shown that the capacity of Europe to diversify its natural gas imports provides it with an effective insurance against the risk of a Russian interruption. Europe substitutes a large part of the lost imports from Russia with LNG from the Middle East. The subsequently lower supply in Asia induces Australia, Indonesia, and Brunei to ship LNG to China and Japan instead of North America. Russia then takes up the baton and sells LNG to North America. The Russian supply interruption leads, to some extent, to a reversal of the direction of LNG flows around the world, with average wholesale prices some 15% higher than in the base case.

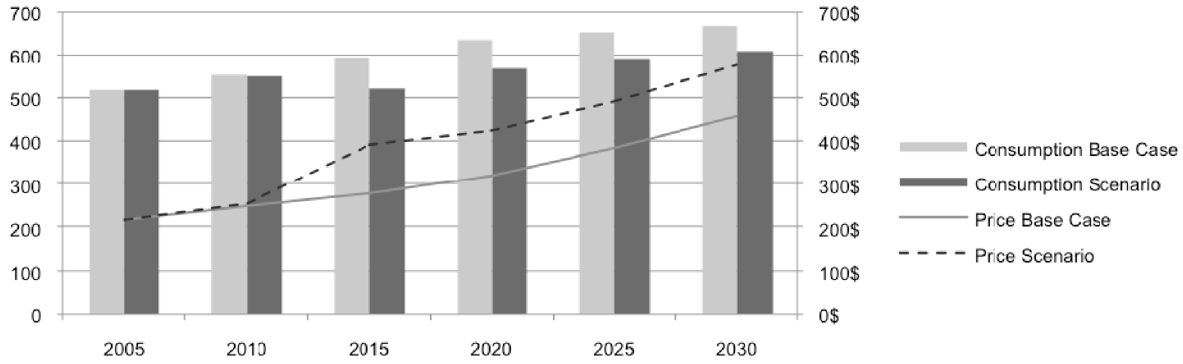

Figure 9: Consumption and average prices in Europe; in bcm/y and $/kcm, eastern promises scenario

Table 1 summarizes the development of Russian exports as well as domestic consumption over the next decades, comparing the scenario to the base case. Russian domestic natural gas consumption would increase by about 12% in 2030 under the scenario assumptions; LNG deliveries to Europe would not take place whereas shipments to the North American Atlantic coast would increase significantly (+350% to 30 bcm/y instead of 6.4 bcm/y) to make up for the diversion of shipments from the Middle East.

		2005	2010	2015	2020	2025	2030
Domestic consumption		376.51	405.53	407.02	421.06	419.01	421.45
		376.51	***400.38***	***460.53***	***481.71***	***478.19***	***473.37***
LNG	Asia	0	9.46	8.32	8.32	8.32	0.66
		0	***9.79***	***8.32***	***8.32***	***8.32***	***0.66***
	Europe	0	0	0	0.78	3.30	5.58
		0	***0***	-	-	-	-
	North America	0	5.18	6.33	16.41	13.88	6.42
		0	***5.18***	***6.65***	***17.18***	***29.18***	***30.00***
Pipeline	Asia	0	0	0	36.54	53.08	78.02
		0	***0***	***0***	***33.56***	***52.46***	***78.81***
	Caspian Region	6.18	4.30	3.41	0.75	0	0
		6.18	***4.45***	***6.20***	***5.55***	***3.39***	***1.02***
	Europe incl. Ukraine	132.45	116.72	149.70	170.22	183.83	185.13
		132.45	***128.38***	-	-	-	-
	Belarus	18.61	19.86	21.75	22.48	22.32	21.99
		18.61	***19.90***	***23.36***	***23.91***	***23.77***	***23.47***
Total		533.75	561.05	596.53	676.56	703.74	719.24
		533.75	***568.08***	***505.06***	***570.24***	***595.32***	***607.33***

Table 1: Russian natural gas exports and domestic consumption (base case / *scenario*); in bcm/y

Total Russian natural gas production decreases by about 15%, which translates into a reduction of its profits by more than 40%. In the base case results, we compute Russian aggregate profits (summing over producer, trader and liquefiers in the Russian nodes) of 1095 billion US$ in the period from 2015 to 2030, while its profits in the "Eastern Promises" scenario are only 623 billion US$. It can therefore be concluded that the politically motivated supply disruption comes with a hefty price tag attached for the Russian state.

7. Other Scenarios

„Shutting off the Middle East"

In this section, we summarize the assumptions and the main results of three additional scenarios, focusing on regional trends and developments. In the scenario "Shutting off the Middle East", we study the impact of a supply shock in the Middle East. This scenario can also be interpreted as the result of a GECF (Gas Exporting Countries Forum) cartel, similar to OPEC in the oil market. Producers in the Middle East may choose to deliberately under-invest in their production capacity to exert upward pressure on prices.[5] Whereas in the base case, production capacity increases considerably in the region, in this scenario we hold production capacity constant for all producers from the year 2010 on.

Simulation results show wholesale prices skyrocketing in the Middle East up to the 200 $ per 1000 m³ level in 2030. When examining the resulting trade flows in this scenario, the striking change vis-à-vis the base case are the increasing intra-regional traded volumes between Middle Eastern countries (8 bcm/y in 2030). Whereas in the base case all countries in the region are virtually self-sufficient in satisfying domestic demand and no intra-regional trade occurs, this no longer holds true in this scenario, triggering substantial investment in pipelines on the Arab peninsula.

LNG exports to North America run dry (-89%), as do long-distance pipeline exports to Europe (-79%). The exports to Asia remain comparatively strong, both by LNG and via pipeline from Iran to India and Pakistan (-50% "only"). Total global LNG regasification capacities are only slightly lower than in the base case. The significant drop in Middle

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[5] This scenario is not a true cartel representation, where the exact amount of withholding would be decided by the profit optimization problem of the cartel members. See Egging, Holz, Hirschhausen, and Gabriel (2009) for another analysis of a gas market cartel.

Eastern liquefaction capacities is partly made up by other producers, such as Western Africa and Latin America. The global liquefaction capacity drops from 650 to 590 bcm/y, while the amounts actually liquefied decrease from 595 to 509 bcm/y. Total natural gas production in 2030 drops from 3905 to 3707 bcm/y.

Freezing daily production capacity in the Arab Gulf countries leads to a significant welfare loss for the Middle East itself. Evaluating net profits in the time frame under investigation (revenue minus production and investment costs for producer, trader and liquefier in each country, 2005 to 2030) shows a 7% decline as compared to the base case for the whole region. Due to the higher prices, consumer welfare surplus is reduced over the same horizon by almost 25%. We therefore conclude that the total halt on capacity expansion would not be optimal neither for the producers nor the consumers in the withholding region.

		2005	2030 base case	*2030 scenario*
Domestic Consumption		191.30	453.52	*318.44*
LNG	Asia (Pacific)	36.54	154.19	*77.66*
	Europe	7.63	20.16	*5.18*
	North America	0	44.90	*4.95*
Pipe	Asia (India, Pakistan)	0	29.07	*9.82*
	Europe	2.80	17.04	*3.54*
	Other Middle East	0	0	*8.09*
Total		**238.27**	**718.88**	***427.68***

Table 2: Distribution of Middle Eastern natural gas; in bcm/y, Middle East scenario

“Tiger and dragon”

The “tiger and dragon” scenario investigates the impact of a strong demand increase in Asia. We focus on China and India since uncertainty about the future natural gas demand in these two developing countries is significant.[6] Demand growth factors in China and India hence were multiplied by 2.5 from 2015 on compared to the base case assumptions. Maximum regasification capacity expansion parameters from 2015 on were multiplied by a factor of three in order to give sufficient potential to meet higher demand levels. The maximum allowed investment in pipelines leading to China and India, including those through transit countries (e.g. from Iran via Pakistan to India) were doubled in each period compared to the base case assumptions.

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[6] Natural gas demand increased by 19.9% for China and by 7.6% for India in 2007 over the previous year. Three LNG import terminals are currently operating in these two countries; more than 20 facilities are proposed. However, there are uncertainties about the realization of a number of projects.

Simulation results show that total consumption levels nearly double in both China and India to 313 and 143 bcm/y, respectively, in 2030 in line with the assumptions of this scenario. At the same time, production levels only increase slightly, resulting in an increasing importance of natural gas imports. These are satisfied by LNG as well as pipeline deliveries. Regasified volumes in 2030 increase by 860% for China and 450% for India as compared to the base case. Pipelines are constructed from Kazakhstan (2015) and Russia (2020) to China as well as from Pakistan (2020) to India, with expansions in later periods. Natural gas prices increase slightly in all world regions mirroring the global impact of Asian demand uncertainty.

The Middle East as a region delivering already today to all major LNG importing regions (i.e. Europe, Asia-Pacific and North America) changes its export pattern significantly. Whereas domestic consumption in 2030 is only slightly lower than in the base case, LNG deliveries to Europe and North America decrease by 20% and 47% respectively; exports to Asia increase by 40%.

Traded volumes and wholesale prices under this scenario underline that the uncertainty about Asian future demand levels for energy sources (in this case natural gas) has a significant impact on forecasts of the whole world natural gas market structure; a demand growth increase by a factor of 2.5 results in LNG volumes redirected from Europe and North America to Asian importers and overall higher natural gas prices.

“Pretty coast California”

This last scenario discusses a situation with specific regional effects. Since US domestic natural gas production was for a long time and until recently expected to decline in the near-term, the country with the second largest consumption worldwide may be increasingly dependent on imports. These can only partially be satisfied by deliveries from Canada, Mexico and Alaska; hence, LNG regasification capacities are expected to grow. However, due to a strong NIMBY (not-in-my-backyard) attitude in California and the Western states, companies facing public resistance already today plan to invest in LNG import facilities in neighboring countries and re-export regasified gas to US markets. The scenario “pretty coast California” investigates the consequences of a legislation prohibiting the construction of any LNG import facility at the Pacific coast. The model is changed in the following way: No regasification capacity is allowed to be built on the US west coast. At the same time more capacity is allowed in Western Canada. Maximum pipeline expansion parameters for North America are doubled. Moreover, the U.S. market can be supplied with additional volumes via the Alaska pipeline (same assumptions as in the base case, with possible investment starting in 2015).

Whereas in the base case 42 bcm/y of regasification capacity are built on the US Pacific coast alone, in the "pretty coast" scenario, LNG import capacities increase in Western Canada, Mexico and at the US Gulf coast.[7] The price effect on California is negligible; the prohibition of US Pacific coast LNG import facilities actually results in lower prices in the short run compared to the base case. This can be explained by the rapid and significant expansion of the pipeline from Mexico in 2015; in the base case, this pipeline is not expanded since LNG import capacities come online in 2020 and the expansion is not economically viable. In the long-run, however, the lack of import capacity leads to lower supplies and natural gas prices rise approximately 4 % compared to the base case.

8. Summary and Conclusions

Table 3 summarizes model changes, main results and conclusions of the six scenarios and selected key figures for the global natural gas trade in the year 2030.

This report presents simulation results of different structural and regional natural gas market scenarios using the World Gas Model. Assuming limited natural gas reserves leads to higher prices in North America compared to the base case, while Europe is not significantly affected. However, Europe would be reliant on a small number of suppliers, raising worries about diversification and security of supply.

A supply shock in the Middle East, on the other hand, would lead to higher prices worldwide. The effects are strongest in the Middle East itself, with export revenue and consumer surplus significantly lower than in the base case. The remaining supplies from the Middle East are directed almost exclusively to Asia, while Africa and Russia fill the gap in the supply to Europe and North America.

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[7] The regasification capacity on the Mexican and Canadian Pacific Coast increases from 5 bcm/y to 10 bcm/y. Another 25 bcm are built in addition to the Base Case expansion on the Gulf Coast.

Scenario	**Assumptions**	**Main results and conclusion**	**Key figures in 2030**		
			Consumption in bcm/y	**Average price** in $/kcm	**LNG**[8]
Base Case			***3758***	***326***	***15.8%***
In the ground	Production horizon fixed at level of today's proven reserves; no exploration	...has high impact on the price in North America …diversification ensures supplies in Europe	3387	405	22.4%
Post Bali planet	Introduction of an environmentally friendly backstop technology	...leads to higher consumer surplus worldwide ...N. America and Asia adopt the new technology quickly ...Europe waits longer before adopting the new technology	3509	292	9.7%
Eastern promises	No exports to Europe from Russia after 2010	…raises prices by 25% in Europe …Russia ships LNG to N.America …leads to lower profits for Russia	3688	374	17.8%
Shutting off the Middle East	Production capacities for Middle Eastern producers are fixed at 2010 levels	...leads to a worldwide price increase ...results in lower profits and reduced consumer surplus in Middle East	3573	353	14.4%
Tiger and dragon	Demand growth factors of China and India multiplied by 2.5	…leads to worldwide price increases …induces the Middle East and Australia to divert exports to Asia	3878	344	17.7%
Pretty coast California	No regasification capacity built on US west coast	… reduces supply and drives prices up in the long run …confirms role of the Middle East as swing supplier, also to the U.S.	3756	326	15.6%

Table 3: Summary of scenario assumptions, conclusions and results

The introduction of an alternative energy source, in the wake of the discussion about global warming and CO_2 emissions, could lead to significantly lower consumption of natural gas and, at the same time, lower the prices and therefore increase consumer surplus globally. While North America and some Asian countries rapidly introduce this new technology, Europe only starts using it moderately in 2025.

In a more politically motivated framework, we examine the disruption of Russian natural gas exports to Europe in 2015. Average prices increase by 40% in Europe in the year of the disruption, and continue on a price trajectory approximately 25% above the base case, with consumption around 10% lower. Russia does not, as one might expect, increase its exports to Asia; instead, it ships more LNG to North America after the supply disruption to Europe.

Since there is a lot of uncertainty about how Asia will satisfy its hunger for energy, one scenario studies the impact of much higher growth rates of natural gas consumption in India and China. This leads the Middle East, Australia and South East Asia to divert

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[8] Share of LNG in global natural gas consumption

some of their LNG exports from Europe and North America to these two countries, with world natural gas prices increasing slightly.

The last scenario focuses on a ban on LNG regasification investments on the US Pacific Coast. It is interesting to see that prices may actually fall in the short run due to this ban; in the long run prices are slightly higher compared to the base case, which does not have these investment restrictions.

For future research, there are many more scenarios worth investigating: what would happen, for instance, if demand decreased significantly, due to a worldwide CO_2 emission trading scheme or a rebound of coal if carbon capture and sequestration proves to be economically feasible. Currently, the formation of an effective cartel out of the Gas Exporting Countries Forum, similar to OPEC in oil markets, is also discussed broadly. However, from a modeling perspective, there are certain limitations in investigating such a scenario. Egging Holz, Hirschhausen, Gabriel (2008) provide a first step in this direction, but more research is needed to compare different types of cartel or collusion of producers.

The WGM allows for stochasticity in future demand projections, production capacities and supply disruptions; however, no stochastic scenarios have yet been investigated. Given the high uncertainty of energy consumption projections in general and the use of natural gas in particular, stochastic scenarios might yield further insight into the future development of the global natural gas market.

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