The World Gas Market in 2030 –
Development Scenarios Using the World Gas Model

Abstract

In this paper, we discuss potential developments of the world natural gas industry through 2030. We use the World Gas Model (WGM), a multi-period strategic representation of the global natural gas sector, including production, trade, and consumption, between 2005 and 2030. We specify a "base case" as reference for our scenario analysis. We then analyze the sensitivity of the world natural gas system with scenarios: i) the emergence of large volumes of unconventional North American natural gas reserves, such as shale gas; ii) on the contrary, tightly constrained reserves of conventional natural gas reserves in the world; and iii) the impact of CO_2-constraints and the emergence of a competing environmental friendly "backstop technology". Scenarios that are regional but have a global impact are: iv) the full halt of Russian and Caspian natural gas exports to Western Europe; v) sharply constrained production and export activities in the Arab Gulf; vi) heavily increasing demand for natural gas in China and India; and finally vii) constraints on liquefied natural gas (LNG) infrastructure development on the US Pacific coast. Our results show considerable changes in production, consumption, traded volumes, and prices between the scenarios. Investments in pipelines, LNG terminals and storage are also 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.

Keywords: natural gas, investments, reserves, climate policy.

1 Introduction

The international natural gas markets are in turmoil: on the one hand, the price rollercoaster is continuing, leading from the low prices of the mid-1990s to record levels in 2008, and then dropping sharply again in the wake of the world economic crisis and oversupplies. It is still open whether natural gas will really become the "transition" energy source on the way to a low-carbon world (e.g. hydrogen economy). Thus, while many gas-fired power plants forecasted around the turn of the decade have been shelved (Stern, 2007), their competitiveness has recovered recently in the wake of the global climate policy debate, and concerns about coal-fired power plants. However, 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. The official forecast for natural gas demand in Europe has been significantly reduced (European Commission, 2007); the Energy Information Agency (EIA, 2009a) has drastically decreased its forecast of U.S. LNG import requirements. The crystal ball remains highly intransparent.

In this paper, we discuss the perspectives of the world natural gas trade until 2030, using the World Gas Model (Egging et al., 2009b). We specify a "base case" which serves as our reference in comparison to other, "what if"-scenarios. This base case is calibrated with forecasts of the world energy markets. We then investigate the sensitivity of supply and prices by simulating a number of scenarios regarding the future development of the natural gas market. The simulation results from the scenario runs provide insights into trends, sensitivities as well as resiliency in the global natural gas market until 2030. Our goal is not to provide forecasts of the future natural gas market, but rather projections of possible development scenarios, for which the base case serves as a reference.

We distinguish several scenarios, of which we analyze some in more detail than the others because they can have a structural impact on the global gas market. We start with potential "game changer" scenarios: i) the emergence of large unconventional natural gas reserves in North America, mainly shale gas, and its impact on international trade and prices. Other important scenarios include ii) tightly constrained (conventional) reserves, and iii) a CO_2-constraint and the emergence of a competing environment-friendly “backstop technology”. Further scenarios focusing on more regional trends are: iv) the full halt of Russian and Caspian exports towards Western Europe, v) sharply constrained production and export activities in the Middle East, vi) heavily increasing demand for natural gas in China and India, and finally vii) constraints on LNG 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 also 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 paper 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 closely as possible (Section 3). Sections 4 to 7 each describe one of the important, global scenarios in detail: the reassessment of natural gas reserves and production capacity in North America, the 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 8 gives an overview of the results of other scenarios: they focus on a disruption of supplies from Russia to Europe, a supply shock in the Middle East; on an exploding demand from China and India; and on a continued NIMBY-policy 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. In Section 9 we summarize the key results and conclude that globally medium- and long-term supply security should not be of major concern, though local effects are significant.

2 Model and Data

2.1 The World Gas Model

The World Gas Model (WGM) is an equilibrium model of the global natural gas market covering the next three decades set up for numerical simulations. We consider only the natural gas sector and competition within this market. While this may be considered as a drawback, it allows us to study specific details of the natural gas market. Moreover, we strive at depicting a realistic picture of the natural gas sector within the energy system, which we try to achieve by obtaining data for the future periods from energy system model forecasts.

The World Gas Model includes more than 80 countries and covers 95% of global natural gas production and consumption in the data set. The WGM comprises endogenous investment in pipelines and storage as well as in regasification and liquefaction capacities. We incorporate demand growth, production capacity expansions as well as 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, namely the traders and regasifiers. Egging et al. (2009b) provide a detailed description of the multi-period model and the data; the World Gas Model is an extended version of the one-period model without investments that covered only the European pipeline and the global LNG market (European Gas Model) in Egging et al. (2008).

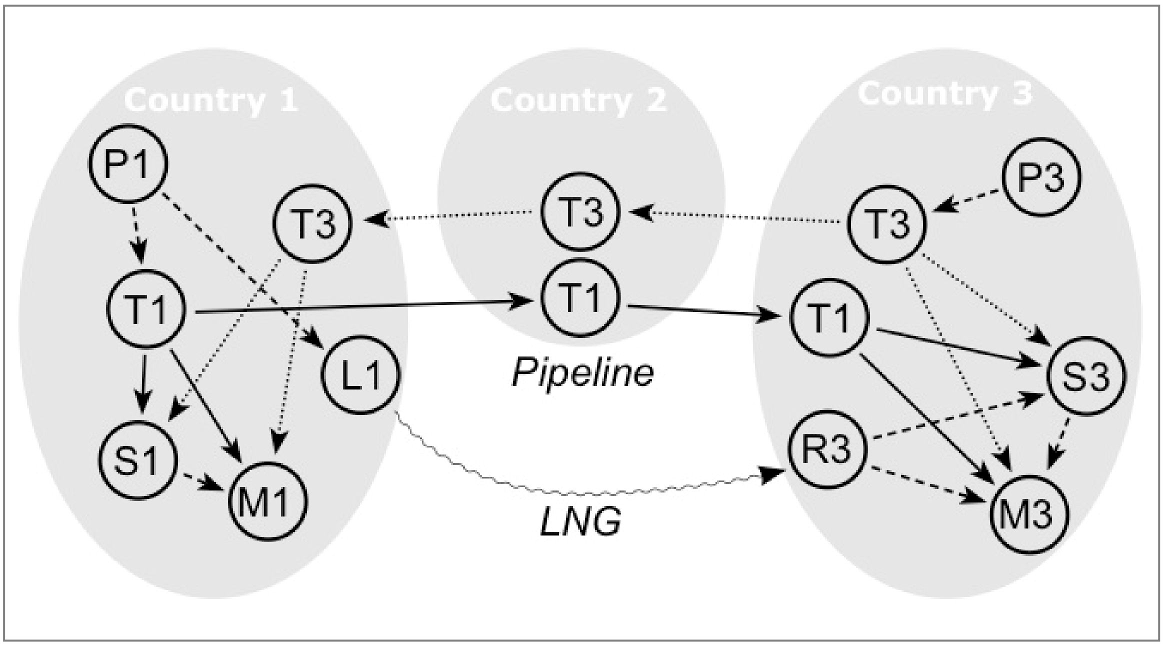

Figure 1: Player types and their interconnection in the World Gas Model

Note: P = producer, T = trader, L = liquefier, S = storage operator, M = final market (demand)

Figure 1 depicts the model structure, including the location of the players in country nodes and the links between the agents. Player types in the model are producers, pipeline traders, liquefiers, regasifiers, storage operators, marketers (implicitly) that represent the consumers in three sectors, namely residential/commercial, industry, and power generation. The consumers are taken into account via their aggregate inverse demand function that is assumed to be linear. All other players are modelled via their respective profit maximization problems under some specific operational or technical constraints. Except for the producers, all players with infrastructure constraints can expand their capacities and decide on the optimal investment in a net present value maximization over the entire model horizon, assuming perfect and complete information on the future periods and the other players' behaviour.

We derive a mixed complementarity problem (MCP) from the optimization problems (Facchinei and Pang, 2003) with market-clearing conditions linking the players' problems. The Karush-Kuhn-Tucker (KKT) conditions of the players' optimization programs are used and solved simultaneously. The numerical solution is obtained from programming the KKTs in GAMS. Using the MCP approach instead of an optimization model allows us to include market power as an important characteristic of international natural gas markets in the behavioural assumptions of some players (traders, regasifiers).

We generally assume 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 with their capacities 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. Modelling producers and traders as separate entities allows to distinguish between production and trade activities; it is also in line with recent regulatory initiatives, namely the „unbundling“ of vertically integrated energy companies. Examples of traders in today's natural gas marketplace include Gazexport for Gazprom (Russia) or GasTerra for NAM (The Netherlands). Depending on their origin and location of operation, traders may have market power à la Cournot; this means that they are in a position to withhold supplies in a respective market and thereby increase prices in order to maximize their profits.

In addition to the possibility to export by pipeline, producers can export the natural gas as liquefied natural gas (LNG). To this end, the producer sells the natural gas to a liquefier located in the same country node who can sell it to any regasifier in the world. 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 possibly fixing to which regasifier. We include LNG contracts known as of today (2008) as the minimum amount sold by a liquefier to a certain regasifier.[1] Assuming that the LNG spot market will develop further over the next decades and given the limited knowledge of contracts to be 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 modelled as Cournot players vis-à-vis the end consumers, in much the same way as traders are. This way, we are able to represent market power in the LNG part of the market, too. The strategic behaviour by most regasifiers and traders leads to natural gas prices generally above marginal costs in the market.

Storage operators act as arbitrageurs between the three seasons in the model (low, high, peak), given the seasonal fluctuation of natural gas consumption. Pipeline operators are not owners of the gas sent through their pipeline but charge a regulated price to the trader for the transport service. An additional congestion fee ensures that the pipeline capacities are allocated economically optimal.

The base year of the WGM data set is 2005; investment projects already under construction at the time of writing are considered. For future investments into natural gas infrastructure (LNG, pipeline, storage), we include assumptions on costs and on limits of expansion per period. The simulation of the global natural gas trade runs until 2040 in five year intervals, but results are only reported up to 2030. We include a yearly discount factor of 10% in the multi-period optimization.

2.2 Data and calibration

The model is 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 parameters for each period and country. POLES projections reflect a worldwide increase in natural gas production and

[1] Similarly, natural gas transported by pipeline in Europe is to a large extent contracted for several decades. However, we do not dispose of a data base to include these contracts in the model.

consumption by 70% in 2030 relative to 2005. Overall, demand is projected to stagnate or even decline in most countries after 2025.

While the PRIMES and POLES forecasts have the advantage of being accepted forecasts, we have not been able to verify some of the underlying assumptions. In particular, it seems that reserve estimates and the forecasts of natural gas production are optimistic for some regions. For this reason, we examine the effects of reserve constraints on the global gas trade in one scenario ("In the Ground scenario", Section 5) and compare the results to the base case which does not include finite reserve horizons for the producers (Section 3).

The calibrated worldwide base case consumption (production)[2] in 2005 is 2368 (2435), and 3757 (3905) bcm in 2030, and results in an average wholesale price of $375 per 1000 m³. We assume an average yearly price increase of 3%, in accordance with PRIMES projections. For infrastructure capacities (pipelines, LNG liquefaction and regasification terminals, storage), project and company information from various sources had to be collected (e.g., *Oil and Gas Journal*, GSE database at www.gte.be). This information was used to include existing additional capacities since 2005 and to assess the maximum allowable capacity expansions per period for the base case.

3 Base Case

The base case follows some general assumptions on the development of the natural gas market that are part of the energy system model forecasts (European Commission, 2006, 2007). This means in particular a steady increase of natural gas production over the whole period that is reflected in our results by a total global production level of about 3,900 bcm/y (3,700 bcm/y of consumption after the subtraction of losses) in 2030 (Figure 2).

We assume a yearly price increase of 3% (in real 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, while the share of natural

[2] We account for losses in liquefaction, regasification, storage and pipelines. Consumption is corrected for 'own consumption' as defined by the IEA.

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.

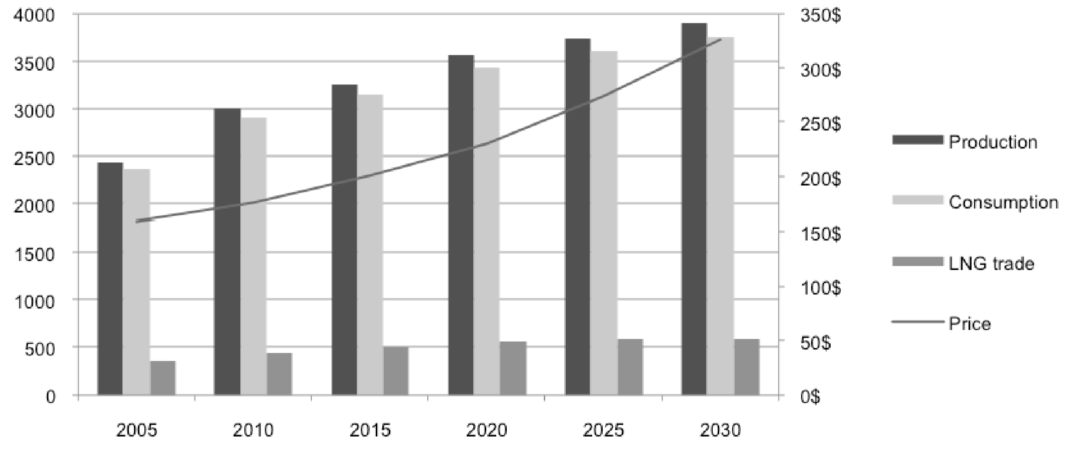

Figure 2: World consumption and production and world average wholesale price; in bcm/y and $/kcm

Figure 3 shows globally traded volumes of natural gas 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. In the base case, North America produces about 60% of its consumption domestically with the remaining 40% satisfied by LNG imports.[3] 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. A large share of consumption is imported from Russia and the Caspian region.

Asia consumes almost 850 bcm/y in 2030 but looking at the country level reveals a differentiated picture: 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, Myanmar, and the Caspian region.

[3] 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 to include it in the base case model run. 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, see the next scenario "Barnett Shale".

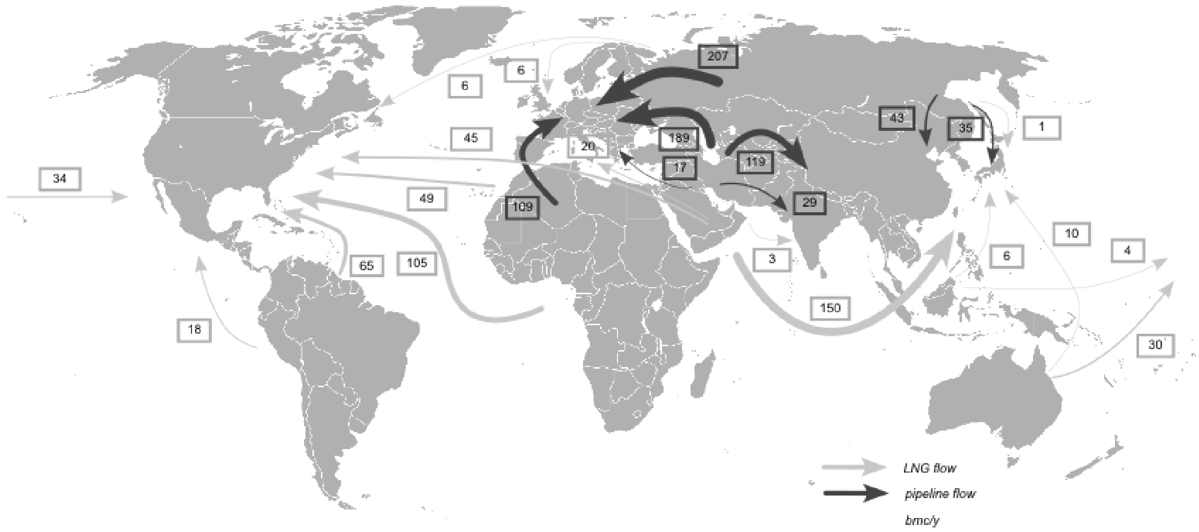

Figure 3: Natural gas trade flows in 2030 by region; in bcm/y, base case

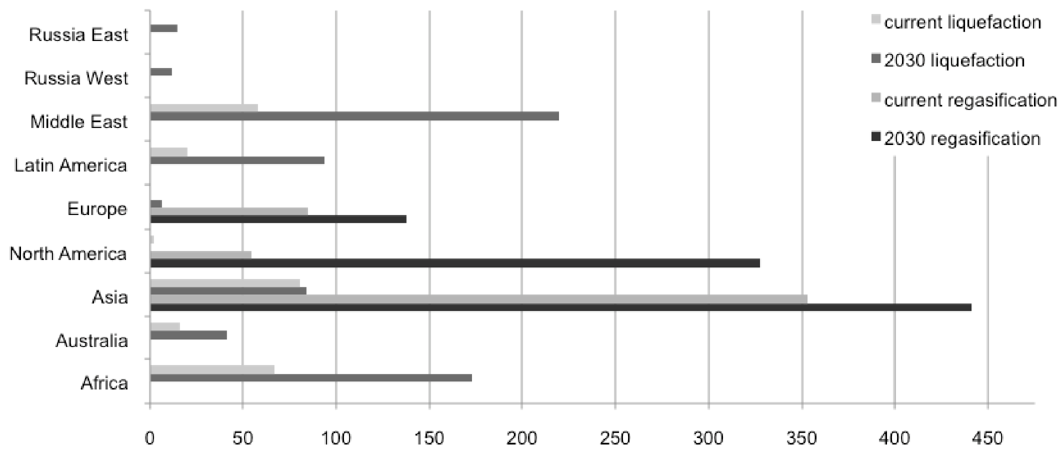

Figure 4: Investments in liquefaction and regasification capacities; in bcm/y, base case

Investments in liquefaction and regasification capacities are reported in Figure 4. While global liquefaction capacities increase from 242 to 652 bcm/y, regasification capacities expand even further from 491 to 945 bcm/y. Thus, we continue to observe proportionally higher regasification capacity than liquefaction capacity reflecting the flexible spot LNG trade assumed, at least for later model runs. 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 in LNG infrastructure is strongest at the beginning of the time horizon and again in 2020; after that, investments decrease due to the demand stagnation in many developed markets.

4 Barnett Shale

In this first scenario, the impact of the recent reassessment of the natural gas reserve situation in North America is investigated. While the exact size of recoverable resources from unconventional shale formations is still unclear, the discoveries will certainly lead to higher natural gas production in North America over the coming decades compared to earlier estimates.[4] The current state of the reassessment EIA (2009b) is incorporated in this scenario by assuming higher production capacities in most US regions and Canada from 2010 on. Since the short-run marginal production costs in the WGM are a function of total production capacity (following Golombek et al., 1995), an increase in capacity leads to lower production costs for the same quantity of natural gas produced.

The effects of the “Barnett Shale” scenario are significant: while North America imports more than 40% of its natural gas consumption in 2030 in the base case, the increase in production capacity with shale gas allows North America to rely on natural gas imports for less than 20% of its consumption in 2030. At the same time, total consumption in the region is 8% higher compared to the base case due to larger natural gas availability and lower prices. The impact of the production capacity shift is most pronounced in the early periods, with North American prices in 2010 being 20% lower than in 2005. Compared to the base case, prices in the US are 15% lower in 2030. The impact on prices in other world regions is less pronounced, ranging from a 9% price decrease in Latin America to 6% in the Middle East and 2% in Europe. The price development is shown in Figure 5 for a number of importing regions and the Middle East that is the most important supply region. Due to lower world demand for LNG and the resulting excess supply on the domestic markets in the Middle East, the price stagnates in this region for the next decade.

[4] We concentrate on North America as there seems to be much less potential for shale gas in other regions of the world, see e.g. IEA (2009).

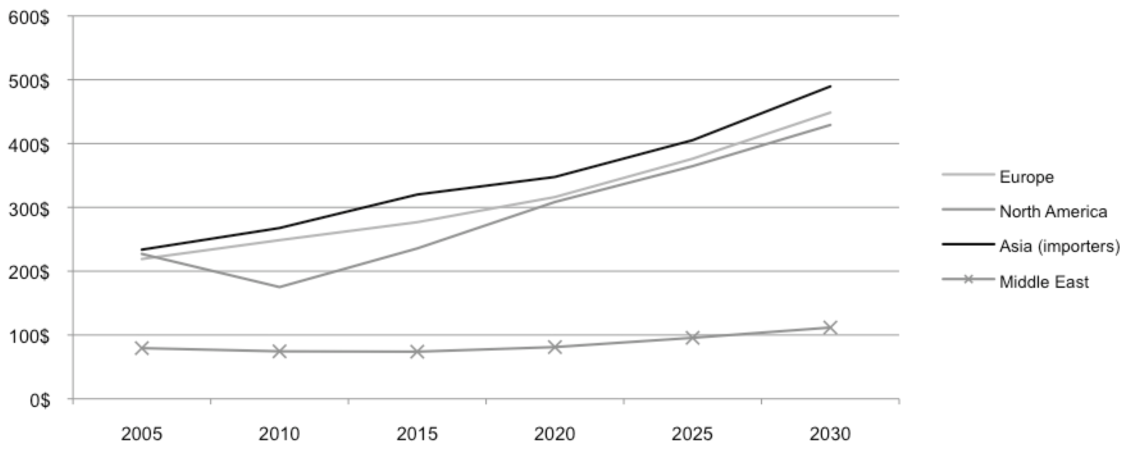

Figure 5: Price development in selected regions, in $/kcm, "Barnett Shale" scenario

The increased domestic production in North America has a profound impact on the global LNG trade (Figure 6). Due to the underlying assumption in the base case that the mature natural gas industry in the US declines over the next decades, more than 60% of global LNG flows are directed to North America in 2030. The total volume of the global LNG trade in this period is 522 bcm/y in the base case. The reassessment of natural gas reserves in North America means a higher level of self-sufficiency, which in turn leads to a global volume of traded LNG of only 396 bcm/y in 2030. Of this, only 40% are directed to the US. This is still higher than some current forecasts (e.g., EIA, 2009a), but significantly lower than expected during the "LNG-rush" a few years ago (see Ruester and Neumann, 2008). North America, in this scenario, receives LNG only from Latin America, Africa and the Middle East. The flows via the Pacific Ocean and exports from Norway and Russia to North America observed in the base case do not occur due to their higher costs.

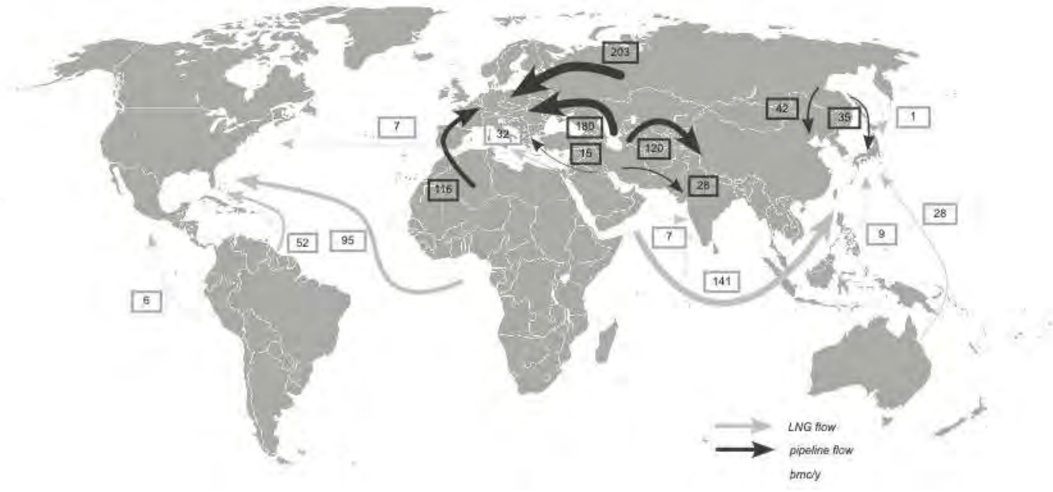

Figure 6: Natural gas trade flows in 2030 by region; in bcm/y, "Barnett Shale" scenario

5 In the Ground

The scenario "In the Ground" is an extension of the base case that updates the exogenously determined limited reserve horizons for all producers. The producers, in their net present value maximization over the entire model horizon, decide when to produce the natural gas given their production capacities. These capacity constraints are determined based on their limited individual reserves. In the base case, the data on production capacity is taken from EC (2006) which includes some optimistic reserve assumptions.

The scenario simulates a tighter 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 from BP (BP, 2008) and the Energy Information Administration (EIA, 2008). Countries with mature production sectors but limited reserves show decreasing production capacities over the next decades while other countries can further expand their production (e.g., West Africa).

As shown in Figure 7, 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 compared to the base case. This reflects the large available reserves in countries such as Iran, Qatar, and Saudi Arabia. At the end of 2007, the Middle East was endowed with 41% of the total proven reserves in the world.

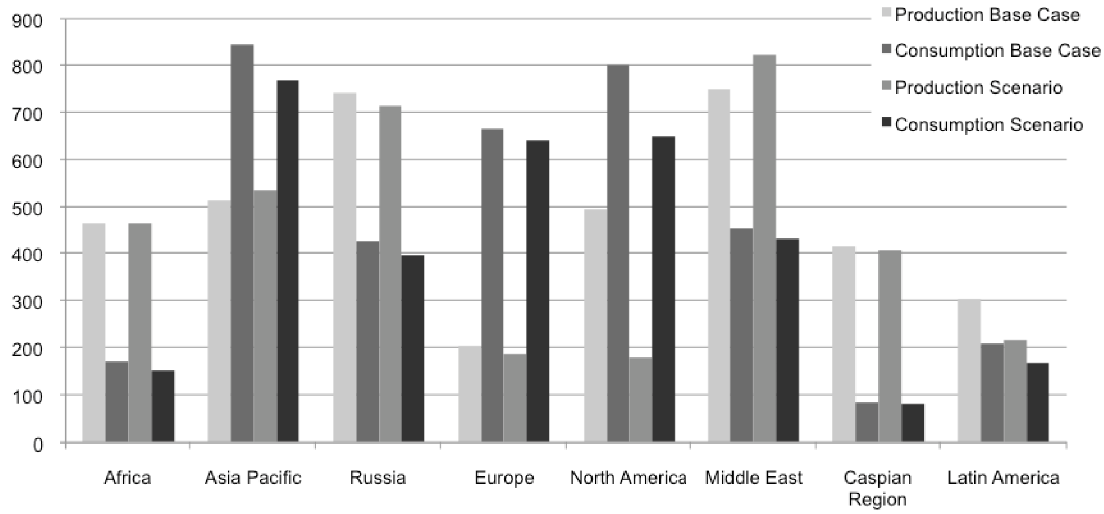

Figure 7: Production and consumption in 2030; in bcm/y, "In the Ground" scenario

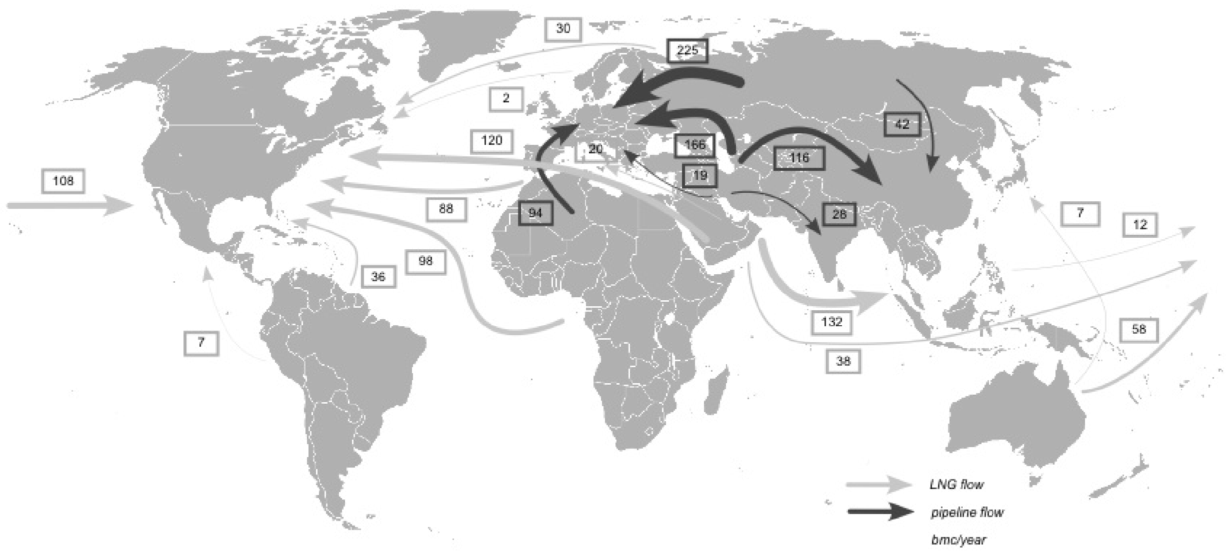

Figure 8: Natural gas trade flows in 2030 by region; in bcm/y, „In the Ground“ scenario

As can be expected, the scenario leads to some considerable 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 8). The Middle East 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 pivotal player in the world natural gas market with virtually all importers relying on it to some extent. It even starts to deliver to the North American West coast via the Indian Ocean and the Pacific basin.

Prices are generally higher in this 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 by about 14% in Asia and almost 40% in Russia and North America. The price increase comes together with a rise of the share of imports in consumption. In 2030, 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, which are complemented by LNG imports from a variety of sources.

6 Post Bali Planet

We now want to examine the advent of an alternative more climate-friendly energy source and that can potentially be substituted for natural gas in consumption. This concept is employed in macroeconomics where it consists in presuming "the current or future existence of a 'backstop' technology that does not depend on non-renewable resources but that is currently very costly, although its cost can be expected to fall over time" (Solow, 2009, 375). 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 in the early years to substitute for natural gas, but is assumed to become economically viable over the next decades. We assume that the backstop technology can substitute for all applications of natural gas, including heating and transportation and that the backstop technology supplier does not have market power.

Figure 9 compares the development of wholesale prices in several world regions to the costs of an equivalent amount of energy from the backstop technology. All natural gas production costs are subject to an (exogenous) annual increase of 3%; wholesale prices subsequently rise by approximately the same rate. 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 deployment of this technology is expanding.

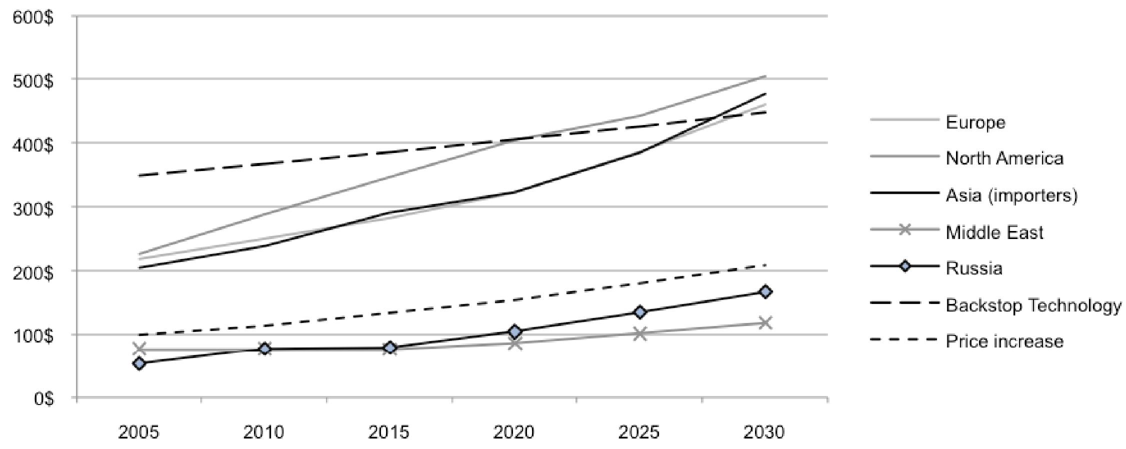

Figure 9: Average wholesale prices (base case), backstop technology costs (post Bali scenario); in $/kcm

As one would expect, the backstop technology is first introduced in those regions where natural gas wholesale prices are highest, namely in North America and parts of Asia. This reduces the total demand for natural gas and, hence, globally leads to lower prices. Europe produces more natural gas domestically and at the same time 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 10). In the scenario, the backstop technology accounts for 15% of energy consumption in 2030 in those sectors which traditionally rely on natural gas.

Figure 11 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 increase of consumer welfare, both because of lower prices and due to more available energy sources.[5]

[5] The increase in welfare is unambiguous only if the backstop technology is not subsidized.

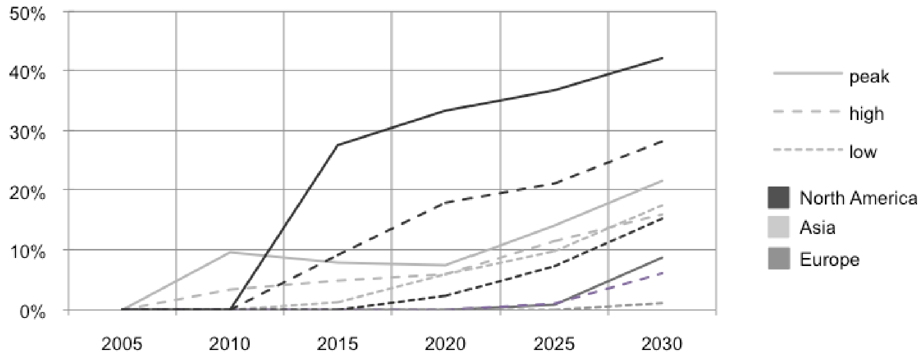

Figure 10: Backstop technology in energy consumption by season, post Bali scenario

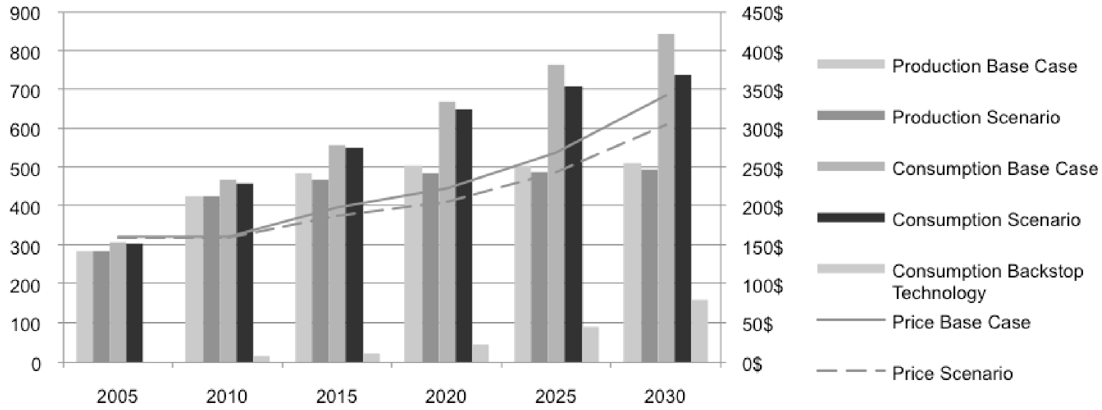

Figure 11: Volumes and average wholesale prices in Asia; in bcm/y and $/kcm, post Bali scenario

7 Eastern Promises

This scenario investigates the effects of a politically motivated move by Russia to stop 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 start in 2015. In this scenario, Ukraine is treated as part of Europe, i.e. it suffers from the Russian supply disruption, unlike Belarus. We want to investigate the adjustment strategies by the European importers to the supply stop from the East.

European countries are immediately hit by the supply disturbance, 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 Norway via Sweden to these countries. These pipelines are constructed between 2015 and 2020, 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 compared to the base case.

However, after the first shock, European natural gas demand picks up again (Figure 12) 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.

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 will 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.

Total Russian natural gas production decreases by about 15%, which translates into a reduction of its profits (summed over producer, trader and liquefiers in the Russian nodes) by more than 40% compared to the base case results. It can therefore be concluded that the politically motivated supply disruption comes with a hefty price tag attached for the Russian state.

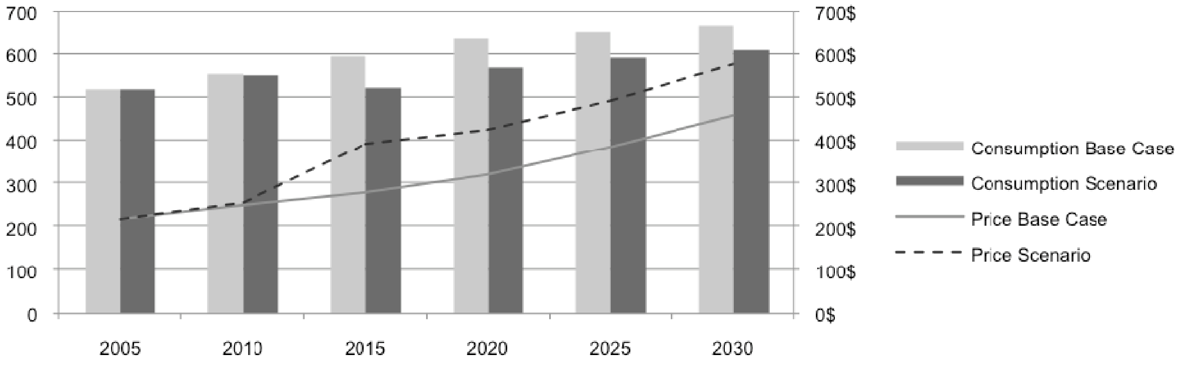

Figure 12: Consumption and average prices in Europe; in bcm/y and $/kcm, Eastern Promises scenario

		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 / *Eastern Promises scenario*); in bcm/y

8 Other Scenarios

8.1 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.[6] 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. There is a striking change in the intra-regional traded volumes between Middle Eastern countries that increase to 8 bcm/y in 2030. Whereas in the base case all countries in the region

[6] 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 et al. (2009a) for another analysis of collusive behaviour.

are virtually self-sufficient in satisfying domestic demand and no intra-regional trade occurs, this no longer holds true in this scenario, triggering some investment in pipelines on the Arab peninsula.

With the missing Middle Eastern production, LNG imports into 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"). However, total global LNG regasification capacities are only slightly lower than in the base case, again reflecting that LNG importers can buy flexibly from all sources. The significant drop in Middle 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 volumes actually liquefied decrease from 595 to 509 bcm/y. Total natural gas production in 2030 drops from 3905 to 3707 bcm/y.

		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: Sales of Middle Eastern natural gas; in bcm/y, scenario "Shutting off the Middle East"

Freezing production capacity in the Arab Gulf countries leads to a significant welfare loss for that region. Evaluating net profits in the time frame under investigation (revenue minus production and investment costs for producers, traders and liquefiers in each country, 2005 to 2030) shows a 7% decline as compared to the base case for the whole region. The negative effect of the strong reduction of quantities on profits is partly compensated by positive impact of the price increase. However, due to the higher prices, regional consumer welfare surplus is reduced over the same horizon by almost 25%. We therefore conclude that the total halt of capacity expansions would not be optimal neither for the producers nor the consumers in the Middle East.

8.2 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.[7] Demand growth factors relative to the first model year in China and India are multiplied by 2.5 from 2015 on compared to the base case assumptions. The regasification capacity expansion potential from 2015 on is 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) are doubled in each period compared to the base case assumptions.

Simulation results show that total consumption levels in 2030 nearly double in both, China and India to 313 and 143 bcm/y, respectively, in line with the assumptions of this scenario. At the same time, domestic 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% in China and 450% in 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 the strong Asian demand increase.

The Middle East region that delivers already today to all major LNG importing regions (i.e. Europe, Asia-Pacific and North America) changes its export pattern significantly. Even though its 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; while exports to Asia increase by 40%.

Traded volumes and wholesale prices under this scenario underline that the uncertainty about future Asian demand levels for energy sources can have 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.

[7] Natural gas demand increased by 19.9% for China and by 7.6% for India between 2006 and 2007 alone. Three LNG import terminals are currently operating in these two countries; more than 20 more projects are proposed. However, there are uncertainties about the realization of a number of projects and the general energy market development, in particular the strength of coal in these countries.

8.3 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 imports can only partially be satisfied by deliveries from Canada, Mexico and Alaska; hence, domestic 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 plan to invest in LNG import facilities in neighbouring 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 U.S. 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 investment is allowed in Western Canada. Maximum pipeline expansion parameters for North America are doubled, such that natural gas from other regions (incl. Mexico) can be brought to the US West coast. 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.[8] 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 pipeline expansion is therefore not economically viable. In the long-run, however, the lack of LNG import capacity leads to lower supplies and natural gas prices rise by approximately 4 % compared to the base case.

[8] 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.

9 Summary and Conclusions

This paper presents simulation results of different structural and regional natural gas market scenarios using the World Gas Model. Table 3 summarizes the scenario assumptions, main results and conclusions of the six scenarios and selected key figures for the global natural gas trade in the year 2030. In the first scenario, the recent reassessment of the North American natural gas reserves, namely the availability of large amounts of modestly priced unconventional gas, mainly shale gas, is examined. Higher production capacity and lower production costs mean that North America depends to a far lesser extent on LNG imports from other regions. Assuming that a substantial level of unconventional production capacity will come online soon, prices in the next years will actually remain modest in the next years in North America.

Taking into account limited natural gas reserves, on the other hand, leads to higher prices in several natural gas consuming regions compared to the base case. North America would be more affected than Europe, when taking into account the current reserve limits given by BP (2008). However, Europe would be reliant on a small number of suppliers, raising worries about diversification and security of supply. 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, decrease 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 after 2010. Average prices increase by 40% in Europe in the starting 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 considerably; instead, it ships more LNG to North America.

Scenario	Assumptions	Main results and conclusion	Key figures in 2030		
			Consumption in bcm/y	**Average price** in $/kcm	**LNG**[9]
Base Case			3758	326	15.8%
Barnett Shale	Higher production capacity in North America from 2010 on	…higher level of self-sufficiency in North America …less global LNG trade	3870	308	11,7%
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 ...North 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 North 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

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 to Europe and North America. Since there is a lot of uncertainty about how Asia will satisfy its hunger for energy, one further 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 some of their LNG exports from Europe and

[9] Share of LNG in global natural gas consumption

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. Then West coast prices may actually fall in the short run due to the availability of other import options (e.g., LNG re-exports from Mexico); but in the long run prices are slightly higher compared to the base case.

For future research, there are 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. From a modelling perspective, there are certain limitations in investigating such a scenario. Egging et al. (2009a) provide a first step in this direction, but more research is needed to compare different types of collusion of the producers. The WGM can also be extended to include stochasticity, e.g. in future demand projections, production capacities and supply disruptions. No stochastic scenarios have yet been investigated but 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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