The World Gas Market in 2030 - Calculation of Development Scenarios Using the World Gas Model[1]

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Abstract

In this paper we provide a discussion of potential developments of the world natural gas industry at the horizon of 2030. We use the World Gas Model (WGM), a dynamic, strategic representation of world natural gas production, trade, and consumption between 2005 and 2030. In particular, we specify a "base case" which defines the business-as-usual assumptions based on forecasts of the world energy markets. We then analyze three structural scenarios, representing i) tightly constrained reserves, ii) sharply constrained production and export activities in the Arab Gulf, and iii) the impact of CO_2-constraints and the emergence of a competing environmental friendly "backstop technology". Another set of scenarios focuses on regional trends: we simulate iv) the full halt of Russian exports to Western Europe, v) heavily increasing demand for natural gas in China and India; and finally vi) constraints on infrastructure development on the US Pacific Coast. 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.

Keywords: natural gas trade, World Gas Model, mixed complementary problem, reserves, infrastructure investments, climate policy

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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 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 intransparent.

In this paper, we provide a balanced discussion about the perspective of the world natural gas industry until 2030. In particular, we specify a "base case" which defines the business-as-usual assumptions based on forecasts of the world energy markets. We then analyze three structural scenarios, representing i) tightly constrained reserves, ii) sharply constrained production and export activities in the Arab Gulf, and iii) the impact of CO_2-constraints and the emergence of a competing environment-friendly "backstop technology". Another set of scenarios focuses on regional trends: we simulate iv) the full halt of Russian exports towards Western Europe, 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 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 close as possible (Section 3). Sections 4 and 5 sketch out structural and regional scenarios. Among the structural scenarios, we estimate a production reduction and the advent of a climate friendly, carbon-constraining policy. The regional scenarios focus on a supply shock in the Middle East, Russia diverting trade to the East (i.e. Asia), China and India with exploding natural gas consumption, and NIMBY-policies pursued in California vis-à-vis LNG imports (Section 5). 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. Section 6 concludes that 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 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 (i.e. traders and regasifiers). See Egging et al. (2008) for a detailed description of the 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 present 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.

The WGM takes into consideration LNG contracts known as of today as the minimum amount sold from each liquefier to a regasifier. Assuming 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.

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 economically optimal.

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.

2.2 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. There are at least two reasons for this. First, 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 this paper 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.

2.3 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 4.1).

The calibrated worldwide base case consumption (production)[2] in 2005 is 2368 (2435), and 3757 (3905) bcm in 2030, and an average wholesale price of \$375 per 1000 m^3. An average yearly price increase of 3%, in accordance with POLES projections, is used. For infrastructure capacities (pipelines, LNG liquefaction and regasification terminals, storage), project and company information from various sources (e.g., Oil and Gas Journal, GSE database at www.gte.be) has been employed. 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 scientific community 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 and consumption over the whole forecasting period up to a level of about 3,900 bcm/y in 2030.

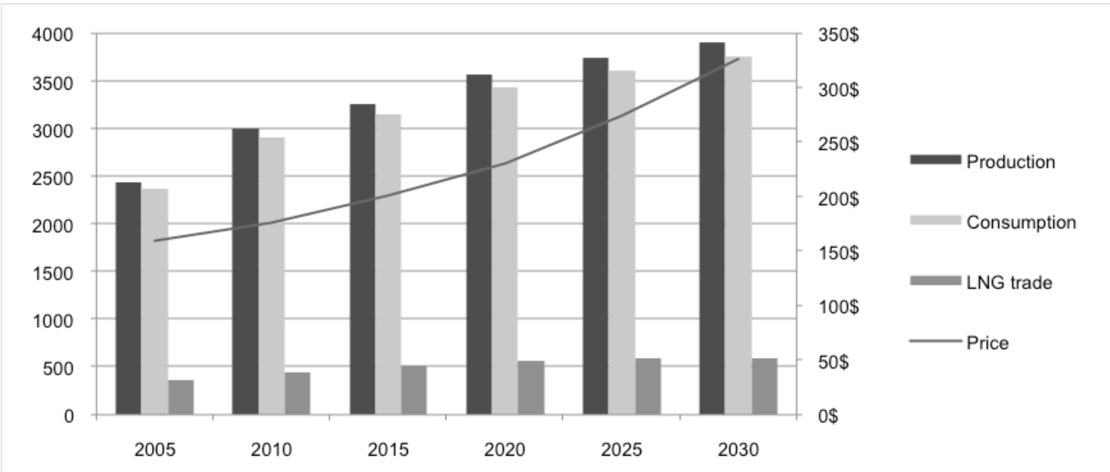

Figure 1: World consumption and production and world average wholesale price; in bcm/y and \$/kcm

The WGM assumes a yearly price increase of 3%. LNG trade grows until 2020 and then reaches a plateau close to 600 bcm/y; this accounts for approximately 15% of total natural gas production. The amount of natural gas consumed in its production markets drops from 60% to close to 50% of total consumption over the time horizon, while the share of natural gas exported by pipeline remains relatively stable (30%).

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.

[2] 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

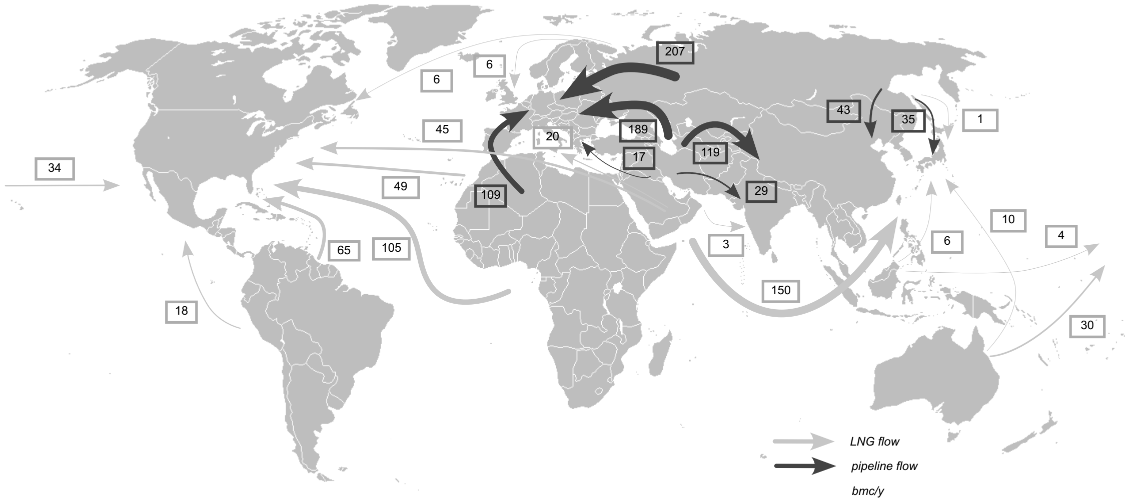

Figure 2: Natural gas flows in 2030 by region; in bcm/y, base case

In the base case, Asia consumes almost 850 bcm/y in 2030. Looking at the country level reveals a very differentiated picture: while Japan and Taiwan rely to a large extent on LNG imports, China and India each produce half of their consumption domestically and import another 40% by pipeline from Russia, Burma, the Caspian region; the Middle East with LNG only plays a minor role. North America produces about 60% of its consumption domestically with the remaining 40% satisfied by LNG imports (apart from intra-regional trades).

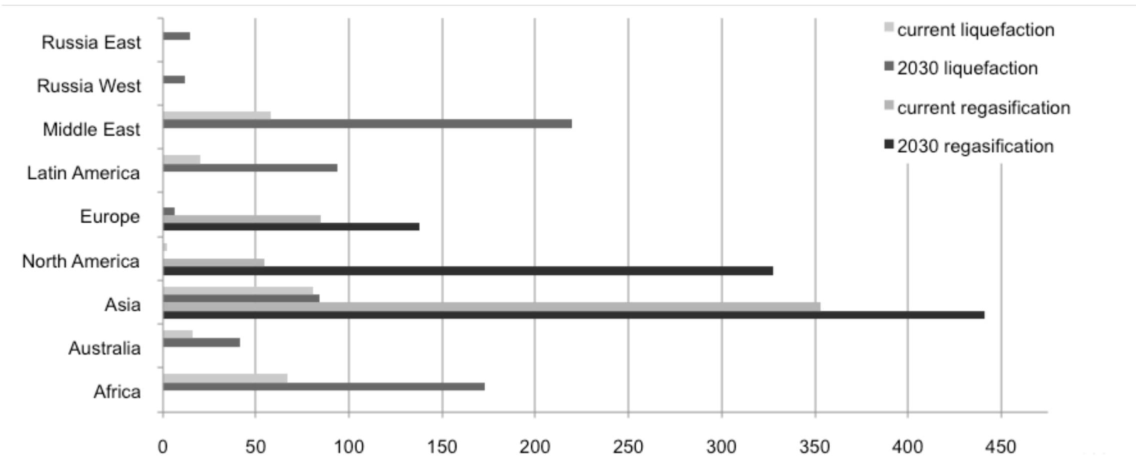

Figure 3: Investments in liquefaction and regasification capacities; in bcm/y, base case

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 being able to import 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.

4 Structural Scenarios

In this section, we present the results of three scenario runs which assume major structural changes in the world natural gas market (i.e. tightly constrained reserves, sharply constrained production and export activities in the Arab Gulf, and the impact of CO_2-constraints).

4.1 „In the ground"

This first scenario is an extension of the WGM base case including exogenously determined reserve horizons for all producers. We do not allow for exploration and only take into consideration proved reserves which with today's technology are economically producible at the time of writing. The data is taken from BP (BP, 2008) and the Energy Information Administration (EIA, 2008). As can be seen in Figure 4, 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.

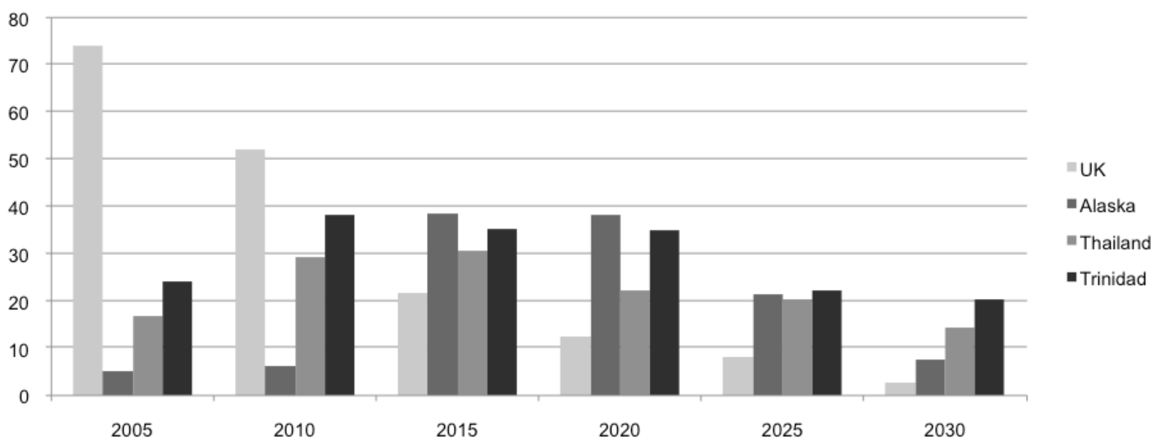

Figure 4: Production in selected countries; in bcm/y, „in the ground" scenario

As shows Figure 5, both North and Latin America considerably reduce their production levels in this scenario, whereas the Middle East is the only region in a position being able to expand its production when compared to the base case. This mirrors the huge available reserves in countries such as Iran, Qatar, or Saudi Arabia; the Middle East at the end of 2007 was endued with 41% of total world proven reserves.

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. However, the Middle East with its huge reserves is at the same time expanding its pipeline deliveries to Europe compared to the base case. 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 Indian Ocean and 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.

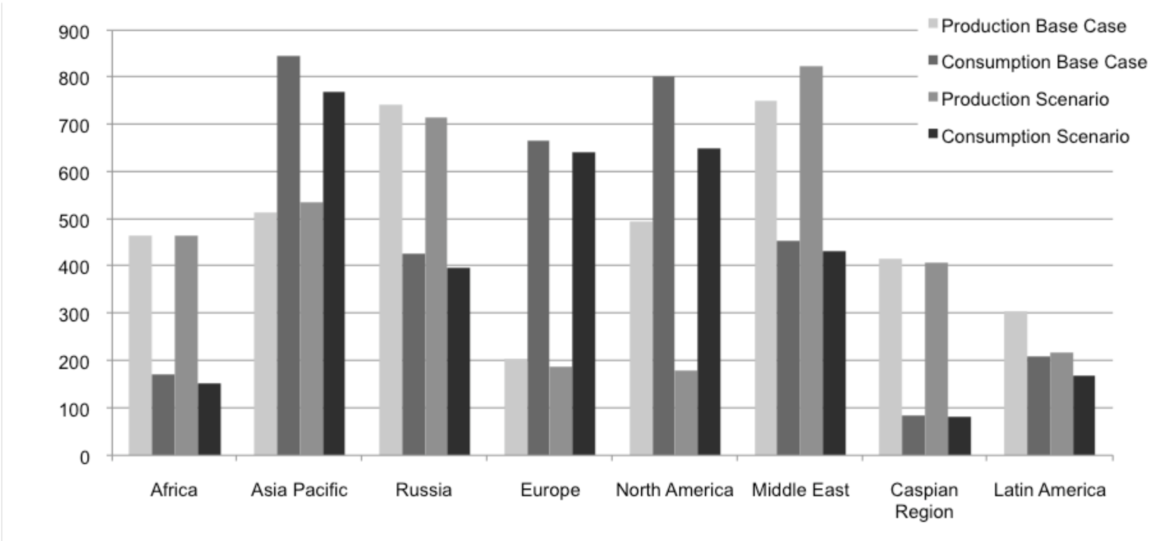

Figure 5: Production and consumption in 2030; in bcm/y, "in the ground" scenario

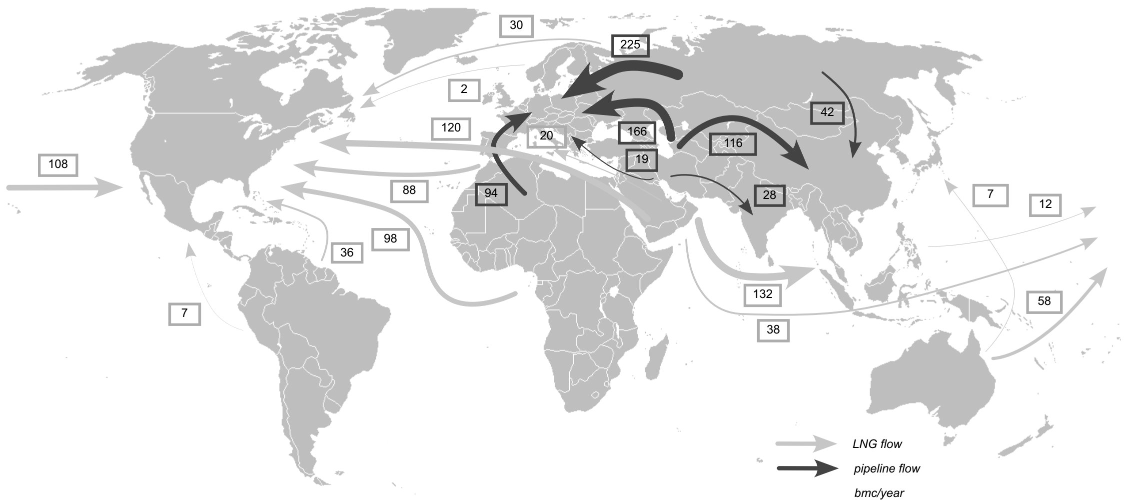

Figure 6: Natural gas flows in 2030 by region; in bcm/y, „in the ground“ scenario

Simulation results also show the high dependency of Europe in 2030 on a limited number of suppliers. While both North America and Europe can satisfy only less than 30% of their consumption with domestic production, North America is supplied with LNG from a wide array of producers. Europe, on the other hand, relies to 50% on imports from Russia and the Caspian region. Political instability in Central Asia or the Black sea region, where most of the imports pass through, could quickly lead to shortages and price increases in European countries.

4.2 „Shutting off the Middle East“

In the second scenario, we study the impact of a supply shock in the Middle East. This scenario can also be interpreted as the result of a GasPEC 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.[3] 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. Due to the production cost curve shape, where production close to full capacity is prohibitively expensive, production still increases slightly during the forecasting horizon due to the high prices in the scenario (see Figure 7). Still, the production expansions are much smaller than in the base case (i.e. the nominal production level in 2030 is 41% lower).

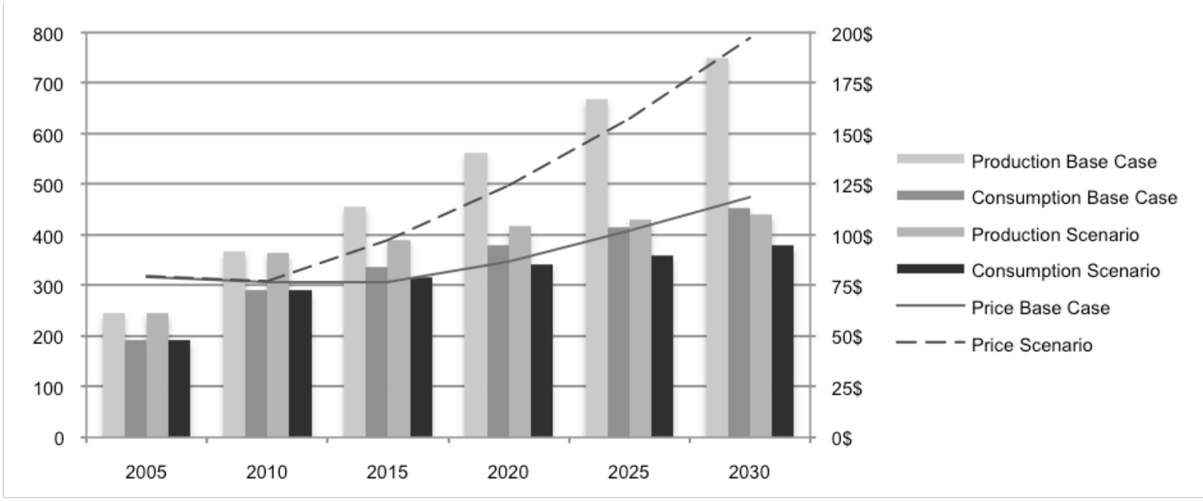

Figure 7: Volumes and average wholesale price in Middle East; in bcm/y and $/kcm, Middle East scenario

Table 1 shows the development of Middle Eastern domestic consumption and exports; 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%). Only 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 Eastern liquefaction capacities is partly made up by other producers, such as Western Africa and Latin America (see Figure 8). The global liquefaction capacity drops from 650 to 590 bcm/y, while the amounts actually liquefied decrease from 595 to 509 bcm/y. Total production in 2030 drops from 3905 to 3707 bcm/y.

[3] This scenario is, of course, not a true cartel representation, where the exact amount of withholding would be decided by the profit optimization problem of the cartel member. See Egging, Holz, Hirschhausen, Gabriel (2008) for another analysis of a gas market cartel.

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

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 argue that the total halt on capacity expansion is not an optimal policy for a cartel.

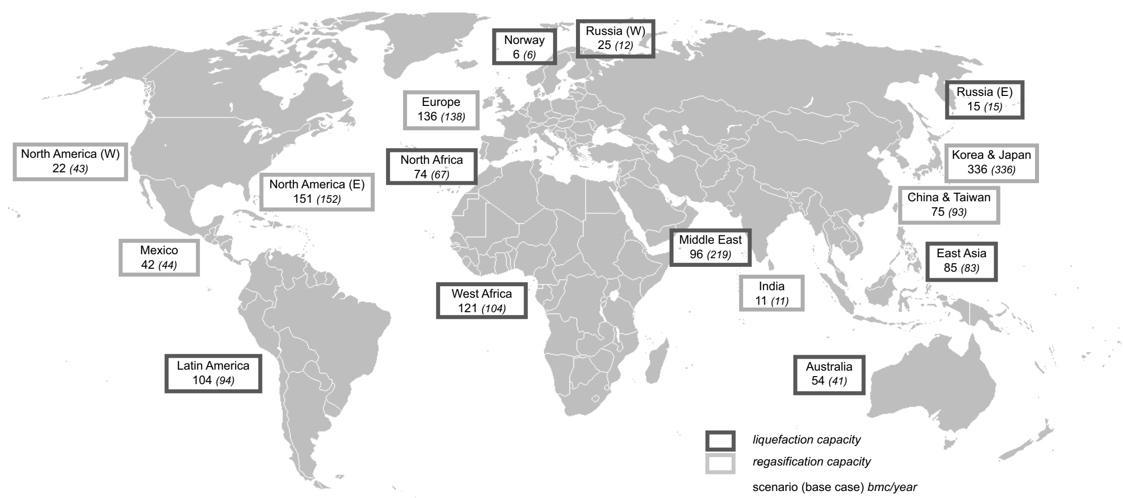

Figure 8: Liquefaction and regasification capacities in 2030; in bcm/y, Middle East scenario

4.3 „Post Bali planet“

In this third 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 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.

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 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 competitive market price (i.e., marginal cost price).

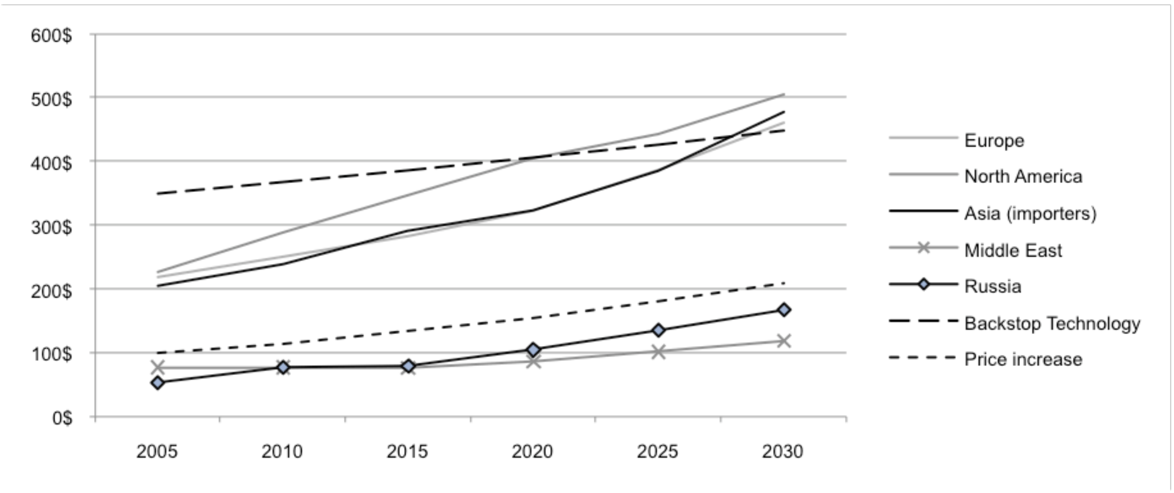

Figure 9: Average wholesale prices (base case), backstop technology costs (post Bali scenario); in $/kcm

As one would expect, the backstop technology is first introduced in those regions where 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 ample 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 10). In the scenario, the backstop technology accounts for 15% of energy consumption in 2030 in those sectors which traditionally rely on natural gas.

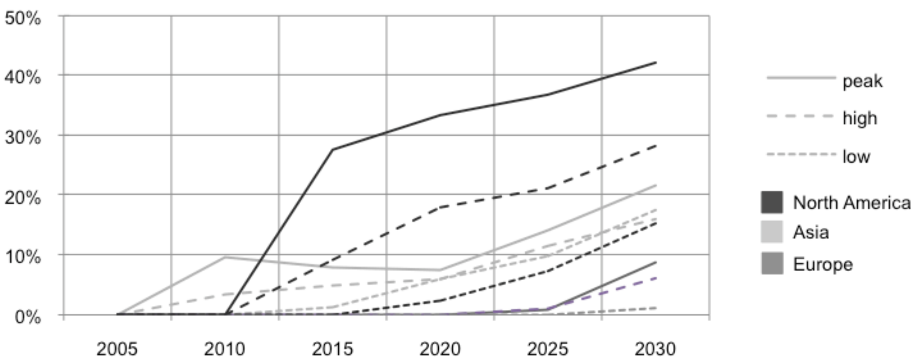

Figure 10: Backstop technology in energy consumption, post Bali scenario

Figure 11 shows that the introduction of a backstop technology leads to a noteworthy decline of wholesale prices compared to the base case (using the example of Asia, trends in other regions are 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.

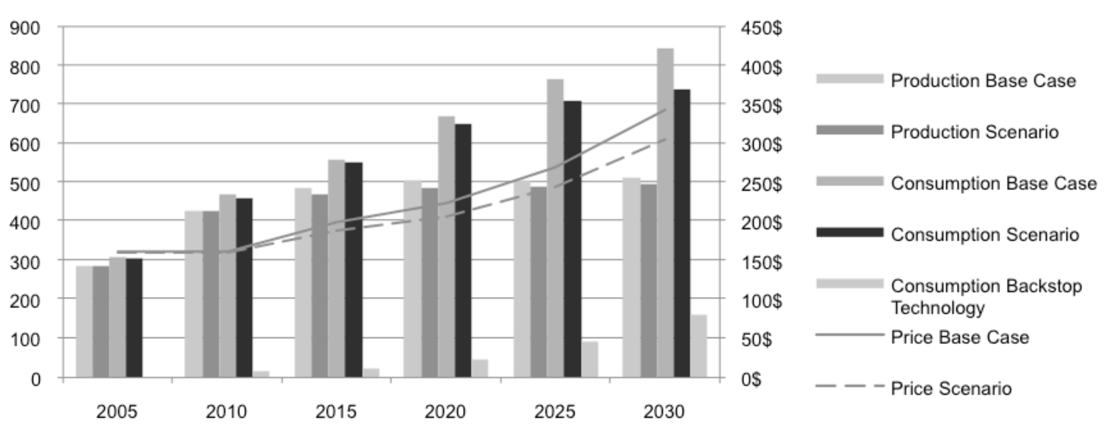

Figure 11: Volumes and average wholesale prices in Asia; in bcm/y and $/kcm, post Bali scenario

4.4 Summary structural scenarios

Table 2 summarizes model changes, main results and conclusions and selected key figures on each of the three structural scenarios in the year 2030.

Scenario	In the ground	Shutting off the Middle East	Post Bali planet
Assumptions	Production horizon fixed at level of today's proven reserves; no exploration	Production capacities for Middle Eastern producers are fixed at 2010 levels	Introduction of an environmentally friendly backstop technology
Main results and Conclusion	...has high impact on the price in North America ...puts Europe in a bad situation in terms of supply security	...leads to a worldwide price increase ...results in lower profits and reduced consumer surplus in Middle East ...is not a good cartel policy	...leads to higher consumer surplus worldwide ...N. America and Asia adapt the new technology quickly ...Europe waits long before using the new technology
Consumption	(3758 bcm/y) 3387 bcm/y	3573 bcm/y	3509 bcm/y
Average price	(326 $/kcm) 405 $/kcm	353 $/kcm	292 $/kcm
Share of LNG	(15.8%) 22.4%	14.4%	9.7%

Table 2: Summary structural scenarios; figures for year 2030, base case reference figures in brackets

5 Regional Scenarios

In this section, we present the results of three scenario runs which assume major regional changes in the world natural gas market (i.e. the full reconversion of Russian exports towards Asia, heavily increasing demand for natural gas in China and India, and constraints on infrastructure development on the US Pacific Coast).

5.1 "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. The interruption is assumed to take place in 2015. Ukraine is (unlike in the standard WGM) treated as part of Europe, while Belarus is still supplied by Russia.[4]

European countries are hit hard 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 after 2010 in this scenario, 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 WGM). 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 effect is significant in both countries, with prices almost twice as high as compared to the base case. Due to the expansion of the pipelines in the following periods, the average wholesale price then returns to the European average path.

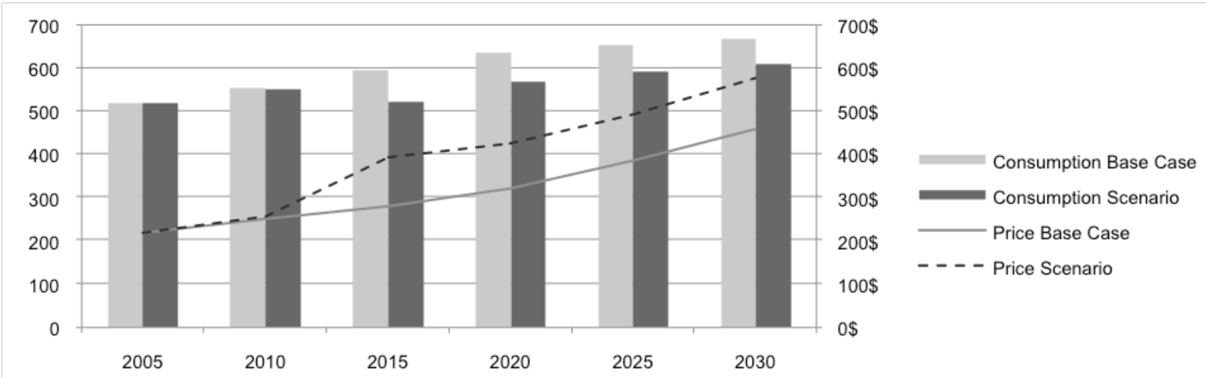

Figure 12: Consumption and average prices in Europe; in bcm/y and $/kcm, eastern promises scenario

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

[4] In the standard WGM, Ukraine and Belarus are one region (UKRBLS)

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 3 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 Pacific coast would increase significantly (+350% to 30 bcm/y instead of 6.4 bcm/y). Russian production in sum decreases by about 15%.

5.2 "Tiger and dragon"

The "tiger and dragon" scenario investigates the impact of a strong demand increase in Asia (with a focus on China and India since uncertainty about the future natural gas demand in these two developing countries is significant) on the global gas industry.[5] Demand growth factors in China and India hence were multiplied by the factor 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. All investment parameters for pipelines leading to China and India, including those through transit countries (e.g. from Iran via Pakistan to India) were doubled compared to the base case assumptions.

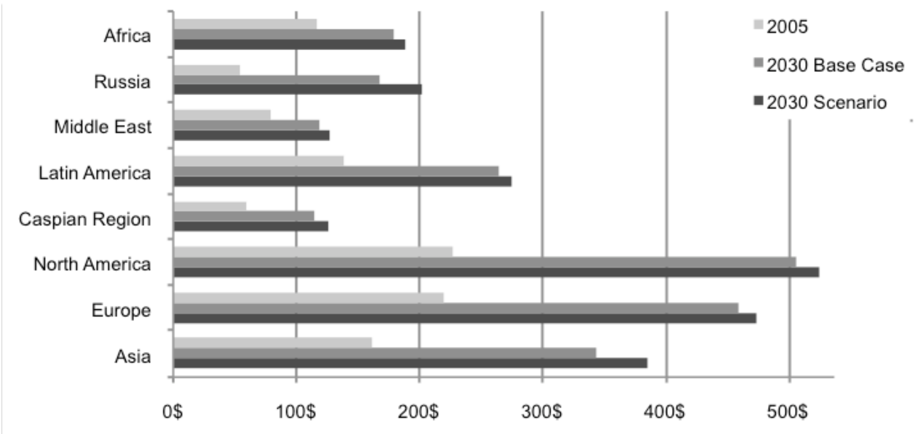

Figure 13: Average wholesale prices by region; in $/kcm, tiger and dragon scenario

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

[5] 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 huge uncertainties about the realization of a number of projects.

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 (see Figure 13).

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 under this scenario. 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% (see Figure 14).

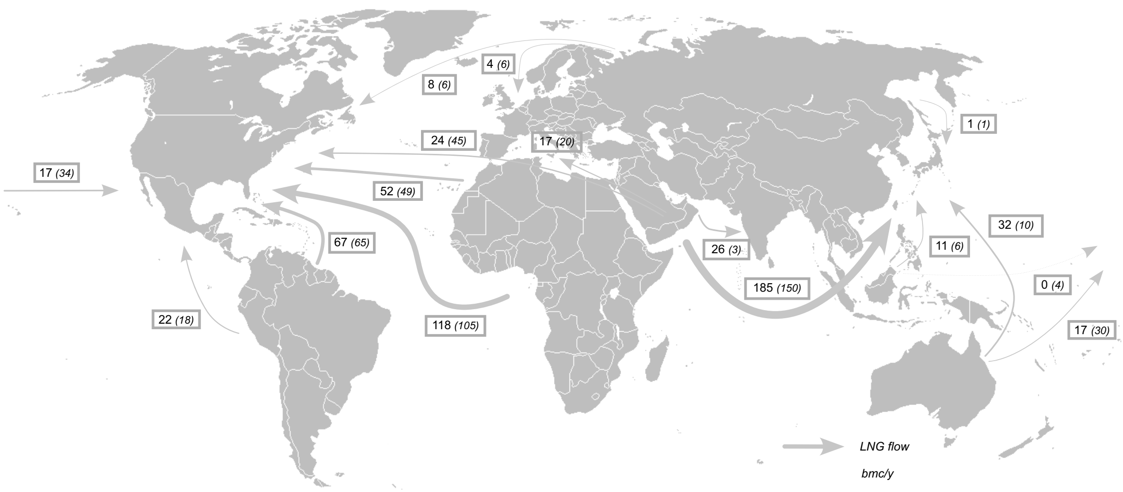

Figure 14: LNG flows in 2030; in bcm/y, tiger and dragon scenario *(base case)*

Traded volumes and wholesale prices under this scenario underline that the huge 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.

5.3 "Pretty coast California"

This last scenario is intended to show that the WGM is not only useful in analysing global dynamics of natural gas trade but can also provide insight to situations that only have regional effects.

Since US domestic natural gas production is expected to decline in the near-term, the country with the second largest consumption worldwide will 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 western states, companies facing public resistance already today 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 potential 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.

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.[6] 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 level.

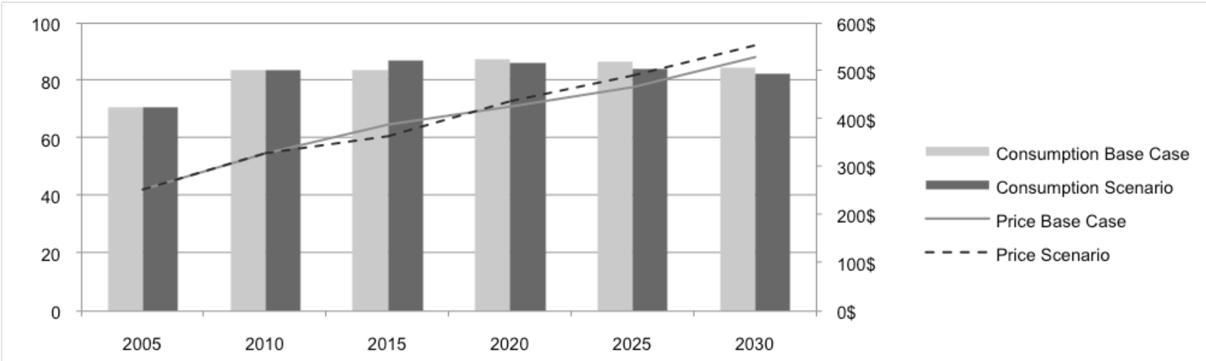

Figure 15: US West coast natural gas consumption and average wholesale prices; in bcm/y and $/kcm

5.4 Summary regional scenarios

Table 4 summarizes model changes, main results and conclusions of the three structural scenarios and selected key figures for the global natural gas trad in the year 2030.

Scenario	Eastern promises	Tiger and dragon	Pretty coast California
Assumptions	No exports to Europe from Russia after 2015	Demand growth factors of China and India multiplied by 2.5	No regasification capacity to be built on US west coast
Main results and Conclusion	…raises prices by 25% in Europe … Russia ships more LNG to North America	…leads to worldwide price increases …induces the Middle East and Australia to divert exports to Asia	…may lead to lower prices in the short run … reduces supply and drives prices up in the long run
Consumption	(3758 bcm/y) 3688 bcm/y	3878 bcm/y	3756 bcm/y
Average price	(326 $/kcm) 374 $/kcm	344 $/kcm	326 $/kcm
Share of LNG	(15.8%) 17.8%	17.7%	15.6%

Table 4: Summary regional scenarios; figures for year 2030, base case reference figures in brackets

6 Conclusions and Future Directions

This paper 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

[6] 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.

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.

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 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 GasPEC, a cartel 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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