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Analysis and assessment of the optimal gas corridors and infrastructure to secure supply in Europe

A model based analysis

F. van Oostvoorn

W. Lise

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Acknowledgement
This report presents the result of a study conducted in task 3 of Work Package 2: 'Optimal gas corridors in Europe', in the framework of the ENCOURAGED project. It concerns a model-based identification and analysis of medium and long-term gas infrastructure in Europe necessary to connect the EU markets with its main gas suppliers in the neighbouring countries. The ENCOURAGED project has been funded by the European Commission under the 6th Framework Programme for Research, Technological Development and Demonstration (Scientific Support to Policies), see www.encouraged.info. Domencico Rossetti di Valdalbero (European Commission, DG Research) has supervised the project and work on behalves of the EC. The study in this report is conducted by ECN Policy Studies and is registered under project number 7.7670.

In 2006 Wietze Lise of ECN has developed the current version of the GASTALE model (as applied in this report) and has conducted the model analysis. The authors of the report are Wietze Lise and Frits van Oostvoorn, the coordinator of ENCOURAGED project, both of ECN. Authors are grateful for the support and guidance of Manfred Hafner, coordinator of work package 2 (WP2) on gas corridors, as well as Andrew Ellis of ECON, Sohbet Karbuz and Benoit Esnault from OME, who provided much of the key data and inputs within the WP2 tasks, that were also necessary to specify the model and conduct the model-based study.

For any questions regarding this project, please contact coordinator ENCOURAGED:

Frits van Oostvoorn
Email: oostvoorn@ecn.nl
Telephone: +31(0) 224 564438.

Abstract
Presented are the results of a model-based analysis of medium and long-term gas infrastructure in Europe necessary to connect the EU gas markets with its main gas suppliers in the neighbouring countries. Different gas scenarios were developed to deal with the uncertainties surrounding the assessment of the optimal gas infrastructure capacities in terms of the required pipeline, LNG and storage facilities for connecting the gas supply and demand between different European countries and particularly mitigate supply security risks for consumers in the next decades.

Executive summary

Scope of the study

In several official communications and publications the EU has repeatedly emphasized its role as a force for stability and a sustainable energy development in Europe and formulated as key energy policy objectives for the EU:

- Enhance the security of energy supply
- Strengthen the internal energy market
- Develop sustainable energy markets

According to many studies for the EC, e.g. the official EU energy scenarios in the Green Paper[1] the dependency of the EU-27 on gas supplies from neighbouring countries is expected to increase from 40% to 70% or more in 2030. Consequently the role of current and future neighbouring countries in the development of the energy markets of the EU, as they are the main gas and oil suppliers and often key transit countries of oil and natural gas to the EU is increasing. But not only the EU imports of oil and gas will grow significantly in the next decades, also electricity exchanges and perhaps in a later period the hydrogen supply from neighbouring countries might also increase in the long term. In this manner these countries will also benefit from the internal market and become a part of the actions of the EU to integrate the energy markets of the EU and its surrounding countries.

To achieve these different objectives the effective development of the economic optimal energy corridors or gas infrastructure between the EU and the neighbouring countries is of crucial importance. The ENCOURAGED project was launched with a key objective "Assessing economically optimal energy corridors for electricity, natural gas and hydrogen between EU and neighbouring countries as well as identifying barriers and benefits and recommended policy measures for reaching a pan-European energy network". In the project the study of the gas corridors between the EU and its neighbouring countries, Work package 2, concerned the following tasks:

- Task 1: Analyse and project gas demand (scenarios) for European countries and review gas market structure, changes in it and its impacts on gas transport to EU markets in long run.
- Task 2: Analyse and assess the gas supply and existing and potential new gas supply routes for connecting the EU to its neighbouring suppliers, as well as supply costs and transit issues.
- Task 3: Model based analysis and assessment of optimal gas supply routes and connections between the EU and its neighbouring countries to secure supply in Europe.
- Task 4: Formulate conclusions, policies and recommendations for realizing these optimal supply routes and connections and drafting a final report.

This report presents the results of task 3, a model-based analysis and assessment of the economic optimal gas corridors and related infrastructure requirements between the EU and its neighbouring suppliers in the medium and long term.

Approach

On the basis of model based analyses we identify so called "Economic optimal gas corridors between the EU and its neighbours" which need to be expanded in the future. For identifying the necessary and optimal locations of supply connections in Europe, we need projections/assumptions on different gas market developments and drivers needing the optimal gas infrastructure for balancing supply and demand in the long run up to 2030. For that purpose dif-

[1] A European Strategy for Sustainable, Competitive and Secure Energy-COM(2006) 105,8.3.2006.

ferent scenarios are developed, namely a so-called Business-as-Usual (BAU) scenario, a high and low gas demand scenario and a 'deferral of investments' scenario.

First, on the basis of the Business-as-Usual (BAU) scenario the required new gas infrastructure (pipeline connections, storage capacity and LNG facilities) is analysed and optimal corridors are identified and assessed. This model-based analysis also provides, by assuming a projection of gas demand, available supply and its costs, the necessary investments in and the investment costs of gas infrastructure facilities (e.g. pipelines, storage and LNG), over the period 2005-2030 in Europe.

Next, by comparing the BAU results with the results of the other alternative scenarios (scenarios related to the key drivers for development of infrastructure investments), we dealt with uncertainties in some key gas market drivers which influence the demand for gas infrastructure. Through this analysis we also assess the robustness of our findings in the BAU scenario and learn where sensitive decisions are located. The main underlying drivers are the changes in gas demand (lower/higher) and delays in investment in gas transport infrastructure (pipeline transport, LNG facilities and storage capacity). Next to influencing infrastructure needs these assumptions also have a direct bearing on gas prices (among other factors, related to congestion) and flexibility and thus supply security in Europe.

Finally we analysed the impacts of short term interruptions in gas supply from the different key suppliers for the year 2010 and 2020 using the BAU scenario. These show how vulnerable the EU will become for gas supply interruptions and what type of investments could enhance the supply flexibility and thus supply security.

The GASTALE model and study assumptions

As a tool for studying the security of gas supply in the EU, the study uses a computational game theoretic model with recursive dynamics to represent investment by transmission and storage system operators. The model solves for a short-run equilibrium in each five-year period, and makes investments at the beginning of each period based on anticipated market situation including congestion costs at the end of each period.

The assumed market structure is as follows. Market participants include producers, consumers, transmission and storage system operators. Producers contract with pipelines and LNG shippers to transport gas to customers in consuming countries. Producers can exercise market power, playing a Cournot game subject to some forward contracting against other producers as well as arbitragers and storage, and anticipate how quantity demanded depends on price. However, owners of transmission and storage are assumed to be regulated or otherwise operated in such a way that transmission is priced efficiently. That is, the price of transmission (or storage) equals long-run marginal cost, unless transmission (storage) capacity constraints are binding, in which case the price of transmission (storage) reflects a congestion premium in order to clear the market for transmission (storage) capacity[2]. Although producers anticipate demand changes in response to price, they do not exercise market power with respect to transmission, that is, they are price taking with respect to the cost of pipeline and LNG shipping.

The ECN GASTALE model is mainly used to study the required gas supply infrastructure necessary to meet the projected gas demand with available gas supply from the key suppliers surrounding the EU in the period 2005-2030. A substantial part of production of natural gas takes place in the EU, which is sufficient to meet about 60% of the demand in 2005. The remaining 40% of demand is met by production outside the EU. The model distinguishes among consumers in ten European regions. Figure 1 illustrates the geographical coverage of GASTALE. For the analysis and identification of optimal gas supply routes all relevant options, including esti-

[2] Because of this assumption, transmission (storage) can be equivalently modelled as being owned by a single transmission (storage) system operator TSO (SSO) who is price-taking.

mated costs of new investments to build capacity are specified in the model. For example, gas supply from Russia can be transited via Central Europe into Germany. Other corridors are between Norway and the UK, three South-North corridors, namely the corridors between Algeria and Spain, Algeria and Italy, Libya and Italy and the two corridors between Turkey and the Balkan, one extending to Italy. As shown in Figure S.1, various LNG supply options to Europe are specified in the model. Finally it is assumed that there is a trend towards a further liberalized market with a few key players (suppliers) in the long run. Gas prices are established via demand/supply equilibrium; there is seasonal flexibility in demand and, finally, producer export capacity to the EU is exogenous in the model (hence, we assume exogenous residual production/supply functions) and investments in transport corridors (pipelines, LNG, storage) are endogenous variables.

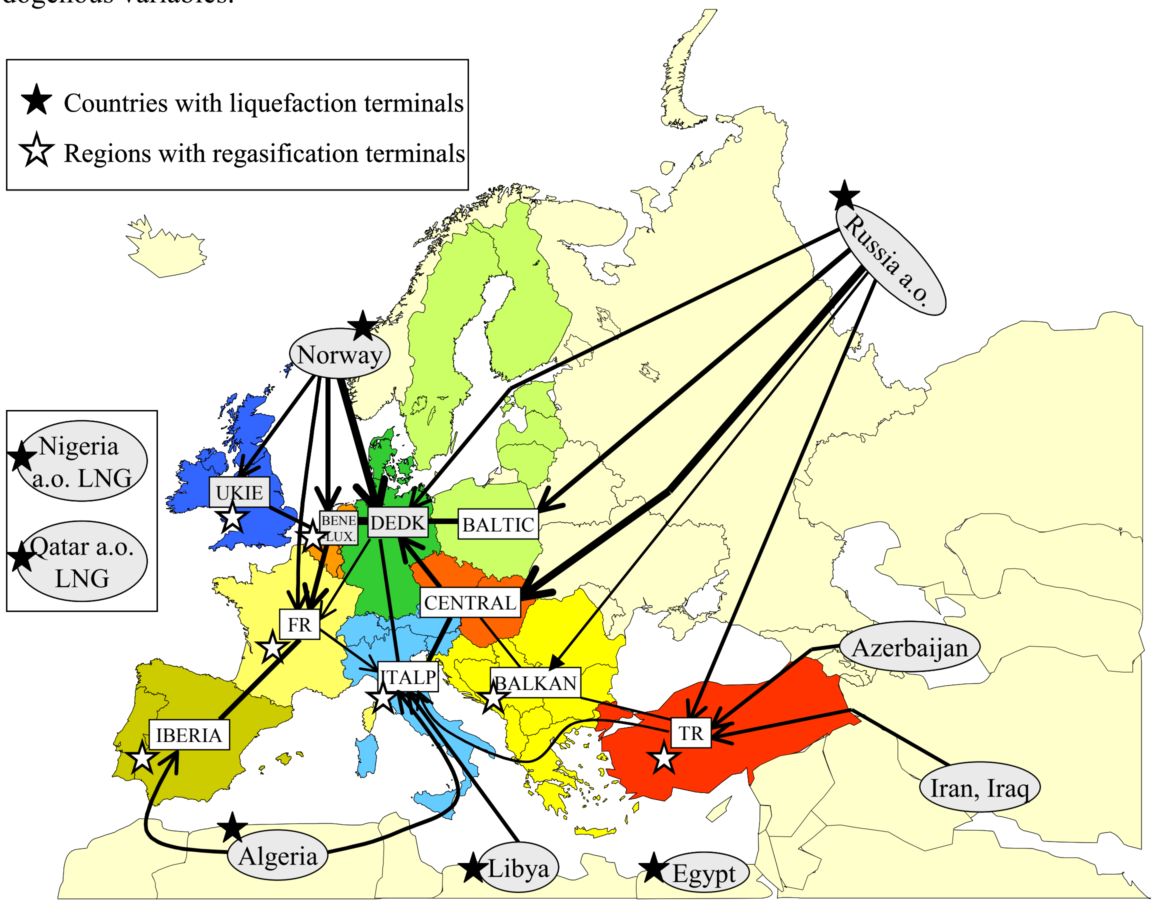

Figure S.1 *Schematic representation of connected consumers and producers in GASTALE for 2005-2030*

Main results and findings

The *BAU scenario* and the analysis of its gas market impacts lead to the following conclusions. According to the model-based analysis and with hindsight several existing *pipelines* to connect the EU are not fully based on economic considerations. An example is the Baltic line between Russia and Germany and the Blue Stream pipeline between Russia and Turkey. An important motive for the (planned) construction of these projects was the strategic advantage gained by the owner of the pipelines. Furthermore, the least-cost option of supplying Norwegian gas to the European market is to 'land' all gas in the UK and from there on transport it further to mainland Europe. The expansion of existing pipelines of Norway to Belgium, Germany and France are economically less attractive than this route. Furthermore, the North-African connection into Europe is used at its maximum capacity, which results in additional production of North-Africa by supplies of *LNG* as a second best option for transporting gas into Europe. Also the Russian option to export LNG to Europe seems to be an attractive supply option. However, such an evolution occurring in the next decade is deemed, unlikely by many gas market experts. In addition, investments in expansion of pipeline connections of Norway to the UK and of Northern Africa to Spain and Italy are economically attractive. LNG is an attractive option from a purely economic point of view and could on economic grounds substitute an increasing part of the existing and newly planned pipeline network. The pipeline connection between Egypt and Turkey is also an economic attractive project, however it is very uncertain when precisely this connection will be realised. This leads to LNG as the second best option for supplying the EU from Egypt.

Regarding upstream *gas supply prices*, the conclusions on the basis of the BAU scenario are that price differences among countries depend on two major factors, namely 1) the distance from the main producer and 2) the impact of strategic price manipulating behaviour and in particular of Russia the largest producer. For instance, prices in France are high due to factor 1), while prices in the Baltic countries are high due to factor 2) from 2015 onwards. Prices are the lowest in Turkey, due to potentially good access to relatively less expensive supplies from nearby producers, namely Russia, Azerbaijan and Iran, making Turkey altogether an important transit hub to the EU. For this reason gas flows from the EU towards Turkey are not attractive in the model analysis and so probably will never occur in the future. Prices in the low demand scenario are lower than the BAU prices, while prices in the high demand and deferral scenario are higher than the BAU prices. Investments are either lower or taking place later in time in the deferral scenario as compared to the BAU scenario. This happens for all three types of infrastructure investments (pipelines, storage and LNG facilities).

Simulation of the *short-term supply security concerns* by analysing the impacts of possible interruption of gas supplies from the several key suppliers to EU in 2020 shows that this will lead to higher gas prices in the consumer countries located close to the interrupted supplies when compared to the BAU scenario. The price impact is higher for disruption of imports from Algeria and Azerbaijan/Iran in 2020 due to higher gas flows from those countries in that year, while the price effect is lower for CENTRAL in 2020, due to availability of alternative gas supplies. Disrupted supplies are mainly compensated by Russia in the Algerian and Caspian gas supply interruption cases, while long distance LNG mainly provides the extra supply in the Russian gas supply interruption case, while due to more Russian transit through Turkey, supplies from Central Asia reduced as well. The need for more investments in intra-EU connections to facilitate reallocation of gas suppliers in the short term is illustrated clearly.

Storage is an important instrument for managing swing production and for arbitrage between low summer demand and high winter demand. Alternatively, excess transport capacity can be constructed which is only used for transport during medium and high demand. However, the latter option would be rarely used in the economic analyses, indicating that storage is more an economic option to deal in the long-term with ‘swing production’.

Concluding: the analyses in this report indicate that substantial *investments* in gas transport corridors are needed to match the rising demand as projected officially in EU scenarios. Especially the pipeline connections running from East to West need to be prioritised in the coming years and decade. Future gas price developments will largely depend upon the sufficient availability of gas from key resource owners such as Russia, Iran, and several Central Asian countries and their strategic price setting behaviour, which are uncertain factors in future gas price developments.

On the basis of the model-based analysis a number of specific conclusions are formulated:
- Already considerable *investments are needed by 2010*. In the longer term substantial investments are needed to build sufficient gas transport infrastructure capacity in Europe to connect the EU with its key suppliers. The total need amounts to about € 20 billion of yearly investments, out of which about 50% are needed for pipelines, 40% for the LNG train, and 10% for storage facilities. Particularly congestion in the East-West route should be avoided because it could drive up gas prices in countries in the EU closest to connections with the main suppliers.

- In the very short run through realizing a number of what we call *‘smart’ investments* (partly already identified in the TEN program) in *EU intra-pipeline connections* between the different EU countries, the market access and competition in EU country markets will increase substantially. This would also bring down the ability of key suppliers/producers to exercise market power at the European gas hubs and would lower gas prices in EU member states by about 14% on average as compared with the BAU scenario.
- Iran and Russia are always (2005-2030) marginal (*price setting*) gas suppliers; Nigeria, Qatar, Egypt and Azerbaijan are sometimes marginal suppliers (2005, 2010) and sometimes reap rents (from 2015 onwards), while other suppliers mainly reap rents (produce at full export capacity to EU).
- *LNG capacity* is forecasted to develop quickly. In 2030 about as much as 20% of total supplies to the EU could be transported in the form of LNG, and 80% via pipelines. LNG comes from Qatar (33%), Nigeria (25%), Algeria (17%), and Egypt (15%), others (10%) using aggregate figures for the period 2005-2030. LNG supplies go to the UK and Ireland (28%), the Iberian Peninsula (19%), Italy (18%), France (15%), BENELUX (13%), and others (7%).
- *Alternative gas demand* scenarios (lower and higher demand ±20%), lead to lower and higher investments (±30%) and lower and higher border supply prices (±10%).
- A *deferral of investments* in gas infrastructure drives up gas prices (+25%) in the next decade and leads to a lower resilience to interruptions in gas supply and, hence, less security of supply for consumer countries. Consequently the continuation of the past and currently observed postponement of investments in Europe (intra EU gas connections and connections between EU and its neighbours) would drive up gas prices, through new ‘bottle-necks’ in the gas infrastructure by around 25% in EU markets in the medium and long run.
- Despite the impressive growth of *LNG terminal capacity* pipelines are expected to stay the most dominant means of gas supply to the EU in the future: varying from 83% (low demand scenario), 81% (high demand & BAU scenario) to 77% (deferral of investments scenario) of total EU gas imports in 2030.
- *Storage* comes forward as the best option for arbitrage between summer and winter demand volumes, whereas LNG is the second best option.
- With hindsight, in the past some *investment decisions* for gas transport projects have not always been based on sound economic reasoning. Examples are the Baltic pipeline between Russia and Germany and the Blue Stream pipeline between Russia and Turkey.

Final, concerning the building of pipeline connections with the EU we can briefly summarize that pipeline connections from North Africa into the EU, from Norway into the UK and Turkey into Balkan need to be assigned the highest priority, as these investments are shown to be the required in the BAU scenario by 2010. Around 2015 the Russia into Central Europe and Turkey into Italy pipeline projects should be given the highest priority. By 2020, the Norway into Benelux and Russia into Balkan pipeline connections should be given a priority. Later in 2025, the Norway into Germany and the Russia into Baltic Region are required as priority projects. Model analysis shows that there are no immediately required additional investments in gas infrastructure by 2030. The Balkan into Turkey and Norway into France connection have a low priority. Note that the Russian into Germany (through Baltic Sea) and Russia into Turkey pipeline (Black Sea) connections are assumed to be built according to current planning, but from a European-wide perspective are not ‘economic optimal’ in the sense that there are other projects that deserve earlier attentions based on there ability to relieve bottlenecks in the gas infrastructure system. The table below summarises when, what (additional) new investments in supply connections are necessary according to the BAU scenario.

Table S.1 *Timing of investments in the capacity expansion of gas corridors between non-EU and EU [bcm/yr]*

From	To	2010	2015	2020	2025	2030
Algeria	Spain	14	14	8	6	6
Algeria	Italy	16	16	8	8	8
Balkan	Turkey	0	0	0	0	0
Libya	Italy	9	8	9	5	4
Norway	Belgium	0	0	6	10	4
Norway	Germany	0	0	0	1	7
Norway	France	0	0	0	0	0
Norway	UK	16	15	10	8	8
Russia	Balkan	0	0	3	4	4
Russia	Poland	0	0	0	7	10
Russia	Slovakia	0	7	36	27	26
Turkey	Balkan	12	14	11	8	8
Turkey	Italy	0	4	6	2	2

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1. Introduction

1.1 Background

European demand for natural gas has grown and is expected to expand considerably in the next decades. This growth is partly induced by environmental policy targets, e.g. from the Kyoto protocol, and European energy market liberalisation. This development poses a challenge for the energy consumers in the EU and other gas importing countries with respect to the resulting increasing dependence on gas imports and consequently also increasing security of gas supply concerns in consuming countries. In this context it is of imminent importance to analyse and assess the medium and long-term gas infrastructure requirements in Europe and particularly those between EU and its neighbouring gas supplying countries. This is particularly important for Europe because it is expected that more and more gas will have to be supplied from producing locations over a longer distances than before. Also the number of different competing options for supplying the EU is growing as are the interactions and uncertainty regarding the necessary optimal infrastructure investment projects.

Growing gas demand and import dependency of EU gas markets on a limited number of gas suppliers from neighbouring countries outside the EU have led to increasing concern about a potential threat to the long-term (2010-2030) security of gas supply for EU consumers. This is particularly so for the New Member States in the EU, who expect a strongly growing gas demand and an import dependency on only one supplier. These supply security concerns are driven by the following structural changes of gas markets in Europe:

- Growing gas demand in the EU and import dependency, expanding from the current 40% up to probably around 70% in 2030.
- The liberalisation of national gas markets in the EU, with unbundling of production, supply, transport and distribution of gas. The fragmented and progressive creation of an integrated European internal gas market. This transition process increases uncertainty for investors in gas production as well as in the infrastructure necessary to connect these increasingly remote production locations outside the EU with the main consumer markets in the EU.
- Instable world energy markets and increasing energy prices.

1.2 Gas Supply Security for Europe

Security of gas supply is of increasing concern in the EU, see the Green Papers (2000 and 2006). For consumers this is basically an issue of risk. All energy supply systems inherently pose a certain level of risk for consumers, but the question is what level and type of risks are acceptable. This depends on the context in which the question is posed. The focus in this study is the medium and long-term gas market in Europe wherein the EU consumer is largely and increasingly depending on natural gas imports. Moreover, the EU mainly depends on a relatively small number of key gas exporters with remote production locations. Further supply security in the energy and gas sector is generally more important, e.g. for political and economic reasons, than supply security in other industries, because of the lack of substitution possibilities in the short term. An example is the importance of gas in electricity supply systems throughout the EU. Today, alternatives to consumption of gas are few and very limited available and need time to be developed. Furthermore, another distinguishing characteristic of gas supply is its complete dependency on monopoly-controlled pipeline networks. Consequently there are generally high costs involved in situations of sudden gas supply interruptions. What constitutes adequate security depends very much on the consumers' willingness to pay for higher security levels, which tends to fall if risks are reduced while at the same time the marginal costs of providing an amount extra security tend to rise. Security of supply can be improved by constructing sufficient alternatives to potential supply disruptions in the form of storage capacity, alternative suppliers and contractual guarantees from the suppliers. These options can cushion sudden disruptions in supply and reduce the impact on prices. In this paper we call a temporary price increase below 20% secure, while we call a temporary price increase below 50% moderately secure.

Unfortunately, optimal levels of security are difficult to assess due to uncertainties, which are subjective and characterised by different perceptions of risks by various stakeholders. What policy makers can do, however, is try to assess if security levels are within a certain and acceptable margin for a majority of consumers.[3] Finally we must emphasise the increasing role of the infrastructure and transport routes, capabilities, location and capacity, are becoming a more and more critical part of the gas supply security situation of the EU and Europe as a whole. Moreover, adequate and timely investments are needed to avoid bottlenecks both in the near and long term for securing gas supply to the main consumer markets against affordable and reasonable prices. Below in Table 1.1 the different components, short versus long term and market versus infrastructure, of the concept of supply security are illustrated.

Table 1.1 *Different components of gas security of supply*

	Operational	Strategic	Long-term
Capacity and infra-structure	Capacity to transport gas & electricity to meet defined peak & daily demand	Network deliverability sufficient to meet peak firm demand in event of defined loss of infrastructure capacity	Network expansion investments to meet expected long term demand growth (given lead times in network development)
Supply and markets	Supply availability to meet both the defined peak & daily demand and to supply a severe period / winter or summer	Ability to meet customers demand in the event of severe disruption to principal supply source	National transmission & international supply companies contracting supplies to cover long term projected demand

Source: Wood MacKenzie, 1998; ENGAGED project, 2003.

In several publications, the EU emphasizes its role as a force for stability and sustainable development in Europe by realising the Internal Market and extending its benefits by integrating the energy markets of surrounding countries. The neighbouring countries play a vital role in that development, as they are the main suppliers and transit counties of oil and natural gas. That role will grow significantly in the next decades and is extended with electricity trade and probably later with hydrogen supply from the neighbouring countries.

The key objectives of the ENCOURAGED project are assessing economically optimal energy corridors for electricity, natural gas and hydrogen between the EU and neighbouring countries as well as identifying barriers and benefits and draft recommendations regarding policy measures that facilitate the creation of a pan-European energy network.

1.3 Objectives & scope of study

To meet the EU objectives for the gas markets the gas supply corridors, connections and broader stated ‘the infrastructure’ for connecting supply locations and countries with gas markets play a crucial role in Europe. The ENCOURAGED study focuses on the identification and assessment of the economic optimal development of the gas infrastructure connecting the EU gas market with the EU’s main suppliers in the neighbouring countries in the long term. This to

3 For a further discussion of these issues consult the final report of the ENGAGED project (Van Oostvoorn, 2003). For a discussion of the gas supply security in the Netherlands see Algemene Energieraad (2005).

secure and guarantee the gas supplies against affordable prices for consumers in the long run. Development of the optimal (flexible, reliable etc) configuration of gas supply infrastructure (corridors) is considered to be the main factor capable of enhancing gas supply security in Europe in the long term.

The objectives of the conducted gas corridors study in the ENCOURAGED project were as follows:

- Task 1: Analyse and project gas demand (scenarios) for European countries and review gas market structure, changes in it and its impacts on gas transport to EU markets in long run.
- Task 2: Analyse and assess gas supply and existing and potential new gas supply routes for connecting the EU to its neighbouring suppliers, as well as supply costs and transit issues.
- Task 3: Model based analysis and assessment of optimal gas supply routes and connections between EU and its neighbouring countries to secure supply in Europe.
- Task 4: Formulate conclusions, policies and recommendations for realizing these optimal supply routes and connections and drafting final report.

The present report concerns the task 3 study and more particularly it presents the applied approach and the results of the model-based analysis for the assessment of the "economic optimal gas corridors and infrastructure necessary to connect the EU markets with its neighbouring countries and suppliers". In the next Chapter 2 the approach, model and main assumptions used in the study are presented and discussed. Chapter 3 gives a description of the business-as-usual (BAU) scenario that represents 'the most likely expected' development of the gas demand, supply and prices of energy in the long term in Europe and presents the gas infrastructure investments necessary to meet projected demand of gas from the different supply sources outside the EU. Thereafter Chapter 4 for elaborating the sensitivity of the BAU results, the different alternative scenarios other than BAU are briefly described and the impacts on the infrastructure requirement are evaluated. In Chapter 5 follow the main conclusions of the study and in the appendixes calibration of demand, main input data and assumptions and at the end also a table summarising the total infrastructure use, investment and operational capacity per scenario and type of facility are presented.

2. Model description and other key assumptions

As a tool for studying the security of gas supply in the EU, this report uses a computational game theoretic model with recursive dynamics to represent investment by transmission and storage system operators. Our model is a multiyear extension of two versions of the GASTALE model developed at ECN (Boots et al, 2004, Egging and Gabriel, 2006). Version 4.4 of GASTALE as used in this report brings together the strengths of both of these models. The model solves for a short-run equilibrium in each five-year period, and makes investments at the beginning of each period based on anticipated market situation including congestion costs at the end of each period.

The assumed market structure is as follows. Market participants include producers, consumers, transmission and storage system operators. Producers contract with pipelines and LNG shippers to transport gas to customers in consuming countries. Producers can exercise market power, playing a Cournot game subject to some forward contracting against other producers as well as arbitragers and storage, and anticipate how quantity demanded depends on price. However, owners of transmission and storage are assumed to be regulated or otherwise operated in such a way that transmission is priced efficiently. That is, the price of transmission (or storage) equals long-run variable cost, unless transmission (storage) capacity constraints are binding, in which case the price of transmission (storage) reflects a congestion premium in order to clear the market for transmission (storage) capacity. Because of this assumption, transmission (storage) can be equivalently modelled as being owned by a single transmission (storage) system operator TSO (SSO) who is price-taking. Although producers anticipate demand changes in response to price, they do not exercise market power with respect to transmission, that is, they are price taking with respect to the cost of pipeline and LNG shipping. These transmission assumptions are consistent with some other models (Boots et al, 2004) and differ from others with more sophisticated representations of transmission costs and technical constraints (O'Neill et al., 1979) and more sophisticated representations of storage costs and technical constraints (Guldmann, 1983).

Additional structural assumptions include the following. The SSO can profit from buying gas in the low demand (and thus low price) seasons, storing it, and selling it to end user sectors in the high demand seasons. Storage operators are assumed to take ownership of the gas they store, so as an alternative modelling assumption, they could exercise market power against demand during seasons when stored gas is sold. Arbitragers/traders within the regions of the EU can buy and sell the gas among three sectors of consumers: power generation, industry, and residential customers. Arbitragers, who are price-takers, purchase the gas from the producers. Hence, arbitragers are only arbitraging among market sectors within a country, and not between countries. Basically, arbitrage makes sure that the border price for different sectors is the same.

The investment game is a unique feature of this model. Its structure is as follows. Investments are undertaken recursively and only for transmission and storage facilities whose capacities are most limiting and have the highest level of congestion. For instance, investment decisions are based on a so-called open-loop information structure of the market. The information is updated for each period of five years. In the current version of GASTALE, we consider four types of investments, namely expansion of liquefaction, re-gasification and pipeline capacity by additional investments of the TSO and expansion of storage capacity by investments of the SSO. The decisions are taken by the corridor managers, namely the TSO for pipeline and LNG transmission facilities and SSO for the storage facilities. They base their investments on expected congestion prices and to bring the level of congestion down to acceptable levels. From literature follows for example that a price increase of 20% above long-run marginal costs per pipeline and LNG facility and a price increase of 10% above long-run marginal costs per storage facility are considered acceptable. While most of the 59 investment options are open decisions in the analysis, two pipeline options are fixed, while four pipeline connections and one liquefaction facility cannot expand beyond a set level, which restrictions generally are not binding before 2020, to bring the results of the analysis more in line with general expectations.

The model shall not consider investments in production capacity by producers; though scenarios are used to determine the amount of production capacity. For instance, Gabriel et al (2003, 2005ab) provide a more complex example of a model that includes capacity-production relationships as well as tradeoffs between gas production in different periods, considering the size of the resource and effect of withdrawal rates on the resource.

The GASTALE model (version 4.4) contains the main consumers and producers of natural gas in Europe[4]. The gas market is typically characterised by a 'mismatch in space between production and consumption', which are connected with each other via (on and offshore) transport pipelines and an LNG shipping network. The model distinguishes among the following market participants:

- Producers (possibly with market power) decide on production and transport to the border of the country of consumption, earning a so called border price.
- Transmission system operators (TSOs) control transport through on- and offshore pipelines and LNG shipping).
- Price-taking arbitragers trade gas among power generation, industries, residential and storage until the border price is equal for each sector).
- Storage system operators (SSOs) control injection and extraction for storage facilities for storage during the low demand season and for consumption during the high and peak demand season).
- Consumers in the different sectors.

Arbitragers are implicit in the effective demand curves facing producers in each country, and are assumed to be competitive in this report[5]. Investments decisions are considered for expanding the capacity of the pipeline network, and the capacity of liquefaction, re-gasification, and storage facilities. A schematic overview of the relation among the actors is given in Figure 2.1.

4 An earlier static version with explicit trader market power is described by Boots et al. (2004). Egging and Gabriel (2006) extended that model by including the inter-temporal trade offs for storage. Neither considered investments or more than one year. The version of GASTALE which is presented here is also inspired by imperfectly competitive electricity market models, namely the COMPETES model (Hobbs et al 2004, 2005; Neuhoff et al 2005) and the EMELIE model (Lise et al, 2006) in which scarce transport capacity is allocated by a system operator in order to clear the market for transportation capacity. For a mathematical description of the model, see Lise and Hobbs (2006).

5 As explained in Boots et al. (2004), these traders can be represented as behaving either competitively or a la Cournot; this results in different forms for the effective demand curves at the border for producer gas. Cournot trader assumptions can be incorporated into the version of GASTALE of this paper using the approach of Boots et al.

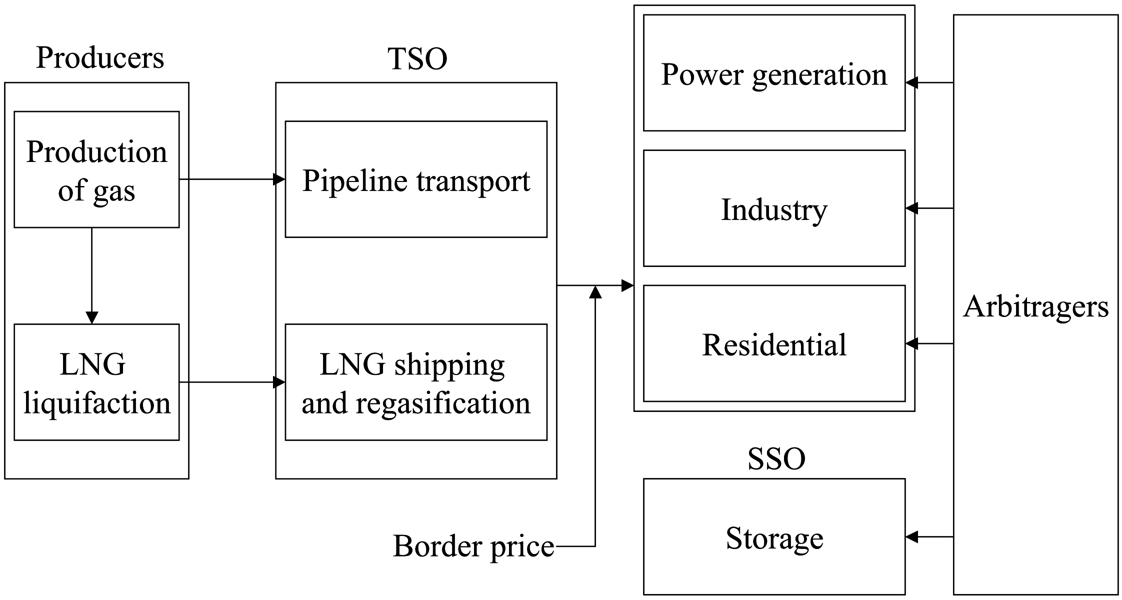

Figure 2.1 *Schematic representation of linkages between producers, TSO, SSO, arbitrage and consumers in GASTALE version 4.4*

GASTALE is a dynamic game theoretic model of the gas industry and is used to study the role of infrastructure and gas corridors in security of gas supply in the period 2005-2030. Each year in the model represents a 5-year period, namely 2005 is equivalent to 2003-2007, and 2010 is equivalent to 2008-2012, and so on. A substantial part of production of natural gas takes place in the EU, which is currently sufficient to meet about 60% of the domestic demand in 2005. Of this 60%, about 50% is produced by countries UK & Ireland (UKIE), Benelux countries (BENELUX), and Germany & Denmark (DEDK), while the other 10% is considered exogenous production and this is subtracted from demand in the model (see Table 2.1 for the precise naming and meaning of country & region abbreviations used in this report). The remaining 40% of demand is met by production outside the EU, namely Algeria, Caspian countries, Egypt, Iran-Iraq, Libya, Nigeria a.o., Norway, Qatar a.o. and Russia a.o. The model distinguishes among consumers in ten European regions, besides the already mentioned internal producers, namely Balkan countries (BALKAN), Baltic countries & Poland (BALTIC), and other country regions CENTRAL, FR, IBERIA, ITALP, and TR, see Figure 2.2 which provides a map of all countries in regions. The data of the model is mainly based on OME (2006) and to some extent on the ENGAGED project (Van Oostvoorn, 2003). The data for storage capacity and liquefaction and re-gasification capacities are taken from the most recent IEA gas information (IEA, 2005).

Table 2.1 *Producers and consumers, names of countries/regions and their model abbreviations*

Country/region	Node	Abbreviation	Full meaning
Algeria	A	AL	Algeria
Azerbaijan	AZ	AZ	Azerbaijan
BALKAN	BK	RO, BG, GR, HR, BA, CS, MK, AL	Romania, Bulgaria, Greece, Croatia, Bosnia-Herzegovina, Serbia, Macedonia, Albania
BALTIC	BT	PL, EE, LV, LT, FI, SE	Poland, Estonia, Latvia, Lithuania, Finland, Sweden
BENELUX	BX	NL, BE, LU	the Netherlands, Belgium, Luxemburg
CENTRAL	CE	HU, CZ, SK	Hungary, Czech Republic, Slovakia
DEDK	D	DE, DK	Germany, Denmark
Egypt	E	EG	Egypt
FR	FR	FR	France
IBERIA	IB	ES, PT	Spain, Portugal
Iran, Iraq	IR	IR, IQ	Iran, Iraq
ITALP	IT	IT, AT, CH, SI	Italy, Austria, Switzerland, Slovenia
Libya	L	LY	Libya
Nigeria a.o.	NG	NG, AN, TT	Nigeria, Angola, Trinidad-Tobago
Norway	NW	NW	Norway
Qatar a.o.	Q	QT, OM, YE	Qatar, Oman, Yemen
Russia a.o.	R	RU, TM, KZ, UZ, TJ	Russia, Turkmenistan, Kazakhstan, Uzbekistan
TR	T	TR	Turkey
UKIE	U	UK, IE	UK, Ireland

Note: Country/region in CAPITALS are consumers, while **bold font** is used to indicate producers.

Below in Figure 2.2 provides a map of the geographical coverage and subdivision of countries and regions (grouping of countries), see also Table 1.2 and shows how these are connected and where LNG terminals are located in Europe in the model GASTALE. Also it shows the different optional or existing connections (pipelines) connecting suppliers and markets.

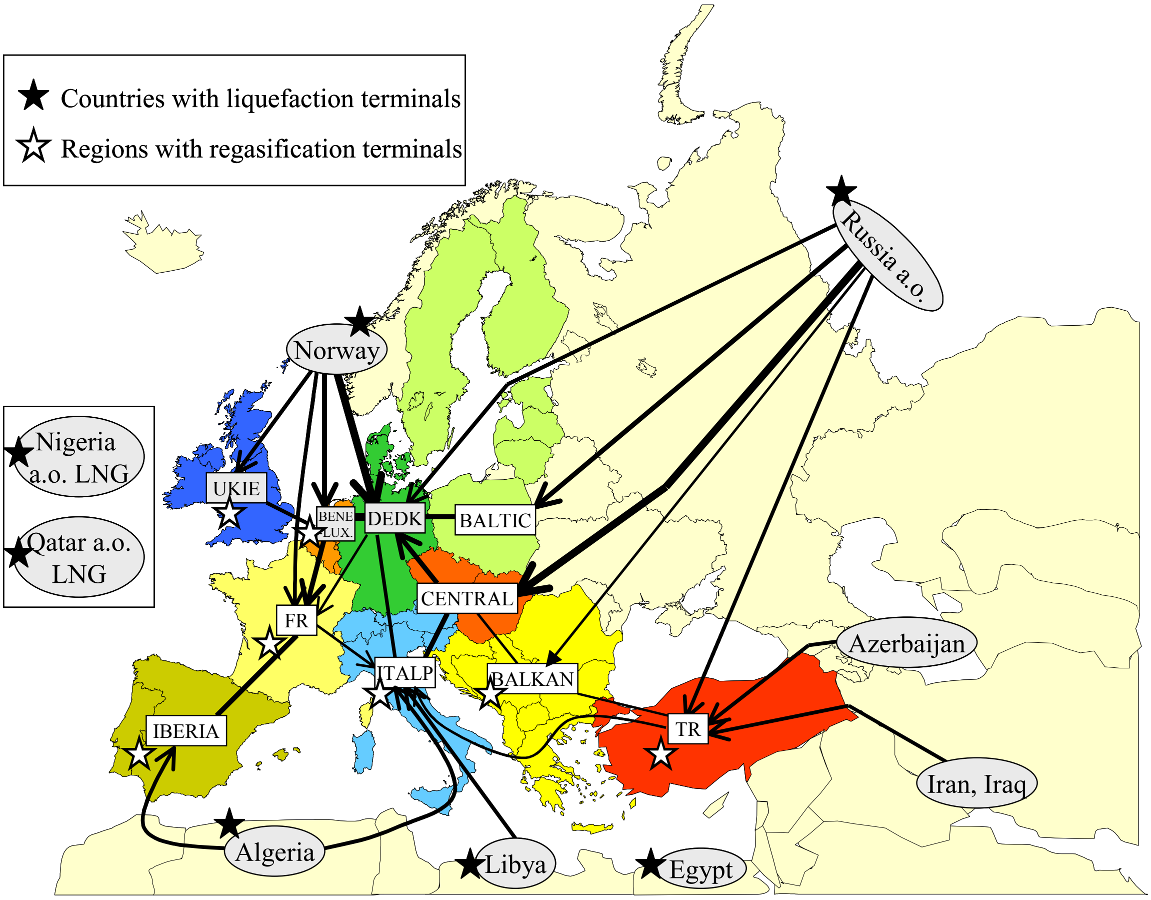

Figure 2.2 *Schematic representation of connected consumers and producers in GASTALE 2005-2030*

In the remainder of this report we proceed as follows. Chapter 2 presents our model analysis for a BAU scenario. Thereafter, Chapter 3 deals with three alternative scenarios representing differences in the development of a number of key gas market drivers. In Chapter 4 we analyse the impact of certain types of supply disruptions in the different scenarios (the BAU and the alternative scenarios) on EU gas market outcomes and gas infrastructure investment requirements. Chapter 5 presents our main conclusions. The appendix contains a discussion on the model calibration and model assumptions on the one hand, and some tables with output data on the other hand.

3. Development of the BAU scenario

To develop the BAU scenario in the GASTALE model, we have to make number of assumptions. First we focus on the behavioural assumptions of producers. One can assume two extreme types of producer behaviour, namely: 1) producers are price takers and 2) producers are fully exercising market power. These two cases reflect two extremes of possible producer behaviour in the liberalised EU gas market. However we assume a somewhat moderate behaviour which more precisely represent behaviour of key supply companies as is observed in the past and today in the EU gas markets. So for the BAU scenario we assume for the supply from Russia a.o.[6] that they exercise less market power than the other suppliers, namely by setting the market power mark-up to 25%, while all other suppliers exercise market power at 75%. From repeatedly running the model over an historical period (calibration) this seems the most realistic market situation in the past and currently because it fitted very well the market shares calculated and historically observed. This can be explained by concluding that so far the Russian supplier's strategy was emphasising expansion of market share more than driving up its prices for gas exports. So it applied its market power only in a very limited degree. This conclusion is also supported by a substantial share of long-term contracts that are influencing the pricing and market shares of suppliers in Europe. This observed market condition can also be interpreted as a situation where 75% of supplies by Russia a.o. are delivered via long-term contracts, while 25% of supplies by other producers are sold via long-term contracts. This also reflects in other words a situation where Russia a.o. are willing to supply gas at a relatively lower cost in order to continue to maintain a substantial market share in the EU market. The level of demand of the BAU scenario over the period 2005-2030 matches the official EU demand forecast very well within a 1% error margin.

3.1 Prices

Average border prices in different European regions as defined in the model are presented in Figure 3.1. The coverage of the consuming countries is provided in Table 2.1. The average border prices consist of production costs (30%), transportation costs (50%) and market-power mark-up (20%). This is an approximation of spot prices at important European hubs and, hence, do represent end-consumer gas prices Since downstream transport and distribution charges are excluded. These prices are representative for an average long-run price development following EU projections.

Figure 3.1 presents the average border prices (being model result) in EU member states in the BAU scenario. We can observe a gradual increase of the border prices of each consuming region in the BAU scenario after 2010. From about 2020 onwards the prices increase gradually. Before 2010 investments take place in such a way that the most crucial bottlenecks in the network (stimulated by high congestion prices), which are removed after 2010 resulting towards an improved level of competition, namely the case where all major producers have sufficient access to all markets to which they can supply cost-effectively in the longer run. As a result the increase in prices gradually slows down after 2020. Furthermore it is remarkable to find the lowest prices in Turkey in all years, which indicates that Turkey may become an important gas artery on the 'East-West route' to the EU-25.[7] There is, for instance, an export of over 30 bcm from Turkey to BALKAN and 10 bcm to region ITALP from 2020 onwards in the BAU scenario.

6 a.o. stands for 'and others'.
7 See also Işık (2004), Roberts (2004) and Kılıç (2006).

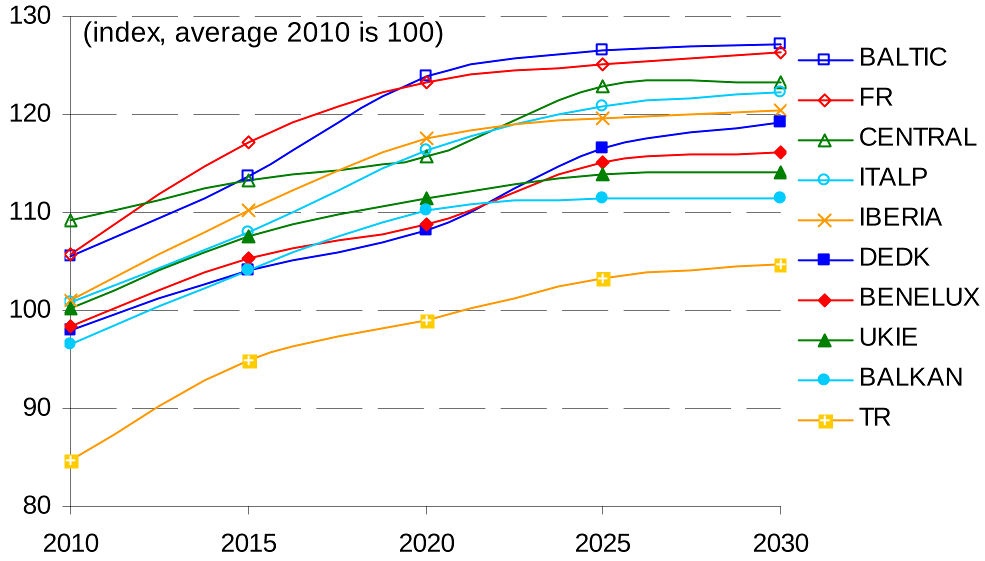

Figure 3.1 *Average border prices in the BAU scenario*

Studying price developments for the BAU scenario in the ten gas consuming regions specified in the model, leads to a number of insights. The regions that are closest to major producers have the lowest prices, namely Turkey (TR) and BALKAN. The relative price differences change once firms behave strategically. The countries from Eastern Europe have only a few alternatives beyond gas production of Russia a.o. and consequently experience the highest price levels, see BALTIC and CENTRAL. The country with the next highest prices is France (FR), which is a result of the absence of substantial own production capacity and the lack of nearby gas supply, implying high transport and other infra costs. The prices in UKIE are the highest in 2005 due to very high peak demand. However, in the long run UKIE prices are relatively low and only slightly higher than the BALKAN prices. The reason for this price relieve in UKIE is that it is economically attractive to remove critical bottlenecks in this region as soon as possible.

3.2 Production and Consumption

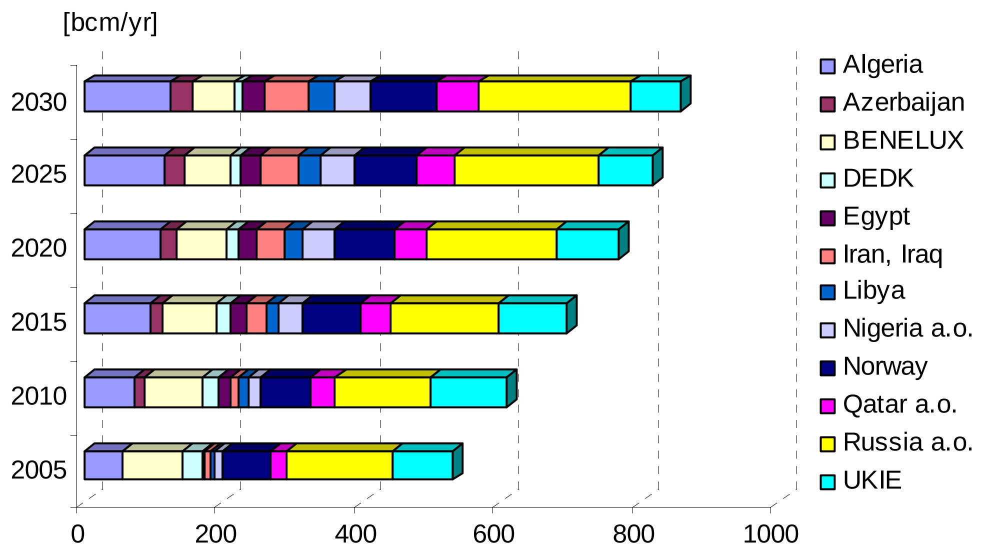

Figure 3.2 *Total yearly production in the BAU scenario*

Figure 3.2 shows the level of gas production in different supplying countries in the BAU scenario. Note that the coverage of the producing countries is provided in Table 2.1. The model is calibrated in such a way that total level of production matches with those from the official DG TREN scenarios 'Energy Trends to 2030' using the Primes model for all presented years. The total share in production of Russia is about 25%, which is a reasonable fit for the future gas supply of Russia to the EU.

The total yearly consumption in the BAU scenario is presented in Figure 3.3. The demand depends on the demand responses per sector through the assumed demand-elasticities. The national or regional demand responses can differ somewhat dependant on the shares of industry, residential and power generation in the overall economy. The total level of consumption also strongly depends on the regional demand forecasts, which is set during the calibration. In the model we assume that the amount of gas needed during the transport of gas is included in the costs for transporting the gas between production and consumption country.

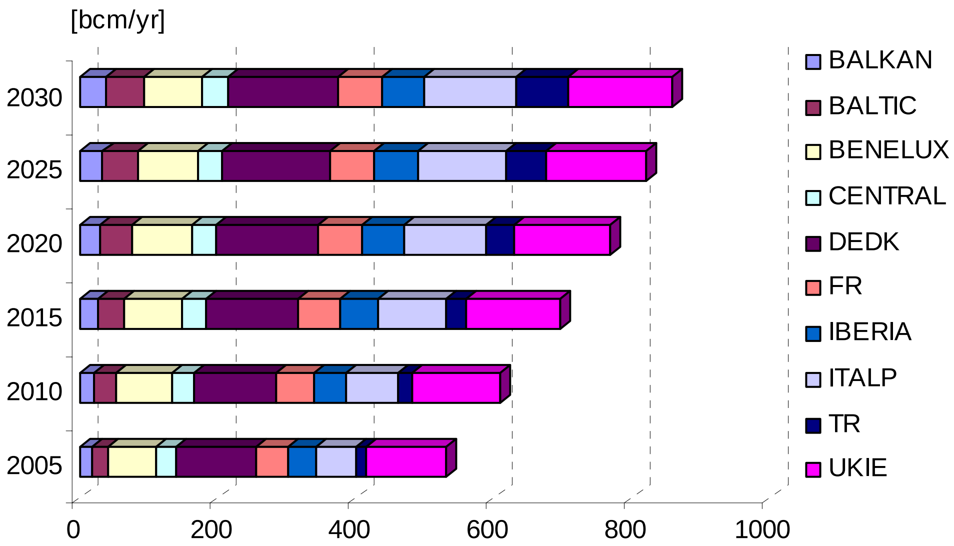

Figure 3.3 *Total consumption in the BAU scenario*

This implies that, due to the mass balance, total figures for consumption exactly match the total figures for production. Hence, the production figures are the net values of delivery minus the gas consumed during transport. Actual production is about 10% higher due to this compressor consumption during transport.

3.3 Potential economic optimal investments in the gas infrastructure in BAU

From the explained BAU scenario we address the key issue of our study namely the identification of economic optimal investments in gas corridors and infrastructures for connecting key suppliers in neighbouring countries with markets in the EU. We present and discuss the calculated optimal transported gas flows, available capacities and new investments needed if the future is characterised by developments by the BAU scenario. By studying these outcomes a detailed insight can be derived in the actual gas flows and consequently investment needs for the new most important gas corridors within and towards the EU.

3.3.1 Storage

Table 3.1 presents the calculated gas flows, capacity and new investments of storage. The table shows that the level of storage use is high in DEDK. A reason for this is the assumption in the model that DEDK will not construct any re-gasification terminals and hence has to obtain all swing production from storage. The level of storage in UK & Ireland (UKIE) is the highest, but, as discussed before, swing production in the UKIE in the BAU scenario is also obtained from re-gasification (LNG terminal) capacity. There are no investments in IBERIA and CENTRAL. In these countries the services of swing production is obtained from other sources, e.g. re-gasification in IBERIA, while demand is served in all periods in countries of region CENTRAL as being the main 'transit corridor countries' between Russia a.o. and the rest of the EU.

Table 3.1 *Calculated gas flows, capacity and new investments [bcm/yr] in storage*

	Actual flows						Capacity						**New investments**				
	2005	2010	2015	2020	2025	2030	2005	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
BALKAN	2	2	3	4	4	5	4	4	3	4	4	5	0.0	0.0	0.5	0.6	0.9
BALTIC	2	2	4	7	9	9	2	2	4	7	9	9	0.0	2.6	2.9	2.4	1.3
BENELUX	3	3	8	11	12	11	3	3	8	11	12	11	0.0	**5.4**	3.6	1.8	0.4
CENTRAL	5	5	7	6	6	5	8	8	7	6	6	5	0.0	0.0	0.0	0.0	0.0
DEDK	17	17	17	21	23	26	20	18	17	21	23	26	0.0	0.0	5.7	4.3	4.8
FR	10	10	11	15	16	16	11	10	11	15	16	16	0.0	1.8	4.7	2.2	1.1
IBERIA	1	1	2	2	2	1	2	2	2	2	2	1	0.0	0.0	0.0	0.0	0.0
ITALP	8	7	13	13	14	15	16	14	13	13	14	15	0.0	0.0	1.1	1.5	2.4
TR	0	1	2	3	5	6	2	1	2	3	5	6	0.0	0.3	1.6	2.0	2.0
UKIE	*4*	*9*	*19*	*25*	*27*	*28*	*4*	*9*	*19*	*25*	*27*	*28*	*5.6*	*11.3*	*7.4*	*3.5*	*3.2*

3.3.2 Pipelines

Table 3.2 presents the calculated optimal gas flows, capacity and new investments of pipelines in more detail for the four major routes, namely North-South, South-North, East-West, and within the EU. Two pipeline connections are never used, namely CE_BK (from CENTRAL to BALKAN) and BK_T (from BALKAN to Turkey). Because of the lowest price levels existing in TR, flows from the rest of EU to TR never occur in BAU scenario. The BT_D (from BALTIC to DEDK) pipeline is used only marginally in the first 15 years. This is because the Ukraine route is economically more attractive. All other pipelines are used to a substantial degree.

Table 3.2 *Calculated gas flows, capacity and new investments [bcm/yr] in pipelines*

	Actual flows						Capacity						**New investments**				
	2005	2010	2015	2020	2025	2030	2005	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
North-South																	
NW_BX	13	11	9	14	21	21	13	11	9	14	21	22	0.0	0.0	6.2	9.9	4.0
NW_D	23	18	23	22	20	24	45	37	31	26	23	26	0.0	0.0	0.0	0.9	7.3
NW_F	11	10	9	6	4	3	16	13	11	9	8	6	0.0	0.0	0.0	0.0	0.0
NW_U	**20**	**33**	**42**	**45**	**45**	**45**	**20**	**33**	**42**	**45**	**45**	**45**	**15.9**	**14.7**	**10.1**	**7.5**	**7.5**
South-North																	
A_IB	11	24	32	36	36	36	11	24	33	36	36	36	14.0	13.5	8.4	6.0	6.0
A_IT	25	36	47	47	47	47	25	37	47	47	47	47	16.1	16.3	7.9	7.9	7.9
L_IT	2	11	17	23	24	24	2	11	17	23	24	24	9.2	7.8	8.8	4.8	4.0
East-West																	
AZ_T	0	12	19	25	29	33	5	13	20	26	31	35	8.4	9.5	9.3	8.9	9.6
IR_T	10	13	27	42	54	63	11	13	28	45	58	68	3.2	17.7	21.2	20.7	19.2
R_BK	14	11	11	12	14	15	18	15	13	14	16	17	0.0	0.0	3.2	4.2	4.5
R_BT	27	24	24	24	28	33	47	39	33	27	29	34	0.0	0.0	0.0	6.7	9.8
R_CE	**99**	**78**	**81**	**102**	**110**	**116**	**109**	**91**	**83**	**105**	**114**	**121**	**0.0**	**7.1**	**36.1**	**26.6**	**26.5**
R_D	3	5	15	23	29	30	5	10	20	30	30	30					
R_T	6	9	12	14	16	16	16	16	16	16	16	16					
Within EU																	
BK_CE	2	8	15	19	22	23	2	8	15	19	22	23	5.8	8.9	6.6	5.5	4.9
BK_T	0	0	0	0	0	0	14	12	10	8	7	6	0.0	0.0	0.0	0.0	0.0
BT_D	5	8	4	0	0	0	31	26	21	18	15	12	0.0	0.0	0.0	0.0	0.0
BX_D	27	45	44	41	42	39	99	82	68	57	47	40	0.0	0.0	0.0	0.0	0.0
BX_F	19	40	35	32	28	25	37	40	35	32	28	25	9.1	1.8	2.7	1.7	2.0
BX_U	19	23	20	16	14	12	20	23	20	16	14	12	6.8	0.0	0.0	0.0	0.5
CE_BK	0	0	0	0	0	0	1	1	1	1	0	0	0.0	0.0	0.0	0.0	0.0
CE_D	49	43	48	68	71	75	54	45	49	69	71	75	0.0	**11.7**	**27.4**	**14.3**	**15.7**
CE_IT	26	19	23	26	31	34	48	40	34	29	35	37	0.0	0.0	1.1	10.4	8.7
D_BT	2	18	19	21	22	22	2	22	22	22	23	22	**20.1**	**4.1**	**3.7**	**4.4**	**3.1**
D_BX	9	12	15	14	13	12	9	22	18	15	13	12	14.0	0.0	0.0	0.3	1.7
D_F	14	11	9	14	16	14	14	12	10	14	16	14	1.1	0.0	5.3	4.3	1.0
D_IT	5	3	2	1	1	1	5	4	3	3	2	2	0.0	0.0	0.0	0.0	0.0
F_IB	4	9	7	5	3	2	4	10	8	7	6	5	6.9	0.0	0.0	0.0	0.0
F_IT	6	16	13	9	7	5	6	17	14	12	10	8	12.7	0.0	0.0	0.0	0.0
IB_F	0	8	10	11	11	12	2	8	10	11	11	12	**5.6**	**3.9**	**2.3**	**2.0**	**2.4**
IT_CE	3	8	9	8	8	7	3	8	9	8	8	7	5.6	2.2	0.8	0.8	0.9
IT_D	8	16	24	21	21	22	8	16	24	22	21	22	10.0	9.9	2.4	3.1	3.9
T_BK	2	14	25	31	34	37	2	14	26	33	36	38	**11.9**	**14.2**	**11.1**	**8.4**	**7.8**
T_IT	2	2	6	10	11	11	2	2	6	10	11	11	0.0	4.1	5.6	2.5	1.5
U_BX	21	70	65	61	53	44	21	74	70	63	54	45	56.6	8.2	4.3	2.1	0.0

Note: For the meaning of the abbreviations of the pipeline connections we refer to Table A.5 in the appendix.

In addition to considering the use of pipelines it is also of interest to consider the congestion that triggers capacity expansion (new investments). The following connections are not expected to face any bottlenecks in the coming decades: BK_T (Balkan to Turkey), CE_BK (CENTRAL to BALKAN, as discussed before), BT_D, BX_D (BENELUX to DEDK), D_IT (DEDK to ITALP), and NW_F (Norway to France). There are also no (endogenous) investments triggered in the connections R_D (Russia to DEDK) and R_T (Russia to Turkey)[8] because these transport capacities are fixed based on earlier taken decisions and (are) build accordingly: further expansions prove to be not economically attractive in the BAU scenario. The NW_F connection is of particular importance as it concerns connections from a reliable 'in EU integrated' outside gas supplier to the EU. This shows that the NW_F pipeline, but also R_D Baltic pipeline, which have both a substantial length offshore, are not economically viable according to our model-based analysis and assumptions. Hence, from this we can conclude that these pipelines have a

8 The R_T connection is economically viable and the capacity could be expanded again from 2020. It is, however, politically unsure whether such a project will be undertaken.

low priority concerning further on economic grounds justifiable optimal capacity expansion of corridors. All other connections are, however, sufficiently congested and require investments at some point of time in the future to mitigate these.

Let us now consider the corridors necessary to supply the EU more closely.
In the *North-South* corridor the NW_U (Norway to UKIE) connection needs a continuous expansion growing from 20 bcm in 2005 to 45 bcm in 2030 (a further expansion by investments is constrained). The NW_BX (Norway to BENELUX) connection expands from 13 to 22 bcm, while both the NW_D (Norway to DEDK) and NW_F connections are gradually depreciated. This investment behaviour shows the effect of the pipeline costs on the ultimate investments, where the NW_U (Norway to UK) pipeline is the most attractive option. The *South-North* corridor is fully congested. Here we even restricted a further expansion by investments in all South-North pipeline connections in the model, which would otherwise occur beyond the observed 'political and technical reality'.

The results for the *East-West* route are most varied. The connections from the Far East (IR_T, AZ_T, Iran and Azerbaijan to Turkey) are continuously expanded. The Russia a.o. to EU connections obtains different investment incentives. Clearly the existing R_CE (Russia to CENTRAL) connection is the cheapest transport route, for which new expansion of capacity investments commence in 2015. Second in priority/row is the R_BK (Russia to BALKAN) connection, which is expanded from 2020 onwards. Third, the R_BT (Russia to BALTIC) connection begins to expand from 2025 onwards. Finally the R_D (Baltic line) and R_T (Blue Stream) connections are controlled exogenously because of not being economic attractive compared to other alternative pipeline connections in this route as explained before.

Within the EU there are also defined 21 other pipeline connections, which are analysed. Out of these, 8 connections need new expansion of capacity investments in all periods due to continuous capacity congestion. These are BK_CE (BALKAN to CENTRAL), BX_F (BENELUX to France), D_BT (DEDK to BALTIC), IB_F (IBERIA to France), IT_CE (ITALP to CENTRAL), IT_D (ITALP to DEDK), T_BK (Turkey to BALKAN), and U_BX (UKIE to BENELUX). Another 5 connections do not need any capacity extensions, namely CE_BK and BK_T (as discussed earlier), BT_D (BALTIC to DEDK), BX_D (BENELUX to DEDK), and D_IT (DEDK to ITALP). Hence, some routes through DEDK are also economically less attractive is observed.

3.3.3 LNG facilities

Table 3.3 presents the calculated optimal gas flows, capacity and new investments of *liquefaction* of gas. This table shows that Nigeria a.o. and Qatar a.o. could become on economic grounds the two main LNG producers for EU, while Egypt and Algeria follow with a more modest capacity. For Norway it is not attractive to export LNG to the EU, while Russia a.o. has an incentive to expand its LNG option and the ability to do so. However this capacity increase is restricted in the model due to geographic and political reasons. Libya and Algeria only switch to LNG once the currently as feasible defined pipeline capacity is fully used.

Table 3.3 *Calculated gas flows, capacity and new investments [bcm/yr] of liquefaction*

	Actual flows						Capacity						New investments				
	2005	2010	2015	2020	2025	2030	2005	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Algeria	19	14	16	26	33	41	27	22	20	32	39	47	0.0	1.2	15.5	12.8	14.1
Egypt	2	17	23	27	29	31	2	21	26	28	31	33	19.2	8.3	6.7	7.2	7.6
Libya	1	1	1	2	7	14	1	1	1	2	7	14	0.1	0.7	0.7	5.9	7.7
Nigeria a.o.	13	18	33	45	50	53	14	24	39	50	54	57	12.9	18.6	17.5	11.9	12.4
Norway	1	1	1	1	0	0	2	2	1	1	1	1	0.0	0.0	0.0	0.0	0.0
Qatar a.o.	24	36	45	47	54	61	27	44	49	49	57	64	21.3	12.3	8.2	15.7	16.9
Russia a.o.	2	10	10	10	10	10	2	10	10	10	10	10	8.5	1.7	1.7	1.7	1.7

Table 3.4 presents the gas flows, capacity and new investments of *re-gasification* of transhipped LNG. The table shows that in 2010 only in four regions the re-gasification capacity is expanded, namely in BALKAN, BENELUX, ITALP and UKIE. In 2015 also France (FR) commences its expansion, in 2020 in IBERIA and in finally in 2025 in Turkey (TR).

Table 3.4 *Calculated gas flows, capacity and new investments [bcm/yr] of regasification*

	Actual flows						Capacity						New investments				
	2005	2010	2015	2020	2025	2030	2005	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
BALKAN	2	4	5	7	8	9	2	4	5	7	8	10	1.5	2.3	2.6	2.2	3.2
BENELUX	6	15	17	23	28	31	6	15	17	23	28	31	**10.0**	**5.0**	**8.7**	**8.4**	**7.7**
FR	16	14	19	21	22	24	16	14	19	21	22	24	0.0	7.2	5.4	4.8	5.3
IBERIA	21	19	25	26	29	29	37	31	26	26	29	30	0.0	0.0	5.2	7.5	5.1
ITALP	4	13	21	29	35	39	4	13	21	33	39	44	**9.7**	**10.5**	**15.8**	**11.0**	**11.4**
TR	3	1	2	2	4	9	6	5	5	4	4	9	0.0	0.0	0.0	0.7	5.9
UKIE	10	32	41	49	59	69	18	58	58	59	69	79	**43.2**	**9.4**	**10.7**	**19.5**	**22.0**

3.3.4 Conclusions

From the tables above we can briefly summarize that the pipeline connections between North Africa into the EU, from Norway into the UK and Turkey into the Balkan need to be assigned the highest priority, as investments are expected to be required by 2010 in the BAU scenario. Around 2015 the expansion of the Russia into Central Europe and Turkey into Italy pipelines are required, so is the next priority. By 2020, Norway into Benelux and Russia into Balkan expansion projects are required and should be labeled as having priority. Later, in 2025, expansion of the Norway into Germany and the Russia into Baltic connection requires upgrading and, hence, should be given priority. There are no important extra additional investment requirements identified by 2030 suggesting that pipelines between the Balkan into Turkey and Norway into France have a lower priority and earlier mentioned connections. The Russia into Germany and Russia into Turkey pipeline connections are built according to current planning.

3.4 Short-term gas supply security (disruption cases) in medium term

Based on the background of the BAU scenario we also analyse the resilience/robustness of the resulted gas supply infrastructure as these are being build according to BAU in 2010 and thereafter (until 2020). It is useful to see how gas market and infrastructure than might cope with a sudden unexpected supply disruption, e.g. with rerouting of gas transport and/or use of extra capacity (flexibility of the system). Gas price and demand/supply movements measure the impacts in the European system. The results are analysed to identify and assess whether *additional* infrastructure investments are necessary to meet a reasonable level of security supply flexibility against reasonable gas prices/costs to/for the EU consumers for short interruptions without the possibility to invest in any infra measures. This situation is especially relevant since January

2006 when Gazprom interrupted its gas supply to the Ukraine for a few days due to a stalemate in negotiations on pricing issues in new gas supply contracts. In model terms we will assume:

- Pipeline availability in 2010 and 2020 will be severely limited for some critical connections separately between EU and non-EU countries.
- A sensitivity analysis will test disruptions between Ukraine-Slovakia, Algeria- Spain/Italy, and Azerbaijan/Iran, Iraq-Turkey.

In order to gain insights into the gas price and volume effects of such a gas supply disruption, three additional cases have been simulated, namely the case where the gas pipeline transport from Algeria is disrupted (*Algerian case*); gas transport from Azerbaijan and Iran/Iraq to Turkey is disrupted (*Caspian case*); and gas transport through the Ukraine is disrupted (*Russian case*). These three cases are simulated for the years 2010 and 2020 and since this disruption cannot be anticipated by investments in such a short time period, we follow BAU investment levels. Arbitrage between summer storage and winter extraction and rerouting of gas is possible. Figure 3.4 shows the resulting price changes for 2010 and 2020 for all three interruption cases.

A somewhat similar analysis was also performed with an earlier version of the GASTALE in model under the ENGAGED study (Van Oostvoorn, 2003)[9]. In comparison to that study we find a lower price response and more regional specific effects. A major reason for this difference is that the current version of GASTALE has storage facilities, while these were absent in the previous version of the GASTALE model. In addition, the full competitive case, which was used in the previous study, typically underestimates the trade flows among EU regions. In the BAU scenario in this report, there is more trade due to the allowance of partial strategic action, where strategic firms would like to obtain a share in as much as possible markets.

Figure 3.4 shows that in the Algerian gas supply interruption case, prices increase the most in direct neighbouring regions, namely FR, ITALP and IBERIA and this effect is more pronounced in 2020. The price effect in the Caspian gas supply interruption case is most pronounced in Turkey, BALKAN region and somewhat in CENTRAL region, with a price increase of nearly 20% in 2010 and an increase of 80% in 2020. The larger price increase in the later year reflects the fact that larger flows are supplied to Turkey and a disruption then leads to a need for larger alternative volumes. In contrast, the price increase is worst in 2010 (versus 2020) in the Russian gas supply interruption case, in which CENTRAL prices increase by 108% in 2010 but only 53% in 2020. This shows the effect that the EU dependence on Russia is reduced to some extend over time, because of the availability of more alternative gas corridors in 2020. The importance of Russian gas supplies in 2020 is demonstrated by a disruption of the Ukrainian pipeline with price increases to be observed all over EU except in Turkey and in BALKAN region, both largely depending on other suppliers. Hence security of supply is most critical (relative high price impact) for interruptions from Russia and the Caspian region in 2010. Hence, note that our model analysis which allows for summer-winter arbitrage and neglects other barriers for adapting supply and demand such as current contracts, institutional, political and regulatory barriers underestimates the price impacts substantially. So the conclusion is that investments in the East-West corridors need particular attention and action for guaranteeing more security of gas supply to the consumers in the EU gas market.

9 For a policy discussion on the issue of supply disruption see for instance Correljé and Van der Linde (2006).

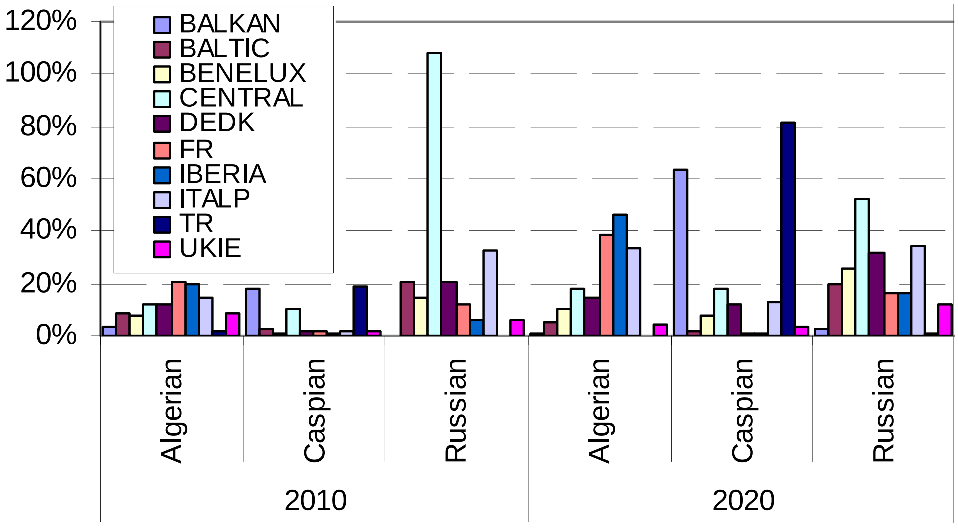

Figure 3.4 *Price increases w.r.t. the BAU scenario due to a supply disruption via three routes in 2010 and 2020.*

Figure 3.5 shows the supply changes that occur due to disruptions and mitigate these and explain the price effects. For the understanding of these flow changes one has to realise that interruption cases concern different shares of total supply to the EU for the different export regions. For example 100% of the supplies of the Caspian are disrupted in the Caspian case, while 70% supplies from Algeria in the Algerian case and only 40-50% from Russia in the Russian case are interrupted, because Algeria has also 30% LNG export and Russia 60-50% export by other pipelines to the EU.

From model-analysis (Figure 3.4) is clear that in the Algerian case additional production is provided by Norway and Russia and in the Caspian case mainly by Russia, but also by Norway and long distance LNG shipments. The most interesting case is the Russian one, where long distance LNG mainly increases production and surprisingly the production of Azerbaijan and Iran decreases as well than. This can be explained by an increasing transit of Russian gas through the Blue stream pipeline from Russia to Turkey that, further downstream, replaces gas formerly supplied/transported from Central Asia.

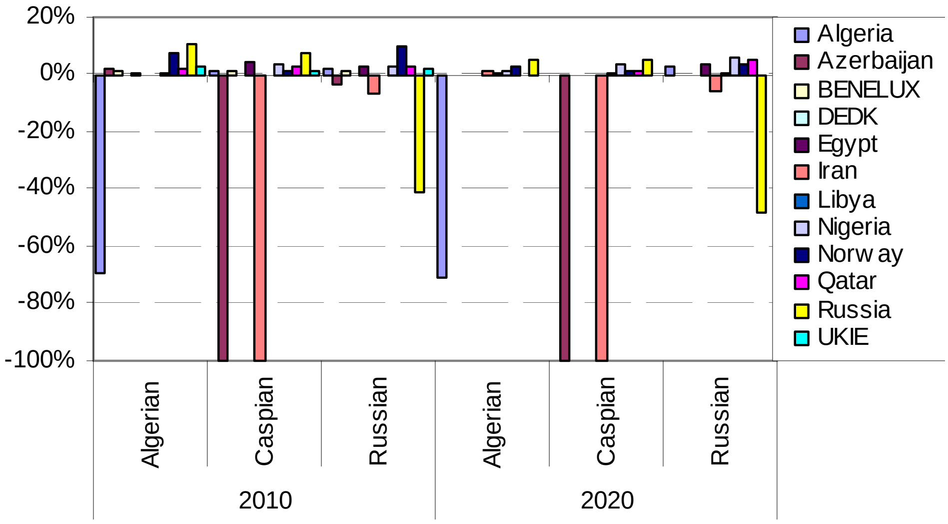

Figure 3.5 *Supply changes increases w.r.t. the BAU scenario due to a supply disruption via three routes in 2010 and 2020.*

4. Impact of alternative scenarios on infrastructure requirements

The previous two chapters presented the consequences of the BAU scenario that is more or less close in its developments to a broader and well-known official Energy scenario of the EU (EC, 2003). This chapter proposes short storylines as an underpinning for the BAU scenario and three alternative scenarios that take the BAU scenario as the starting point. The focus is on the main driving factors of these scenarios are a possible deviation in external developments that might highly influence the structure and capacities of gas infrastructure in the long term and therefore the assessment of optimal gas corridors, i.e. siting, routing and capacities of infrastructure such as LNG, storage and pipelines.

At the same time we can more properly explain some results that arise from the BAU analysis. Note that each alternative scenario must not only have a coherent justification with consistent drivers but it must also be consistently translated into changes in the model specifications and parameters. Below follows a short characterisation of how the various alternative scenarios compared to or deviating from the BAU scenario.

4.1 Definition of the different scenarios

4.1.1 Alternative scenario 1: Low gas demand

There are several very recent (compared with 2002/03 expectations) trends that change long run expectations concerning the development of gas demand in Europe. These are:

- Continuation of the current high oil prices and therefore high gas prices at the EU borders. Relatively low GDP growth rates and confidence in investments in gas-consuming technologies result.
- A possible nuclear renaissance, increased use of electricity from renewable energy sources (RES-E), and coal gasification power plants. The low demand projections in OME (2005) are used to specify this scenario. It is clear that in particular the demand in the power sector decreases in the longer term in this scenario.
- In order to keep the model calculations realistic (consistency of specification changes), it is useful to change the demand elasticity (more elastic +20%), because the level of demand has already decreased considerably, there will be an abundance of gas, thereby making easy substitutions more likely.
- Other changes in the model specification to secure consistency are a reduction of 20% as compared to the BAU levels of the exogenous capacity of export to the EU in Egypt, Nigeria a.o., and Qatar a.o over the period 2005-2030, while the production capacity of other producers are the same as the BAU levels. These three producers can only serve the EU market by shipping gas in the form of LNG. This reduction is a consequence of a less attractive EU market for gas suppliers (stronger down stream competition for relatively smaller markets in EU, causing smaller revenues and profits), caused by these lower gas demands.

4.1.2 Alternative scenario 2: High gas demand

However for a variety of reasons and for a number of drivers it is plausible in the long run that the demand for gas will increase beyond the levels assumed in the BAU. From a security of supply point of view, the EU must be prepared for such a possibility too.
The drivers could be:

- A return to a period of lower oil and gas prices at the EU borders. So gas prices after a few years of turmoil and high world oil prices decline to levels which were common a few years ago. Relatively high GDP growth rates and confidence in investment in gas-using technologies result.

- Environmental targets such as meeting the Kyoto agreement and other targets for Greenhouse gas emission reduction.
- Insufficient penetration of renewable energy sources. The resistance against the nuclear option continues leading to decommissioning of existing nuclear power plants. The high demand projections in OME (2006) can be used to formulate this scenario.
- In order to keep the model realistic (consistency of specification changes), it is useful to assume also that demand is less elastic (for example -20%), because the level of demand has already increased considerably, reducing the availability of spare production capacity, leading to somewhat lower substitution possibilities.
- Other changes in the model specification to secure consistency are an increase of 20% as compared to BAU levels of the exogenous capacity of export to the EU in Egypt, Nigeria a.o., and Qatar a.o over the period 2005-2030, while the production capacity of other producers are the same as the BAU levels. This increase is a consequence of a more attractive EU market due to higher profits for suppliers to EU, caused by the higher gas demand by consumers.

4.1.3 Alternative scenario 3: 'Deferral of investment in gas infrastructure'

Vertically integrated companies and long term contracting of gas have characterized the gas markets in the past decades in the EU. So therefore the development of (and investments in) the required gas transport and related infrastructure facilities followed 'automatically'. In the present uncertain market environment, such investments are often postponed. To understand the influence of currently postponed investments in long distance pipelines, storage capacity, and LNG facilities, an alternative scenario is developed where investments are delayed. This implies the following assumptions:

- A driver for this scenario is that there are perceived market risks concerning the EC administration, because banks want fixed contracts for providing loans, while the EC wants competition. As a result, there are investment delays in all projects concerning pipelines, LNG and storage. We simulate this by assuming that investment costs are considerably higher with 30% higher costs.
- It is very difficult to build LNG re-gasification terminals leading to low LNG investments as well. The 'not-in-my-backyard' syndrome can be illustrated by the Italian case, where 15 LNG terminals are proposed, while only 1 is currently being built, namely off shore in the coast of Venice. Offshore LNG terminals are typically also more expensive.

4.2 Gas demand (assumption) and prices (result) in different scenarios

Again the impacts for the gas markets and infrastructure are analysed with the model to see how different key drivers of the gas market influencing the need for gas infrastructure are developing in the alternative scenarios. Figure 4.1 presents total quantity demanded in the four scenarios, which particularly illustrates how the low and high gas demand scenarios compare to the gas demand in the BAU. There is a relatively low demand in the Deferral scenario, because the slowing down of investments lead to higher gas supply prices, which lead to lower gas demand due to the assumed demand elasticity and the consumer response.

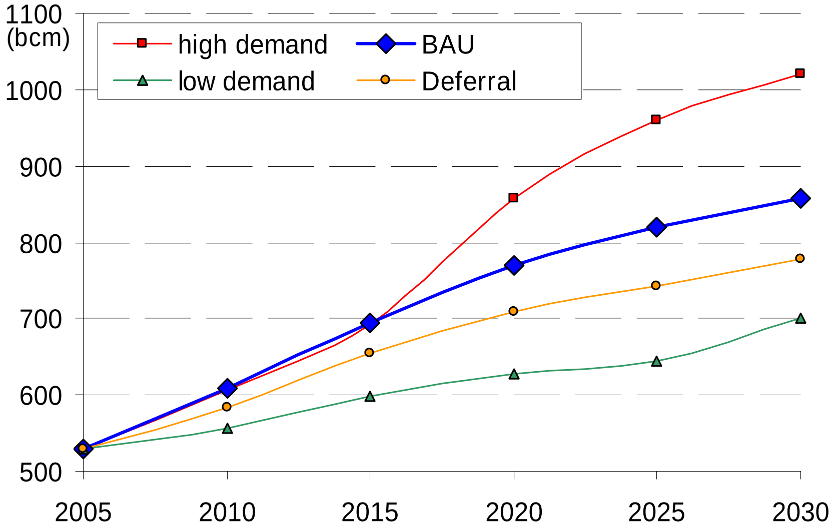

Figure 4.1 *Total demand for gas in the EU*

In order to compare the different scenarios for identifying infrastructure needs in the long run, Figure 4.2 presents the total (quantity-weighted) average prices in the EU. Prices in the low demand scenario are lower than the BAU prices, while prices in the high demand and deferral scenario are higher than the BAU prices. Hence, the prices under the four scenarios can be clearly distinguished. Prices are strictly increasing from 2010 onwards. Prices in the high demand scenario are higher than the prices in the BAU scenario in 2010 and 2015, due to the assumed lower price elasticity of demand.

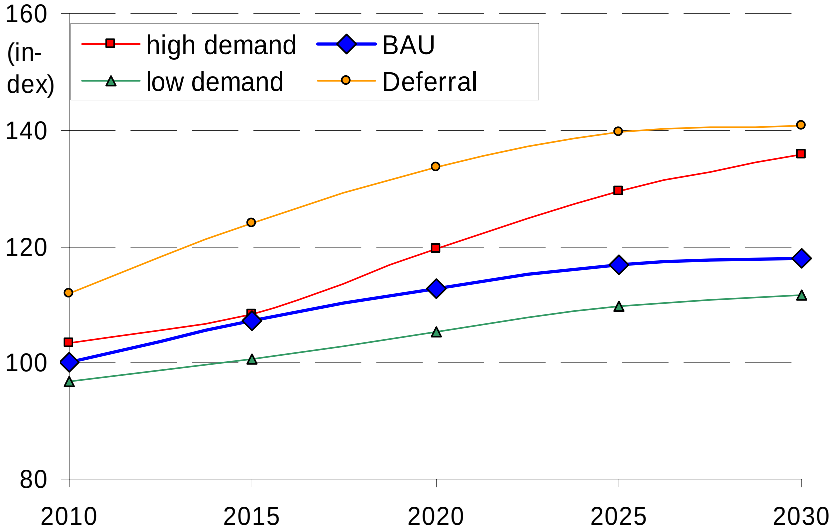

Figure 4.2 *Total average gas prices in the EU*

4.3 Gas infrastructure and gas corridors in the different scenarios

Aggregated gas flows and investment patterns are summarised in Figure 4.4 until Figure 4.7. Investments are either lower and/or later in the Deferral scenario as compared to BAU. This result holds for all four types of investments, namely capacity expansion of storage, pipelines, liquefaction and re-gasification. There is a slight increase in the share of LNG capacity as compared to pipeline capacity.

The following insights can be derived from Figure 4.4 to 4.7. Storage requirements are gradually increasing over time. The amount of storage in the alternative scenarios varies. In 2010, due to delayed investments the amount of storage is the highest in the deferral scenario. From 2015 onwards the amount of storage is the highest in the high demand scenario due to the rapidly increasing demand. The storage option is used to full capacity from 2015 onwards in the high demand and deferral case and from 2020 onwards in the low demand scenario.

Pipelines remain the dominant mode of transport in the future, where pipelines provide the following percentages of total transport in 2030: 83% (low demand scenario), 81% (high demand scenario) and 77% (deferral scenario). This variation is typically influenced by the definition of the scenarios, where LNG liquefaction capacity is 20% higher in Egypt, Qatar a.o. and Nigeria a.o. in the high demand scenario, 20% lower in the low demand scenario and unchanged in the deferral scenario. This can also explain why LNG investments are the lowest in the low demand scenario, while the other investments are the lowest in the deferral scenario, namely the LNG export capacity is somewhat reduced implying a lower need for investment in LNG transport corridors.

It is shown that within-EU investments constitute 56% of total investments in the low demand scenario, see Appendix A. This drops to 52% in the high demand scenario and to 45% in the deferral scenario. This clearly illustrates that delays in investments largely impact the gas corridors between the EU and non-EU producers.

4.4 Investment cost and seasonal flexibility in the different scenarios

Figure 4.3 presents the total investment cost requirements. Inspection of Figure 4.3 reveals that the investment costs in the deferral and low demand scenarios are quite similar[10], while the investments in the high demand scenario are considerably higher. This is especially true for the year 2020, which requires a doubling of the invested amount in the high demand as compared to the other two scenarios. This increase in investments is especially involves the expansion of pipelines.

Investment expenditures in all scenarios follow the trend in BAU quite closely. However in the deferral scenario 30% of the investment costs are concerning investment projects within the EU and 70% of the investment costs concern investment projects facilitating gas transport towards the EU. In the low demand the investment cost within the EU increase to 38%, while they decrease to 26% in the high demand scenario.

[10] Note, however, that the similar cost in the deferral scenario translates into much less capacity, since investments are assumed to cost 2.5 times as much in the deferral scenario.

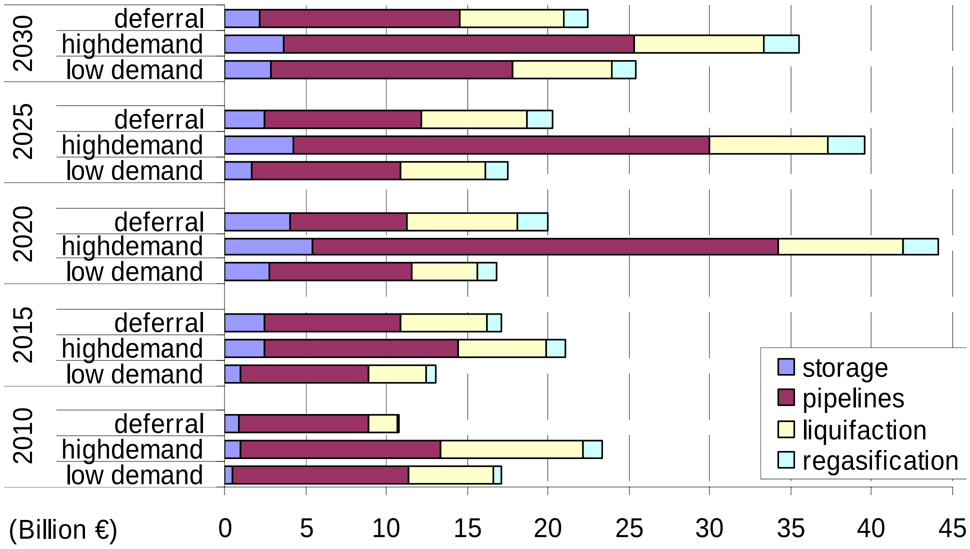

Figure 4.3 *Total yearly investment cost in period 2005-2030*

Figure 4.4 presents for the four scenarios and four EU regions the investment requirements in storage capacity, which must become operational in time steps of five years starting from 2010. Inspection of the figure yields that by 2010 only new storage capacity is added to UKIE, irrespective of the considered scenario. From 2015 onwards additions to storage capacity also take place in BENELUX, DEDK, and FR. There is a lower need for storage in the low demand scenario.

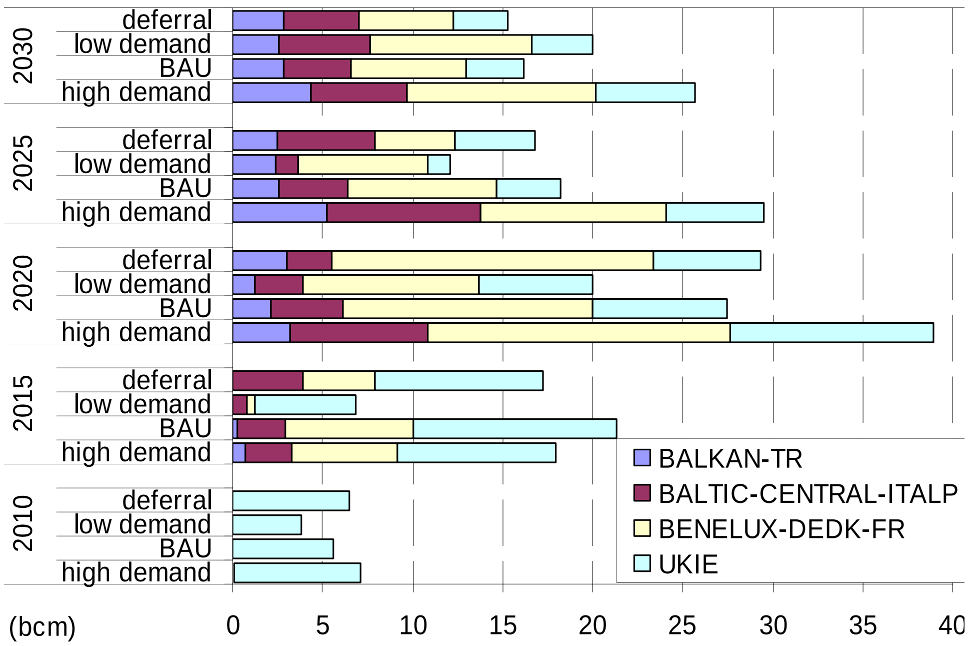

Figure 4.4 *Total investments in storage capacity in period 2005-2030*

Figure 4.5 presents for four scenarios and four EU regions the investments required in pipeline capacity. More precise analysis reveals that the largest pipeline expansion is needed in connections between the EU countries. Concerning the non-EU to EU connection, in the first decade most investments are undertaken on the South-North route, while in the second decade most investments are undertaken on the East-West route in the BAU and high demand scenario and for all scenarios by 2030.

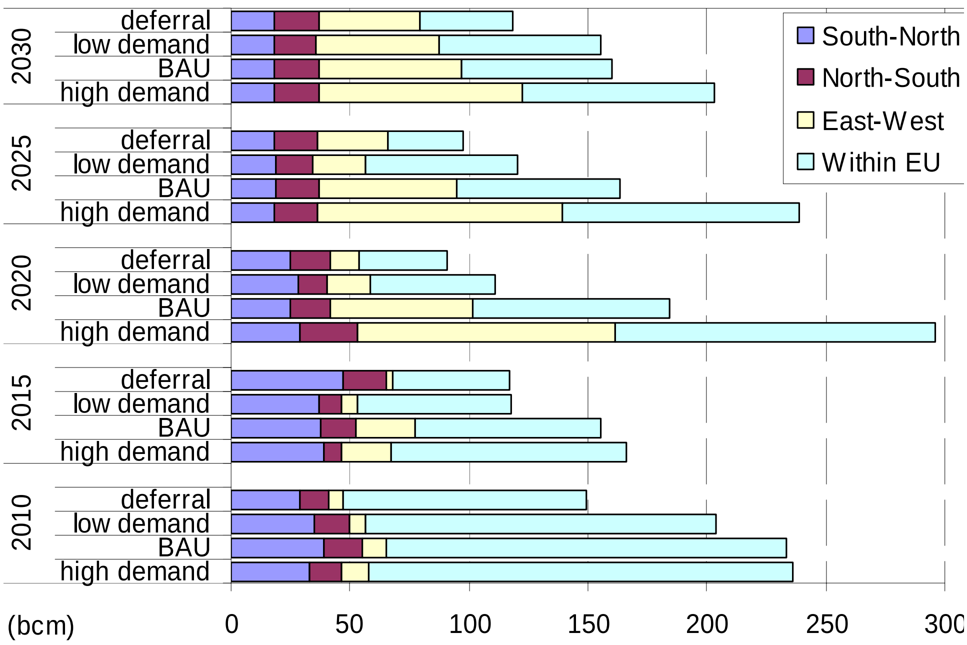

Figure 4.5 *Total investments in pipeline capacity*

Figure 4.6 presents for four scenarios and four EU regions the new investments required in liquefaction capacity. Inspection of the figure yields that the majority of new investments take place in Nigeria and Qatar (together 56%), Northern Africa follows as the second largest LNG supplier Algeria-Libya (20%), Egypt (19%), while the contribution of Russia (6%) is low. New investment in LNG for Libya and Algeria take place only after 2015. Russian LNG is operating at full capacity in all scenarios except the deferral scenario, where the full capacity is reached by 2020.

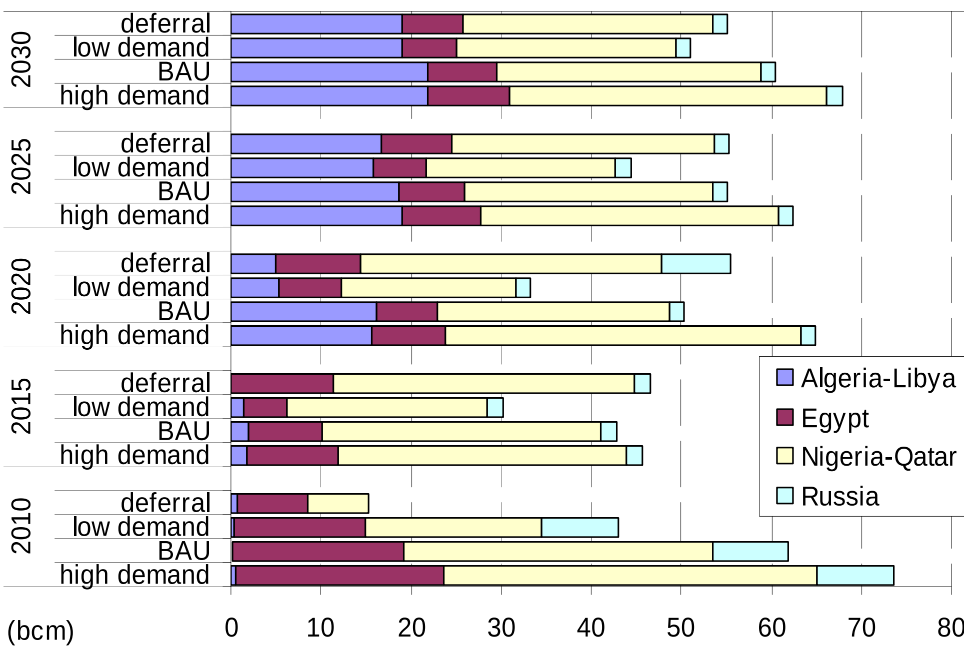

Figure 4.6 *Total investments in liquefaction capacity*

Figure 4.7 presents for four scenarios and four EU regions the new investments required in re-gasification capacity. Inspection of the figure yields that by 2010 re-gasification capacity is mainly added in UKIE, which is also used for arbitrage (i.e contributing to system flexibility) between the summer and winter demand.

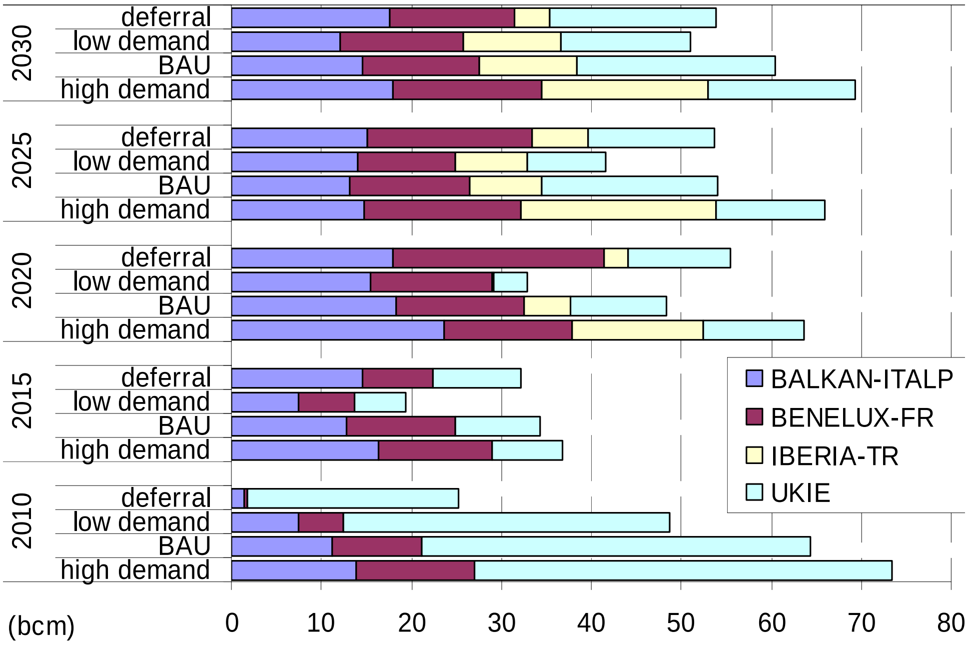

Figure 4.7 *Total investments in re-gasification capacity*

After 2010 there are re-gasification capacity additions in BENELUX, FR, BALKAN, and ITALP. After 2015 there are re-gasification capacity additions in IBERIA and TR.

Concerning the capacity to arbitrage (system flexibility) that exists between the low and medium/high demand seasons (Figure 4.8) we conclude that Russia a.o. loses its role of swing producer in the high demand and the deferral scenario. Storage has become the main instrument for swing production, which also translates into somewhat higher investments in storage capacity.

Storage is an important instrument in accommodating fluctuations in production and for the arbitrage between low summer demand and high winter demand. Alternatively excess transport capacity can be constructed which is only used for transport during medium and high demand. Figure 4.8 provides insight into swing production. In the high demand, the swing production in 2030 is fully covered by storage. In the deferral scenario, a flexibility of 4 bcm is provided by Norwegian production in 2030. The amount of storage is the lowest in the low demand scenario dropping to 65% of total swing production. In addition to storage (102 bcm), Russian (14 bcm), Norwegian (10 bcm), other pipelines (8 bcm) and other LNG (23 bcm) is used for swing production in 2030.

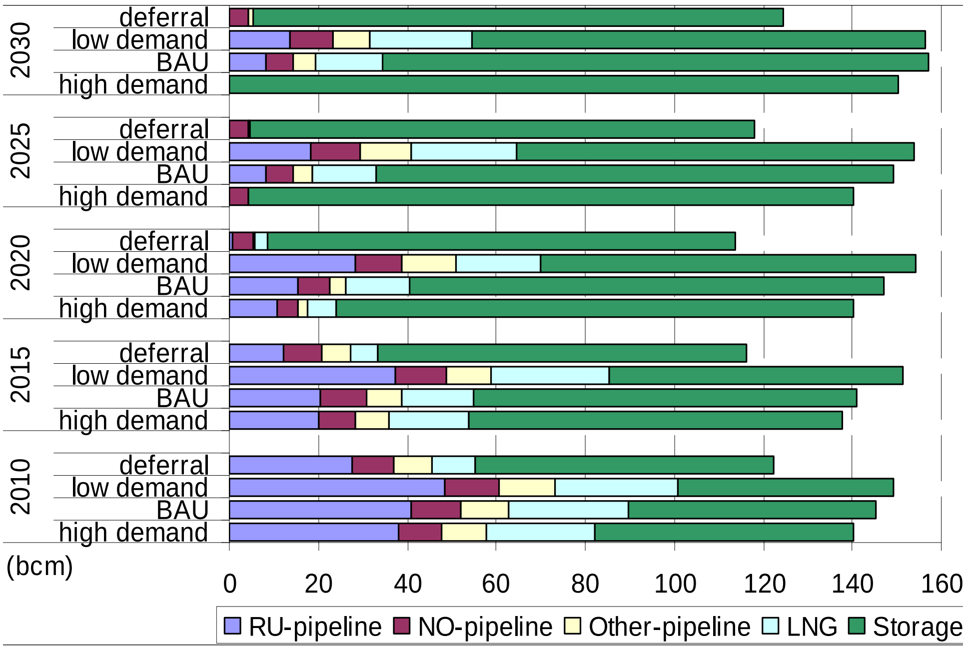

Figure 4.8 *Flexibility of production capacity between summer and winter demand.*

5. Conclusions

The model based analysis in this report is based on a number of assumptions. First, there is a convergence towards a liberalized market with a supply consisting of only a few players in the long run. Second, prices are established via demand/supply equilibrium. Third, there is seasonal flexibility and a gas demand per country/region split up over three sectors. Fourth, producer export capacity to the EU is exogenous. Finally, investments in gas transport corridors (pipelines, LNG, storage) are endogenous determined in the model calculations.

The *BAU scenario* and the analysis of its gas market impacts lead to the following conclusions. According to the model-based analysis and with hindsight several existing *pipelines* to connect the EU are not fully based on economic considerations. An example is the Baltic line between Russia and Germany and the Blue Stream pipeline between Russia and Turkey. An important motive for the (planned) construction of these projects was the strategic advantage gained by the owner of the pipelines. Furthermore, the least-cost option of supplying Norwegian gas to the European market is to 'land' all gas in the UK and from there on transport it further to mainland Europe. The expansion of existing pipelines of Norway to Belgium, Germany and France are economically less attractive than this route. Furthermore, the North-African connection into Europe is used at its maximum capacity, which results in additional production of North-Africa by supplies of *LNG* as a second best option for transporting gas into Europe. Also the Russian option to export LNG to Europe seems to be an attractive option. However, such a development seems unlikely in the next decade by many gas market experts. In addition, investments in expansion of pipeline connections of Norway to the UK and of Northern Africa to Spain and Italy are economically attractive. LNG is an attractive option from a purely economic point of view and could on economic grounds substitute an increasing part of the existing and newly planned pipeline network. The pipeline connection between Egypt and Turkey is also an economic attractive project, however it is very uncertain when precisely this connection will be realised. This leads to LNG as the second best option for supplying the EU from Egypt.

Regarding upstream *gas supply prices*, the conclusions on the basis of the BAU scenario are that price differences among countries depend on two major factors, namely 1) the distance from the main producer and 2) the impact of strategic price manipulating behaviour and in particular of Russia the largest producer. For instance, prices in France are high due to factor 1), while prices in the Baltic countries are high due to factor 2) from 2015 onwards. Prices are the lowest in Turkey, due to potentially good access to relatively less expensive supplies from nearby producers, namely Russia, Azerbaijan and Iran, making Turkey altogether an important transit hub to the EU. For this reason gas flows from the EU towards Turkey are not attractive in the model analysis and so probably will never occur in the future. Prices in the low demand scenario are lower than the BAU prices, while prices in the high demand and deferral scenario are higher than the BAU prices. Investments are either lower or taking place later in time in the deferral scenario as compared to the BAU scenario. This happens for all three type of infrastructure investments (pipelines, storage and LNG facilities).

Simulation of the *short-term supply security concerns* by analysing the impacts of possible interruption of gas supplies from the several key suppliers to EU in 2020 shows that this will lead to higher gas prices in the consumer countries located close to the interrupted supplies when compared to the BAU scenario. The price impact is higher for disruption of imports from Algeria and Azerbaijan/Iran in 2020 due to higher gas flows from those countries in that year, while the price effect is lower for CENTRAL in 2020, due to availability of alternative gas supplies. Disrupted supplies are mainly compensated by Russia in the Algerian and Caspian gas supply interruption cases, while long distance LNG mainly provides the extra production in the Russian gas supply interruption case, while due to more Russian transit through Turkey, supplies from

Central Asia reduced as well. The need for more investments in intra-EU connections to facilitate reallocation of gas suppliers in the short term is illustrated clearly.

Storage is an important instrument for managing swing production and for arbitrage between low summer demand and high winter demand. Alternatively, excess transport capacity can be constructed which is only used for transport during medium and high demand. However, the latter option would be rarely used in the economic analyses, indicating that storage is more an economic option to deal in the long-term with ‘swing production’.

Concluding; the analyses in this report indicate that substantial *investments* in gas transport corridors are needed to match the rising demand as projected officially in EU scenarios. Especially the pipeline connections running from East to West need to be prioritised in the coming years and decade. Future gas price developments will largely depend upon the sufficient availability of gas and strategic pricing by key resource owners such as Russia, Iran, and several Central Asian countries.

On the basis of the model-based analysis a number of specific conclusions are formulated:

- Already considerable *investments are needed by 2010*. In the longer term substantial investments are needed to build sufficient gas transport infrastructure capacity in Europe to connect the EU with its key suppliers. The total need amounts to about € 20 billion of yearly investments, out of which about 50% are needed for pipelines, 40% for the LNG train, and 10% for storage facilities. Particularly congestion in the East-West route should be avoided because it could drive up gas prices in countries in the EU closest to connections with the main suppliers.
- In the very short run through realizing a number of what we call *‘smart’ investments* (partly already identified in the TEN program) in *EU intra-pipeline connections* between the different EU countries, the market access and competition in EU country markets will increase substantially. This would also bring down the ability of key suppliers/producers to exercise market power at the European gas hubs and would lower gas prices in EU member states by about 14% on average as compared with the BAU scenario.
- Iran and Russia are always (2005-2030) marginal (*price setting*) gas suppliers; Nigeria, Qatar, Egypt and Azerbaijan are sometimes marginal suppliers (2005, 2010) and sometimes reap rents (from 2015 onwards), while other suppliers mainly reap rents (produce at full export capacity to EU).
- *LNG capacity* is forecasted to develop quickly. In 2030 about as much as 20% of total supplies to the EU could be transported in the form of LNG, and 80% via pipelines. LNG comes from Qatar (33%), Nigeria (25%), Algeria (17%), and Egypt (15%), others (10%) using aggregate figures for the period 2005-2030. LNG supplies go to the UK and Ireland (28%), the Iberian Peninsula (19%), Italy (18%), France (15%), BENELUX (13%), and others (7%).
- *Alternative gas demand* scenarios (lower and higher demand ±20%), lead to lower and higher investments (±30%) and lower and higher border supply prices (±10%).
- A *deferral of investments* in gas infrastructure drives up gas prices (+25%) in the next decade and leads to a lower resilience to interruptions in gas supply and, hence, less security of supply for consumer countries. Consequently the continuation of the past and currently observed postponement of investments in Europe (intra EU gas connections and connections between EU and its neighbours) would drive up gas prices, through new ‘bottle-necks’ in the gas infrastructure by around 25% in EU markets in the medium and long run.
- Despite the impressive growth of *LNG terminal capacity* pipelines are expected to stay the most dominant means of gas supply to the EU in the future: varying from 83% (low demand scenario), 81% (high demand & BAU scenario) to 77% (deferral of investments scenario) of total EU gas imports in 2030.
- *Storage* comes forward as the best option for arbitrage between summer and winter demand volumes, whereas LNG is the second best option.

- With hindsight, in the past some *investment decisions* for gas transport projects have not always been based on sound economic reasoning. Examples are the Baltic pipeline between Russia and Germany and the Blue Stream pipeline between Russia and Turkey.

Final, concerning the building of pipeline connections with the EU we can briefly summarize that pipeline connections from North Africa into the EU, from Norway into the UK and Turkey into Balkan need to be assigned the highest priority, as these investments are shown to be the required in the BAU scenario by 2010. Around 2015 the Russia into Central Europe and Turkey into Italy pipeline projects should be given the highest priority. By 2020, the Norway into Benelux and Russia into Balkan pipeline connections should be given a priority. Later in 2025, the Norway into Germany and the Russia into Baltic Region are required as priority projects. Model analysis shows that there are no immediately required additional investments in gas infrastructure by 2030. The Balkan into Turkey and Norway into France connection have a low priority. Note that the Russian into Germany (through Baltic Sea) and Russia into Turkey pipeline (Black Sea) connections are assumed to be built according to current planning, but from a European-wide perspective are not 'economic optimal' in the sense that there are other projects that deserve earlier attentions based on there ability to relieve bottlenecks in the gas infrastructure system. The table below summarises when, what (additional) new investments in supply connections are necessary according to the BAU scenario.

Table 5.1 *Timing of investments in the capacity expansion of gas corridors between non-EU and EU [bcm/yr]*

From	To	2010	2015	2020	2025	2030
Algeria	Spain	14	14	8	6	6
Algeria	Italy	16	16	8	8	8
Balkan	Turkey	0	0	0	0	0
Libya	Italy	9	8	9	5	4
Norway	Belgium	0	0	6	10	4
Norway	Germany	0	0	0	1	7
Norway	France	0	0	0	0	0
Norway	UK	16	15	10	8	8
Russia	Balkan	0	0	3	4	4
Russia	Poland	0	0	0	7	10
Russia	Slovakia	0	7	36	27	26
Turkey	Balkan	12	14	11	8	8
Turkey	Italy	0	4	6	2	2

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Appendix A Model calibration, inputs, assumptions and results

A.1 Model calibration of demand

In order to calibrate the model, prices have to be found to fix the location of the linear demand curves in the model. This can be done by assuming that firms are competitive. The ownership structure is not relevant in the competitive case, as firms cannot exercise market power. We take the realised levels of demand in 2005 as fixed and try to find under which costs the gap between demand and supply can be closed. However, this leads to demand being met exactly in the competitive case, while in reality the gas market is typically characterised by market imperfections. Assuming firms to behave a la Cournot would be somewhat more realistic, but this generally exaggerates the actual level of exercised market power. For instance, under the price elasticities assumed, the level of demand in the Cournot case would be about 20% lower than in the competitive case. Alternatively, it is also possible to increase the demand under perfect competition by 12%.

A BAU scenario is therefore derived where firm's ability to exercise market power is reduced, namely the case where Russia a.o. exercise market power on 25% of their export potential to the EU, while all other firms exercise market power on 75% of their export potential to the EU. This is equivalent to assuming that Russia supplies 75% of its capacity under fixed long term contracts, and others supply 25%, with the remainder being sold in the short-term market where market power can be exercised. This is the most realistic case as it applies market power only partially that is a more likely outcome in a market, which is characterised by a substantial share of existing long-term contracts. The BAU scenario also reflects the situation where Russia a.o. are willing to supply gas at a relatively lower cost in order to continue to have sustain a market share of 25% in the EU market. A similar procedure is followed to obtain the Directorate General of Transport and Energy (DG TREN) PRIMES (EU, 2004) forecast demand in each year, namely by increasing the demand in all EU countries by 6%, 10%, 13%, 15% and 16%, for the years 2010, 2015, 2020, 2025 and 2030, respectively. In the BAU scenario, due to demand response, the total demand as forecasted by DG TREN PRIMES is derived for the period 2005-2030. Hence, in the calibration procedure we choose fixed demand Q^0 for perfect competition (1.12*DG TREN PRIMES), obtain P^0 from competitive run, assume price elasticity and derive demand curves, and solve for BAU solution based on forward contracting assumptions. Figure A.1 illustrates the calibration procedure.

Finally to parameterise the model GASTALE 4.4, we also needed to make assumptions concerning the cost of incremental capacity. Typically the costs of undertaking investments, the depreciation and interest rates are important factors in establishing whether an investment is worthwhile. Depreciation of capital is assumed to be 3.3% per year for pipelines (lifetime of 30 years), liquefaction and re-gasification and 1.7% for storage (lifetime of 60 years). The real interest rate is set at 10% per year in the BAU case. This interest rate is commonly used for private sector investments (NCEDR, 2005). A higher interest rate would make investments more expensive and as a result a lower rate of investment can be expected

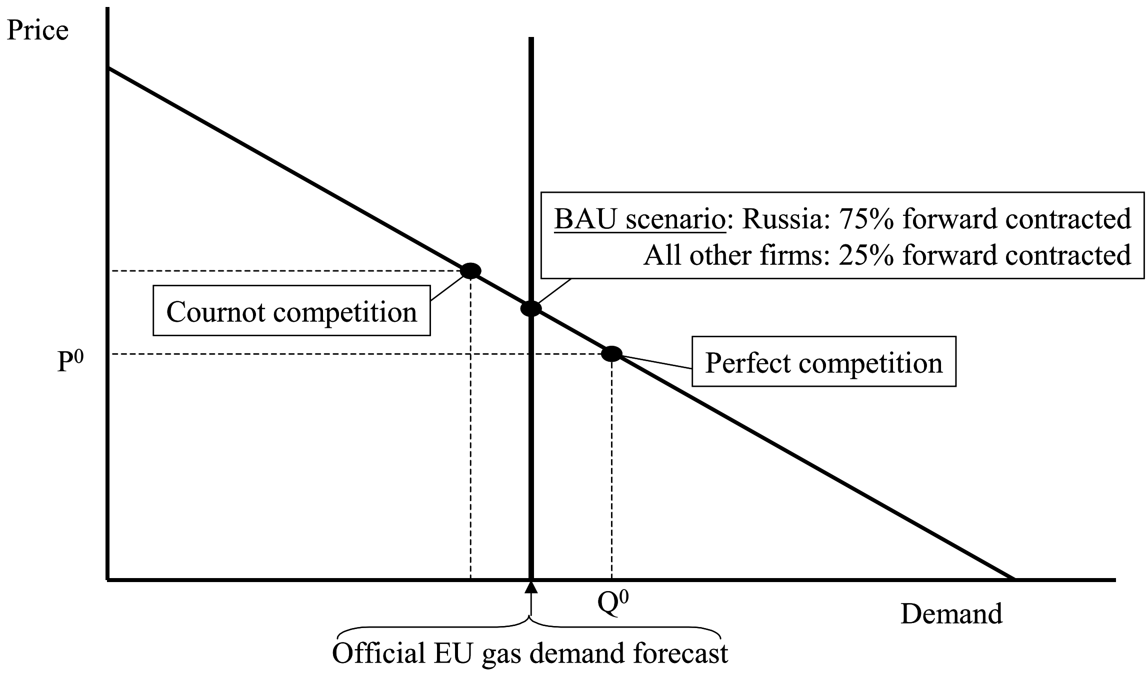

Figure A.1 *Calibration of the GASTALE model*

A.2 Demand and supply side assumptions

The DG TREN Primes forecast consumption and elasticities are used to calibrate linear demand curves for consumer sectors in each consuming region. The input data for consumption is given in Table A.1 The consumption in BALKAN, BALTIC, CENTRAL, FR, IBERIA, ITALP, and TR is actually demand in that market, net of local production, which is assumed to be consumed locally. Marginal distribution costs also include the capital costs of the distribution network, which are customarily passed on to the final consumer in the gas market.

We assume average retail price elasticities of -0.25 for households, -0.40 for industry and -0.75 for power generation, which are equal across all consuming countries. As a result, price elasticities of demand will be higher in the wholesale market. These are point elasticities in the competitive case consisting of price-quantity pairs in each season, year, and consuming country considered. While the exact level of elasticities is always difficult to establish, the relative differences can be justified. Households generally have little scope for switching and are given the lowest elasticity. Industries have more flexibility in planning their operation, and are assigned a somewhat higher elasticity. Power generators, however, can even switch to other technologies when the gas price varies, e.g. coal, and they are provided with the highest elasticity.

Table A.1 *Natural gas distribution costs and consumption over the period 2005-2010*

Country	Market segment	Distribution costs	Demand 2005	2010	2015	2020	2025	2030
		[€/kcm]	[bcm/yr]	[bcm/yr]	[bcm/yr]	[bcm/yr]	[bcm/yr]	[bcm/yr]
BALKAN	Industries	20	5.27	5.46	6.59	7.97	9.15	10.43
BALKAN	PowerGeneration	15	6.09	7.55	10.16	12.33	14.06	16.05
BALKAN	Residential	120	6.68	7.41	8.79	9.87	10.26	11.11
BALTIC	Industries	45	6.66	8.18	10.23	11.35	12.38	13.73
BALTIC	PowerGeneration	15	7.72	11.01	13.44	16.65	20.66	24.24
BALTIC	Residential	125	11.32	14.10	15.94	17.79	18.48	18.78
BENELUX	Industries	10	24.31	24.66	24.74	24.80	25.21	26.00
BENELUX	PowerGeneration	5	25.99	31.70	34.19	38.40	37.90	33.80
BENELUX	Residential	200	20.68	22.19	22.97	23.40	23.45	23.60
CENTRAL	Industries	45	11.48	12.06	12.81	12.75	12.53	12.18
CENTRAL	PowerGeneration	20	6.05	8.48	10.26	11.01	12.39	14.02
CENTRAL	Residential	100	11.39	11.54	11.91	11.94	11.80	11.33
DEDK	Industries	15	38.56	41.27	42.60	44.41	46.35	49.09
DEDK	PowerGeneration	2	20.43	23.50	39.80	44.26	48.48	45.07
DEDK	Residential	210	50.42	51.55	48.27	52.73	56.65	61.37
FR	Industries	13	20.27	21.46	21.76	21.46	21.59	21.31
FR	PowerGeneration	4	4.69	9.96	11.66	12.62	13.07	11.68
FR	Residential	185	19.93	22.15	24.07	27.20	27.87	28.29
IBERIA	Industries	22	12.76	14.69	16.03	17.19	18.51	19.30
IBERIA	PowerGeneration	15	19.82	24.54	31.64	34.69	34.24	30.11
IBERIA	Residential	280	6.00	7.93	9.74	11.45	11.62	11.65
ITALP	Industries	21	12.71	15.00	18.84	22.86	25.38	27.99
ITALP	PowerGeneration	10	19.71	28.04	35.97	45.89	51.66	52.01
ITALP	Residential	195	24.92	29.63	36.93	43.38	44.55	46.60
TR	Industries	45	2.37	3.42	5.84	9.21	14.64	18.55
TR	PowerGeneration	15	6.79	10.32	14.62	22.84	30.99	40.96
TR	Residential	125	4.62	6.85	9.86	12.56	16.46	21.27
UKIE	Industries	10	27.41	27.40	29.75	30.10	31.15	33.68
UKIE	PowerGeneration	3	46.47	53.58	63.71	66.00	71.03	74.80
UKIE	Residential	160	46.44	49.59	49.58	49.88	49.83	50.52
	Total		527.96	605.21	692.70	766.98	822.35	859.49

Source: Distribution costs are based on Van Oostvoorn (2003), while the consumption data are based on OME (2006), where the EU DG-TREN primes scenarios are used (EU 2004).

The total regional consumption is divided over the three periods in the year, namely low, medium and peak demand, representing 'apr-sep; feb, mar, oct, nov; and jan-dec'. The allocation of seasonal demand is based on the number of degree-days as pointed out in Van Oostvoorn (2003). The demand for residential heating is for instance much higher in winter and nearly negligible in summer.

Table A.2 shows the assumed initial values for the capacity and marginal operational cost of storage. The marginal costs of storage also include the transport of stored gas between the storage facility and the gas transport network. Furthermore, the capital costs of constructing a storage facility and connecting it to the gas transportation grid are included as well.

Table A.2 *Storage capacity, marginal cost of storage and additional capital costs in 2005*

Country	Storage Capacity [bcm/yr]	Marginal storage Costs [€/kcm]	Additional capital costs of storage capacity [€/cm]
BALKAN	4.1	35	3.5
BALTIC	1.7	35	3.5
BENELUX	3.1	34	3.4
CENTRAL	8.4	35	3.5
DEDK	19.7	32	3.2
FR	10.8	34	3.4
IBERIA	2.1	44	4.4
ITALP	15.6	40	4.0
TR	1.6	35	3.5
UKIE	3.6	34	3.4

Source: Derived from IEA (2005); marginal storage costs are based on Egging and Gabriel (2006), while additional investment are taken as 10% of the marginal costs.

We assume that gas is simultaneously extracted from several fields that may have different unit costs. Production capacity gives the yearly capacity of the fields that are exploited, which have different marginal costs. A profit-maximising producer who extracts from two or more fields extracts gas from a particular field until its marginal cost equals the marginal cost of the other fields, including opportunity costs of leaving gas in the ground. Thus, the marginal cost of producer *f* equals the marginal cost of its active fields. The marginal cost functions are divided into two segments: one segment (designated by variable q_f) which is nonlinearly increasing for the first 90% of the export production capacity Q_f, and a second segment (designated by variable q_f^{peak}) for production in excess of of 90% of capacity.

$$CQ'_f\left(q_f\right) = A_f + B_f q_f + C_f \ln\left(1 - q_f / Q_f\right) \qquad A_f, B_f > 0, C_f < 0, q_f < 0.9 \times Q_f$$

$$CQ'_f\left(q_f^{\text{peak}}\right) = D_f \qquad D_f > 0, q_f^{\text{peak}} < 0.1 \times Q_f$$

The expected long run marginal costs (*CQ'*) over the period 2005-2030 from Hafner and Karbuz (2006) are taken as input for deriving the parameters A_f, and C_f. From this, we derive the *average* marginal costs for the first 90% of capacity and they correspond to the long run marginal costs. The long run marginal costs increase over time for Norway and Russia a.o., which leads to nonnegative values of B_f. The marginal costs are constant (as denoted by D_f) for the last 10% (peak) production capacity. Note that the value of D_f can be derived from A_f, B_f and C_f. by assuming that the MC function is continuous at exports = $0.9Q_f$. The assumption of a constant marginal cost for the last 10% is necessary for numerical stability of the solution procedure.

Table A.3 *Parameter values of the marginal production cost function*

Producing country/region	A_f	B_f	C_f	D_f
Algeria	13	0	-5	29.51
Azerbaijan	10	0	-8	36.42
BENELUX	5	0	-12	44.63
DEDK	6	0	-12	45.63
Egypt	15	0	-5	31.51
Iran, Iraq	7	0	-5	23.51
Libya	12	0	-5	28.51
Nigeria a.o.	15	0	-5	31.51
Norway	12	0.10	-8	62.37
Qatar a.o.	10	0	-5	26.51
Russia a.o.	5	0.02	-4	28.05
UKIE	20	0	-10	53.03

Source: Based on data from OME (2006) and Van Oostvoorn (2003).

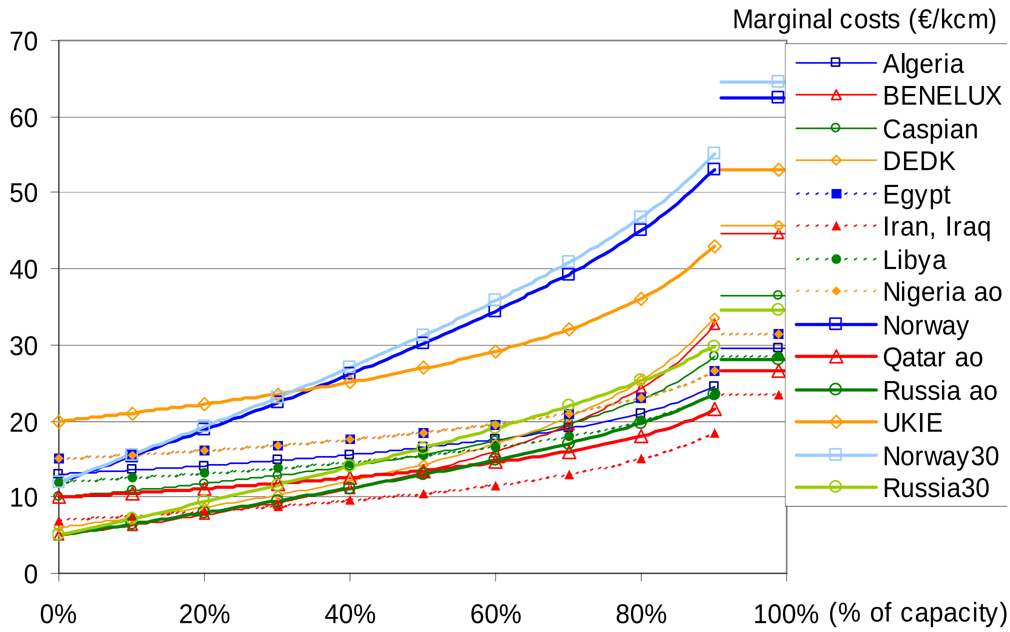

Figure A.2 *Variation in marginal production costs*

Table A.4 shows the major gas producing (and exporting) countries relevant for Europe's gas supply. For countries outside the EU, assumed production capacity is smaller than actual production because we are only interested in the capacity available for supply (export) to Europe.

Table A.4 *Producing countries gas export potential to the EU [bcm/yr]*

	2005[a]	2010	2015	2020	2025	2030
Algeria	78	85	100	115	123	130
Azerbaijan	0	14	20	26	31	35
BENELUX	90	85	78	70	65	60
DEDK	30	24	21	17	14	11
Egypt	12	23	26	28	31	33
Iran, Iraq	15	29	42	55	65	75
Libya	10	12	19	25	32	38
Nigeria a.o.	24	28	39	50	54	57
Norway	92	94	95	95	98	100
Qatar a.o.	30	49	49	49	57	64
Russia a.o.	197	216	241	266	291	316
UKIE	125	120	105	90	80	70
Total	702	779	833	886	938	989

Source: Derived from OME (2006) and expert judgement.

[a] Note that these numbers refer to gas export *potential* to the EU as used in the model, which are considerably higher than the actual export to the EU in 2005.

A.3 Gas corridors: transmission and supply assumptions

Transmission of gas can take place in two manners. Table A.5 presents the transportation costs and capacity for the pipeline network, while Table A.6 shows the assumed transport costs through LNG shipping. The LNG liquefaction costs of Russia a.o. are higher than in other countries due to the challenging circumstances in which gas would need to extracted from gas fields in the Arctic Sea. The liquefaction and re-gasification capacities associated with LNG transport are shown in Table A.7.

In addition, four pipeline corridors are physically restricted, because the pipeline connections are either political risky, infeasible beyond a certain capacity or contractually restricted. These physical restrictions are also needed because the parameterised model tends to overinvest there. This concerns the internal corridor NW_U, which cannot exceed 123 mcm per day and three South-North corridors, namely A_IB, A_IT and L_IT, which respectively cannot exceed 99, 129 and 66 mcm per day. These restrictions are due to political decisions.

Some pipelines would not be built based on market economic principles as applied in GASTALE. Therefore, two pipelines are fixed in the model, because the political decision to build and maintain them has already been taken, namely R_T (44 mcm in 2005-2030) and R_D (14 mcm in 2005, 27 in mcm 2010, 55 mcm in 2015 and 82 mcm in 2020-2030).

Finally, due to geographic, political and strategic reasons it is unlikely that Russia a.o. will transport LNG to Europe. In order to show the potential the model allows Russia a.o. to have a modest maximum of 10 bcm liquefaction export potential of EU.

Table A.5 *Distances on and off shore, capacity, pipeline marginal transportation costs, and additional investment cost for new capacity in 2005*

Country out	Country in	Interface	Distance on shore [km]	Distance off shore [km]	Marginal transportation cost [€/kcm]	Investment cost [€/m^3]	Capacity [bcm/yr]
Algeria	IBERIA	A_IB	1500	47	19.3	3.9	11.5[a]
Algeria	ITALP	A_IT	1650	150	23.9	4.8	25.0[a]
BALKAN	CENTRAL	BK_CE	1200	0	14.4	2.9	2.5
BALKAN	TR	BK_T	850	0	10.2	2.0	14.0
BALTIC	DEDK	BT_D	650	0	7.8	1.6	30.9
BENELUX	DEDK	BX_D	700	0	8.4	1.7	98.6
BENELUX	FR	BX_F	550	0	6.6	1.3	36.6
BENELUX	UKIE	BX_U	200	225	7.1	1.4	20.0
Caspian	TR	CA_T	1650	0	19.8	4.0	5.0
CENTRAL	BALKAN	CE_BK	1200	0	14.4	2.9	0.9
CENTRAL	DEDK	CE_D	350	0	4.2	0.8	54.4
CENTRAL	ITALP	CE_IT	800	0	9.6	1.9	48.3
DEDK	BALTIC	D_BT	650	0	7.8	1.6	2.3
DEDK	BENELUX	D_BX	700	0	8.4	1.7	9.0
DEDK	FR	D_F	1000	0	12.0	2.4	13.6
DEDK	ITALP	D_IT	950	0	11.4	2.3	5.1
FR	IBERIA	F_IB	1150	0	13.8	2.8	3.6
FR	ITALP	F_IT	800	0	9.6	1.9	5.6
IBERIA	FR	IB_F	1150	0	13.8	2.8	2.5
Iran, Iraq	TR	IR_T	2600	0	31.2	6.2	11.5
ITALP	CENTRAL	IT_CE	800	0	9.6	1.9	2.8
ITALP	DEDK	IT_D	950	0	11.4	2.3	7.8
Libya	ITALP	L_IT	1000	600	28.2	5.6	2.5[a]
Norway	BENELUX	NW_BX	150	875	20.2	4.0	13.0
Norway	DEDK	NW_D	400	750	20.6	4.1	45.0
Norway	FR	NW_F	450	1050	27.5	5.5	16.0
Norway	UKIE	NW_U	400	350	12.2	2.4	20.0[a]
Russia a.o.	BALKAN	R_BK	3825	0	45.9	9.2	18.3
Russia a.o.	BALTIC	R_BT	4200	0	50.4	10.1	47.0
Russia a.o.	CENTRAL	R_CE	3850	0	46.2	9.2	109.0
Russia a.o.	DEDK	R_D	2300	1200	52.8	10.6	5.0[b]
Russia a.o.	TR	R_T	2800	400	44.4	8.9	16.0[b]
TR	BALKAN	T_BK	850	0	10.2	2.0	2.5
TR	ITALP	T_IT	2000	200	29.4	5.9	2.5
UKIE	BENELUX	U_BX	200	225	7.1	1.4	21.1

Source: Derived by comparing Van Oostvoorn (2003) with OME (2006).

Note: The model allows for transhipment, e.g. from Russia a.o. to CENTRAL and then from CENTRAL to DEDK. Russia a.o. can also transport directly to the DEDK, although the capacity is low. The investment costs for additional new capacity are assumed to be 20% of the total long-run marginal costs. The LRMC are calculated using the formula: 0.012 * distance on shore + 0.021 * distance off shore (North and Baltic Seas) + 0.027 * distance off shore (Black and Mediterranean Seas).

[a] Limited from above over the period 2005-2030.

[b] Fixed capacity over the period 2005-2030.

Table A.6 *LNG marginal transport costs in 2005 [€/kcm]*

Transport to:	Transport from: Algeria	Egypt	Libya	Nigeria a.o.	Norway	Qatar a.o.	Russia a.o.
BALKAN	6.9	6.5	6.3	12.0	14.0	11.0	14.0
BENELUX	7.8	12.8	9.5	12.9	6.0	17.2	6.0
FR	6.9	11.9	8.7	12.0	6.9	16.3	6.9
IBERIA	4.5	9.5	6.5	9.7	9.2	14.0	9.2
ITALP	5.1	8.7	6.2	10.3	12.2	13.1	12.2
TR	7.8	5.8	6.3	12.9	14.9	10.3	14.9
UKIE	7.6	12.6	9.4	12.8	6.2	17.0	6.2
Liquefaction	30.0	30.0	30.0	30.0	36.0	25.0	38.0
Regasification	10.0	10.0	10.0	10.0	10.0	10.0	10.0

Source: Based on Van Oostvoorn (2003) and OME (2006).

Table A.7 *LNG regasification and liquefaction capacities in 2005*

Country	Producer	Consumer	Regasification capacity [bcm/yr]	Regasification Additional capital cost [€/cm]	Liquefaction capacity [bcm/yr]	Liquefaction Additional capital cost [€/cm]
Algeria	1	0	0	0	26.9	6
BALKAN	0	1	2.5	2	0	0
BALTIC	0	1	0	0	0	0
BENELUX	1	1	5.5	2	0	0
Caspian	1	0	0	0	0	0
CENTRAL	0	1	0	0	0	0
DEDK	1	1	0	0	0	0
Egypt	1	0	0	0	2	6
FR	0	1	16.4	2	0	0
IBERIA	0	1	36.8	2	0	0
Iran, Iraq	1	0	0	0	0	0
ITALP	0	1	3.5	2	0	0
Libya	1	0	0	0	0.8	6
Nigeria a.o.	1	0	0	0	13.8	6
Norway	1	0	0	0	2	7.2
Qatar a.o.	1	0	0	0	27.4	5
Russia a.o.	1	0	0	0	2	7.6
TR	0	1	6.5	2	0	0
UKIE	1	1	18.3	0	0	0

Source: Derived from IEA (2005). The marginal costs for using liquefaction and regasification facilities are included in the LNG transport marginal costs. 1 = yes, 0 = no for presence of producer and consumer (column 2 and 3).